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Systematic Conservation Assessments for Marine Protected Areas in New South Wales, Australia

Thesis Submitted by

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For the degree of Doctor of Philosophy

In the School of Marine and Tropical Biology,

Faculty of Science, Engineering and Information Technology

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Statement of the Contribution of Others

Ron Avery provided a foundation for this work through his previous assessment of the Tweed-Moreton marine bioregion. Ron was also an equal partner and author on the biodiversity assessment for the Manning Shelf. Ron helped develop, refine and map the broad scale environmental classification, researched literature and data sets to support the assessment and helped develop options for marine protected areas. Ron also mapped near shore reef, sand and intertidal habitats and other data for most of NSW.

Nick Otway developed the project proposal, funding, supervision and scientific foundation for the bioregional assessments. Andrew Read and Bob Creese assisted with financial, scientific and management support for the projects.

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Staff at the NSW National Parks and Wildlife Service Conservation Assessment Unit provided the C-Plan conservation planning software, while Bob Pressey, Mal Ridges and Matthew Watts provided technical support, guidance and license codes. Chris Margules, Paul Walker (CSIRO) and Dan Faith (Australian Museum) assisted through discussions and demonstrations of approaches to reserve selection. Andrew Taplin introduced me to Spexan while its authors Ian Ball and Hugh Possingham provided the Marxan simulated annealing software adapted for the Great Barrier Reef Marine Park Authority.

For Cape Byron Marine Park:
Andrew Page, Nicola Johnston and other Cape Byron Marine Park staff organised project planning, logistics, data collection, consultation and wrote draft and final plans for the park. Vanessa Mansbridge provided maps of the draft and final zone plans and other data. Andrew Bickers and Katrina Baxter carried out the sidescan and video surveys of the marine park and provided the fine scale classification and GIS data for subtidal habitats and benthic assemblages. Simon Banks and David Scotts provided the classification of intertidal habitats. Greg West and Danielle Morrison provided maps of estuarine vegetation and expert advice and support on GIS throughout all projects.

Kellie Lobb entered, modelled and mapped data for the recreational surveys. Nick Brown entered, modelled and mapped data for the commercial fishing surveys. The late Doug Chapman analysed commercial fisheries catch returns data and estimated the costs of buying out commercial fishing endorsements. The NSW Marine Parks Authority provided a professional facilitator for the community workshops. Matthew Watts ran the initial Marxan simulations for the Cape Byron ecological and social data twice in one night. The Cape Byron Advisory Committee and other participants at the draft zone plan workshops provided local knowledge and advice.

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My father (Gordon) who never got to see me finish this and my mum (Shirley) who just might.

Abstract

Science and planning for marine conservation is a complex, cross-disciplinary task. Marine conservation involves many objectives and there is much uncertainty in how ecosystems and their human populations behave. It is therefore important for environmental managers to access the best available information and expertise and to support research that improves conservation outcomes.

This thesis demonstrates through several case studies, how the systematic use of information, decision support tools and consultation can be used to identify sites for marine protected areas (MPAs) and plan for future research. The studies differ in their immediate goals and the information available. All however, benefit from linking explicit objectives to spatial databases and tools that allow scientists, managers and communities to explore and evaluate management scenarios using realistic data.

C-Plan, Marxan, Multiple Criteria Analysis and a Geographic Information System (GIS) atlas of 35 data sets are used to identify comprehensive, adequate and representative systems of MPAs throughout the state of New South Wales (NSW), Australia. The studies identify many potential locations for MPAs in the Manning, Hawkesbury, Batemans and Twofold Shelf marine bioregions and provide information and tools to implement these options. Two of these options have now been established and zoned as large, multiple use marine parks near Port Stephens and Batemans Bay. Decisions have yet to be made on options for a third large marine park in the Hawkesbury Shelf bioregion.

Potential locations for MPAs were identified from a review of MPA network design theory and criteria derived from national identification and selection guidelines. The proposed options for multiple use marine parks aimed to include representative and complementary examples of biodiversity surrogates defined for ‘ecosystems’ (five estuary types and three ocean depth zones) and ‘habitat’ types (mangrove, saltmarsh, seagrass, rocky shore, beach, reef and island). MPAs were also selected to include important sites for threatened Grey Nurse Shark (*Carcharias taurus*), fishes, birds, mammals, wetlands and other values. Criteria with unique conservation values had a greater influence in identifying specifc locations for MPAs. However, almost all options scored highly for a wide range of different criteria and contributed features to complement the overall value of the MPA network.

Options for large marine parks were selected to include the highest complementary conservation values in continuous sections of coast, estuary and ocean. However, many other smaller sites outside of these parks were identified for their high conservation values. These could be included within smaller local MPAs, within other marine parks or at least be targeted by other conservation strategies.

Where possible, locations were chosen that adjoined sections of coast and catchment with a high degree of protection in terrestrial protected areas and low levels of urban, industrial and agricultural land use. However, in the more populated regions, many distinctive areas of high conservation value were found near urban and industrial developments. Management for these areas is therefore all the more urgent and still requires attention.

Once a marine park in NSW is declared, a zone plan is required to allocate various levels of protection. These include highly protected 'no-take' sanctuary zones, habitat protection zones where recreational fishing is permitted and general use zones that allow some forms of commercial fishing. Broad scale bioregional assessments helped identify the general location of the Cape Byron Marine Park and assisted in initial planning. However, additional finer scale ecological, social and economic data were required to zone different levels of protection within the park. Detailed sidescan sonar, underwater video, aerial photography, field studies and community surveys were therefore commissioned and used to map ecological, social, and economic values.

C-Plan, Marxan and interactive GIS were then used with community workshops to develop plans that addressed conservation goals while minimising impacts on commercial, recreational and cultural interests. While a consensus among community representatives was not achieved for all areas, a plan for the park was developed that represented a range of conservation values in different zones while allowing for different human activities. This two stage approach combines broad and fine scale assessments in a cost effective way to quickly obtain reliable data for large areas of coast and ocean.

The assessments also demonstrate the value of uniting information and expertise from scientists, managers and communities in practical, science based approaches to ecosystem management. Initial proposals for NSW and previously for the Great Barrier Reef Marine Park, indicated that very little data would be available for these systematic marine conservation assessments. However, in both cases the number of useful data sets was greater than expected and provided convincing support for decision making. Many sites scored strongly for many different important values and while there was some duplication among similar data sets, this corroboration provided additional checks against uncertainty.

Collating, formatting and analysing many data sets is a specialised, labour intensive task. However, this cost is only a small fraction of the time and effort that goes into consultation and administration. Therefore, despite the effort involved, systematic assessments that provide a solid foundation of evidence are likely to reduce the overall time required in negotiations to establish MPAs. The MPAs established after the assessments in this thesis were substantial, and were implemented within a relatively short time span. This suggests that a systematic, information based approach is cost effective when compared to the more *ad hoc* approaches used previously in these regions and elsewhere.

The hierarchical approach used to map marine ecosystems and their components was applied at several different spatial scales and at varying levels of complexity. This environmental classification provided a comprehensive and cost effective way to describe large areas where only basic information was available. However, it also provided a nested framework to accommodate more detailed information and targeted research without necessarily biasing decisions towards only well studied locations. The hierarchical exploration of goals, criteria and measures through multiple criteria analyses encouraged a more thorough exploration of objectives and highlighted where more research was required. These gaps included offshore subtidal habitats, variation in species assemblages, the nature of ecological processes among marine and adjacent terrestrial ecosystems, and the impacts and values of human activities.

The level of knowledge in these fields is encouraging at a theoretical level and for specific, well studied sites. However, it is still difficult to generalise this information to the scale of whole ecosystems and regions. While techniques to map and model large ecological systems are increasingly available and affordable, better support and coordination for this work would benefit all aspects of marine research and management.

The different GIS based decision support tools used to integrate complex data sets and assess alternative MPA networks were all highly effective. All provided similar results, indeed data input, goal selection, reserve design and planning unit size and shape appeared to have a greater influence on results than the particular tool used. As these readily available and easily used tools tend to have different complementary strengths, it may, therefore, be more important to use at least one or preferably more than one tool, rather than dwelling on whether one particular approach is superior.

C-Plan was useful in providing a rapid statistical assessment of irreplaceability under changing scenarios of different targets, data and the selection or exclusion of planning units. This made it a useful ‘hands on’ tool for participatory conservation planning. Marxan provided a flexible and powerful tool for goal oriented reserve design with the ability to include criteria for reserve size, spatial aggregation, replication and other aspects of reserve configuration. Both were able to incorporate costs specified as areas or percentages of ocean occupied by MPAs or as more complex, customised estimates of social and economic impacts on fishing and other competing activities.

Unlike C-Plan and Marxan, the multiple criteria models built in Criterium Decision Plus did not inherently take into account the complementarity of sites in contributing towards conservation targets. However, this method was able to integrate previously calculated estimates of irreplaceability from C-Plan with over 60 other quantitative and qualitative measures for alternative sites in a hierarchically structured tree of MPA goals, priorities and scores. This tool also provided a way to assess sites according to varying priorities provided by different individual users.

These decision support tools employ relatively sophisticated techniques which continue to undergo development. The assessments explore only part of this potential but the information presented here can be easily re-analysed with new data, priorities and issues in marine research and management. The key element enabling these possibilities is the use of GIS to spatially integrate, manipulate and display this information.

MPAs are not the only way to manage and understand marine ecosystems. However, multiple use MPAs, in particular, are ideal venues to test and refine realistic hypotheses about marine ecosystems and their management. The geographic models and methods described in this thesis provide the spatial foundation on which to develop and design tests for such hypotheses. They are powerful tools to integrate diverse information and to model the potential effects of management interventions under varying scenarios. They therefore represent an important opportunity to channel the results of individual research projects into an wider, systematic and adaptive approach to ecosystem science and management.

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1 Introduction

"The art is in saying only as much as the experiment has shown"

Robert Pirsig (1974) 'Zen and the art of motorcycle maintenance.' Bantam Books, New York.

This thesis aims to demonstrate how systematic assessments of current knowledge can improve planning for marine protected areas (MPAs) and promote research and adaptive management for marine ecosystems. Using case studies from the Great Barrier Reef and NSW in Australia, I show how complex marine management objectives can be assessed using information, modelling tools and expertise from scientists, managers and the community.

The diverse goals of marine protected areas and other marine conservation programs represent a significant challenge. However, explicitly modelling these goals provides a way to systematically assess a range of independent information sources. By providing a comprehensive source of information, systematic assessments can help to differentiate among alternatives and make decision making more flexible, transparent, accountable and repeatable. In this chapter, I discuss the objectives, background and justification for the thesis and introduce the topics addressed in subsequent chapters.

1.1 Objectives of the thesis

The primary objective of this thesis is to identify a comprehensive, adequate and representative network of MPAs for NSW. My aim is to summarise current knowledge of broad scale patterns in marine biodiversity, environments and processes in a systematic way that can be used to assist managers in making decisions for the conservation and sustainable use of this region.

I first review marine protected area management, ecosystem science, and the systematic methods available to define, map and assess conservation values for MPAs. These techniques are then used to assess MPA goals, criteria and performance measures using spatial planning units in a Geographic Information System (GIS) with a variety of reserve selection modelling tools.

The thesis also aims to demonstrate the capabilities of information systems and analytical tools and to promote the integration of data from many sources as one way to address ecosystem scale problems in marine ecology and management. This is an important way to advance scientific research and to complement the way that knowledge is compiled and tested verbally in the scientific literature. Sharing and presenting data to a wider forum through some of the techniques presented in this thesis is also a means of promoting ongoing research. Figure 1.1 summarises the primary goals and criteria of the thesis as a conceptual multiple criteria model.

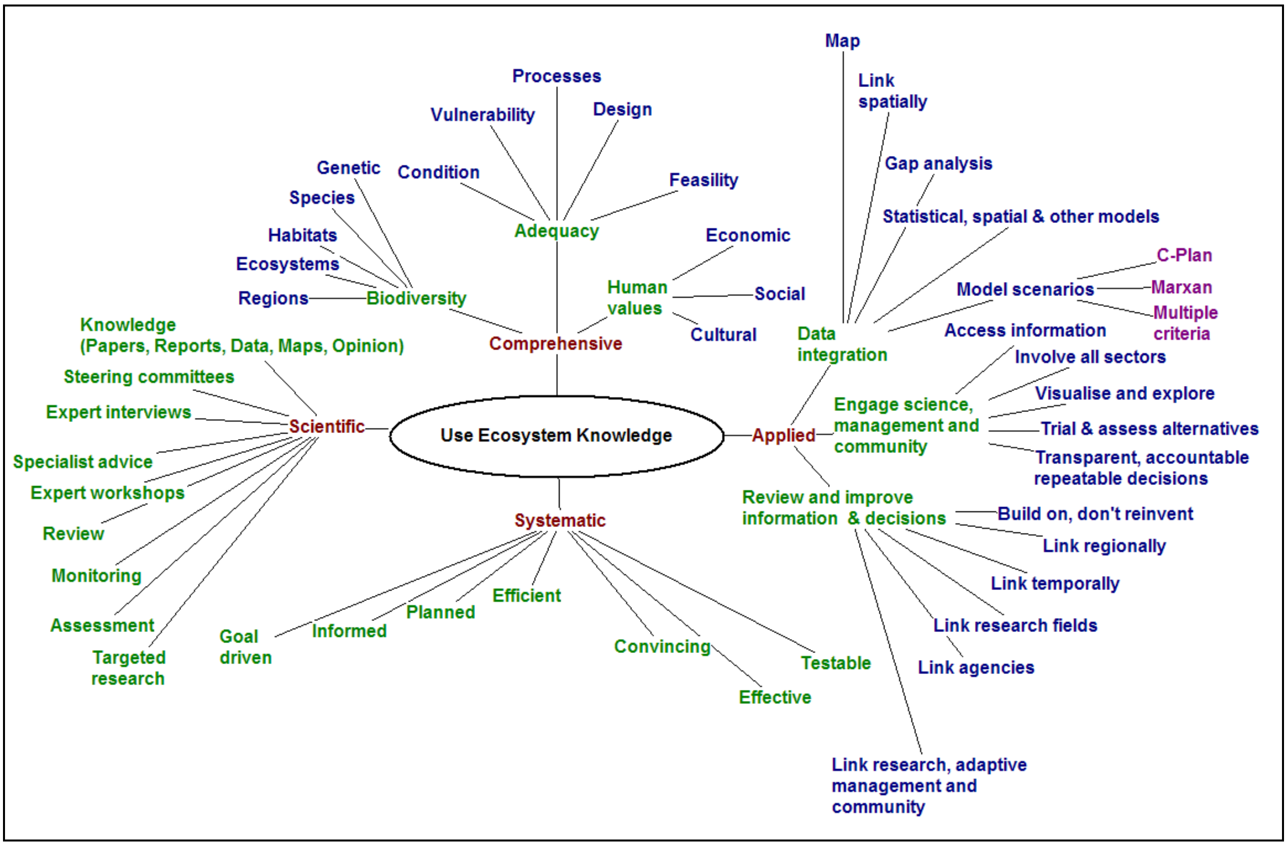


Figure 1.1 Goals and criteria to systematically identify comprehensive, adequate and representative marine protected areas using the best available ecological knowledge.

1.2 Human impacts on marine ecosystems

It has long been recognised that the earth's ecosystems are being substantially altered by the increasing scale and impact of human activities (Ray 1975, Holt and Talbot 1978, Sobel and Dahlgren 2004). Many of these changes adversely affect the environment and the survival of many species. While the effects are more readily observed on land (Beatley 1991, Upton 1992, Milewski 1995), impacts in marine and coastal environments have become increasingly apparent and are the subject of large body of literature and research (Hatcher *et al.* 1989, Norse 1991, Smith and Buddemeier 1992, Gray 1997).

Reviews of changes in different habitats range from cautiously optimistic (Hall 2002, Thompson *et al.* 2002) to dire (McClanahan 2002), but all predict that marine ecological conditions will deteriorate, particularly in less developed regions. The most optimistic forecasts are based on hope for the increasing use of conservation measures like the establishment of MPAs and all reviews propose that the keys to success are research and the education of environmental managers and the community.

The changes described range from numerous direct impacts at local scales, to indirect, but far-reaching effects operating at regional (Wilkinson 1999, Pogonoski *et al.* 2000, Wolanski and De'Ath 2005) and global scales (Wilkinson 1992). These effects have been especially well documented for tropical regions and coral reefs in particular (Aiello 1996, Berkelmans and Oliver 1999, McClanahan 2002, Sweatman *et al.* 2002), but also for seagrass meadows (Duarte 2002), mangroves (Alongi 2002), saltmarshes (Saintlan and Williams 2000, Adam 2002), beaches (Brown and McLachlan 2002), rocky intertidal shores (Thompson *et al.* 2002), kelp forests (Steneck *et al.* 2002), estuaries (Kennish 2002), continental shelves (Hall 2002), pelagic ecosystems (Verity *et al.* 2002) and the deep ocean (Hyrenbach *et al.* 2000).

Impacts include effects associated with coastal development (Collier *et al.* 1998, GBRMPA 1998, Underwood 1998, Wolanski and De'Ath 2005), aquaculture (Karakassis *et al.* 1999, Macintosh *et al.* 2002), shipping (Davis 1977, Smith 1985, Kaly and Jones 1988, 1994, ANZECC *et al.* 1997, Rogers and Garrison 2001), mining (Brown and Dunne 1988, Smith *et al.* 1990), sedimentation (Fisk and Harriot 1989, Fabricius and Wolanski 2002, Ellis *et al.* 2002), pollution (Hanna and Muir 1990, Vogt 1995, Peters *et al.* 1997, Burns and Codi 1998, Rees *et al.* 1998, Cavanagh *et al.* 1999, Williamson and Morrisey 2000, Davies and Birch 2003), invasive species (Lavoie *et al.* 1999, Wasson *et al.* 2001), climate change (Harriot 1985, Brown 1987, Smith and Buddemeier1992, Hoegh-Guldberg 1999), fisheries (Hutchings 1990, Jones *et al.* 1992, Laurenson *et al.* 1993, Thrush *et al.* 1995, Kennelly *et al.* 1998, Koslow and Gowlett-Holmes 1998, Pauly *et al.* 1998, 2002, Freese *et al.* 1999, Gray 2000, Jennings *et al.* 2001, Guenette *et al.* 2002, Kaiser *et al.* 2002) and tourism and recreation (Hawkins and Roberts 1992, Wilkinson 1992, Allison 1996, Davis and Harriot 1996, Nelson and Mapstone 1998, Harriot 2002, Moss and McPhee 2006, Shears *et al.* 2006). The impacts are many and diverse and often involve complicated interactions with unpredictable indirect effects on other species, habitats and ecosystems (Hughes 1994, Babcock *et al.* 1999, Pinnegar *et al.* 2000).

1.3 Marine Protected Areas

MPAs are a pragmatic solution to reduce some of these impacts given "that humans can impact environments and ecosystems faster than they become aware of their effects" (Verity *et al.* 2002). There are various interpretations of what MPAs are, and this can unfortunately confuse their role and the way they are applied. However, it is generally accepted that MPAs include not only highly protected 'no-take' marine reserves but also other areas managed effectively for the conservation of biodiversity, ecological processes and cultural resources.

The World Commission on Protected Areas (IUCN 1994) describes a protected area as:

"An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, and managed through legal or other effective means."

By definition, this general description of all protected areas specifically includes MPAs and is adopted by the Australian Department of Environment and Heritage (www.deh.gov.au). A special version for marine areas adopted by the IUCN and other international and national bodies defines MPAs as:

"*Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment*" (Kelleher and Kenchington, 1992).

This marine version of the definition differs slightly in that it is defined by the act of reservation rather than by the objectives of the area although objectives are listed in the IUCN's "Guidelines for Establishing Marine Protected Areas" (Kelleher and Kenchington, 1992) as:

- maintain essential ecological and life support systems
- ensure the sustainable utilization of species and ecosystems and
- to preserve biotic diversity.

The definition is altered further in the draft National System of MPAs policy for the United States as:

"Any area of the marine environment that has been reserved by Federal, State, territorial, tribal or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein."

In this definition, marine ecosystems and biodiversity are regarded as resources, and the policy admits the potential for confusion when it cautions that:

"Without further clarification, the key terms of 'area,' 'marine environment,' 'reserved,' 'lasting,' and 'protection' found in the MPA definition are subject to a range of interpretations and lead to an uncertain scope for the National System. Without clear definitions for these five key terms, identifying the sites that should be considered MPAs for the purposes of participating in the National System would be unclear and efforts to fully implement the Order would be fragmented, diffused, and ultimately unsuccessful." (www.mpa.gov)

The New Zealand Department of Conservation and the New Zealand Ministry of Fisheries (2006) have agreed on another definition for their "Marine protected areas policy and implementation plan" which defines an MPA as:

"*An area of the marine environment especially dedicated to, or achieving, through adequate protection, the maintenance and/or recovery of biological diversity at the habitat and ecosystem level in a healthy functioning state"*

The New Zealand version allows for the inclusion of areas that while not specifically dedicated to the protection of biodiversity, achieve some level of protection in the course of managing for some other perhaps related objective, such as fisheries management. It includes areas under management for recovery, presumably because impacts have already occurred. The definition also specifically restricts protection, maintenance and recovery to "the habitat and ecosystem level" but omits the need to protect biological communities, species or finer scales of biodiversity.

Furthermore, the definitions of 'habitats' and 'ecosystems' and 'healthy functioning state' are open to interpretation, difficult to quantify and potentially restricted in their scope. In the context of the classification being drafted for this process (Department of Conservation, Ministry of Fisheries 2007a), "habitats and ecosystems" are defined as specific surrogate categories of substratum and depth and used to specify the minimum level of representation required in the MPA system. While additional finer scale information on assemblages, species, processes, and other criteria may be considered during this process, the policy states that these do not necessarily require representation in MPAs.

An accompanying "Protection Standard" (New Zealand Department of Conservation, Ministry of Fisheries 2007b) aims to operationally define activities that might disqualify an area from being regarded as an MPA and thereby promote other areas to MPA status, which may incidentally have some level of protection, even though they do not explicitly have the conservation of biodiversity as a management objective. The latter have been taken to include areas with some level of protection or at least restraint including areas managed under fisheries, mining, transport, resource planning and biosecurity legislation. The danger is that small changes in the definitions of MPAs, habitat classifications and "protection standards" may be used politically to promote an existing system of "incidental MPAs" as sufficient for biodiversity conservation and then subsequently use this as an argument against establishing additional MPAs.

A major difference among definitions is that those that specify biodiversity conservation as the objective for the area provide a permanent and universal guideline against which all subsequent definitions, classifications, legislation, decisions, management and outcomes can be evaluated. There is considerable value in having management based on defined objectives (Jones 1994, Slocombe 1998, Barber and Taylor 2004, Edvardsson 2004) rather than on hypothetical outcomes that may or may not be realised or proven or on arbitrary classifications or rules that are subject to revision, differences of opinion or varying circumstances.

For example, the IUCN protected area categories (IUCN 1994, 2000) provide a goal based, internationally recognised alternative to schemes such as the New Zealand MPA "protection standard". Each of the IUCN categories are defined by their primary goal, with accompanying definitions and guidelines for selection and governance. The different categories include various objectives and corresponding levels of protection ranging from strict nature and wilderness reserves, to areas managed mainly for recreation and sustainable use (Appendix 7). These categories are universal enough in their range and generality of goals to embrace many management options and they provide clear direction for the development of specific measures, protection standards and assessments.

Because of the potential for confusion and the misuse of verbal definitions, Chapter Two describes an explicit model of MPA goals and criteria which provides a way to operationally define conceptual goals in terms of specific objectives, criteria and performance measures. This is particularly important in the context of this thesis which addresses the selection and zonation of multiple use MPAs in Queensland and New South Wales. Within these large MPAs, a mosaic of different areas or zones are managed according to objectives aligned with several of the IUCN categories.

Many reviews have emphasised that the most immediate and demonstrable benefits from MPAs are those arising from fully protected "no-take" marine reserves (Halpern 2000, Roberts and Hawkins 2000, Roberts *et al.* 2001, Warner and Halpern 2002) but there are also legitimate reasons to establish MPAs with varying levels of protection. One, is that fully protected areas on their own, may not be sufficient to address all impacts (Allison *et al.* 1998). Because of their impact on existing activities, single highly protected areas are often limited in size and therefore may be unable to address the range of biodiversity, ecological processes and human activities operating at much broader ecosystem scales. Large multiple use MPAs, which include systems of highly protected areas and other zones, have however the potential to conserve a wide range of conservation values within areas large enough to include whole ecosystems, regions and a diverse range of human activities. The benefits of this approach include greater coordination in reserve design, planning, finance, compliance, monitoring and education and a more integrated approach to threat management.

The Great Barrier Reef Marine Park is probably the best known example of a large, multiple use MPA (Craik 1996) and marine parks established in NSW under the *Marine Parks Act 1997* are based on this model (Brunckhorst 1998). In NSW, for example, legislation for marine parks is based on the primary objectives of the *Marine Parks Act* to "conserve marine biological diversity and marine habitats" and "maintain ecological processes." These objectives are specifically aimed at conserving whole ecosystems. The *Act* also includes human activities as an integral component of this ecosystem approach. Where consistent with the primary aims, the *Act* aims to "provide for the ecologically sustainable use of fish (including recreational and commercial fishing) and marine vegetation" and "provide opportunities for public appreciation, understanding and enjoyment."

Multiple use MPAs in NSW and Queensland include many, 'no-take' sanctuary areas which protect fish, invertebrates, plants and seabed from fishing and other extractive activities. However, these highly protected areas are buffered within other zones assigned different levels of protection and supported by integrated management of whole ecosystems throughout the entire multiple use MPA. The latter zones include those that allow limited recreational angling and commercial fishing and integrated management includes tools, legislation and advocacy to control impacts from within and outside the MPA including the effects of adjacent coastal development, pollution from catchments (Johnson *et al.* 1999, Done 1998, Koop *et al.* 2001), fisheries practices (Gribble and Robertson 1998, Russ *et al.* 1998, Fox and Knuckey 2001), dredging (Smith and Rule 2001) mining (Prideaux 1999), shipping (Roberts 2006), aircraft (Brown 1990) anchoring (Harriot and Fisk 1990), crowding (Inglis *et al.* 1999), off-road vehicles, trampling and diving (Davis and Harriot 1996, Harriot *et al.* 1997, Rouphael and Inglis 1997).

There is a consensus among most marine ecologists that MPAs, and especially 'no-take' reserves, can provide a variety of ecological, economic and social benefits (AAAS 2001). These benefits are the subject of many studies and reviews (Halpern 2000, Roberts and Hawkins 2000, Roberts *et al.* 2001, Warner and Halpern 2002) and there is a growing body of evidence that for many species, even small reserves can result in a greater abundance of larger individuals inside marine reserves (Jones *et al.* 1992, MacDiarmid and Breen 1992, Jennings *et al.* 1996, Edgar and Barrett 1999, Gladstone 2001, Kelly *et al.* 2000, Schroeter *et al.* 2001, Willis *et al.* 2001, Langlois and Ballantine 2005). There is also evidence these animals can 'spill-over' into surrounding areas (Russ and Alcala 1996, Roberts *et al.* 2001, Kelly *et al.* 2002). Other benefits include effects on sex ratios, fecundity and other life history characteristics (Harmelin *et al.* 1995, Pillans *et al.* 2005), as well as protection of habitat and indirect benefits for other species and habitats through trophic cascades and other interactions (Pinnegar *et al.* 2000, Shears and Babcock 2003, Langlois *et al.* 2006).

While there are benefits for species with relatively small home ranges (Barrett 1995), there may also be benefits for more mobile species (Zeller and Russ 1998, Marsh 2000, Allen *et al.* 2000, Hyrenbach *et al.* 2000, Gillman 2001, Willis *et al.* 2001, Curley *et al.* 2002, Hooker *et al.* 2002, Grech and Marsh submitted, Slooten *et al.* 2006), particularly at regularly used migration (Otway and Parker 2000), breeding (Johannes 1983, Johannes and Squire 1998, Lindeman *et al.* 2000, Russell 2001, Brodie and Clarke 2003) and feeding sites (Colman *et al.* 1997, Heyman *et al.* 2001).

Many MPAs are established primarily for the protection of biodiversity, but MPAs are increasingly used as tools in sustainable fisheries management. These can provide security for both biodiversity and fisheries (Bohnsack *et al.* 1999, Ward and Hegerl 2003) and protect against the effects of fishing gear, over-fishing and the by-catch of non-target species (Ballantine 1997, Ward *et al.* 2001). Although there are many examples of effects within the boundaries of MPAs, there are fewer documented cases of benefits extending to fisheries outside of MPAs (Russ and Alcala 1996, Roberts *et al.* 2001, Russ 2002, Butcher 1999, Galal *et al.* 2002, Pillans *et al.* 2005). This may, at least partly be due, to the more subtle nature of many effects and the lack of studies targeting these more ambitious projects. This is one application of MPAs that has received little attention in NSW. MPAs in this region, may by default, have these effects, but there has been no comprehensive use of MPAs as part of fisheries management plans and few studies (Butcher 1999) have been designed to assess benefits to fisheries or other effects beyond the most easily predicted outcomes.

MPAs have a vital role in marine research and education as reference areas where scientists, managers and communities can study and understand how marine ecosystems behave in the absence of fishing and other activities. Without these areas, it is impossible to understand how marine ecosystems behave naturally and how human activities have altered the ocean.

While MPAs are already the focus of much marine research, there are many aspects of MPA performance that require investigation. These topics include the effectiveness of compliance (Gribble and Robertson 1998, Davis *et al.* 2004, Kritzer 2004), displacement of fishing effort (Russell 1997), effects on larval supply and recruitment (Planes *et al.* 2000, Warner *et al.* 2000, Manriquez and Castilla 2001, Sale *et al.* 2005) and variations in benefits for different species, locations and human activities (Rogers and Beets 2001, Tupper and Rudd 2002, Shipp 2003, Nardi *et al.* 2004, Langlois and Ballantine 2005).

Most importantly, managers and scientists need to understand how to sustain marine ecosystems within and outside of the boundaries of MPAs. All of these questions warrant using a systematic approach to MPA selection and scientifically assisted, long term programmes of adaptive management to extract the most knowledge from each new MPA.

1.4 Science and management

In dealing with a range of human induced impacts, managers constantly need to make long-term decisions using the best available information. However, this information is rarely accessible in formats that can be readily applied to decision making. As a result, planning is often done on an *ad hoc* basis.

In a survey of 22 managers at the Great Barrier Reef Marine Park Authority, most agreed on the types of information they would like to use but disagreed on how easily they could access this information (Bollard-Breen 2006). Most planners said that ecological and social data were seldom used, as it was difficult to access and interpret. They often relied on precedents from past decisions, previous policy, the requirements of existing commerical and social activites and input from internal and external consultation. However, most respondents wanted to access all relevant information in an easy to interpret format; share information between State and Federal agencies; obtain detailed site information about the values and use of reef areas; look at relationships in the data; and identify where conflicts could occur between use and conservation.

In a survey of 38 conservation plans in the United Kingdom (Pullin *et al.* 2004), 71% of the plans were justified as a continuation of traditional management practices, 29% by habitat management handbooks and 16% by secondary reviews of literature. Only 11% made use of primary scientific literature. When 141 managers were asked about the most frequently used sources of information used to support their decision making, 60% replied ‘existing management plans’, 49% replied ‘expert opinion from outside the group’, 47% replied ‘handbooks, books or reviews’, and 46% replied ‘personal accounts of traditional management practices’. The least used sources were web based materials, popular articles (4%) and published scientific papers (23%).

When asked why they did not access primary scientific literature more frequently, most said it was too time consuming to access (65%) or read (60%), and 25% said it was ‘too technical and difficult to interpret in the context of their decision making.’ When asked to scale the relative inputs of ‘experience based information’ versus ‘evidence based information’, 75% rated experience-based information as more important while 5% thought evidence-based information was more influential. The authors suggested that the managers “were not making full or systematic use of information available to support decision making” and “frequently rely on the *status quo* of continuing with an established but unevaluated practice.”

Guikema and Milke (1999) surveyed 22 government and non-government organisations involved in biological conservation, natural resource management, recreation in natural areas and strategic planning and decision support. Only five agencies indicated using some form of quantitative tool for conservation planning. The rest reported relying on managerial experience and political process. For the five agencies reporting use of quantitative methods, almost all reported using basic scoring and ranking methods (Table 1.1).

Table 1.1. Summary of conservation planning procedures: current practice (Guikema and Milke 1999).

Conservation agency	Summary of process used
NZ Dept of Conservation – Conservancy	Negotiation and interpretation of guidance documents. Some project scoring
NZ Dept of Conservation – Regional	Project scoring with cut-off scores
US National Parks Service - conservation planning	Project scoring with weighted additive aggregation model
US National Parks Service - staff planning	Gap analysis based on current and required staffing level
Australian Nature Conservation Service – selecting protected areas	Scoring of areas
Hong Kong	Ranking of projects by criteria
World Conservation Union	Criteria scoring, conversion of scores to values and an additive aggregation model

The importance of these difficulties in linking science with conservation management is well recognized and the gap between science and management is often significant, even where substantial resources are devoted to both (Done 1998). Part of this dilemma may have arisen from the contrasting perspectives of scientists and policy makers. In Table 1.2, Crosby *et al.* (2000) highlight differences in these priorities and some of the problems in applying ecological research to immediate management problems.

Woodley and Ottesen (1992) identified four factors limiting the use of science in decision making at the Great Barrier Reef Marine Park Authority. Firstly, research results were not comprehensive or conclusive and variables could not be controlled to establish precise cause and effect relationships without uncertainty in variable, complex ecosystems. Secondly, scientists often gave results that were highly qualified, which although rigorous, did not provide quick and simple solutions and there were also issues with intellectual property. Thirdly, consensus among scientists was not always possible, with heated disputes within and among disciplines, requiring managers "to develop conflict resolution skills when dealing with scientists, in the same way as dealing with conservationists and developers." Fourthly, decisions were made 'within a legal and administrative framework involving public participation and statutory time limits…and scientists unfamiliar with this process … expressed frustration and concern with the manner in which research results (were) used – or not used' (Woodley and Ottesen 1992).

Table 1.2. Contrasting perspectives between scientists and policy makers in how they view and deal with similar parameters (Crosby *et al*. 2000).

Ends and Means	Scientists	Policy makers
Goal, purpose:	Seek truth	Public welfare, represent constituents
Basic orientation:	Understand, explain	Act, decide
Mechanisms:	Unbiased methods, impersonal	Adversarial, opposing interests, highly personal
Real World Affairs:	Problems to be solved	Problems to be resolved
Currency:	Knowledge, expertise	Power, influence
View of personal judgement:	Mistrustful stick to data	Essential, need to act before being certain
Time and Attention Spans	Scientists	Policy makers
For System:	Long, incremental	Short – must act now
For individual:	Next grant, tenure	Next election
Cognitive demands:	Depth, detail, little range	Huge range, little depth
Attention span:	Long	Short – situational press
Accountability and Rewards	Scientists	Policy makers
Responsible to:	Standards, peers	Constituency
Real-world accountability:	Low	High
Rewarded for:	Experimenting	Being right
Career Incentives:	Successful research, publishing	Power, orchestrating outcomes
Idealized mode of action:	Autonomy	Being a team player
Communicate and Interact	Scientists	Policy makers
Primary means:	Written	Personal, face to face
Role of interpersonal skills:	Low relevance to work quality	Heart of work effectiveness
Value characteristics in colleagues:	Knowledge, analytical power, creativity	Loyalty, judgement, knowledge
Language imagery:	Precise, impersonal, technical	Understandable, inclusive, personal

While these problems are relevant, managers and scientists must still work with the complexity entailed in trying to conserve whole ecosystems, and the many species, habitats, processes and threats they include. The inability of science to provide simple answers to these ‘wicked’ or ‘trans-science’ problems (Miller 1993), has led to what have become known as ecosystem approaches to management and ecological research.

1.5 Ecosystem management

Research and management for individual species and sites has a major role in conservation research and management. However, it cannot hope to address all ecosystem components at the scales required by many environmental problems. Similarly, general ecological theories and paradigms have a crucial role in research and management strategies. However, for these to be applied at the scales demanded by applied management, they often require basic information on the distribution, abundance and diversity of organisms, and the environments and the processes that effect their survival. In response to this complexity, there has been a shift in ecological management towards strategic broad scale, ecosystem and landscape approaches to conservation management and planning (Ray 1975, Franklin 1993, Noss 1996, Sherman and Duda 1999, Pitcher 2000, Trombulak *et al.* 2004). This approach is now an integral part of government policies, agreements and legislation and recognised internationally among many scientists, institutions and conservation groups.

Global marine conservation initiatives include the International Coral Reef Initiative, the Global Coral Reef Monitoring Network and the IUCN program for a Global System of Marine Protected Areas (Kelleher *et al.* 1995). These and other programs have worked with scientists, managers and communities to develop definitions, guidelines and reviews for marine protected areas throughout the world. Planning at these scales encompasses whole nations, regions and even the large intervening areas of deep ocean basin (Hyrenbach *et al.* 2000).

Australia has commitments to protect marine biodiversity under such agreements as the Convention on Biological Diversity (UNEP 19994), the World Heritage Convention (Lucas *et al.* 1997), the Intergovernmental Agreement on the Environment (Commonwealth of Australia, 1992a), the National Strategy for Ecologically Sustainable Development (Commonwealth of Australia 1992b), the National Strategy for the Conservation of Australia’s Biological Diversity (Commonwealth of Australia 1996) and a commitment to establish a National Representative System of Marine Protected Areas (ANZECC 1998ab).

In response, Australian marine managers and scientists have led an ongoing programme to establish and manage representative systems of MPAs within each of 65 marine bioregions and provinces throughout Australian waters. The Federal government has helped to fund and coordinate programs to establish MPAs in inshore waters through each State government, expanded the network of highly protected areas in the Great Barrier Reef Marine Park and established MPAs in Commonwealth waters of the Great Australian Bight, Ningaloo, Tasmanian sea mounts, Elizabeth and Middleton Reefs, Ashmore Reef, Cartier Island, the Cod Grounds, and offshore of NSW Marine Parks at the Solitary Islands and Lord Howe Island. The Commonwealth is now developing regional marine plans for the vast areas of the Australian economic exclusion zone that will include processes to identify and establish representative marine protected areas.

Decision making for these MPAs requires information ranging from spatial scales of metres to thousands of kilometres for a diverse range of physical, biological, social, economic and cultural criteria. However detailed information at such scales is rarely available, even for well known species. Marine surveys are often difficult and expensive and many habitats are hidden underwater in areas exposed to harsh weather conditions. The detailed studies that exist for some species, communities and habitats are usually restricted to particular locations which represent a small fraction of the ocean's area. Extrapolating these results to other areas is fraught with uncertainty. Similarly, applying general paradigms and theories to specific sites may be unreliable for all but the simplest of predictions. There is therefore an urgent need to develop methods to apply the knowledge we have of relatively simple, small scale phenomena to complex large scale systems, while still exercising good judgement.

1.6 Ecosystem science

The increasing demand for ecological science in managing human interactions with large, complex ecosystems has led to 'integrated', 'ecosystem' approaches to environmental research and management (Ray 1975, Agardy 1994, Christenseen *et al.* 1996, Sherman and Duda 1999, Smith and Smith 2001, Ward and Hegerl 2003) and an increasing advocacy for area based strategies like MPAs (Caddy 2000, AAAS 2001, Ward *et al.* 2001). However there are legitimate concerns over the necessarily approximate nature of ecosystem concepts and definitions (Inglis 1992, Simberloff 1998, Goldstein 1999, O'Neill 2001). These are at least partly due to the complexity itself and our current limits in easily understanding and describing ecological relationships and processes (Table 1.4). While interactions in physics and chemistry are often deterministic and highly predictable, more complex systems can be more stochastic, chaotic and difficult to predict using general theories. The difficulties in developing precise theories in ecology have been referred to as "a constipating accumulation of untested models, most of which are un-testable" and ecology has been described as being in a state of "paradigms lost" (Schoener 1972, Woodwell 1978, Schrader-Frechette and McCoy 1994ab).

The spatial and temporal scales of whole ecosystems are difficult, if not impossible, to fully control or replicate in a classical experimental setting (Schindler 1998). These challenges have led some researchers to describe ecology as diverging into 'two cultures' (Holling 1998). A so-called applied 'integrative' or 'functional' ecosystem oriented, inductive, conservation ecology and a more traditional deductive 'pure', 'deep' or 'compositional' ecology (Miller 1993, Jacob 1994, Schrader-Frechette and McCoy 1994ab, Wells 1995, Callicott *et al.* 1998). Differences between these extremes are summarized by Holling (1998) in Table 1.4.

Table 1.3 Increasing complexity and decreasing understanding of natural systems and the research fields and tools used to study them (adapted from pers. comm. A. Mazanov 1983).

Increasing complexity, scale & variability ↓

Decreasing understanding ↓

Objects	Research	Tools
Matter & energy	Physics	Observations, theories, experiments & laws
Molecules	Chemistry, molecular biology	Manipulative experiments
Cells	Biochemistry, microbiology, cellular biology	Electron microscopy
Tissues	Physiology	Microscopy
Species	Population biology and ecology	Field surveys & experiments, population modeling, statistics
Communities	Community ecology	Multivariate studies
Habitats	Landscape ecology, geology, geography	Remote sensing
Ecosystems	Ecosystem ecology, environmental science, sociology, economics, politics	GIS, systems modeling, decision support, management experiments, social and economic surveys, advocacy
Regions	Biogeography, evolutionary biology, global ecology	Information networks, digging
Space, time…	Physics, astronomy, philosophy …	Radiotelescopes …

Analytical ecology has been termed a 'science of the parts' and aims to reduce uncertainty to a point where acceptance is unanimous, however it may do so at the cost of being small in scale. The science of the 'integration of the parts' differs from the 'essentially experimental, reductionist' analytical ecology in that it is "fundamentally interdisciplinary and combines historical, comparative and experimental approaches at scales appropriate to the issues." It "has emerged regionally in new forms of resource and environmental management where uncertainty and surprises become an integral part."

It is a science "concerned with integrative modes of inquiry and multiple sources of evidence" and one that "has the most natural connection to…social sciences" and "provides a bridge between analytical science, policy and politics" (Holling 1998). It therefore lends itself in many ways to strategies in ecosystem management such as establishing networks of MPAs. While there have been attempts to resolve confusion in the terminology and principles of ecosystem ecology (Grumbine 1997, ANZECC 1999, Callicott *et al.* 1999, Trombulak *et al.* 2004), this is still a science very much in its infancy. However, the most compelling reason to pursue its development is that it aims to directly confront issues dealing with the very systems that humans and other organisms depend on.

Table 1.4. Comparing the two cultures of biological ecology (Holling 1998).

ATTRIBUTE	ANALYTICAL	INTEGRATIVE
Philosophy	• narrow and targeted • disproof by experiment • parsimony the rule	• broad and exploratory • multiple lines of converging evidence • requisite simplicity the goal
Perceived organisation	• biotic interactions • fixed environment • single scale	• biophysical interactions • self-organisation • multiple scales with cross scale interactions
Causation	• single and separable	• multiple and only partially separable
Hypotheses	• single hypotheses and null • rejection of false hypotheses	• multiple competing hypotheses • separation among competing hypotheses
Uncertainty	• eliminate uncertainty	• incorporate uncertainty
Statistics	• standard statistics • experimental • concern with Type I error	• non-standard statistics • concern with Type II error
Evaluation goal	• peer assessment to reach ultimate unanimous agreement	• peer assessment, judgement to reach a partial consensus
The danger	• exactly right answer for wrong question	• exactly right question but useless answer

Ecosystem approaches are realistic given the widespread and cumulative nature of ecological problems (Peters *et al.* 1997) and because they acknowledge that ecosystems and impacts:

- operate at a wide range of spatial and temporal scales (Ray 1991, Sherman and Duda 1999)
- include species and habitats beyond the commercially valuable, charismatic, threatened or well studied areas that receive most attention (Franklin 1993, Jones and Kaly 1998)
- involve functional interactions and dependencies among species, physical environments and processes (Ray and McCormick-Ray 1992a, Hughes 1994, McClanahan 1997, Babcock *et al.* 1999, Castilla 1999, Langlois *et al.* 2006)
- are dynamic, non-linear, non-equilibrium and stochastic (Brown and MacLeod 1996, Levin 1998)
- include humans and their social, economic and cultural values and behaviours (Kenchington *et al.* 1992, Bohnsack and Ault 1999, Agardy 2000, Ward and Hegerl 2003)
- may require pragmatic and innovative approaches to research and management (Holling 1998)
- will depend on governance and cooperation among individuals, disciplines, institutions and nations for progress to made (Ray 1991, Kenchington 1992, Alexander 1993, Kinzig 2001).

A perceived danger in relying on ecosystem ecology is in directing effort and resources away from research targeted at more specific goals and principles. However, ecosystem science should aim to incorporate the scientific principles and predictions of experimental research, modelling and other disciplines within a broader systematic framework that tests our ability to manage and adapt to changes in our environment.

Techniques that aim to apply the rigour of classical experiments to marine ecosystems include the use of mesocosms (Schindler 1998), exclusions and other field experiments (Underwood 1981, Hurlbert 1984, Jones *et al.* 1988, Thrush *et al.* 1995, Chapman and Underwood 1996, Ellis *et al.* 2002), before and after, control and impact monitoring designs (Underwood 1993, 1996, Underwood *et al.* 2003) and an overall framework of adaptive management. Adaptive management aims to apply a scientific approach to identifying and testing alternative management hypotheses through deliberate, experimentally designed ecosystem interventions (Walters 1986). Walters and Holling (1990) describe three levels of adaptive management as:

- evolutionary ‘trial and error’, in which initial choices are haphazard, but later choices may give better results
- ‘passive adaptive’ where historical data at each time are used to build a single best model to determine a management response and
- ‘active adaptive’ where data at each time are used to structure a range of alternate models and experimental designs to distinguish clearly among effects by making the best possible use of opportunities for replication and comparison.

Without reasonable information on the marine ecosystems involved, MPA selection processes are likely to be ‘trial and error’ experiments at best and their results likely to provide only marginal improvements. With at least a systematic approach to inform decisions, a ‘passive adaptive’ process may help promote intelligent choice. Various scenario modelling tools may also assist in recognising a range of alternative hypotheses and exposing uncertainties using what information is available. The following assessments in this thesis aim to apply MPA selection processes to at least this level.

However, an active adaptive strategy requires that MPA networks are experimentally designed to distinguish among competing hypotheses. MPAs provide an ideal opportunity for large scale experimental manipulations but the involvement of scientists during planning is often minimal. The design of monitoring programs to test the effectiveness of MPAs is usually only considered after the MPAs have been established. They are usually (but not always e.g. Langlois and Ballantyne 2005) based on a single unreplicated reserve, with limited data collected before establishment and a minimum number of control sites used for comparison.

Research is also usually restricted to simple hypotheses on whether or not there has been an effect. Opportunities to test different reserve sizes, shapes or configurations are usually disregarded as are investigations into more complex effects on surrounding areas and fisheries. This area remains a wasted opportunity for research and management to improve MPAs at a time when information for planning and advocacy is most critical. The systematic assessments in this thesis are a step towards a more rigorous approach to ecosystem research and MPA planning, but represent only a small part of the solution.

1.7 Systematic assessments to identify MPAs

Systematic assessments for protected areas aim to identify strategies that logically meet explicit conservation goals using available scientific data, theories and models. Because they involve many goals and stakeholder interests, these assessments often focus on ways to combine information from many sources to predict outcomes for different management scenarios.

The methods are explicitly goal driven, but often approximate. From a classical science perspective, they are essentially exploratory and usually based on the joint analysis, display and interpretation of many data sets. They are however, directly targeted at informing management in a field where certain predictions are unlikely and where priorities differ among managers and different sectors of the community. The assessments are, to large extent, information resources that allow scientists, managers, and communities to explore the potential effects of alternative management plans. This approach has evolved with an increasing emphasis on ecosystem wide planning, the coordinated establishment of protected areas and the development of computer modelling and Geographic Information Systems (GIS) (Lourie and Vincent 2004, Leslie 2005). Improvements in information technology have greatly assisted this approach, but technology is not necessarily an essential component of systematic assessments.

As early as 1975, the Australian Marine Sciences Association published "Guidelines for the establishment of Underwater Parks and Reserves in Australian waters" and Ray (1975) describes a process that includes the essential components of a systematic planning approach. It is based on an ecosystem approach to management and describes most of currently recognised goals and criteria for MPA selection, data collection, mapping, selection of sites, management tools, research, monitoring and performance assessment. Such processes have been reviewed, adapted and refined many times and a number of guides, manuals and workshop proceedings now exist for applications to terrestrial (Purdie 1987, Margules *et al.* 1988, IUCN 1994, 2000, Margules and Redhead 1995, Thackway 1996b, Davey 1998, Pressey 1999ab, Margules and Pressey 2000, Knight *et al.* 2006ab) and marine protected areas (Kelleher and Kenchington 1992, Ray and McCormick Ray 1992b, Pressey and McNeil 1996, Thackway 1996a, ANZECC 1998ab, 1999, Ward *et al.* 1998, Benzie 1999, Kelleher 1999, Vanderklift and Ward 2000).

Expression of intent for MPA
↓
Step 1
Define the objectives
↓
Step 2
Classify spatial units to sample within
↓
Step 3
Select what attributes to measure
↓
Step 4
Assess surrogates
↓
Step 5
Design and conduct survey
↓
Step 6
Data modelling or interpolation
↓
Step 7
Validation
↓
MPA selection process

Figure 1.2. Schematic representation of a 7-step operational framework (Vanderklift and Ward (2000).

Vanderklift and Ward (2000) summarise the collection of biological information for this process in Figure 1.2. To be comprehensive, this should also include the consideration of social, economic and cultural information and include some form of performance assessment and feedback mechanism (Ward *et al.* 1998). The biggest challenges in this process are in assembling enough information of relevance to the questions asked and in integrating, interpolating and interpreting information at scales appropriate for management. While there are many gaps, even the existing knowledge for many marine ecosystems can represent a lot of information to be managed and interpreted.

An understanding of this knowledge is necessary if management is to have a comprehensive and up to date 'whole ecosystem' view of marine conservation issues. However, this information is often fragmented among many different studies for specific sets of sites, times, species and habitats with little coordinated planning to direct research effort. Many of these studies address specific hypotheses or taxonomic questions which introduce sampling biases that can make inferences about spatial distribution and temporal trends unreliable.

Literature reviews aim to define general patterns and trends and meta-analyses are sometimes used to quantify overall patterns in research results from many studies. These integrate the conclusions of research, but do not often present the individual results of studies or make the underlying data available to assess or develop alternative hypotheses or interpretations.

However, a growing number of researchers and institutions now electronically store, document, and share large databases of spatially explicit data for whole regions, groups of species, habitats and ecosystems (Hamilton *et al.* 1995ab, Blake 1996, Grassle 2000). Many research programs also set out to systematically survey regions, habitats and taxa. Finally, there are also regional assessments, like the studies in this thesis, that aim to collate and use this data to provide decision support for ecosystem scale decisions in environmental management.

Dealing with large amounts of data is challenging and there are limitations in using data that is collected for different purposes. However, systems and processes have evolved to address such problems. GIS techniques to map and integrate data from different sources have been available for over 30 years (Cocks and Baird 1991). Aerial and marine remote sensing techniques and biological survey methods to sample large areas have advanced in many different ways and have become increasingly efficient (Kennelly and Underwood 1984, Stoms and Estes 1993, Burrage *et al.* 1996, Pitcher *et al.* 1999, Riegl and Piller 2000, Ducrotoy and Simpson 2001, Harvey *et al.* 2001, Kostylev *et al.* 2001, Cappo *et al.* 2003, Ekebom and Erkkila 2003, Fitzpatrick 2003, Francis *et al.* 2003, Hewitt *et al.* 2004, Parsons *et al.* 2004, Spencer *et al.* 2005, Wright *et al.* 2006, Morrison and Carbines 2006). The ability of statistical modelling techniques to smooth, extrapolate and predict the distributions of habitats and organisms from these data has also improved markedly (Faith 1991, Walker and Cocks 1991, Stoner *et al.* 2001, De'Ath 2002, MacKenzie *et al.* 2005, 2006, Hobbs and Hillborn 2006, Leathwick *et al.* 2006a, Wintle *et al.* 2006).

Goal driven, computer optimisation techniques designed to integrate diverse ecological and social data were tested as early as 1983 for the initial zone plan of the Cairns section of the Great Barrier Reef Marine Park (Cocks *et al.* 1983) and Bakus (1982) describes how multiple criteria analysis can be used to integrate information to help select and manage coral reef reserves. Since then a wide range of spatially explicit modelling techniques have been used to assess options for protected areas using information on habitats (Pressey and Nichols 1989, Faith and Walker 1994, 1996a, Belbin 1995, Pilav-Savic *et al.* 1996, Pressey *et al.* 1997, Airame *et al.* 2003, Banks *et al.* 2005, Buxton 2005, Stewart and Possingham 2005), species (Kirkpatrick 1983, Margules *et al.* 1988, Margules 1989, Margules *et al.*

1994, Csuti *et al.* 1997, Beck and Odaya 2001, Cook and Auster 2005, Fox and Beckley 2005, Leathwick *et al.* 2006b), species richness and biodiversity hotspots (Williams *et al.* 1996, Gladstone 2001, Beger *et al.* 2003, Gladstone and Davis 2003), genetics (Faith 1992, 1994, Faith *et al.* 2004), vulnerability (Bedward *et al.* 1992, Faith and Walker 1996a), consultation (Pressey 1998, 1999ab), boundary length (Nicholls and Margules 1993, Possingham *et al.* 1999, McDonnell *et al.* 2002, Leslie *et al.* 2003, Moilanen and Wintle 2006), connectivity (Briers 2002, Cabeza 2003, Rouget *et al.* 2006), uncertainty (Cabeza *et al.* 2004, Moilanen and Cabeza 2005), extinctions (Margules *et al.* 1994), persistence (Moilanen and Cabeza 2002, Faith *et al.* 2003) climate change (Araujo *et al.* 2004) and economic and social costs (Faith and Walker 1996c, Mardle and Pascoe 1999, Richardson *et al.* 2006).

These tools, models and underlying and data are usually used with GIS to link many data sets through shared locations and to display and analyse results in a spatially realistic setting. These systems are powerful tools for data visualisation and analysis and are particularly useful when dealing with area based strategies like MPAs (Bushing 1997, Kraak and MacCeachren 1999, Lewis *et al.* 2003).

GIS were previously considered as specialist technologies for trained operators, usually in geography. However, they have become increasingly accessible to a wider class of users and are now an important tool in many fields of ecology, modelling and community based management. Their realistic, visual capabilities and flexibility make them particularly useful for workshops and other participatory decision making processes that can include scientists, managers and the community (Craig and Elwood 1998, Elwood and Leitner 1998, Calamia 1999, Kerrigan *et al.* 1999, Harris and Weiner 1998, Talen 2000, Scholz *et al.* 2004, Leslie 2005, Bruce and Eliot 2006, Close and Hall 2006).

These techniques can make research and management more transparent and accountable as the rationale and information behind decisions can be shared and made available for ongoing review and future research. The current challenges however, lie not with the technology, but in the availability of suitable data and in incorporating these methods into mainstream planning, consultation and science. Answers to these challenges lie in making use of these tools in ‘real world’ applications to create an awareness of how effective they can be in applied environmental research and management.

1.8 Structure of the thesis

The structure of this thesis attempts to follow a logical path describing how to identify and select MPAs. It initially reviews goals and objectives for MPAs and develops detailed criteria to help determine the information, methods and processes required. The thesis then describes the relevance and limitations of the information and methods used and demonstrates how these techniques can be used to identify systems of MPAs using several case studies as examples. In the following chapter, I review goals and criteria for marine protected areas and develop a conceptual multiple criteria model for marine protected areas in Australia and New Zealand. These criteria are used to determine the types of information necessary for decision-making, which in this case, includes a range of different data sets describing many aspects of marine ecosystems for many locations.

Chapter 3 then reviews methods used to describe marine ecosystems and ways to integrate, store and analyse the resulting information. The chapter first considers the benefits and limitations of using physical and biological surrogates to estimate pattern in the distributions of environments and organisms. This includes the development of bioregionalisations and classifications using a range of approaches. It then describes the use of Geographic Information Systems to map and integrate this information and how modelling tools can be used to develop and evaluate different scenarios for MPA networks.

Chapter 4 outlines the primary data sources and methods used to map and describe marine ecosystems in NSW and the methods used to assess locations for their suitability as MPAs. In Chapter 5, I summarise the types of MPAs established in NSW, and their aims, limitations and capabilities. I also briefly describe the existing MPA system and how it was established.

In Chapters 6 to 8, I present case studies used to identify options for MPAs in four marine bioregions in NSW. These bioregional assessments were conducted across broad spatial scales using coarse surrogates for biodiversity and approximate indicators of condition and vulnerability. The chapter describes the systematic evaluation of alternative locations for MPAs using graphs, maps and two decision support tools, C-Plan (NPWS 2001) and Criterion Decision Plus (InfoHarvest 2000). Recommendations from these studies are summarised in these chapters but presented in more detail in Appendices 2-4. The results of these studies are now being used to implement a representative system of marine protected areas in NSW and have so far, resulted in the declaration of large, multiple use marine parks near Port Stephens and Batemans Bay.

In Chapter 8, I combine information from the above assessments and a previous study (Avery 2001) within databases and models for ongoing marine conservation planning in NSW. These include state-wide models built using C-Plan and in Marxan, the reserve selection software adapted for the Great Barrier Reef Marine Park Authority. I also develop a multiple criteria model in Criterion Decision Plus to assess options for large marine parks in the Hawkesbury and Batemans Shelf marine bioregions.

Chapter 10 uses the Cape Byron Marine Park as a case study to show how finer scale ecological, social and economic data, public consultation and local knowledge can be used to help develop detailed plans for MPAs. Once large, multiple use marine parks are declared in NSW, the government is required to develop a zone plan for each park and assign different locations to zones with varying levels of protection and restrictions on extractive human activities. ArcView GIS, C-Plan and the Marxan simulated annealing algorithms are used to analyse social and ecological data and develop zoning options according to a range of criteria. The data and models are then used in an interactive 'participatory GIS' with managers and community representatives to develop draft plans and provide recommendations to the State government. The zone plan for the park has now been implemented and incorporates many of these recommendations.

The final chapter of the thesis discusses the benefits and limitations of these approaches and suggests how they can be improved. Despite using only approximate data, the assessments provided convincing support for environmental decisions based directly on recognised conservation goals. The assessments also establish an organised framework to methodically plan new research and management and the information systems and tools to store, explore, and incorporate new information.

Many of the techniques have existed in some form for over 20 years, but marine managers and scientists have been slow to exploit this potential. These methods have however, become more readily available and cooperation among scientists and institutions has provided greater opportunities for their use. The techniques aim to improve conservation planning and research in the following ways.

1. Explicitly linking management objectives and information with problems and decisions.
2. Increasing access to information for managers, scientists, stakeholders and communities.
3. Promoting transparent, accountable and repeatable decision making.
4. Preserving and integrating knowledge from many digital, paper and anecdotal sources.
5. Establishing information systems and processes to build on existing research.
6. Identifying information gaps for future research.
7. Providing products for data visualisation, education and awareness.
8. Assessing complex ecosystem scale interactions and emergent properties.
9. Sharing ideas, priorities and decisions among scientists, managers and communities.
10. Generating realistic models to prioritise, test and plan conservation research and management.

There are substantial benefits in systematically integrating information for ecological planning and research but still many barriers to success and large gaps in our knowledge of marine ecosystems. I present the spatial representation, integration, preservation and use of ecological knowledge as a fundamental responsibility for ecological science. It is a field still in its infancy, but one with the potential to change the way we manage and understand ecosystems and our place in them.

Statement of the contribution of others in Chapter 2.

Ron Avery and I together adapted the main conceptual criteria and their interpretation for MPAs in NSW from national guidelines, policy, literature and consultation. Ron also researched and summarised most of the ecological reserve design guidelines included in Appendix 1. I developed the conceptual multiple criteria models to represent and interpret these goals and criteria.

2 Goals and criteria for marine protected areas

The number of specific objectives for MPAs, and especially multiple use MPAs, is potentially very large. While some MPAs are established to protect particular values, most attempt to conserve a range of habitats, species and processes and manage a wide array of human activities. As part of a network, there is also the potential to select MPAs that can collectively meet many objectives.

To do this requires clearly articulated goals and ways to consistently apply criteria. For MPAs, this step is particularly important, as it is unlikely that a site will actually be removed from a network after it has been established. The cost of an ineffective MPA is at least, the potential loss of a successful MPA located at an another, more effective location. A lack of clearly defined goals is likely to undermine support for a reserve and lead to an *ad hoc* selection of areas of potentially low value. It will also fail to provide direction for the data collection, survey designs, site assessments, regulations and performance assessment (Day 2002, Day *et al.* 2003). Objectives help to direct management planning, strategies and activities. They also ensure accountability and help to avoid ‘goal displacement’ (Barber and Taylor 2004). The more vague that goals are, the more likely the reserve will be managed according to external criteria that may have little to do with conservation or the benefits that an MPA can provide.

The paradox in defining ecosystem based goals, such as those for selecting and managing a system of marine protected areas, is that goals should be universal enough to include all of the potential benefits and problems likely to occur, yet be specific enough to be measurable for individual locations and situations (Edvardsson 2004). It can be difficult to impose a consistent structure or priority for goals and criteria or relate how these should link to the actual information and selection methods used or, to the decisions that are made.

Many authors have therefore, compiled lists of criteria, often summarised under separate headings (Margules and Usher 1981, Smith and Theberge 1986, Theberge 1989, Jones 1994, Salm and Price 1995, Jones 2001). Some authors separate criteria into those aiming to conserve ecosystems and those aiming to sustainably manage and provide for human activities. Jones (1994) however, lists conservation goals under headings for ‘Scientific’, ‘Economic’ and ‘Cultural,’ as does Roberts *et al*. (2003), although they also include a category for ‘Feasibility/Practicality’. Leslie (2005) groups objectives under biodiversity conservation, sustainable fisheries and scientific research. Others like Done and Reicheldt (1998) are more specific in advocating for selection and assessment based on explicit and measurable ecological outcomes.

Agardy (1997) organises ‘myriad’ objectives under seven broad goals, including some that are not overtly recognised elsewhere. The first, is to assign a sense of place of place to an area to encourage ownership, a function of MPAs that is often overlooked. The second is to provide a testing ground for management. The third is to provide social benefits. The fourth, to regulate levels of natural resource harvest. The fifth and sixth include the protection of 'sensitive or ecologically valuable' areas and 'species of special concern'. The seventh is to buffer against unforeseen management mistakes. In a previous paper, she lists 10 similar, but somewhat different objectives for MPAs (Table 2.1).

Table 2.1. Objectives of marine protected areas (Agardy 1993)

1. To safeguard traditional sustainable uses.
2. To serve as centres for public education and schooling.
3. To act as models for training programs in coastal zone management.
4. To serve as research stations for monitoring and ecological research.
5. To provide controlled habitats for ecological restoration.
6. To guarantee public access to shorelines.
7. To institute a means to limit entry to an area or to a particular group of users.
8. To facilitate the political empowerment of local users who might not otherwise be represented.
9. To allow coordination of existing management facilities.
10. To provide a salient example of how to achieve sustainable use of coastal marine resources.

Pollard (1977, 1980) summarises the objectives of MPAs as areas for: 1. conservation of ecosystems, genetic diversity and fauna and flora to repopulate surrounding areas; 2. provide scientific undisturbed representative areas for applied ecology on the effects of human activities and pure ecological and biological studies; 3. education for students and instilling conservation values in the general public; and 4. passive recreational use. However, he points out that there is considerable overlap among the categories and that arbitrary distinctions can be drawn within categories.

Cleary there are problems in defining how general and more specific criteria for protected areas are defined within a similar, consistent framework. Slocombe (1998) recommends several desirable characteristics for goals and objectives based on the theory and practice of ecosystem management (Table 2.2). He concludes that "ecosystem management needs a linked set of criteria and goals that vary by place, scale and time that are pursued in an ongoing, adaptive process." These characteristics are strongly reflected in the objectives and recommendations of this thesis and the way in which goals and criteria are modelled and analysed in the following sections.

Table 2.2. Desirable characteristics of ecosystem management goals and objectives based on the theory and practice of ecosystem approaches and management (Slocombe 1998).

1. Imply and reflect specific values and limits (normative).
2. Reflect ‘higher’ values and ethical principles and rules (principled).
3. Reflect the wide range of interests, goals and objectives that exist (integrative).
4. Work with, not artificially reduce, complexity (complex).
5. Accept and recognise the inevitability of change (dynamic).
6. Synthesize a wide range of information and knowledge (transdisciplinary).
7. Be applicable to a wide range of ecosystem types and conditions.
8. Involve actors, stakeholders, public (participatory).
9. Be inherently tentative and evolving as conditions and knowledge change (adaptive).

2.1 National and NSW goals and criteria for MPAs

The following assessments are based primarily on the Australian National MPA goals and identification and selection criteria (ANZECC 1998ab, 1999). These criteria, adopted by the NSW Marine Parks Authority (NSW Marine Parks Authority MPA Strategy Working Group 2001), were developed to promote consistency throughout Australian jurisdictions. They reflect over 30 years of international and national discussion, published research and practical management experience in protected areas (Ray 1975, Kelleher and Kenchington 1992, Ray and McCormick-Ray 1992ab, Thackway 1996, Davey 1998, Kelleher 1999).

Table 2.3 lists national goals and Table 2.4 lists national criteria recommended for the identification of marine protected area (MPA) options on ecological grounds. Table 2.5 lists national selection criteria recommended for the selection of MPAs from among the ecological options identified. These goals and criteria are the basis for the conceptual multiple criteria models described in the following section. These models also aim to include criteria from other overseas studies, MPA policies developed for NSW (NSW Marine Parks Authority MPA Strategic Working Group 2001), the objects of the *NSW Marine Parks Act 1997*, the *NSW Fisheries Management Act 1994* and the *National Parks and Wildlife Act 1974* and an environmental classification developed with Ron Avery and the NSW Marine Parks Scientific Committee.

Table 2.3. National goals for Australian marine protected areas (ANZECC 1998ab).

The **primary goal** of the National Representative System of MPAs (NRSMPA) is to establish and manage a comprehensive, adequate and representative system of MPAs to contribute to the long term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels.

The **secondary** goals are to:

- promote development of MPAs within the framework of integrated ecosystem management
- provide a formal management framework for a broad spectrum of human activities, including recreation, tourism, shipping and the use and extraction of resources
- provide scientific reference sites
- provide for the special needs of rare threatened or depleted species and threatened ecological communities
- provide for the conservation of special groups of organisms – for example, species with complex habitat requirements or mobile or migratory species or species vulnerable to disturbance and which may depend on reservation for their conservation
- protect areas of high conservation value including those containing high species diversity, natural refugia for flora and fauna and centres of endemism
- provide for recreational, aesthetic and cultural needs of indigenous and non indigenous people.

Table 2.4. National identification criteria for marine protected areas.

1. Representativeness (Figure 2.3)

Will the area:

- represent one or more ecosystems within an IMCRA bioregion, and to what degree
- add to the representativeness of the NRSMPA, and to what degree
- reasonably reflect the biotic diversity of the marine ecosystems from which they derive?

2. Comprehensiveness (Figure 2.2)

Does the area:

- add to the coverage of the full range of ecosystems recognised at an appropriate scale within and across each bioregion
- add to the comprehensiveness of the NRSMPA?

3. Ecological importance (Figure 2.3)

Does the area:

- contribute to the maintenance of essential ecological processes or life-support systems
- contain habitat for rare or endangered species
- preserve genetic diversity
- contain areas on which species or other systems are dependant e.g. contains nursery or juvenile areas or feeding, breeding or resting areas for migratory species
- contain one or more areas that are a biologically functional, self-sustaining ecological unit?

4. International or national importance (Figure 2.3)

Is the area rated, or have the potential to be listed on the world or a national heritage list, declared a Biosphere Reserve or subject to an international or national conservation agreement?

5. Uniqueness (Figure 2.3)

Does the area:

- contain unique species, populations, communities or ecosystems
- contain unique or unusual geographic features?

6. Productivity (Figure 2.3)

Do the species, populations or communities of the area have a high natural biological productivity?

7. Vulnerability assessment (Figure 2.4)

Are the ecosystems and/or communities vulnerable to natural processes?

8. Biogeographic importance (Figure 2.3)

Does the area capture important biogeographic qualities?

9. Naturalness (Figure 2.4)

To what extent has the area been protected from, or not been subjected to, human induced change?

Table 2.5. National selection criteria for marine protected areas.

1. Economic interests (Figure 2.5)

Does the site:

- make an existing or potential contribution to economic value by virtue of its protection, e.g. for recreation or tourism, or as a refuge or nursery area or source of supply for economically important species
- have current or potential use for the extraction of, or exploration for, resources
- have importance for shipping and/or trade
- have importance to traditional users including commercial fishers
- contribute to local or regional employment and economic development?

2. Indigenous interests (Figure 2.5)

Does the site:

- have traditional usage and/or current economic value
- contain indigenous cultural values
- have native title considerations
- have importance for maintaining indigenous ecological knowledge?

3. Social Interests (Figure 2.5)

Does the site have existing or potential value to the local, national or international communities because of its heritage, cultural, traditional, aesthetic, educational, recreational or economic values?

4. Scientific Interests (Fig. 2.5)

Does the site have existing or potential value for research or monitoring?

5. Practicality/feasibility (Figure 2.4)

Does the site:

- have a degree of insulation from external destructive influences
- have social and political acceptability, and a degree of community support
- have access for recreation, tourism, education
- have compatibility between an MPA declaration generally and its uses
- have relative ease of management, and compatibility with existing management regimes?

6 Vulnerability assessment (Figure 2.4)

Is the site vulnerable and susceptible to human-induced changes and threatening processes?

7. Replication (Figure 2.4)

Will the site provide replication of ecosystems within the bioregion?

2.2 Conceptual multiple criteria goals for MPAs

MPAs should be selected and managed according to the reasons for which they are established. To implement general goals requires an interpretation of what the goals aim to achieve and these goals should also form the basis of subsequent performance assessments. The practical application of such guidelines requires specific criteria that should also relate directly to more universal goals. A hierarchical model can assist in describing these relationships.

The following multiple criteria model (Figures 2.1 to 2.5) was built using the ‘brainstorm’ function in Criterium Decision Plus (InfoHarvest 2000). The model expresses general goals as a functional hierarchy of successively more detailed criteria. The model is object oriented in that each criterion inherits the general qualities of the parent criteria higher in the hierarchy. Modeling relationships between goals, criteria and available information explicitly maps the chain of logic between what is ideally required, what may be possible and ultimately what is actually achieved.

For the assessments in Chapters 6-9, these models were used to evaluate goals and criteria in terms of specific measures derived from available ecological data (Figures 2.1-2.5). In this chapter, the model is used to systematically describe some of the goals and criteria that would ideally be considered to identify and select MPAs.

Figure 2.1 to Figure 2.5 represent one possible hierarchy of specific criteria nested within more general criteria and an overall goal. Annotations in Table 2.4 and Table 2.5 link all national goals and criteria to the model hierarchy in Figure 2.1 to Figure 2.5. The model is not meant to be exhaustive and in the interest of simplicity, an attempt was made to limit criteria to the most relevant. Structural relationships in the hierarchy were simplified, where possible, to produce a parsimonious model that might be easily understood and applied. Alternative models are possible and more extensive explorations of these are considered part of the approach.

The model may appear to include more criteria than can be practically applied, but most of these criteria will at some time, require consideration in decisions for MPAs. To exclude criteria, risks having unrecognised criteria influence decisions without being formally recognised. Where detailed data is unavailable, heuristic judgements can be made. Comparisons between the conceptual and applied models also provide a systematic way to assess data limitations and identify where more information is needed.

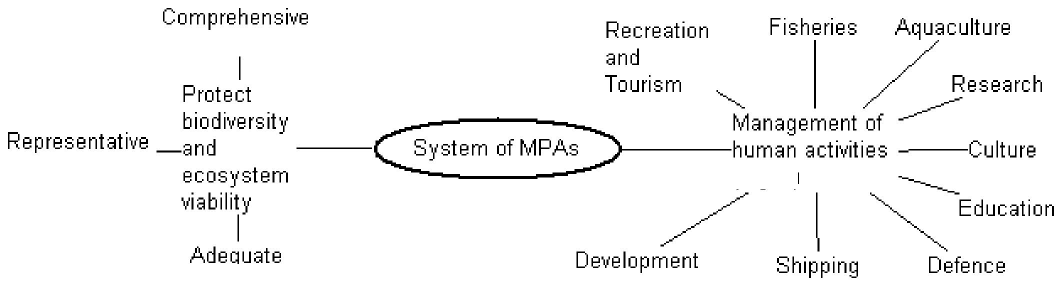


Figure 2.1. Primary and secondary goals for a system of marine protected areas.

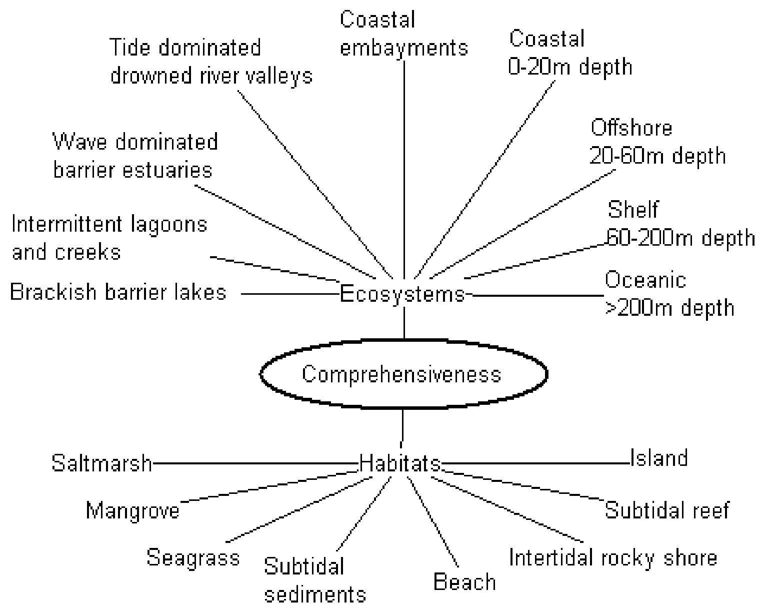


Figure 2.2 Criteria for comprehensiveness.

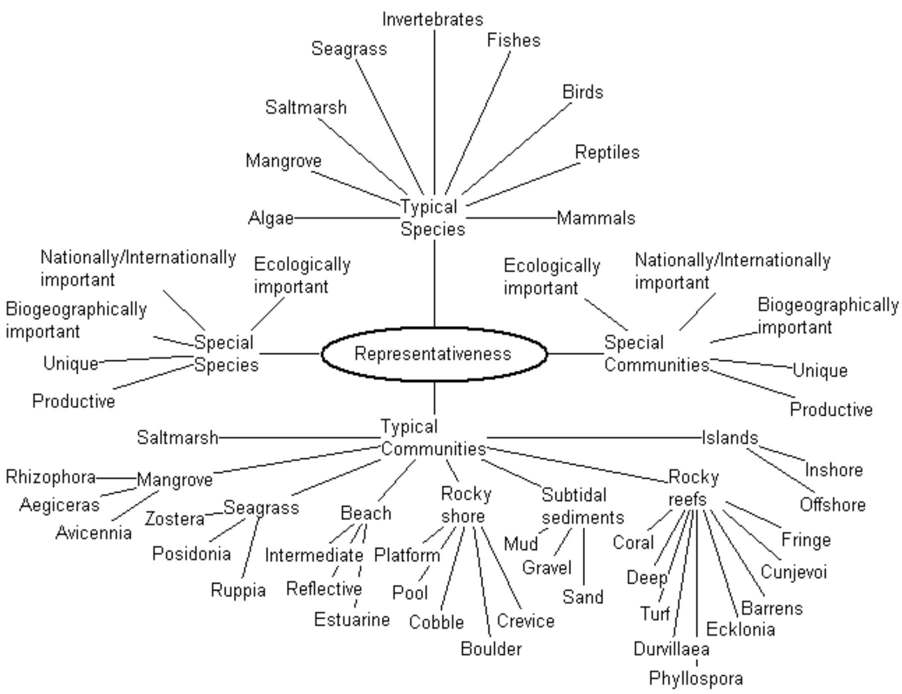


Figure 2.3 Criteria for representativeness.

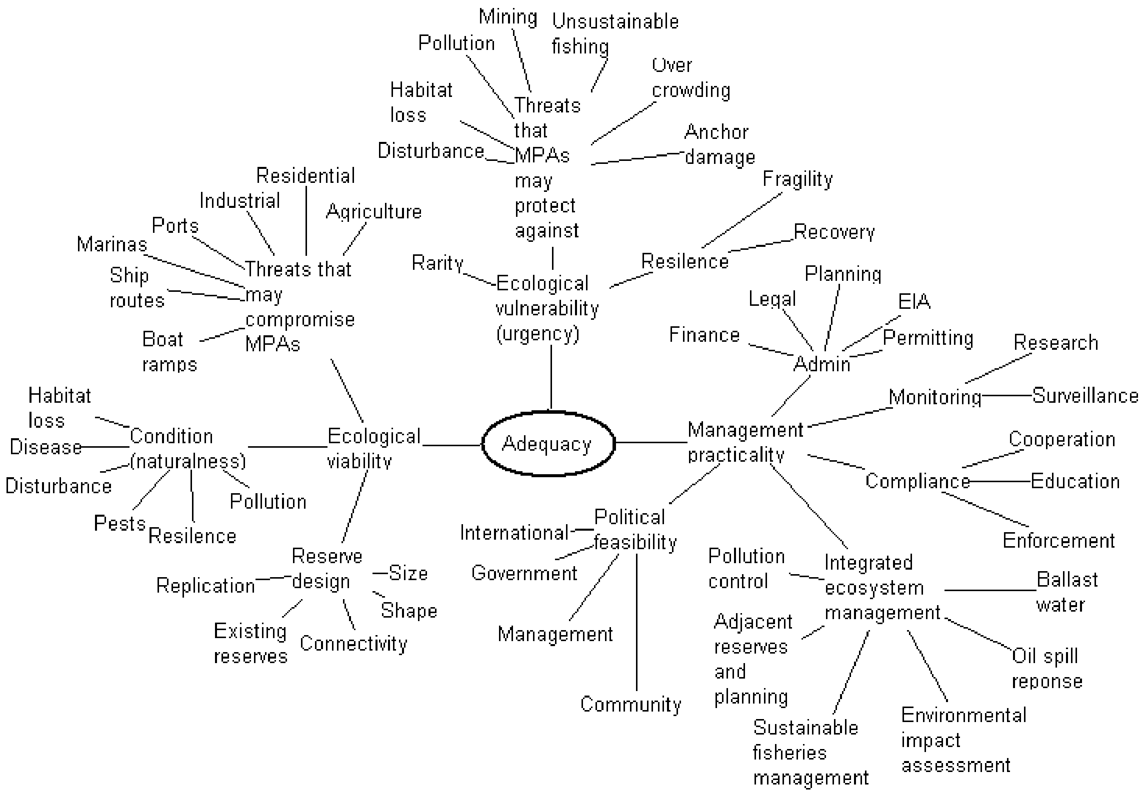


Figure 2.4 Criteria for adequacy.

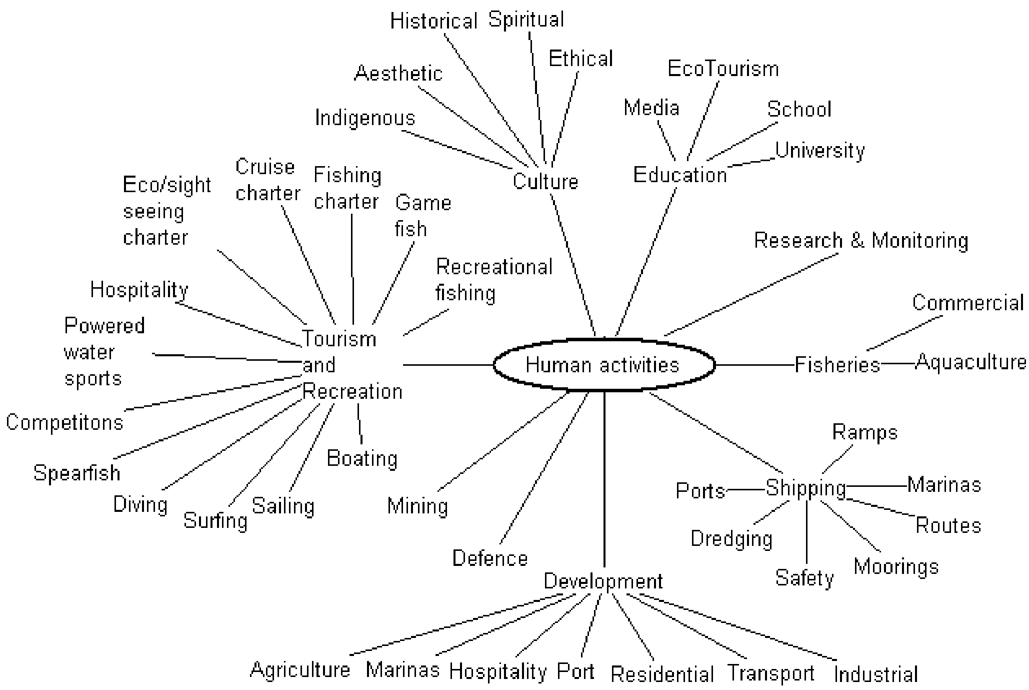


Figure 2.5 Criteria for human activities.

2.3 Protection of biodiversity and ecosystem viability

The multiple criteria models group the identification and selection criteria for MPAs into two main branches (Figure 2.1): primary goals to protect biodiversity and ecosystem viability and secondary goals to provide for human use. Ecological criteria for the broad scale assessments are organised under three main branches: comprehensiveness, representativeness and adequacy. The broad scale assessments for the Manning, Hawkesbury, Batemans and Twofold Shelf bioregions were constrained to identify options for MPAs using only these ecological criteria. In Chapters 6-9, this conceptual model is used to apply the Simple Multiple Attribute Rating Technique (SMART) to assess general MPA goals as a function of standardised criteria scores for alternative MPA sites.

However, more detailed site assessments of fine scale ecological data and social, economic and cultural values were planned once broad options were identified. These criteria are, for example, incorporated in the assessment for the Cape Byron Marine Park Zone Plan described in Chapter 10. In the following sections, I describe the rationale behind the main ecological criteria and also the criteria addressing social, economic and cultural values.

2.3.1 Comprehensiveness

Comprehensiveness is defined as including ‘the full range of marine ecosystems and habitats’ within MPAs (ANZECC 1998ab). Strictly speaking, ecosystems and habitats are too complex and dynamic to define and map accurately. However, ‘surrogate’ measures can be used to approximately map generally recognised broad scale patterns in physical and biotic environments as a proxy, or indicator to represent coarse scale patterns in biodiversity. The ‘ecosystem’ surrogates are defined as types of estuary classified by Roy *et al.* (2001) and offshore depth zones (0-20 m, 20-60 m, 60-200 m and >200 m). The ‘habitat’ surrogates are defined as the environments provided by seagrass, saltmarsh, mangrove, rocky shore, reef, beach, islands and sediments. These ‘ecosystems’ and ‘habitats’ (Figure 2.2) were defined in an environmental classification based on broad scale differences in geomorphology, depth, substratum and exposure. The classification is essentially two-dimensional in definition and application. However it does seek to include the influence of three-dimensional features and processes throughout the water column, particularly in the effects of islands, different estuary types, offshore depth zones and the influence of features such as the East Australian Current. The classification only applies to the relatively shallow waters of the continental shelf, in deeper waters a vertically stratified classification might be appropriate as has been applied elsewhere.

The classification was developed with Ron Avery and discussions with NSW Marine Parks Scientific Committee. The largely physical differences in these environments are assumed to reflect a corresponding diversity in different habitats, species, and ecological processes. These assumptions are based on scientifically documented patterns observed for species studied in

NSW waters or similar locations and are summarised in Chapter 4 and elsewhere (Avery 2001, Breen *et al.* 2003, 2004, 2005, 2006). The aim of the following assessments is to represent all of these features in MPAs for each marine bioregion defined in NSW by Pollard *et al.* (1997) for the Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998).

2.3.2 Representativeness

Representativeness is taken to mean that areas included in MPAs should ‘reasonably reflect the biotic diversity of the marine ecosystems from which they derive’ (ANZECC 1998ab). That is, while comprehensively sampling the range of biotic variation, MPAs should also include a reasonably unbiased and sufficiently large, representative proportion of the variation within this range.

The intention of this approach is to protect typical species, processes and areas as well as well known, charismatic, rare, threatened, scenic, recreational or convenient elements of biodiversity (Pressey 1995). A representative system of MPAs should protect both typical and ‘special’ components of biodiversity (Inglis 1992, Jones *et al.* 1992, Jones and Kaly 1998).

Figure 2.3 describes representativeness as a function of typical and special communities and species. In practice, typical communities and species may be represented through finer scale physical and biological surrogates, species assemblages, broad scale species surveys, incidental sightings and descriptive records of communities and populations.

Special species and communities in Figure 2.3 include rare, endemic, threatened, ecologically important, unique, productive and biogeographically, internationally and nationally important communities and species. In NSW, threatened communities and species include those communities, populations and species listed as endangered and vulnerable under the *NSW Fisheries Management Act 1994* and the *NSW Threatened Species Conservation Act 1995*.

The life history characteristics of 'potentially threatened' species (Jones and Kaly 1998) should also receive consideration in locating and designing MPAs. These include species:

- with unusually restricted geographic ranges
- with unusually restricted breeding sites
- which are very large, long lived or have low fecundity
- subject to large-scale, mass mortality
- subject to prolonged periods of recruitment failure
- which are highly susceptible to stress
- which are extreme habitat specialists
- which are obligate supra-tidal, intertidal, estuarine and coastal embayment species
- species which are, or have been subject to over exploitation.

Noss (1990) also nominates species worthy of 'special' conservation status that serve as:

- ecological early warning indicators
- keystone species on which other diversity depends
- umbrella species whose large area requirements protect other species and
- flagship species that provide support for MPAs because of their public popularity.

One aspect of representativeness and adequacy not explicitly included in the conceptual model is genetic variation. The potential role of MPAs in maintaining genetic variation within and between marine species, populations and sub populations of fish and invertebrates is significant (Polunin 1983). Populations depend on this variation to survive disturbance, disease, competition and changes in their environment. For many endangered terrestrial animals and plants, the maintenance of genetic variation is the most critical factor affecting their survival.

A number of phylogenetic measures have been proposed that aim to implicitly include inter and intraspecific genetic variation in estimates of representativeness, but few have been implemented in the selection of marine protected areas (Vane-Wright *et al.* 1991, Faith 1992, 1994, Moritz 1994). While there is a tendency for marine protected area programs to represent biodiversity as coarse scale surrogates, consideration should also be given to the finer scale genetic diversity that maintains populations and drives the evolution of marine organisms.

2.3.3 Adequacy

Adequacy is defined as ‘the required level of reservation to ensure the ecological viability and integrity of populations, species and communities’ (ANZECC 1998ab). Adequacy includes criteria that affect the ability of MPAs to sustain the biodiversity they aim to conserve. It involves consideration of vulnerability, condition, reserve design, connectivity and practical MPA management (Figure 2.4).

Vulnerability

Vulnerability may be interpreted in two ways. Where there is a range of options available for the protection of a feature, it may be preferable to include areas that are least threatened and select locations where survival is more likely (Jamieson and Levings 1998). This approach may apply when threats originate from outside the MPA and are beyond the immediate control of MPA management. An example might be in selecting marine areas at locations less prone to pollution (Edgar and Barrett 2000) or less likely to be impacted by development.

However, where there are only a few examples of a habitat or species, there may be urgent reasons for protecting the areas most threatened, particularly where threats operate inside the MPA and are under some control of MPA management. This urgency would include habitats or species that might otherwise be lost without the protection of a MPA.

Condition

Condition or 'naturalness' reflects whether an area has already undergone some degree of impact. If an area has been affected by pollution, disturbance, pests, disease, habitat loss, or over-exploitation, the ecological viability of the area, as well as the diversity of organisms present may be affected.

Ecological reserve design

Ecological viability requires consideration of reserve design including the size, shape, replication and configuration of reserves within a network. Reserve design criteria aim to ensure that individual MPAs and the overall reserve system remain ecologically viable. There are many general recommendations for reserve design in the scientific literature (Ballantine 1991, 1997, Roberts 1998, Chiappone and Sealey 2000, Allison *et al.* 2003) and workshops where specific principles have been developed for a project (Day *et al.* 2002, Fernandes *et al.* 2005). These recommendations were reviewed for the bioregional assessments and used to help identify potential MPA sites (Appendix 1 summarised from Breen *et al.* 2004.)

Reserve design theory for marine protected areas is receiving increasing attention in the development of reserve selection algorithms (see Chapter 3) and marine population modelling (Fairweather 1991, Crowder *et al.* 2000, Dahlgren and Sobel 2000, Tuck and Possingham 2000, Walters 2000, Watson *et al.* 2000, Gerber *et al.* 2003, Lubchencho *et al.* 2003, Shanks *et al.* 2003, Sobel and Dahlgren 2004). There is also an increasing amount of research into understanding the life histories of the marine organisms including information on movement (Lowry and Suthers 1998, Pitt and Kingsford 2000, Otway and Parker 2000, Willis *et al.* 2001, Curley *et al.* 2002, Gillanders *et al.* 2001, Gillanders 2002ab, Stewart 2003, Slooten *et al.* 2006), spawning (Colin and Bell 1991, Ferreira 1993, Gray and Miskiewicz 2000, Jenkins *et al.* 2000, Hall and Hanlon 2002), fecundity (Brown-Peterson *et al.* 2000), dispersal (Leis 1986, 2002, Cole *et al.* 2000, Grantham 2003), recruitment (Armsworth 2000, 2002, Hughes *et al.* 2002), mortality (Gray *et al.* 2002), hydrodynamics (James *et al.* 1990, 1998, Burrage *et al.* 1994, Kleypas and Burrage 1994, Black *et al.* 1995) and reserve configuration (Gaines *et al.* 2003, Gerber *et al.* 2003, Largier 2003, Leis 2003, 2006, Palumbi 2003).

Practical applications of this kind of information or theoretical models to MPA design and management are however rare. A combination of these approaches with the types of spatial models developed in this thesis may, in the future, provide a more rigorous approach to designing MPA networks.

Management practicalities

Management practicalities also affect the ability of MPAs to adequately conserve biodiversity. Criteria that need to be considered in identifying MPAs include:

- education (recognition of values, regulations and boundaries)
- cooperation (best practices, consultation, voluntary compliance, volunteer work)
- planning, regulation and enforcement considerations
- prospects for research and monitoring designs to aid adaptive management
- benefits from integrated ecosystem management of surrounding areas
- ease of administration, planning, permitting, impact assessment and finance, and
- political and community support to establish and make the MPA system work.

Education

For a system of MPAs to be effective, community support is essential. Support can only be gained if people are properly informed and educated about the value of MPAs. For management processes to be seen as transparent, people need to be made aware of the reasons for MPAs and how decisions are made. The complexities of MPA management can also lead to misinterpretation of management strategies. Education can help avoid confusion, create support and allay unjustified fears in the community (Alder 1996).

Some locations are particularly suited to educational activities and may already have programmes in place. Areas recognised for their high natural values are often good subjects for documentaries and printed articles that can be entertaining, informative and promote marine conservation to audiences internationally.

Providing information for local displays, tours, businesses, schools and other agencies provides tangible benefits to the community and opportunities for community input. In these instances, education can involve all age and community groups including children and the broader community, as well as those stakeholders most directly affected by MPAs. Some of the best education programs involve bringing people and marine ecosystems together and many MPAs are well known for this (Ballantine 1997).

Planning, regulation and enforcement

In an integrated system of MPAs, there needs to be coordination of planning and compliance among MPAs, and among management jurisdictions. In NSW, there are three agencies responsible for MPA management, and several other agencies with marine responsibilities. There is therefore, much scope for cooperation as well as potential for confusion over jurisdiction. In addition, responsibilities for marine bioregions in NSW are shared with the Federal Government (e.g. for part of Jervis Bay and waters more than 3 nm offshore) and with neighbouring state governments (for sections of the Tweed-Moreton and Twofold Shelf bioregions).

MPA design also needs to take into account strategies and restrictions already in place. In this way, they may take advantage of existing regulations, programs and facilities, avoid legal complications, and minimise additional impacts on existing use. Care should also be taken to ensure that ecological objectives are not compromised by differences in jurisdiction and that management includes negotiation among all agencies involved. For example, where MPAs are declared to the high water mark, measures should be taken to ensure that the mangrove and saltmarsh habitats inland of this boundary are also conserved. These considerations apply to a wide range of issues including catchment management, agriculture, development, fisheries, national parks, pollution, shipping, waste management and law enforcement. Opportunities for integrated management exist across all these areas in surveillance, research, monitoring, education, consultation, best practices, pest control, risk assessment and rehabilitation.

Research

MPAs have a crucial role as reference sites in understanding changing marine environments and the impact of human activities. Without reference sites where impacts are controlled, there are no baselines for distinguishing natural from human disturbances or for differentiating the causes of impacts from sources as diverse as fishing, land use, pollution, pests, development or climate change. Without this knowledge, our ability to detect problems, and develop and test effective solutions, is severely limited.

In particular, without consideration of experimental design in the identification, selection and design of MPAs, it may be very difficult to assess whether the reserves are even effective in achieving their objectives. Important considerations here are the replication of MPAs within a range of habitats and levels of protection, an interspersed allocation of these ‘treatments’ (Hurlbert 1984) and procedures to assess compliance (Davis *et al.* 2004) and ecological responses.

As the design of reserve networks and research programs share similar guidelines, even small alterations at the MPA design stage can have significant implications for future research and assessment (Kingsford 1999). The partnership between research and management should be regarded as an ongoing and iterative process of adaptive management to gradually improve the design and management of MPAs.

As research in marine environments is often difficult and costly there are significant advantages in cooperative research among MPA agencies and other agencies, universities, industries, organisations and individuals involved with marine environments. Consideration of existing research programs, infrastructure and expert knowledge can have important benefits for research, monitoring and conservation.

2.4 Managing and providing for human activities

Table 2.5 and Figure 2.1 and Figure 2.5 list criteria under the secondary goal to: 'manage and provide for human activities'. Criteria for human activities are scheduled by national guidelines into a separate site 'selection' process. Where consistent with ecological goals, the selection process aims to minimise restrictions on human activities, and even enhance cultural, social and economic values. Often the ecological options for MPAs are flexible enough to allow for a variety of human uses.

Figure 2.5 lists just some of the interests potentially affected by MPAs. It is evident, even in this simplified view, that there is potential for conflict between conservation values and competing interests. Careful consideration of human activities is therefore required if MPAs are to be implemented. From a more positive point of view, the economic, social and cultural benefits from MPAs are often substantial. Nature based tourism and the associated services provide significant income and employment for many coastal regions (De Groot 1991, Agardy 1993, 2000, Dixon 1993, Driml 1994, 1999, Driml and Common 1995, Constanza *et al.* 1998, Cocklin *et al.* 1998, Access Economics 2005). The recognition that MPAs create for the conservation values of an area tends to promote MPAs as tourism destinations and also generates support for marine conservation and research generally. Where compatible with conservation goals, the selection and management of MPAs should therefore, seek to exploit this potential.

MPAs can also provide cultural benefits for local communities through economic opportunities and by protecting traditional use and spiritual values. However, for some communities, MPAs may also threaten these values. In most regions, there are now legal requirements for cultural involvement in considering locations for MPAs and careful planning is required to engage with traditional owners and custodians (Kenchington and Bleakly 1994, Smyth 1995, Schnierer and Woods 1998). Subject to intellectual property rights, indigenous knowledge should be included in MPA selection processes. In many areas local customs, cooperation and compliance are the main factors in establishing and maintaining MPAs (Kenchington and Bleakly 1994, Wolfenden *et al.* 1994, Gilman 1997) but careful consideration needs to be given to the manner and settings in which consultation occurs (Fiske 1992, Beaumont 1997, Helvey 2004, Crawford *et al.* 2006).

Information on human activities is also necessary to understand where impacts are likely to occur. Existing databases for permits (Alder 1993), charges and vessel logbooks (Valentine *et al.* 1997, Davis and Tisdall 1999, GBRMPA 1999), surveillance reports, surveys (Fleming 1991, Steffe *et al.* 1996, Queensland Transport 2001) and censuses can provide useful information to help anticipate potential impacts. Input from public consultation, interviews and other forms of social research can also provide important data on the distribution of human activities and on the aspects of marine ecosystems that people value most (Schafer and Inglis 1999, Williams *et al.* 2000, Breen 2006, Innes *et al.* 2006). As most decisions in selecting MPAs have a spatial component, it makes sense to map, or ask survey respondents to map, the geographic distribution of these activities and the values they consider important. This information provides a direct quantitative input from individuals into planning the locations of MPA boundaries. It also enables social, cultural and economic values to be directly compared with ecological values measured at the same locations.

Stakeholders often spend much time observing marine ecosystems and can contribute valuable information on species distributions, habitats, vulnerability, condition and threats. When used cautiously, such information can provide important knowledge on local conditions, habitats and organisms (Johannes 1982, Calamia 1999, Berkes *et al.* 2000, Calheiros 2000, Johannes *et al.* 2000, Huntington *et al.* 2002). Williams and Bax (2002) for example, used data from commercial fishers' logbooks and GPS plotters to map large areas of the continental shelf off southern NSW and Victoria. The fishers in this study provided boundaries of different habitats and descriptions of benthic invertebrates and fishes that were verified in subsequent scientific surveys using sonar and underwater video.

It is likely that, if designed accordingly, MPAs can benefit surrounding fisheries. However, the goal of enhancing effects such as 'spill over' was not specifically addressed in the identification or selection of MPAs in this thesis. This goal is currently not a priority in policy or research for MPAs in NSW, although it could create substantial support for MPAs. The contribution of MPA planning to economic (Dixon *et al.* 1993), social (Breen 2006) and cultural values is one of the least developed areas of MPA research and management and requires receive greater attention.

Davey (1998) lists eleven reasons why plans for MPAs fail, six of which involve stakeholder input:

- they do not address key issues
- they fail to involve stakeholders
- they rely too much on external experts and fail to involve local people
- they are weak on implementation
- they fail to raise political support for protected areas as a worthwhile concern
- they are poorly publicised.

There are many ways in which consultation can be enhanced through advisory committees (Vasseur and Renaud 1997), community meetings, information sessions, displays, the media and through the availability of staff for public communication (Innes *et al.* 2006). Effective consultation encourages public confidence and a sense of ownership and contributes to the effectiveness of MPAs in adequately conserving marine biodiversity. In Chapter 10, I describe some techniques to integrate social, economic and cultural information with ecological data during consultation for the Cape Byron Marine Park.

3 Methods to identify Marine Protected Areas

"If the only tool you have is a hammer you tend to see every problem as a nail"

Abraham Maslow

Marine research is constrained by factors such as weather, depth and the sheer scale of oceanographic systems. Even the best resourced research program can only hope to estimate some aspects of the ecology and biology of a few of the many marine species, habitats and processes. Most marine research has occurred at a limited number of sites sampled at select points in time. However, the extent of human influence, the potential for cumulative and synergistic impacts, and the need to provide convincing evidence to support management requires consistent information across large areas for a variety of ecosystem characteristics. This work also requires reliable systems, tools and effort to integrate and interpret data for scientists, managers and communities. This chapter describes how systematic methods in information collection, analysis and presentation can be used to help identify and select systems of MPAs.

3.1 *Ad hoc* and systematic selection of reserves

The selection of many protected areas has tended to be opportunistic or based on values for recreation, scenic beauty or other special characteristics. These so called *ad hoc* approaches have, in many cases, led to a relatively biased selection of areas that potentially neglects the conservation of less accessible, inconspicuous or less charismatic habitats and species (Pressey 1994a). If marine protected areas are to conserve a comprehensive range of ecosystems and species, a more organised approach to identification and selection is required.

The need for more transparent and accountable decisions also favours a systematic approach. Establishing and managing MPAs is often a difficult and costly process and the decisions made will affect the welfare of marine ecosystems and the human communities that depend on them. In many cases, there will be no second opportunity to correct decisions. It is therefore right to allow for sufficient resources, expertise and time to plan.

Many early developments in systematic protected area assessments occurred in terrestrial conservation planning in Australia. Typical problems included choices about which areas should be selected to protect habitats and species from clearing for timber and agriculture. The scale and urgency of these problems provided the impetus for many advances in applied conservation ecology, reserve design, and computer assisted decision support systems.

One of the most important principles to come out of this work is the need to protect representative areas of biodiversity. Pressey (1995) refers to protecting the 'crown jewels' of near pristine, scenic, highland wilderness habitats which are usually spared from land clearing and development but ignoring lowland habitats that may include a larger representation of biodiversity. He describes many of these flat, arable habitats as the 'walking wounded' and 'irretrievably stuffed'.

This need to protect a representative range of biodiversity is a concept that has driven much of the research to identify and map ecological 'surrogates' for biodiversity and the develop reserve selection algorithms to efficiently represent this diversity within protected areas for the least cost. The use of computer based methods is not essential to the process, but can make the interpretation of large amounts of data less laborious and more accessible. The use of these methods in planning for marine protected areas has not been widespread until recently. However, an early application was initially tested alongside the planning process for the Cairns section of the Great Barrier Reef Marine Park (Cocks *et al.* 1983) and Bakus (1982) explored the use of multiple criteria analysis to select marine reserves. Other early assessments have used a systematic approach to assess potential MPAs, albeit without the kinds of tools now available.

Ward *et al.* (1998) provide a general description and 'tool kit' for systematic reserve selection which they term 'Marine BioRap', "a methodology and set of analytical tools for identifying and assessing, in less than 18 months, priority areas of marine biodiversity." The process is a marine version of a terrestrial 'BioRap' process (Margules and Redhead 1995) which can be summarised as follows.

1. Define objectives.
2. Review, choose and collate data
3. Select physical and/or biological variables to predict diversity.
4. Model the spatial distribution of this diversity.
5. Target minimum amounts of diversity to be represented.
6. Use algorithms and other tools to optimise representation and minimise cost.
7. Incorporate other ecological, social, economic, and management considerations.
8. Combine these techniques with consultation.
9. Evaluate site selection.

3.2 Representing spatial patterns in biodiversity

One of the more difficult problems in systematic protected area assessments is choosing a set of variables that can be applied consistently across large regions to summarise the complex diversity in marine ecosystems. For almost all situations these variables, often termed surrogates or proxies for biodiversity, will represent only a small proportion of the full detail of species, habitats and physical and biological processes. They are often based on predictions from a limited data set of sparse observations. Their validity therefore relies on assuming that only the most conspicuous and well known patterns will be adequately described. While surveys can provide reliable information about some species at some places and times and perhaps information on some related species, they are unlikely to be informative about other groups of organisms (Faith and Walker 1994).

Figure 3.1 shows a conceptual representation of relationships among the environmental domains of a sample of fishes, other unsampled fishes and organisms, physical environments and other unknown factors. The implication is that while surrogates can infer distributions about some features, few will be comprehensive in capturing all variation.

Despite this, surrogates can be effective at describing gross spatial patterns in biodiversity providing that the assumptions linking the surrogate with the target biodiversity can be reliably demonstrated in some way. Surrogates for biodiversity can be grouped into environmental predictors, biological predictors, models that combine and interpolate physical and biological data and 'delphic' or expert consensus methods. These approaches are described in the following sections.

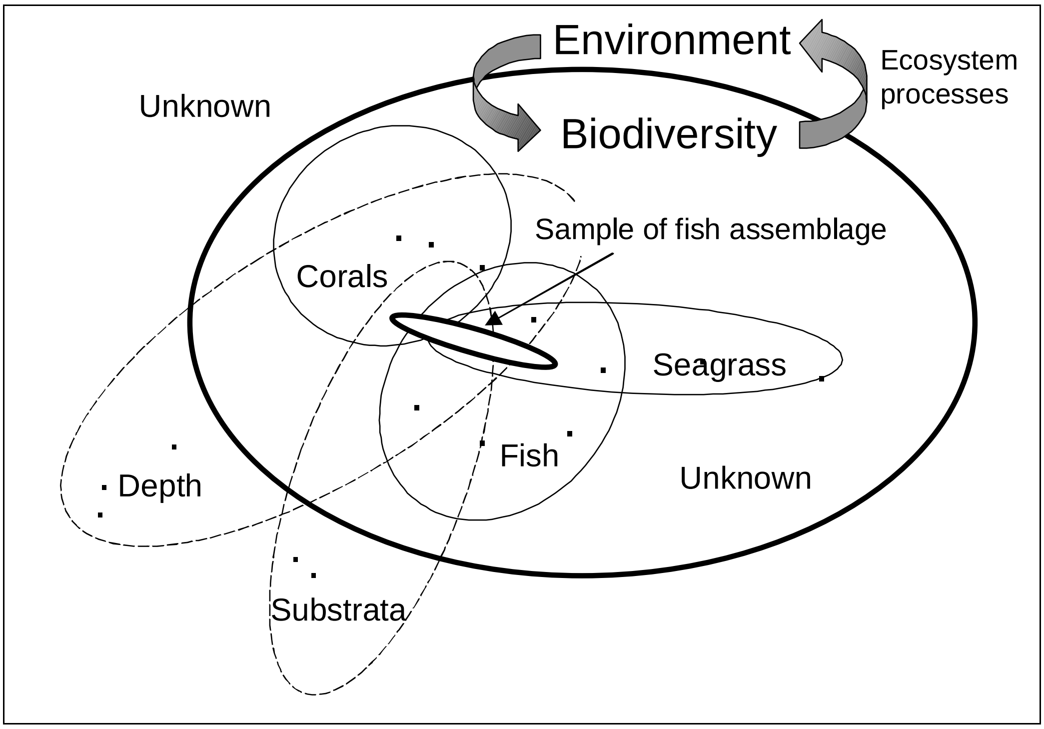


Figure 3.1. Conceptual diagram of potential correlations and relationships among physical environments, biodiversity, unknown or unmeasured variables and one survey of fishes.

3.2.1 Mapping of physical and biogenic features

This approach assumes, on the basis of ecological theory and research, that the physical or biogenic features mapped, will correlate with variations in ecological processes, habitats and the distributions of organisms. For broad scale patterns in biodiversity, general relationships of this kind are often well documented (Day and Roff 2000, Roff and Taylor 2000, Roff *et al.* 2003). It is reasonable, for example, to expect that the types of organisms in deep sea trenches will differ from those on continental shelves or in estuaries, or that assemblages of rocky shore species are distinct from the types of organisms found in seagrass beds or on coral reefs. Otway (1999), for example provides an example of how species richness increases as additional types of intertidal habitat are sampled.

A major advantage of this approach is that extensive physical surveys often already exist and can provide rapid, cost-effective predictors of major patterns in biodiversity. Sources of information include bathymetric models of the seabed, oceanographic surveys and geomorphological classifications of coastlines, estuaries and substrata. The increasing availability of technologies in sonar, aerial photography and satellite imagery mean that almost continuous coverages for some attributes can be obtained. This approach has the advantage of potentially capturing undescribed and perhaps unknown components of biodiversity (Faith and Walker 1996a, Vanderklift *et al.* 1998, Ward *et al.* 1999). It also has advantages in including a range of physical habitats and processes that may be important in maintaining biodiversity and evolution. For many areas, physical predictors will also provide a more stable predictor of long term patterns in biodiversity.

The disadvantage of this approach is that at finer scales, the relationships among physical and biological factors become more complex and include interactions with local biological effects such as competition, herbivory (Randall 1974, Potts 1977, Harmelin-Vivien *et al.* 1992), predation (Fairweather and Underwood 1991), recruitment (Williams 1983, Meekan *et al.* 1993) and biogenic modifications in habitat (Bologna 2000, Monteiro 2002, Hewitt *et al.* 2005). At local scales, physical predictors may only explain a small component of biological variation (Stevens and Connolly 2004). Ecological relationships may also involve indirect higher order interactions, synergisms and alternate states that may be dependent on a history of disturbance and other processes (Done 1992, Done and Potts 1992, Hughes 1994, Connell 1997).

Geographic overlays of several major environmental factors like temperature, depth and substratum may be useful in defining habitat differences among broad regions but simply intersecting an increasing number of physical variables to predict species assemblages at smaller scales may not be so successful. The key here may be to only rely on physical categories that can be clearly supported by documented differences in biodiversity and ecological processes. These categories are often well defined, and may also be easily recognised and accepted by the broader community. However, while they may describe conspicuous differences in biological assemblages, they may still fail to represent subtler differences in the distributions of many species and ecological processes. Examples of these include the differences in sediment infauna and epifauna associated with small structural isolates on the seabed (Thrush *et al.* 2001, Hewitt *et al.* 2005,) or in areas adjacent to reefs (Barros *et al.* 2001) or around seagrass (Tanner 2005).

3.2.2 Biological surveys sampling organism distribution and abundance.

Direct observations on the location, abundance and other characteristics of organisms range from incidental sightings, museum collections (McCarthy 1998) and commercial harvest data (Pease, 1999), to dedicated statistically designed surveys (Otway 1999, De'Ath 2000, De'Ath and Fabricius 2000, Ninio *et al.* 2000, Otway and Parker 2000, Gladstone and Davis 2003, Shears *et al.* 2006, Morrison and Carbines 2006).

Where available, data that is collected systematically can provide reliable information on the distributions of the organisms sampled, and these distributions may also indirectly include other organisms associated with the sampled biota. However, for surveys and particularly museum collections and incidental sightings, there are often biases in the taxa, locations and habitats sampled. Faith and Walker (1994) and others (Kati *et al.* 2004) have also highlighted how different groups of organisms with different distributions may not provide good indicators for each other.

Observed biological distributions may also not persist with time, and in this respect, physical classifications can provide a more enduring surrogate. The biggest problem with species data is that it can be difficult and expensive to collect and identify and that observations are usually more sparse than for physical surveys. Both physical and biological data will however, usually require some level of interpolation and remote sensing for biological data is improving and being integrated with biological field survey techniques (Davis *et al.* 1990, Stoms and Estes 1993).

3.2.3 Modelling from biological, physical and spatial predictors.

Where data is sparse, it may be useful to interpolate patterns across the region of interest. Both physical and biological data sets are composed of individual sample points, although the distributions of biological data points are often more sparse and more irregular. Both however, usually require interpolation with, preferably, an estimate of the uncertainty of the predictions. The danger is that interpolations can give the impression that more is known than is the case.

Interpolation can be done subjectively, but there are a range of mathematical interpolation and smoothing methods that can be used. Interpolation may be based on correlations among physical data or among species data alone. However, where relationships can be established between physical predictors and species distributions, these correlations can be used to interpolate species occurrences at sites where only physical data is available. Where the prediction of the spatial distribution of organisms is the main goal, regression against spatial coordinates alone can be very effective (Legendre 1994, Fernandes *et al.* 2005). However, modelling the functional relationships between physical predictors and species assemblages can also provide information on the underlying environmental causes of species distributions (Nicholls 1989, 1991, Swartzman *et al.* 1994, Leathwick *et al.* 2006a).

The statistical methods available to produce these interpolations include univariate models (Cerco and Moore 2001), multivariate cluster analyses (Riegl and Riegl 1996, Stevens 1998, 2002, Vanderklift *et al.* 1998), ordinations (Emanuel *et al.* 1992, Valesini *et al.* 2003), probabilities of occurrence and detection (Polasky *et al.* 2000, MacKenzie *et al.* 2005, 2006), classification and regression trees (Walker and Cocks 1991, De'Ath and Fabricius 2000, Leathwick *et al.* 2006a), general linear (Nicholls 1989, 1991) and additive models (Stoner *et al.* 2001) and spatially explicit geostatistical techniques (Rodriguez and Farina 2001, Rueda 2001, Fortin, Dale *et al.* 2002, Fortin and Dale 2005). Several of these techniques are able to fit non-linear and higher order interactions. Non-parametric permutation tests (Anderson 2000), likelihood estimates and Bayesian analyses (Hobbs and Hillborn 2006) can also assist in dealing with some of the other problems associated with ecological data.

The prediction methods chosen depend on the nature of the data and on what purpose is intended. For example, reducing the dimensions of multivariate data into groups of species or regions of similar habitat or fauna can clarify the dominant patterns in complex data sets. These summaries are useful for providing readily interpreted, graphic representations of patterns in biodiversity for planning, management, education and awareness. The resulting bioregionalisations are often used as the foundation for conservation planning but can become embedded in management policy as standard universal measures of biodiversity for conservation targets. It therefore needs to be recognised that they necessarily impose a reduction in the information available for subsequent analyses and decisions and may mask patterns in individual variables and neglect unsampled species.

On the other hand, most reserve selection algorithms, for example, implicitly aim to maximize representation for many individual habitats or species. A prior reduction in the dimensionality of the data for these methods may therefore be unnecessary and can result in subtle differences being ignored. In selecting a bioregion or other category, it may also be difficult to determine which particular species or other features are being targeted. Leathwick *et al.* (2006b) found for example, that using the predicted distributions of individual fish species as data in reserve selection algorithms generated a more representative system of MPAs for the New Zealand Exclusive Economic Zone than using a single compiled biological or physical regionalisation.

Algorithms may also give undue emphasis to the boundaries between classified bioregions which are often approximate and open to interpretation. The boundaries of the Interim Marine and Coastal Regionalisation for NSW (IMCRA 1998) for example, define five bioregions in the state. However, analyses for the initial derivation of these bioregions (Pollard *et al.* 1997) and subsequent studies (Pease 1999), define several alternative regions depending on the taxa and physical features analysed and for many years incorrect boundary locations were commonly reported before significant errors in coordinates were even detected.

Faith and Walker (1996a), Belbin (1995) and Pillar (1999) also note that categorical summaries lose information on the differences that exist between and within categories or regions. Different clusters or regions are sometimes assumed to be homogenous and equally distinct from each other when this is unlikely to be true. Faith and Walker suggest that this can be avoided by modelling variation as a continuous gradient and using a selection approach that minimizes the sum of the environmental dissimilarities between points and areas within the reserve system.

There are also methods that make use of indicator (MacNally and Fleishman 2004), keystone (Hurlbert 1997, Edinger and Risk 2000), umbrella and flagship species (Mouillot *et al.* 2002). These and other biodiversity indices (Foggo *et al.* 2003) may be useful in the right circumstances, but unless verified, may not provide reliable predictors for other components of biodiversity (Hurlbert 1971, Kershaw *et al.* 1995, Gibbons *et al.* 1997).

3.2.4 Delphic consensus of experts

This technique, in various forms, involves providing people with the relevant expertise, a set of objectives and having them reach a consensus in opinion. According to McArdle (1995), the method has its origins with the

"...Pythia, the prophetess at Delphi (who) produced uttered incomprehensible gibberish while stoned out of her mind on burning laurel leaves (cyanide poisoning), which obliging and politically astute priests of Apollo interpreted for the supplicant so that whatever actually happened, no blame could come on them, the original teflon bureaucrats. The thought of groups of marine scientists getting stoned out of their minds at meetings, and the hovering bureaucrats interpreting the resulting advice to their ministers so that none of the blame would attach to them is too far fetched..."

Despite this somewhat flippant interpretation, McArdle goes on to say that the experience and knowledge in such forums can complement other data and analyses which in turn can provide a core for discussions to focus on. In practice therefore, it may be useful to combine elements of all of the above approaches, providing that data and expertise are available. In most cases, there will be range of experience, information and classifications that can all provide meaningful input to planning. Management programs often attempt to seek the one ideal data set, classification or method that will explain everything. While this may seem more efficient and provide results that are easier to interpret, it may sometimes be better to work with complexity, rather than ignore information on the grounds that there is only one correct approach .

3.3 Decision support tools for MPA planning

Decision support is about providing and organising information to assist in decision making. In its broadest sense it can range from literature reviews, database reports and GIS displays, to computer assisted models analysing multiple criteria and providing scenarios for alternative decisions. Decision support is meant only to facilitate human decision making but is useful where large amounts of information and complex problems are involved. Identifying options for MPAs from a potentially large range of possibilities, criteria and information sources is one management area likely to benefit from decision support.

The following sections review some of the decision support tools that have been useful in conservation planning. These include GIS, simple scoring techniques, reserve selection algorithms and multiple criteria analysis. Other potentially valuable techniques include the use of expert systems (Muetzelfeldt *et al.* 1989, Ritchie 1989, Rykiel 1989, Leimbach 1994), fuzzy logic (Burrough *et al.* 1992, Fang 1997, Zeng and Zhou 2001, Zeng *et al.* 2003, Jenkins 1997), neural networks (Tan and Smeins 1996) and other knowledge based systems (Zhu *et al.* 1998, Reynolds 1999, Saunders and Miller 2002). The latter methods have rarely been applied to marine protected areas (although see Jenkins 1997, 1999) and are not reviewed in detail here. However, there is considerable potential for their development and application in marine conservation research and planning.

3.3.1 Geographical Information Systems and databases

The primary question in identifying where MPAs are to be located is defined spatially. The aim is to identify the best areas to locate MPAs to conserve biodiversity given that protection will come at some cost and opposition from competing forms of use. Another consideration is how to synthesise within one framework, a range of information derived from many different disciplines, data sources and formats. A third basic problem is how to communicate this knowledge to managers, stakeholders, communities and politicians for many different locations, situations and scales of observation.

One development in the last 20 years has done much to address all three of these challenges. Geographic Information Systems are unique in that they mathematically map points, lines, shapes, regions, grids, processes and three dimensional objects in geographic space and can link each of these features (topology) to many different quantitative and qualitative data sets of descriptive attributes. This GIS environment is therefore capable of representing, in realistic detail, the landscapes, habitats, species, processes and human values that comprise ecosystems and link these directly with the mathematical and descriptive tools of modern science.

The raster grid cell capabilities of GIS also enable remotely sensed data from satellite, aerial photography, radar, sonar and video to be directly imported and geographically aligned with other spatial data sets. Directional and temporal attributes in line features can be used to represent flows and processes and the movements of organisms (Klimley *et al.* 2001, Willis *et al.* 2001) and propagules. When coupled with remote sensing systems, GIS can be used to quickly and accurately map large areas of coastal and submerged habitats and species using high resolution photography (Ekebom and Erkkila 2003), radar (Mason *et al.* 2001), LIDAR (Francis *et al.* 2005), multi-spectral camera, single beam (Pitcher 1999), sidescan sonar (Bickers 2004), multi-beam sonar (Wright *et al.* 2002) and video (Kostylev *et al.* 2001, Cappo *et al.* 2003, Fitzpatrick 2003, Jordan and Barrett 2003, Hewitt *et al.* 2004, Parsons *et al.* 2004, Morrison and Carbines 2006).

Grid data and vector (shape) data can be easily coupled to most other databases or modelling tools. Both are compatible with a range of mathematical modelling techniques including fuzzy set methods (Jenkins 1999, Zeng and Zhou 2001), expert systems, gap analyses (Bushing 1997, Powell 2000), individual based models, statistical models (Skidmore and Gauld 1996, Stoner *et* *al.* 2001, Fernandes *et al.* 2005) and geostatistical models (Lathrop *et al.* 2001, Pettigas 2001, Rodriguez and Farina 2001, Rueda 2001).

Measurements from non-GIS data sets that have at least some locational information can be readily linked to sites or approximate planning units to create new multivariate datasets derived from many different data sets. In this way, a wide range of information for different species, habitats, social, economic and management values can be integrated within the same model (Mallawaarachchi *et al.* 1994, 1996, 2001). GIS provides an ideal spatial environment to view the results of multivariate statistical analyses (Bollard-Breen 2006), predict and interpolate spatial distributions for species and environmental values (Kerrigan *et al.* 1999, Leathwick *et al.* 2006a) and to design research and monitoring programs (Nicholls 1989, Belbin and Austen 1991).

GIS can also quickly generate large ‘site by attribute’ datasets for use in reserve selection algorithms and to display and manipulate results for different scenarios. GIS are now also being used in ‘participatory’ and exploratory analyses that enable scientists (Kerrigan *et al.* 1999, Lewis *et al.* 2003), managers, stakeholders (Pressey 1998) and communities (Bruce and Eliot 2006) to work together with large, ecosystem-scale data sets. The powerful visualisation capabilities of GIS in two and three dimensional spatial formats is realistic and easily interpreted (Goodchild *et al.* 2000). For most people, GIS provides a more intuitive way to view information on natural systems than more abstract representations like summary statistics, graphs, ordinations and streams of numeric values in database tables.

However, the acceptance of GIS into mainstream ecology and marine science has been slow. This is surprising given the spatial context of many ecological questions, the evolution of fields like landscape and seascape ecology (Ray 1991, Fairweather and Quinn 1992, Jones and Andrew 1992), and the development of methods in spatial statistics (Dale *et al.* 2002, Liebhold and Gurevitch 2002, Fortin and Dale 2005) and modelling (Guenette and Pitcher 1999, Walters 2000, Walters *et al.* 2000).

GIS has been most frequently applied in geography, geology and planning to map landforms, vegetation and human infrastructure with a tendency towards descriptive rather than quantitative analysis. In ecology, and particularly marine ecology, there has been a strong emphasis on experimental techniques. However, in experimental approaches space, as a variable, is often ignored or randomised to avoid confounding with the immediate variables of interest. This approach has extended beyond laboratories and standard treatment plots to field experiments and regional monitoring programs which, until recently, have tended to ignore their obvious spatial context.

Data from many regional programs can provide an important input to spatial models and broad scale conservation planning. For this to be done however, requires at least approximate spatial coordinates, and the systematic sampling of whole regions, not just isolated sites. It also requires that data be made available to integrated programs that extend beyond the immediate focus of individual research projects and that these opportunities are recognised when initially planning and designing field studies.

Finally, GIS are the preferred tools to accurately map, edit, document and communicate the legal boundaries that define MPAs. The following chapters will demonstrate how GIS can be used to integrate data on ecosystems, develop models to assist in conservation planning and eventually establish MPAs to help conserve marine ecosystems and manage their use.

3.3.2 Planning units.

Planning units are predefined geographic areas used to integrate different data sets, compare values among regions and assess alternative plans. They are usually contiguous non-overlapping polygon cells or raster grids that partition the area of interest into a network of units that can be selected, compared, assessed and included or excluded from hypothetical reserve systems.

Each cell is assigned a unique numerical code, descriptive attributes and values, and spatial attributes of size, shape and location. Manually or automatically selecting a cell or group of cells also selects the values associated with the planning units for display or as inputs into analyses. Planning units may be any shape but can be:

- square, hexagonal or other regularly shaped cells
- irregular polygons based on natural or man made boundaries or
- combinations of both regular and irregular cells.

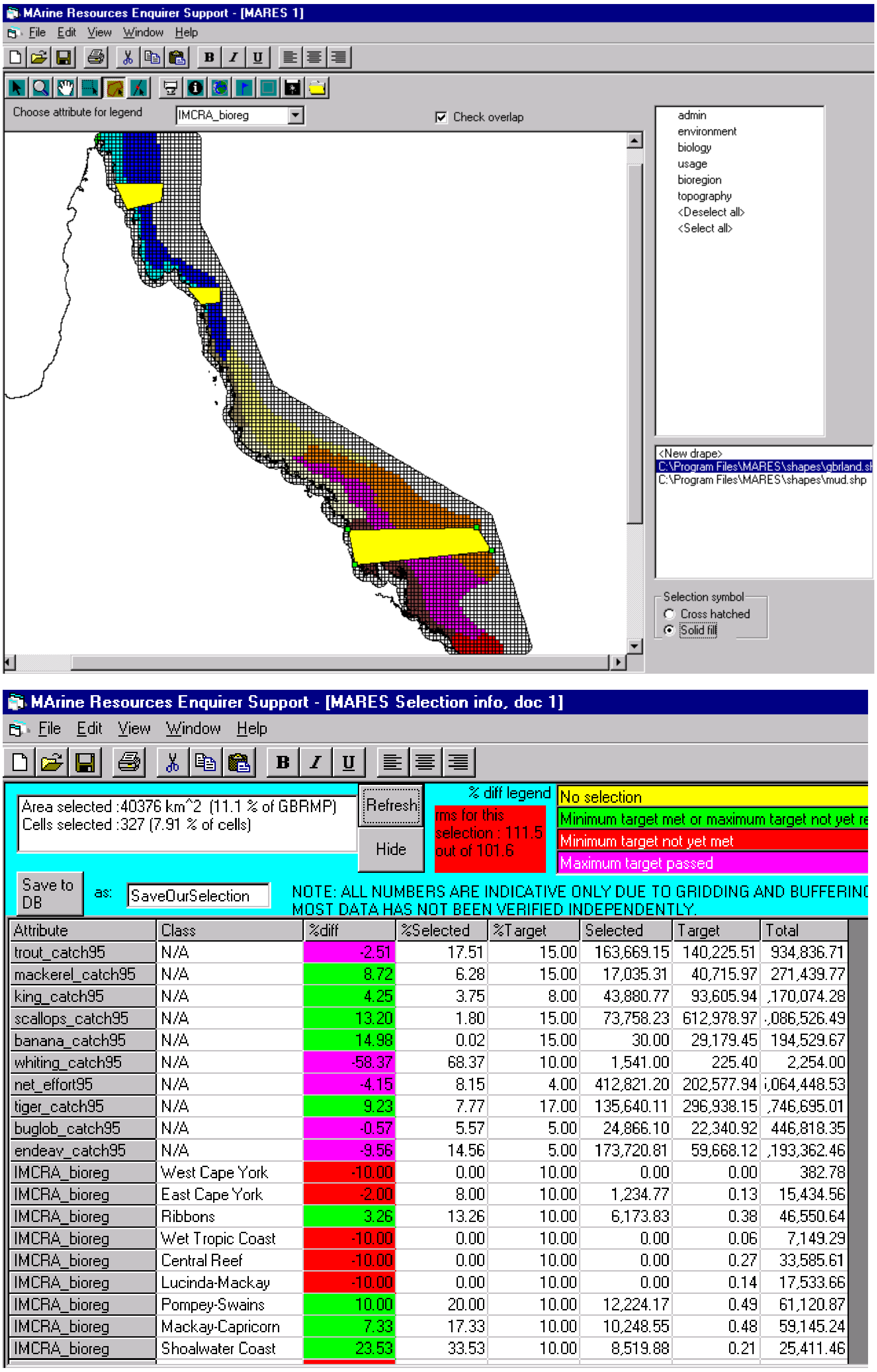
The size and shape of the planning units should reflect the scale and accuracy of the information used, the scale at which MPA options need to be identified and the computational limitations of the software and computers employed. The use of regular cells of equal area may mean that initially, most units have an unbiased opportunity to include conservation features. Smaller irregular cells are less likely to include large areas of different features, however their shape can be used to closely follow natural landforms, jurisdictions, or other boundaries (e.g. high tide mark). This can be important, when tailoring specific, realistic reserves for some audiences.

Empirical trials have shown that planning unit size can significantly affect the outcome of analyses. Where a selection method is required to reach a critical threshold, larger planning units are more likely to ‘overshoot’ area targets (Pressey and Logan 1994, 1998). Smaller planning units, may however, not be large enough to include more than one conservation feature. In the latter situation, the selection methods may be unable to discriminate among the relative value of alternate units and selection can become arbitrary. It is therefore worthwhile to trial a range of planning unit sizes and it may even be worth considering different units for different purposes within the same project.

3.3.3 Simple scoring and graphic techniques.

If goals and criteria have been defined, and information or expert opinion is available, locations can be assessed using quantitative scores, ranks or qualitative values. Tables of individual values can be used to help identify suitable areas or aggregate totals of weighted or unweighted scores can be used as a measure of suitability (Rabe and Savage 1979, Purdie 1987). In NSW, this approach has been used to assess estuarine and intertidal aquatic reserves (Otway 1999, Frances 2000), coastal lagoons (Healthy Rivers Commission 2002) and estuaries (Bell and Edwards 1980, Digby *et al.* 1998). Conservation values can also be displayed on charts but graphical methods can be limited in situations where there are large numbers of sites, variables or categories.

Displays of these measures for planning units in a GIS allow spatial patterns to be rapidly identified at a range of scales. Pantus (1998a) for example, developed a prototype GIS based scoring model (MARES) as a stand-alone ESRI MapObject application for the Great Barrier Reef Marine Park Authority (Figure 3.2). The model displays, colour-codes and updates tabled scores for criteria as different planning units are selected. This tool provided information on the areas and percentages of different bioregions and habitats represented in different marine park zoning options, as well as the potential costs for different commercial fisheries. This prototype, stand-alone GIS tool was designed to be widely distributed to managers, scientists, stakeholders and communities. The NSW National Parks and Wildlife reserve selection tool, C-Plan (NPWS 2001) has a similar capability but also estimates the statistical irreplaceability of a site in contributing new species and habitats to existing networks (Pressey and Nicholls, 1989). C-Plan and other related techniques are reviewed in the following section.



Attribute	Class	%diff	%Selected	%Target	Selected	Target	Total
trout_catch95	N/A	-2.51	17.51	15.00	163,669.15	140,225.51	934,836.71
mackerel_catch95	N/A	8.72	6.28	15.00	17,035.31	40,715.97	271,439.77
king_catch95	N/A	4.25	3.75	8.00	43,880.77	93,605.94	,170,074.28
scallops_catch95	N/A	13.20	1.80	15.00	73,758.23	612,978.97	,086,526.49
banana_catch95	N/A	14.98	0.02	15.00	30.00	29,179.45	194,529.67
whiting_catch95	N/A	-58.37	68.37	10.00	1,541.00	225.40	2,254.00
net_effort95	N/A	-4.15	8.15	4.00	412,821.20	202,577.94	,064,448.53
tiger_catch95	N/A	9.23	7.77	17.00	135,640.11	296,938.15	,746,695.01
buglob_catch95	N/A	-0.57	5.57	5.00	24,866.10	22,340.92	446,818.35
endeav_catch95	N/A	-9.56	14.56	5.00	173,720.81	59,668.12	,193,362.46
IMCRA_bioreg	West Cape York	-10.00	0.00	10.00	0.00	0.00	382.78
IMCRA_bioreg	East Cape York	-2.00	8.00	10.00	1,234.77	0.13	15,434.56
IMCRA_bioreg	Ribbons	3.26	13.26	10.00	6,173.83	0.38	46,550.64
IMCRA_bioreg	Wet Tropic Coast	-10.00	0.00	10.00	0.00	0.06	7,149.29
IMCRA_bioreg	Central Reef	-10.00	0.00	10.00	0.00	0.27	33,585.61
IMCRA_bioreg	Lucinda-Mackay	-10.00	0.00	10.00	0.00	0.14	17,533.66
IMCRA_bioreg	Pompey-Swains	10.00	20.00	10.00	12,224.17	0.49	61,120.87
IMCRA_bioreg	Mackay-Capricorn	7.33	17.33	10.00	10,248.55	0.48	59,145.24
IMCRA_bioreg	Shoalwater Coast	23.53	33.53	10.00	8,519.88	0.21	25,411.46

Figure 3.2. Screen view of the prototype MARES GIS decision support tool developed by Pantus (1998a). The display shows selected hypothetical no-take zones in yellow on a background map of the Queensland IMCRA bioregions. The spreadsheet shows the areas and percentages of bioregions selected, fisheries catches likely to be affected, threshold targets and performance in meeting or exceeding thresholds.

3.3.4 Selection algorithms, complementarity and irreplaceability

To meet criteria for representativeness, a system of MPAs should aim to represent a comprehensive range of different habitats and species. However, there are usually economic, social and political constraints on how much of the marine environment can be included within MPAs. There are now several computer assisted techniques that aim to represent multiple habitats, species or other conservation features while minimising costs to competing activities. These approaches will generally achieve these goals more efficiently than simple scoring techniques or *ad hoc* selection (Lomolino 1994).

Maximum covering problems and minimum set problems

Mathematical reserve selection algorithms either aim to select areas that maximise representation of a set of conservation features for a given cost constraint (a maximal coverage problem) or conversely, meet threshold targets for a set of conservation features while minimising costs (a minimum set or minimum area problem, Cabeza and Moilanen 2001). For situations involving a few areas and values, this can be done manually by inspection. However, with increasing numbers of sites and features, the problem rapidly becomes more complex and mathematical algorithms are best used to identify solutions from potentially millions of possible combinations of sites (Possingham *et al.* 1999).

The techniques can be categorised as either exact or inexact (Cabeza and Moilanen 2001). Linear integer programs use branch and bound algorithms to solve for the exact combination of sites that optimises representation for a given cost. This method was used by Kirkpatrick (1983) to identify representative areas of Tasmanian forest to be protected from logging. This approach has been demonstrated to provide optimal solutions for relatively small (Underhill 1994, Church *et al.* 1996) to medium size data sets (Fisher and Church 2005), but as the number of sites and features increase, the time taken to reach a solution can become impractical.

Inexact methods include iterative heuristic algorithms that repeatedly apply a set of rules in a step-wise manner to sequentially add sites to a reserve network until a stopping condition is met. Inexact methods also include 'stochastic global search' methods (Cabeza and Moilanen 2001) like the simulated annealing algorithm included in the reserve selection software Spexan and Marxan (Ball and Possingham 1999, 2000).

Iterative heuristic algorithms

In iterative heuristic algorithms, decision rules within each iteration are used to resolve ties between planning units and to prioritise criteria. Rules are applied in order of priority, so that if several sites of equal value 'tie' for first place according to one rule, a second rule is used to choose the best site using a different criterion.

Many variations and sequences of these rules can be used including, selecting those sites with the most unrepresented features (a greedy algorithm), the rarest features or the highest irreplaceability. Different rules can also be used to select for costs, vulnerability (Faith and Walker 1996b, Pressey and Taffs 2001) and reserve design by selecting the nearest sites to existing reserves (Nicholls and Margules 1993, Briers 2002).

As an example, these sequential decision rules might include the following:

Rule 1. Select the planning unit that includes the rarest habitat not already included.

Rule 2. If there is more than one unit that satisfies Rule 1, select the unit with greatest number of unrepresented habitats.

Rule 3. If there is more than one unit that satisfies Rule 2, select the unit that occupies the least area…and so on.

After finally selecting a site, scores are adjusted to take into account the features added to the reserve network and the rules are applied again. In this way, the algorithm adds sites that complement the features already represented in the network and prioritises those features required to meet targets.

Irreplaceability

The potential value of a site in meeting targets will change as each new site contributes additional features to the network. Pressey *et al.* (1994) define this value conceptually as 'irreplaceability', "...the likelihood that an area will be required as part of a conservation system that achieves the set of targets"; or "...the extent to which the options for achieving the set of targets are reduced if the area is unavailable for conservation."

In explaining this concept Pressey *et al*. state that: "If an area is totally irreplaceable, then no matter how a system of conservation areas is designed for a region, it will have to include that area. Put the other way, if that area loses its conservation values, one or more of the conservation targets for the study area will become unreachable."

Csuti *et al.* 1997 estimated irreplaceability by counting how frequently planning units occurred in different optimal solutions from a branch and bound algorithm. However, these algorithms can be slow for large problems. Ferrier *et al.* (2000) however, developed rapidly calculated statistical estimators of irreplaceability. These irreplaceability statistics are incorporated in the C-Plan reserve selection with links to GIS displays in ArcView.

C-Plan

C-Plan generates an initial view of the predicted irreplaceabilities of all plan units that rapidly provides an indication of which sites are likely to achieve targets efficiently. However, as sites are added to the reserve network, targets are gradually met for some features. As a consequence, planning units containing those features decrease in irreplaceability and this is reflected in negative changes in the colour scale of these units mapped in the GIS. Conversely, irreplaceability for units with features not represented tends to increase as options for reserves are gradually used up, and this is reflected by positive changes in their colour scale.

When all targets for features in a site have been met, irreplaceability for that site approaches zero and the colour of the planning unit in the GIS display fades to white. Units with unrepresented targets increase in value and are highlighted in the map, and units likely to contribute most towards specific, individual feature targets can also be identified and highlighted.

Site irreplaceability and *summed* irreplaceability, are two of several different measures that can be calculated. Site irreplaceability is a measure of the overall likelihood that an area will be required as part of a conservation system to achieve a set of conservation targets. Values for site irreplaceability range from totally irreplaceable (1.0) to zero irreplaceability (0.0) and sites can have any value between these extremes.

A unit with a *site* irreplaceability of 1.0 may indicate that a planning unit is irreplaceable for one or perhaps several conservation targets. However, *summed* irreplaceability is also related to how many conservation targets a planning unit is likely to contribute to. It is derived by summing the individual site irreplaceabilities estimated for each individual conservation target. Summed irreplaceability can therefore range from 0 to numbers greater than 1, depending on how many feature targets are set.

C-Plan allows an operator to add and subtract plan units to and from the reserve system while immediately seeing the effect of these changes on irreplaceabilities, percentage goals and the area protected for different features and sites. The program is therefore a powerful ‘participatory GIS’ tool that enables managers and community representatives to interact directly with the goals, data and spatial boundaries of proposed reserves. The program can also save a significant amount of time for operators and technical staff in building and analysing GIS coverages of alternative proposals.

Marxan and simulated annealing

Simulated annealing is a type of algorithm included in Marxan, a computer program adapted by Ball and Possingham (2000) for the Great Barrier Reef Marine Park Authority (Day *et al.* 2002). It is based on a program developed for terrestrial conservation (Spexan) and written in C, but derived from an earlier, less accessible version, SIMAN, written in FORTRAN at the Department of Applied Mathematics at Adelaide University.

Like C-Plan, Marxan works from a basic data matrix of values (areas or occurrences) for the conservation features (e.g. habitats or species) represented within each planning unit (site) and a related table of costs associated with the decision to include each plan unit in a reserve network. Recent versions of C-Plan are able to use the same main data files as Marxan and call and display Marxan simulations from a C-Plan interface. The two programs complement each other in a number of ways. While both include a selection of heuristic algorithms, C-Plan allows a user to manually select, query, include and exclude plan units and rapidly update statistical irreplaceability maps in ArcView GIS.

Marxan however also includes the ability to influence the spatial arrangement of the planning units selected by the reserve design algorithm. This includes the capacity to:

- minimise boundary length to area ratios and produce a network of more compact reserves (that is less likely to be influenced by edge effects and may be easier to enforce and manage)
- specify minimum reserve sizes, numbers of reserves and the replication of features in reserves
- specify minimum separation distances between reserves for independent replication and representation across geographic gradients.

Algorithms in Marxan aim to minimise an objective function (Equation 1) of the sum of the costs of the plan units in a given reserve system and the sum of the penalties incurred for not meeting specified targets for conservation features.

Equation 1. $\sum_{\text{sites}} \text{Cost} + \text{BLM} \times \sum_{\text{sites}} \text{Boundary} + \sum \text{CFPF} \times \text{Penalty} + \text{Cost Threshold Value}_{(t)}$

The Cost of a plan unit can be measured as the area it includes or some other measure (such as fisheries catches). A cost can also be assigned to the boundary length (or any other boundary cost) of adding a planning unit. A coefficient known as the boundary length multiplier (BLM) adjusts the relative importance of minimising boundary length over other costs and penalties.

The Conservation Feature Penalty Factor (CFPF) is used to weight the relative importance of meeting targets for conservation features. The penalty is roughly the additional cost and modified boundary cost needed to represent features not already adequately represented in the reserve system. A very small or zero value boundary length multiplier tends to generate a reserve system that is highly fragmented but efficient in terms of occupying a small area. A large boundary length multiplier aggregates plan units into larger clumps, but sometimes at an increasing cost in area and, where the CFPF is low, possible failures in meeting conservation targets. The Cost Threshold Value is an optional feature that applies an additional penalty once a specified or time dependent threshold cost has been exceeded (Ball and Possingham 2000).

The program includes variations of different stepwise heuristic algorithms, an iterative improvement algorithm and a simulated annealing algorithm. The heuristic algorithms work by sequentially adding sites to a reserve network according to stepwise criteria until a stopping condition is met. Iterative improvement algorithms randomly add, subtract and/or swap plan units that improve an initial ‘seed’ network to find a local minimum.

Simulated annealing works in a similar manner to iterative improvement. However, in the early stages of simulated annealing, when a parameter described as the ‘temperature’ is set high, both ‘good and bad changes’ to minimise the objective function are accepted. As the algorithm progresses through a set number of iterations, the 'temperature' gradually decreases, and changes that do not decrease the objective function are rejected more frequently until only improvements in the solution are accepted. By randomly accepting many different plan units early in the algorithm, the program avoids local minima and can potentially identify a greater number of near optimal solutions.

For problems with many sites, measures like irreplaceability and heuristic selection methods are more likely to find efficient solutions (represent more conservation values for less cost) than simple scoring or *ad hoc* approaches. However, unlike branch and bound methods, heuristic algorithms are less likely to find perfectly optimal solutions (Cocks and Baird 1989; Underhill 1994). However, they can rapidly find approximate solutions for relatively complex problems. In addition, these approaches may identify a potentially greater variety of near optimal, alternative solutions, which can be advantageous where flexibility is important.

If the simulated annealing algorithm is run repeatedly (e.g. 100 times), it will generate 100 near optimal solutions to the problem. This variety of options may therefore be more flexible in providing solutions to meet other design criteria and in suggesting compromises between conflicting conservation and stakeholder requirements. The frequency with which planning units occurs in a set of solutions from many runs also provides a readily interpreted measure of irreplaceability (e.g. 0-100% of runs) that can be mapped. The 'best' solution of all runs as well as any other near optimal solution can also be mapped individually.

Zonation

Other approaches to incorporating reserve design in selection algorithms are recommended by Moilanen *et al.* 2005. These are implemented in a backward step-wise algorithm called 'Zonation'. The algorithm starts from a set of all sites, then iteratively discards low value sites from the edges of the remaining area to 'maintain the structural connectivity' of the remaining habitat. Sites are removed gradually, leaving the most important sites till last. A 'nested zoning' which reflects the order of site removal can then be mapped to indicate site priority (Moilanen and Wintle 2006).

Aggregated reserves can also be obtained by smoothing species distributions before selection procedures and incorporating probabilistic measures of uncertainty, persistence and dispersal (Araujo *et al.* 2004, Cabeza *et al.* 2004, Moilanen and Cabeza 2005). Species persistence can be iteratively defined as species' responses to habitat loss change with the changing structure and quality of the evolving reserve network (Cabeza 2003, Moilanen and Wintle 2006).

For computational reasons, all of the above methods require specific thresholds or targets to be set for either costs or conservation features. These can be used prescriptively according to agreed policy or used to explore the consequences of alternative scenarios. Targets can be set identically for all features or set individually to reflect priorities for specific features and situations. While specific targets are required for the computation of most reserve selection algorithms, reaching agreement among managers and stakeholders on the 'correct' targets to use can be difficult. While some standard targets have been recommended, these might logically be quite different for various habitats and species, for different contexts (e.g. targeting an absolute area or a % of a habitat, a park, a bioregion or some other region) or different purposes (e.g. fisheries or biodiversity conservation). A complete reliance on these statistics can also obscure the importance of other criteria (e.g. Figures 2.1 to 2.4) which might not be summarised so easily (Agardy *et al.* 2003).

In the assessments conducted in this thesis, specific thresholds were not pre-determined, but a range of suggested targets were trialled in consultation with managers and stakeholder representatives. These methods are well suited to exploring the outcomes of using a range of targets, although it is difficult to portray all scenarios within a written document. For simplicity, examples using arbitrary targets or a range of targets of equal value for each conservation feature are described. The methods however, allow for much greater flexibility and this capability is ideally used in conjunction with input from managers, scientists and stakeholders.

Environmental Diversity

Faith *et al.* (1996a) describe a quite different approach that avoids splitting continuous environmental variation into surrogate categories and having to set targets for an arbitrary number of landscapes or habitat types. They suggest deriving an 'environmental space' from ordinations of environmental factors and species distributions and using distances in this space to select sites that best span this environmental diversity.

The rationale is that "the number of species represented by a set of areas will be large to the extent that on average, the distance from any point in the space to its nearest protected area is small. The expected complementary value of an area (the relative number of additional species it contributes) is indicated by the extent to which addition of the area to a partial set reduces the sum of these distances."

This is a special case of a 'p-median criterion' and forms the basis of a number of reserve selection algorithms which can also incorporate various costs, vulnerabilities and the results of multiple criteria analyses reflecting the preferences and attitudes of interest groups.

3.3.5 Hierarchical multiple criteria analysis models.

The conceptual 'trees' of MPA goals and criteria described in Chapter 2 can be used to model the degree to which alternative sites meet an overall goal calculated as a function of their scores against prioritised criteria. There are many forms of these analyses and they have been reviewed in detail by Mardle and Pascoe (1999). The methods have been widely applied in business management and environmental impact assessment (Edwards 1977, www.expertchoice.com), with some applications in fisheries (Mardle and Pascoe 1999) and in selecting protected areas (Bakus 1982, Fernandes 1996, Rothley 1997, Guikema and Milke 1999, Villa *et al.* 2002). The techniques can incorporate weighting of criteria, calculation of trade offs, representation of uncertainty, sensitivity analyses of the relative influence of different criteria, and the ability to combine and assess alternative models, data and sources of opinion.

The simplest is the Simple Multi Attribute Rating Technique (SMART) which evaluates alternatives according to hierarchical tree of detailed criteria nested within several levels of more general criteria which ultimately converging to single, broad goal. For each alternative, standardised scores are assigned to the most specific criteria. The overall aggregate score in achieving the main goal is calculated as a function of the standardised scores for the many sub-criteria, weighted according to priorities assigned to criteria at each level in the tree. Guikema and Milke (1999) use this technique to prioritise projects for the New Zealand Department of Conservation.

The Analytical Hierarchy Method (AHP, Saaty 1980) is a similar technique which uses the dominant eigen vectors from matrices of pair-wise comparisons among criteria to determine the relative importance of weights and, or scores. The pair-wise comparisons are usually derived from questionnaires or interviews of stakeholders or others involved in decision making. This approach was used by Fernandes (1996) to assess community preferences in the management of Saba Marine Park and by Villa *et al.* (2002) to develop a zone plan for the Asinara Island National Marine Reserve.

In either method, the scores and priorities for criteria and alternatives can be derived from quantitative or qualitative data and the method permits information from widely different sources to be integrated within a single analysis. Priorities for criteria within each level of the tree may represent policy, law or stakeholder preferences or the reliability and relevance of different data sets for each criterion. Sensitivity and trade-off analyses can also be used to determine how the priority for a criteria would need to change before it produces a different outcome. In this way, criteria that are most likely to influence decisions can be isolated and alternatives likely to satisfy a range of different priorities can be identified as compromises.

In this thesis, the SMART technique is used to assess goals and criteria for all estuaries and sections of coast and ocean in the Manning Shelf bioregion. In the Hawkesbury, Batemans and Twofold Shelf assessments, this technique is used to compare nine different options for large marine parks.

3.3.6 Expert advice, anecdotal information and delphic workshops

The advice of scientists, managers, stakeholders and communities should be part of any process to identify and select MPAs. Much of the scientific information used to assess MPA options is collected for purposes other than the selection of MPAs. It is therefore prudent to have experts familiar with the methods and phenomena to interpret the strengths and limits of the data. They can also advise on additional sources of information and where data is sparse, they can provide expert judgements on the predicted distributions of species, communities, processes and sites of special ecological significance. They may also be best qualified to recommend what protective measures are likely to succeed in conserving biodiversity and ecosystem processes.

For many criteria there will be few, if any, data. There may however, be substantial knowledge to be gained from unpublished scientific observations and the experiences of many stakeholders. To estimate social and economic costs, information is also required on the locations and natural features most valued by stakeholders. Systematic survey data on these values is rarely available at the scales required for the selection of MPAs, and thus the people involved in marine activities are often the best, and sometimes the only, source.

These ‘informal’ sources can accessed through surveys and interviews and through workshops of representatives. The main challenges here are dealing with the potentially large number of possible contributors, and obtaining an unbiased representation of views. Voluntary submissions are often required as part of official consultation processes. These provide an opportunity to obtain information on specific values and locations of concern to different individuals and groups. Such submissions can however, be dominated by those most likely to be affected or concerned by changes in management. They should therefore be interpreted cautiously and where possible, independently verified. Statistically designed social and economic surveys, field observations and other independent sources can help in checking and supporting anecdotal information.

Workshops require guidance and direction to be useful, especially given the number of individuals involved and their often varied backgrounds and perspectives. Clear objectives and terms of reference are needed and an independent facilitator is desirable. Good information, tools and specific tasks to complete can also help to focus discussion on achieving outcomes.

3.4 Regional marine biodiversity classifications

There is an increasing trend towards coordinated programs to identify and establish systems of marine protected areas. These include global assessments, regionalisations (Kenchington and Bleakley 1994, Kelleher *et al.* 1995), databases (Grassle 2000) and many programs aiming to establish networks of MPAs. For many areas, a classification of marine regions has been a first step in describing broad patterns in marine ecosystems (Ray *et al.* 1975, Dethier 1992, McDonald and Cocks 1993, Hamilton *et al.* 1995, Hamilton and Cocks 1995ab, Walls 1995, IMCRA 1998, Day and Roff 2000, Roff and Taylor 2000, Roff *et al.* 2003, Fernandes *et al.* 2005).

All of these regionalisations provide a simplified representation of the environment and presumably the associated biota. They are, as such, only approximate surrogates. It is often possible that several different versions of a regionalisation are developed that emphasise one or more characteristics. This is not surprising given the aim is to summarise patterns for many species, habitats and processes in just two dimensions. What is critical is whether the regionalisations are fit for a particular use, and that they are understandable, explainable and defendable (Thackway 1995, 1996). In the following sections, I will review some national marine regionalisations developed for Australia, and the classifications and MPA assessment processes developed within several State and Commonwealth jurisdictions in Australian waters.

3.5 Australian national marine classifications

Several early marine and coastal classifications of Australian waters have been proposed on the basis of both physical and biological characteristics (Ekman 1953, Knox 1963, Wilson and Gillett 1971, Wilson and Allen 1987, Gill 1974, Galloway *et al.* 1980, McDonald and Cocks 1993). However, the first apparent marine regionalisation developed specifically for marine and estuarine protected area planning resulted from a workshop endorsed by the Council of Nature Conservation Ministers (CONCOM 1985).

It proposed a classification of three coastal and offshore zones with geographic regions in each zone. These were further subdivided by substratum and then by biotic descriptors (Table 3.1). This regionalisation was then modified by the Australian Committee for the World Conservation Union (ACIUCN) in their proposal for a national system of coastal and marine protected areas.

At their first workshop in 1994, the newly formed Australian and New Zealand Environment and Conservation Council (ANZECC) identified the need to develop a regional or 'meso-scale' regionalisation, to be known as the Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998). This involved both Commonwealth and State agencies.

The Commonwealth defined provinces for the Australian coast and for offshore territories in the Antarctic Ocean and the Kerguelen, Christmas, Cocos, Macquarie, Norfolk and Lord Howe Islands and Elizabeth and Middleton Reefs. For the Australian continental shelf, the Commonwealth developed separate pelagic and demersal provinces for waters inshore of the 200 m isobath and offshore of 200 m. The inshore regionalisation included not just provinces, but also 'biotones' or regions of overlap where species assemblages underwent gradual change between provinces. These regionalisations were based primarily on differences in fish species composition and richness, physical oceanographic data and benthic topography and sediment type.

Each State developed meso-scale (100's – 1000 km) regionalisations within each inshore province for all waters out to the 200 m isobath. The Queensland component of the inshore IMCRA was derived from a cluster analysis of eleven biological and physical variables assigned to 30 arc second grid cells (Page and Stevens 1995, Stevens 1995, Stevens 1998). The variables used included sedimentary basins, carbonate and mud fractions in sediments, bathymetry, cyclone incidence, rainfall, tidal range, reef morphology, mangrove, saltmarsh, littoral crab biogeography and hard coral genus richness.

In Western Australia, physical and biological data were used in delphic workshops to develop bioregions (Chevis 1995, Wilson 1995). In South Australia, physical and biological data and delphic workshops of experts were also used to derive bioregions (Edyvane and Baker 1995). In Tasmania, multidimensional scaling (MDS) was used to develop bioregions from temperature data and systematic sampling of biological communities (Edgar *et al.* 1997). The data collected in these surveys also provided a basis for the selection of MPAs and for subsequent monitoring programs (Edgar and Barrett 1997). In the Northern Territory, data for fish assemblages, mangroves and a range of physical characteristics were overlayed in a GIS to derive biophysical regions (Ferns and Bilyard 1995).

In Victoria, a biophysical regionalisation was supported by remote sensing, collation of existing seabed data (Jenkins 1999a, Jenkins and Catlin 1999) and ground truthing of coastal marine habitats to produce a habitat classification. This was subsequently used to help select a system of 13 ‘no-take’ Marine National Parks and 11 Marine Sanctuaries covering 540 km^2 or 5.3% of state waters (Ferns 1999, Ferns and Hough 1999). In NSW, Pollard, Ortiz and Pethebridge (1997) defined bioregions using multivariate analyses for a range of different physical and biological data sets including information on the distributions of fishes, invertebrates and algae.

The resulting combined, national IMCRA (1998, Figure 3.3) includes 65 different marine bioregions and provinces to help plan a national system of marine protected areas. By including the characteristic biodiversity of each bioregion within a network of MPAs, the program aims to ensure that marine ecosystems are effectively managed for the conservation of biodiversity and sustainable use.

Commonwealth jurisdictions are currently developing regional plans to manage a range of use using a variety of tools including MPAs. These plans use habitat classifications, biological data, maps of economic and social values and extensive consultation to develop strategies. A plan for the South East Region has recently been completed and work is now focussing on other areas. The Commonwealth has also implemented MPAs for specific purposes such as complementing state marine parks with Commonwealth Reserves in waters offshore of Lord Howe Island and the Solitary Islands and providing protection for a major Grey Nurse Shark aggregation site at the Cod Grounds, near Laurieton, off NSW.

The Commonwealth Great Barrier Reef Marine Park Authority also recently completed a systematic assessment and new zone plan for the Great Barrier Reef Marine Park. The new plan allocated additional ‘no-take’ zones increasing the area closed to fishing from 4.5% to 33% of the total area. These new zones aim to protect a more representative selection of biodiversity by including a minimum of 20% of the area of each of 70 bioregions developed for the assessment. The following section briefly describes the biodiversity classification phase of this project as a case study that incorporates many of the methods reviewed in this chapter and led to the development of the Marxan reserve planning software.

Table 3.1. Proposed classification scheme to assist in the identification of major marine habitats for the selection of marine and estuarine protected areas: habitat categories (CONCOM 1984).

Level 1 Geographic zone	Level 2 Substratum	Level 3 Biotic descriptor	Level 1 Geographic zone	Level 2 Substratum	Level 3 Biotic descriptor
A. Coastal (from High Water Mark to 200m isobath) 1. North coast 2. NW Shelf 3. W Coast 4. SW Coast 5. Great Aust Bight 6. S Gulf coast 7. S Coast 8. Bass Strait 9. Tasmanian 10. SE Coast\ 11. NE Coast 12. Great Barrier Reef 13. Gulf of Carpentaria	Hard Soft	1. Mangal/ saltmarsh 2. Algal/kelp 3. Seagrass 4. Coral 5. Other epifauna 6. Inconspicuous biota	B. Oceanic (200m isobath to 200 nautical miles) 14. W Oceanic 15. S Oceanic 16. SE oceanic 17. NE oceanic C. Oceans (Beyond 200 nautical miles) 18. Indian ocean 19. Southern Ocean 20. Tasman sea 21. Coral Sea	Hard Soft Island Reef Name	1. Other epifauna 2. Inconspicuous biota 1. Mangal/ saltmarsh 2. Algal/ kelp 3. Seagrass 4. Coral 5. Other epifauna 6. Inconspicuous biota

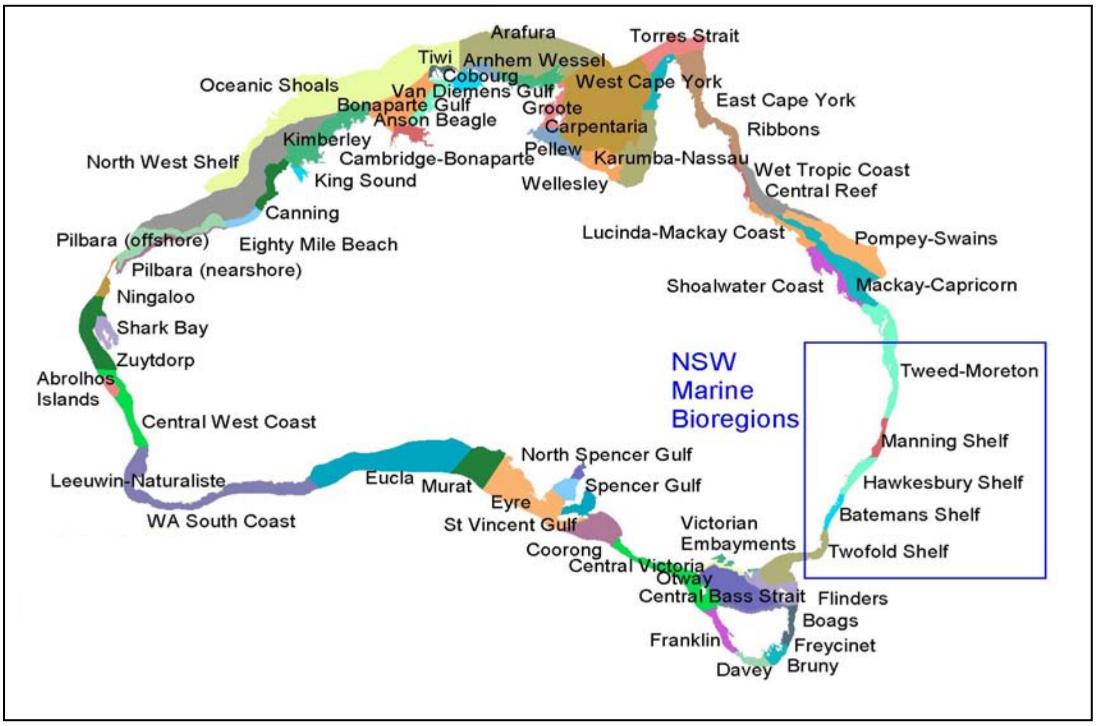


Figure 3.3 Interim Marine and Coastal Regionalisation of Australia (IMCRA).

3.6 Classification of marine biodiversity in the Great Barrier Reef World Heritage Area

This classification formed part of the Great Barrier Reef Marine Park Authority's (GBRMPA) Representative Areas Program (Kerrigan *et al.* 1999, Day *et al.* 2002, Lewis *et al.* 2003, Fernandes *et al.* 2005) to assist in allocating varying levels of protection within different zones of this multiple use marine park. The classification phase was based on literature reviews of systematic protected area assessments (Margules and Redhead 1995, Phillips 1996, 1998, ANZECC 1998ab, 1999, Pantus 1998b, Ward *et al.* 1998, Breen and Lloyd 1999, Day and Roff 2000) and designed to provide information for systematic reserve selection tools, consultation and planning. The major planning question addressed was where to locate representative, highly protected 'no-take' areas and other zones in the World Heritage Area to provide for the conservation of biodiversity and the management of sustainable use.

This classification and overall planning process was overseen by a scientific steering group of representatives from regional scientific and tertiary education institutions with expertise across a range of disciplines in marine science (Appendix 5). This committee provided critical reviews of the methods proposed and support for the intent of the project.

An initial gap analysis to assess the representation of IMCRA bioregions within the existing system of zoning (Figure 3.4) indicated that no-take zones occupied less than 5% of the marine park and this area included mainly shallow coral reef and very little intervening sediment, deep reef or other habitats. Most of this protection was allocated among a few bioregions with the largest area of protection within a single cross shelf transect in the Far Northern Section of the park (Poiner *et al.* 1999). This analysis clearly indicated that the existing system of zoning was highly unrepresentative of the range of habitats and biogeographic regions. However, it was determined that a finer scale regionalisation than the IMCRA would be required to identify new representative areas for additional levels of protection.

A physical classification derived from GIS overlays of interpolated depth (Figure 3.5), slope (Figure 3.6), substratum (Figure 3.10), exposure (Figure 3.8) and temperature (Figure 3.9) was initially trialled. Depths estimated from a 30 arc second (~ 900 m) gridded bathymetry data set for Australia (Buchanan 1999) were used to map broad depth zones, and derive estimates of slope and aspect using the spatial analyst extension in ArcView 3.0 (Figure 3.7). Aspect was then used to classify the coast, islands, mid shelf reefs and outer reefs as exposed or sheltered. Previous projects had already digitised and classified most shallow reefs, coast and islands from satellite imagery and aerial photos. Maxwell's (1968) 'Atlas of Great Barrier Reef' included maps of mud, sand and carbonate fractions which had previously been digitised for GIS. Approximate summer and winter mean isotherms (Figure 3.9) provided a general indication of seasonal differences in temperature between the northern and southern ends of the reef and inshore and offshore areas.

These five data sets were 'unioned' in GIS overlays to produce physical categories formed by the intersection of the different classes in each data set. However, if more than a few classes within each data set were used, many different categories and spurious overlaps resulted. If a few broad classes in each data set were selected on the basis of their presumed biological importance, this problem was greatly reduced, but the resulting patterns were still difficult to substantiate in terms of species assemblages or ecosystem processes (Figure 3.10). Moreover, geophysical classifications of the region had already been proposed (Hopley 1982, 1983, Hopley *et al.* 1989) and it was apparent that extensive data sets for many taxa and descriptions of cross shelf and other spatial patterns in biodiversity existed for at least some areas (Done 1982, Dinesen 1982, 1983, Williams 1982, Williams and Hatcher 1983, Riddle 1988). Several institutions in the region also had well developed research programs and scientists with experience in these waters. Some of these scientists (T. Done, D. Williams and A. Ayling) had already provided delphic maps of patterns in the distributions of corals, fishes and benthos for the marine park and there were several regional data sets suitable for numerical modelling.

A systematic search for all available broad scale biological and physical data sets of the region was therefore conducted in conjunction with interviews with over 70 marine science and reserve design experts. A questionnaire (Appendix 6) was sent to the scientists prior to the interviews, and the results recorded and transcribed for later reference. The interviews assisted in providing:

- access to additional data sets
- information on physical drivers limiting and controlling the distributions of different taxa
- maps of the distributions of biota and important feeding, breeding, migration or other special areas and threats to these biota and processes
- anecdotal information for areas (e.g. the continental slope) where few data were available
- reserve design requirements for different species
- software trials with DIVERSITY, C-Plan and Spexan (the precursor to Marxan)
- contacts with other scientists with information
- potential workshop participants
- research priorities and opportunities to address knowledge gaps.

From this process, over 80 different data sets were mapped and some additional projects were funded to provide data from cross-shelf surveys of inter-reef seagrasses, algae and epifauna (Coles *et al.* 2000), mapping of *Halimeda* bioherms from previous acoustic surveys (Drew and Abel 1988), and collation of fare sheet, public works and other geological seabed data and facies (Jenkins 1999b).

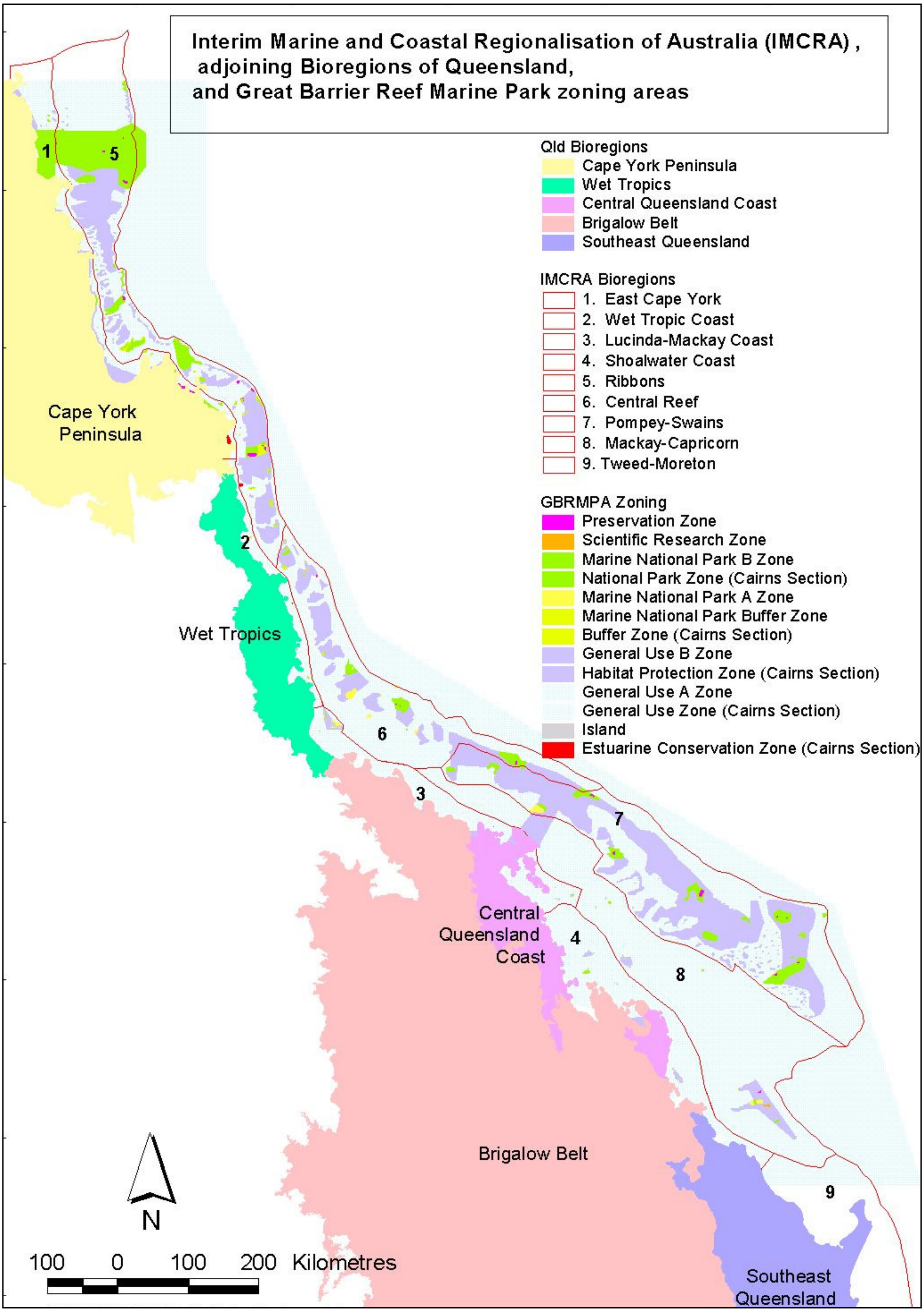


Figure 3.4. IMCRA (marine) and IBRA (terrestrial) bioregionalisations for Queensland and previous GBRMPA zone plan with no-take areas protected from fishing coloured green (4.5%) and bright pink or orange (<1%) (D. Breen. Unpublished map GBRMPA 1999).

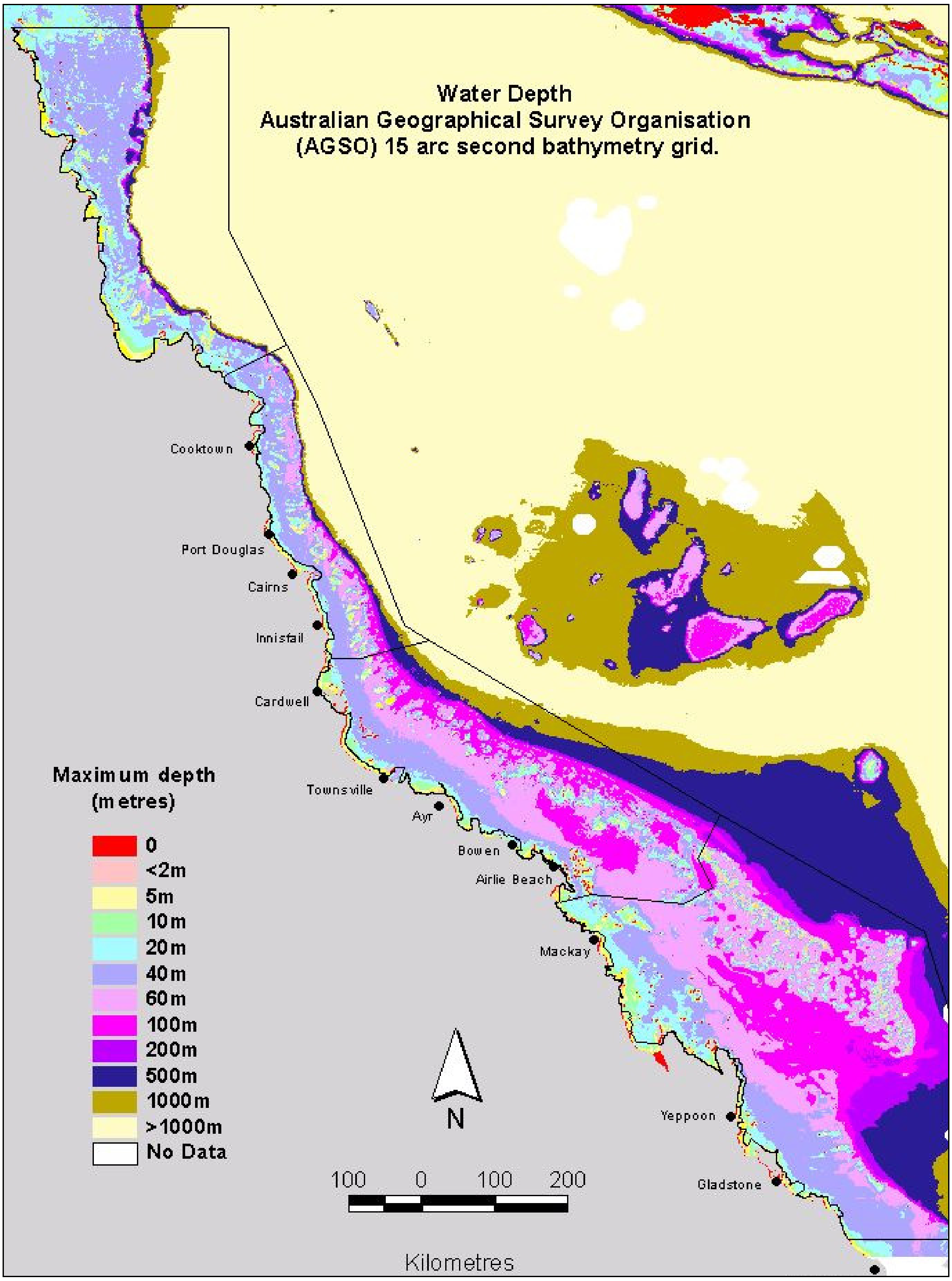


Figure 3.5. Gridded bathymetry (30 arc second) for the Great Barrier Reef region and adjacent offshore areas (data from Buchanan, Australian Geological Survey Organisation 1999).

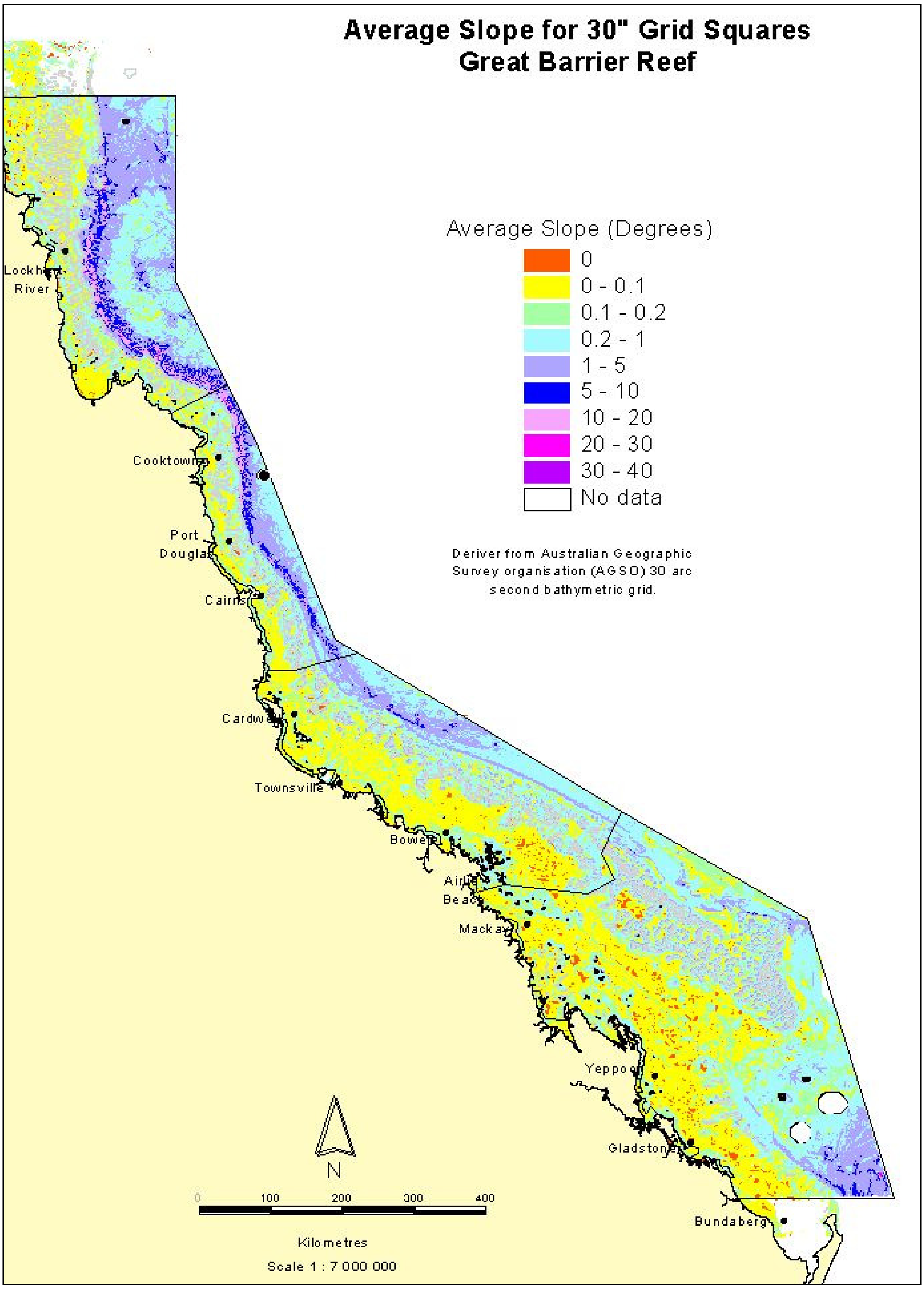


Figure 3.6. Average slope derived from the 30 arc second gridded bathymetry data (derived from data from Buchanan, Australian Geological Survey Organisation 1999).

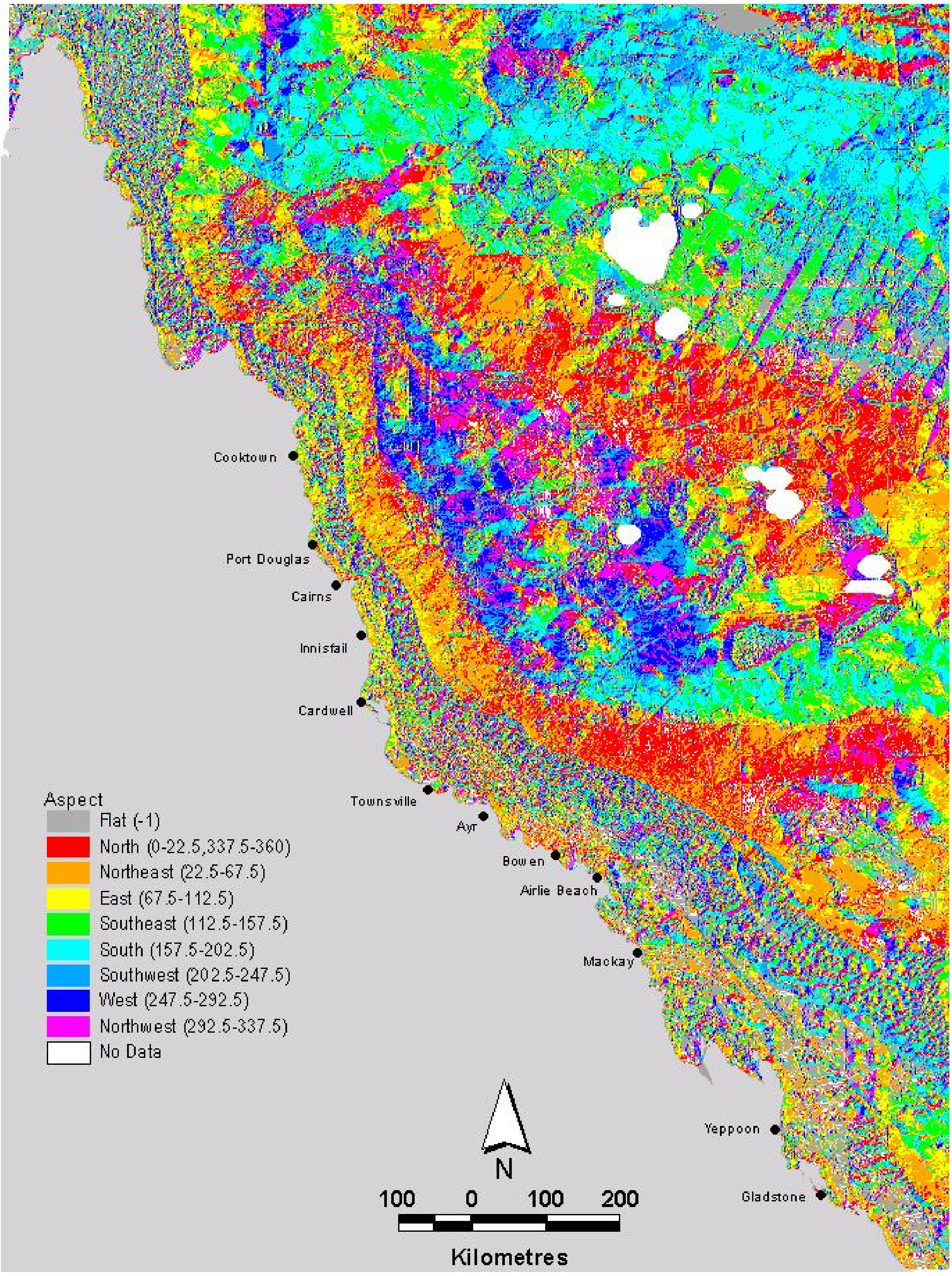


Figure 3.7. Aspect (degrees from north) derived from the 30 arc second gridded bathymetry data (derived from data from Buchanan, Australian Geological Survey Organisation 1999).

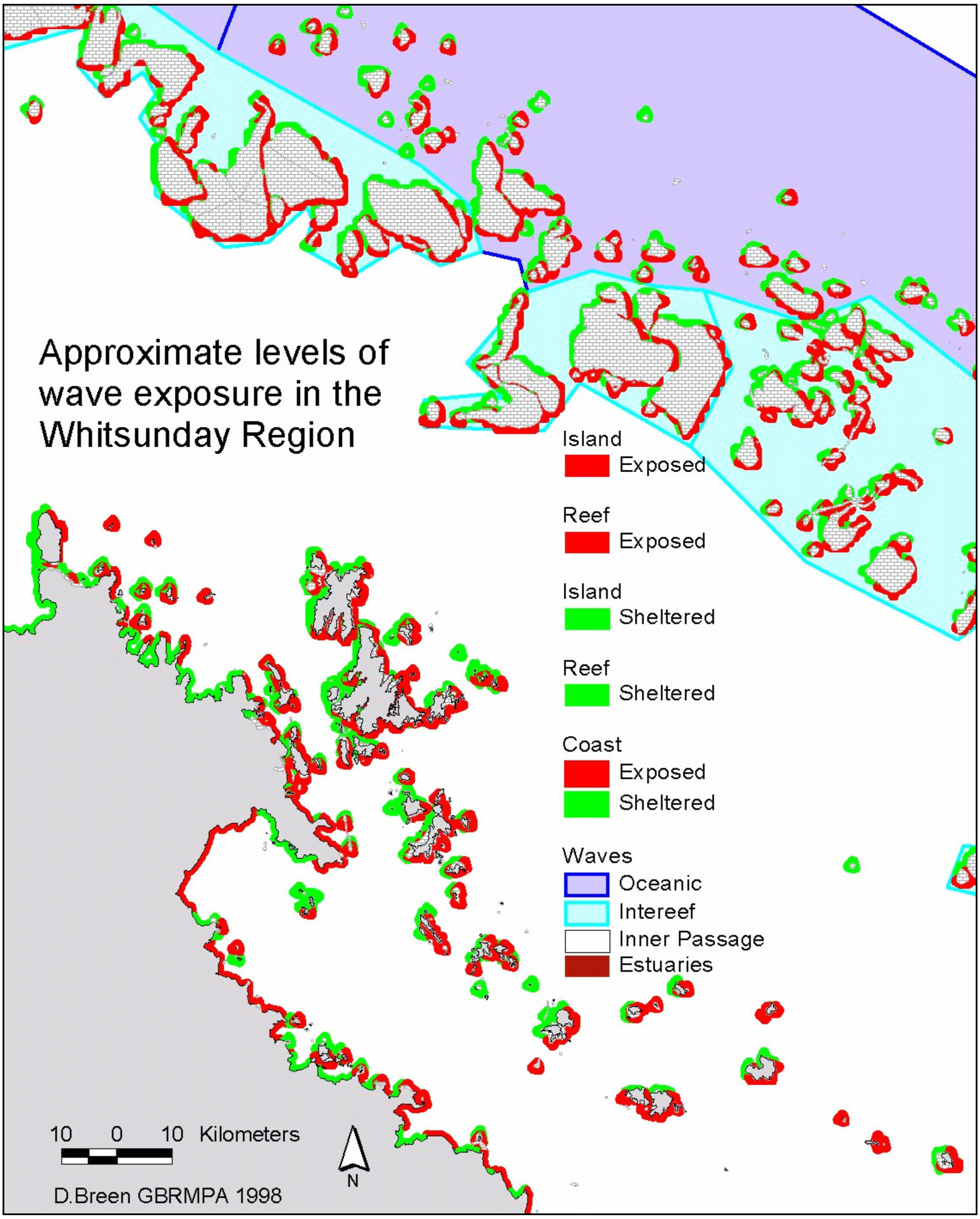


Figure 3.8. Exposure of coast, islands, midshelf and outer reefs modelled from aspect (derived from data from Buchanan, Australian Geological Survey Organisation 1999).

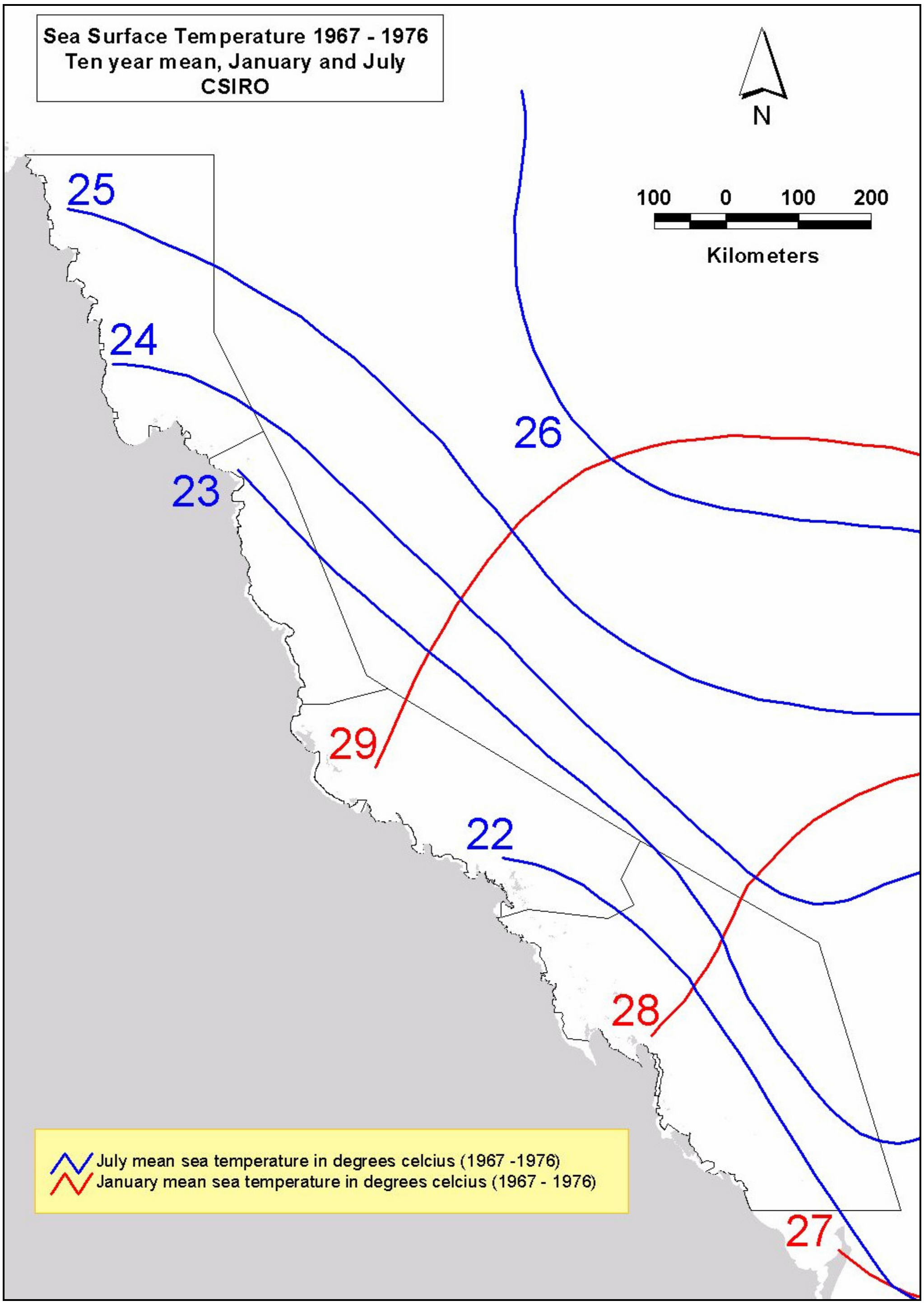


Figure 3.9. Ten year mean monthly isotherms for the Great Barrier Reef (data from CSIRO Division of Marine Research).

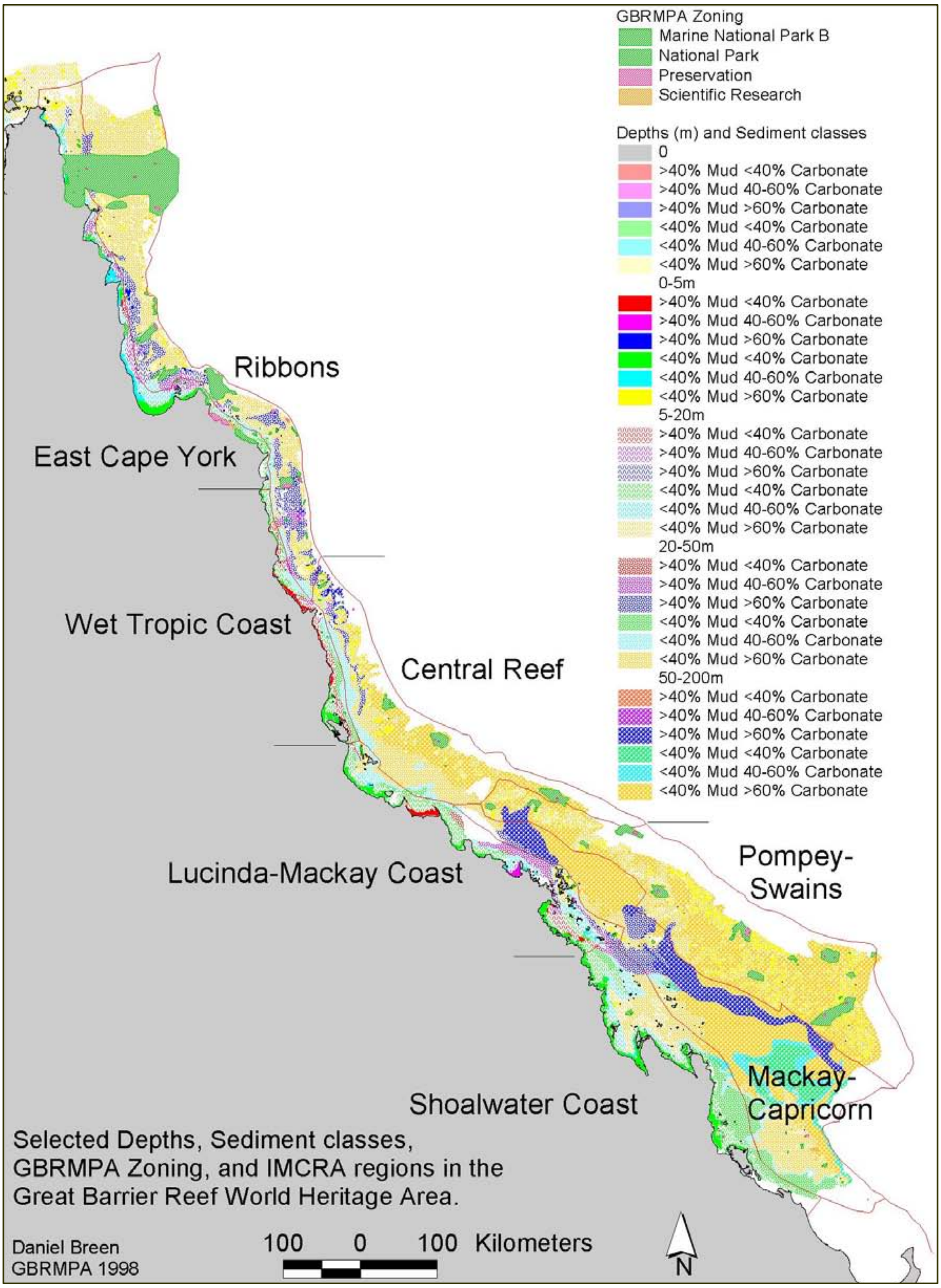


Figure 3.10. Selected depth and sediment categories within the previous GBRMPA zone plan (derived from data on sediments digitised from Maxwell 1968, depths from Buchanan 1999, bioregions from IMCRA 1998).

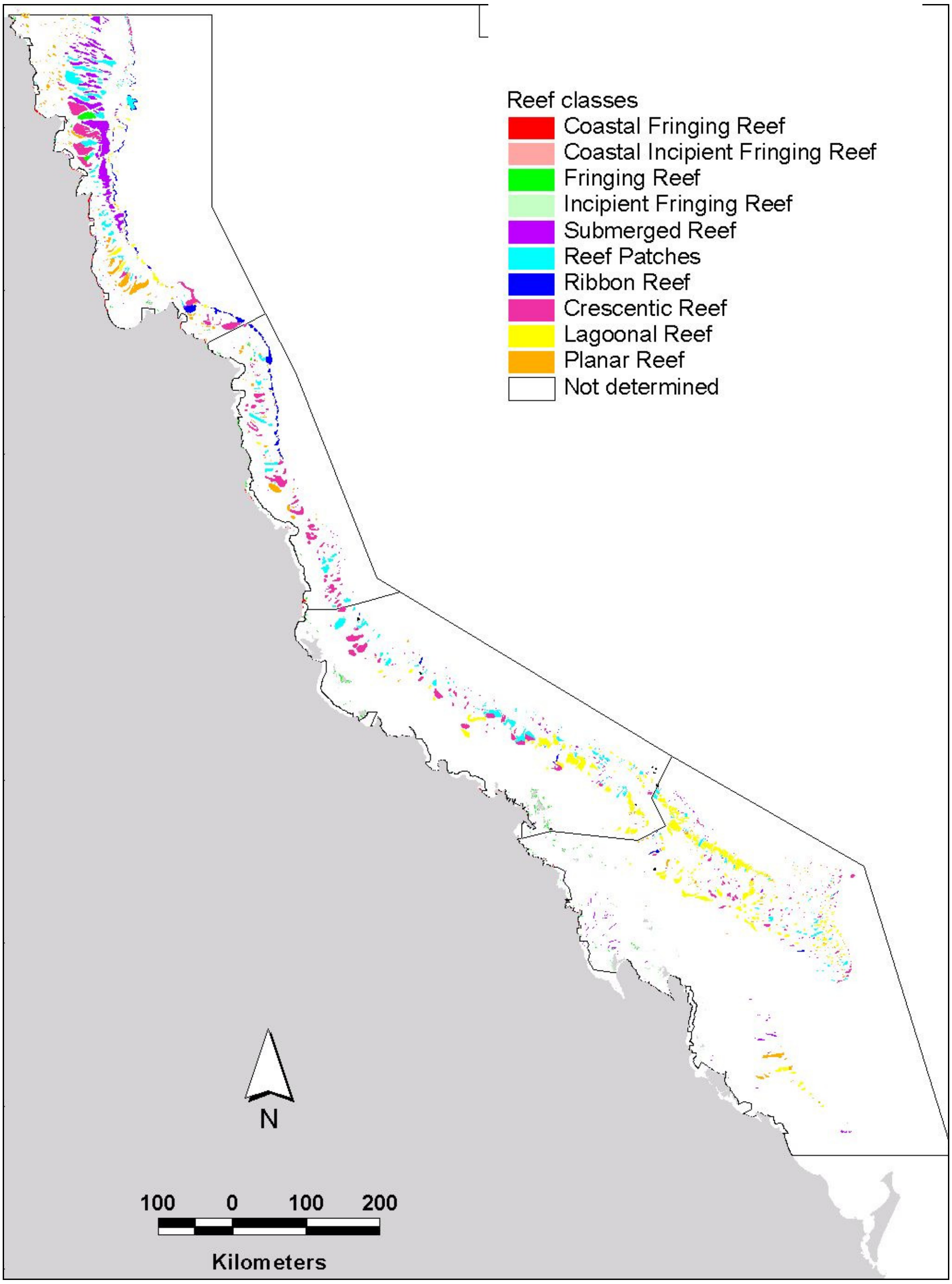


Figure 3.11. Morphological reef types of the Great Barrier Reef (data from Hopley 1983).

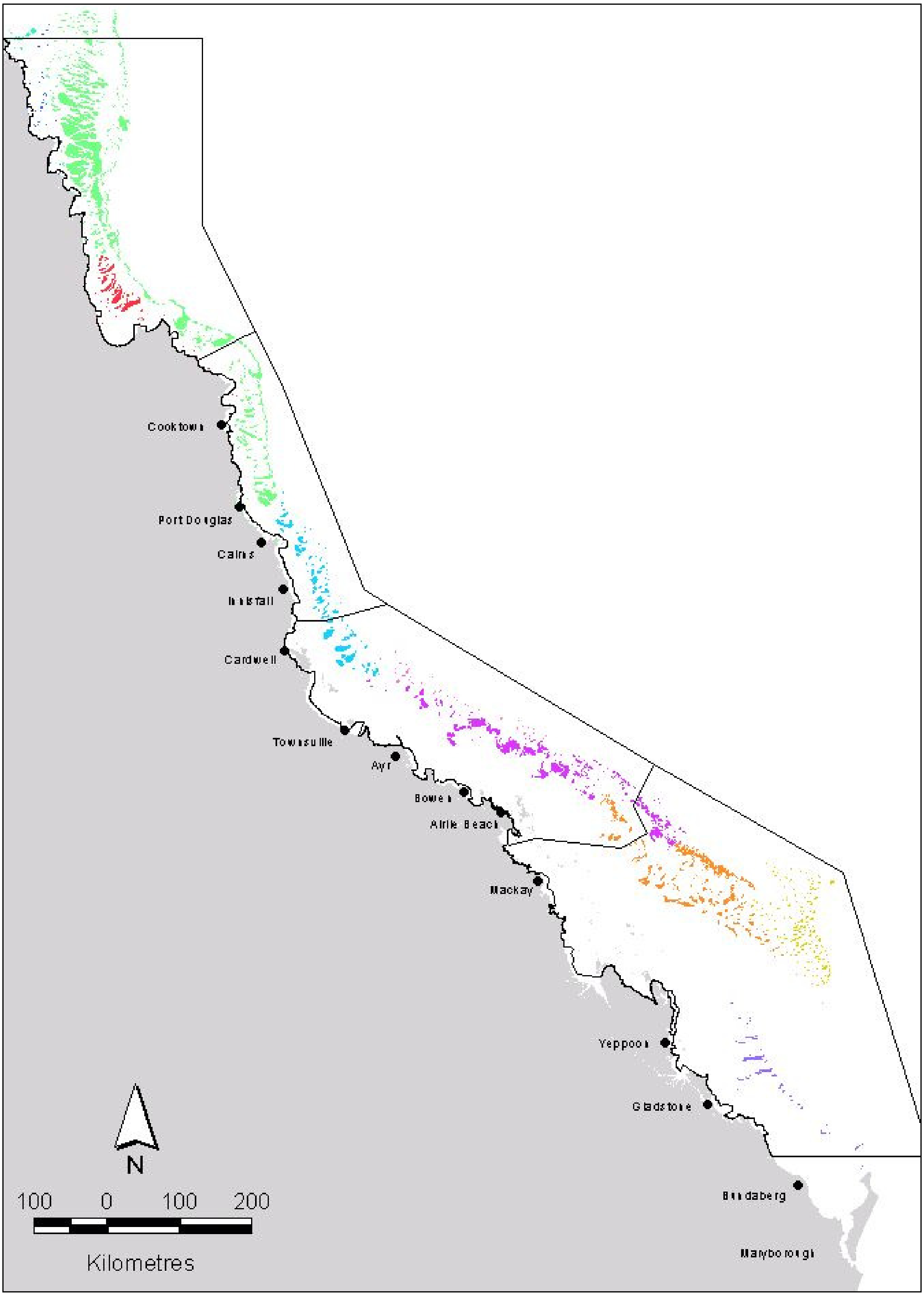


Figure 3.12. Regionalisation of reef morphologies for the Great Barrier Reef (data from Hopley 1982).

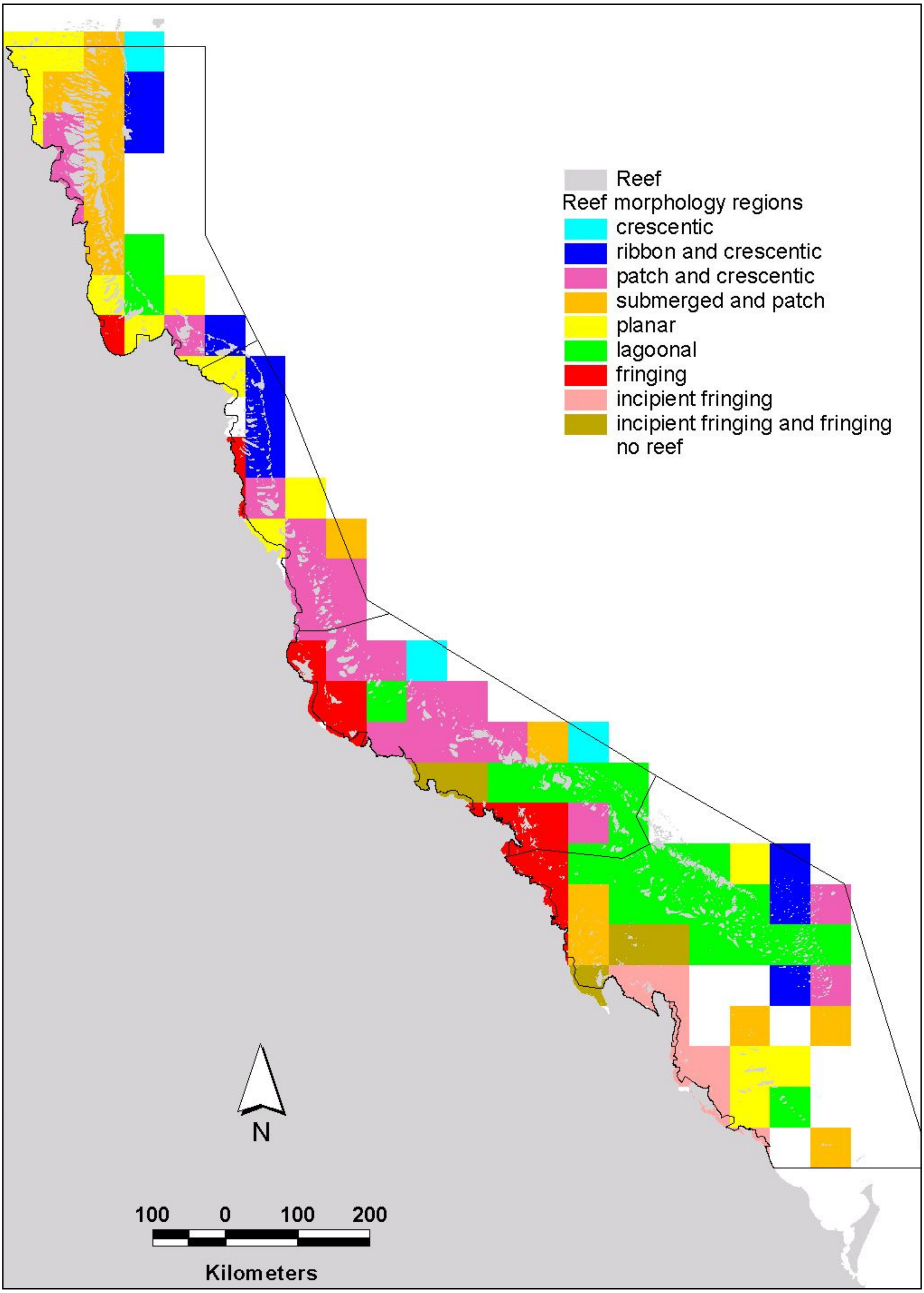


Figure 3.13. Numerical classification of reef morphologies for the Great Barrier Reef (data from Hopley *et al.* 1989).

The Authority contracted a biostatistician to undertake statistical modelling for those data sets with sufficient species observations throughout the region. Multivariate classification and regression tree analyses (MCART, De'Ath 1999, De'Ath and Fabricius 2000, De'Ath 2002) were used to relate species assemblage data for soft corals, hard corals (two data sets), fishes (two data sets), reef benthos, algae, seagrasses, epifauna (Coles *et al*. 2000) and sediments to two spatial predictors, cross-shelf and along-shelf position.

Coordinates for the centre point of each reef or inter-reef GIS polygon were first standardised on a scale across the shelf from between 0 at the coast and 1.0 at the 200 m isobath[1]. Positions along the longest axis of the region (approximately north north west) were standardised to between 0 at the far northern end to 1.0 at southern extreme[2]. These spatial predictors provided greater predictive power than other physical explanatory variables such as sediment or distance to river mouths. For each of the ten data sets, MCART analyses were used to successively split the region by cross shelf and along shelf positions into smaller areas containing increasingly homogenous assemblages of organisms until permutation tests indicated that predicted groups were not statistically different (De'Ath 1999).

The resulting models were then used to interpolate bioregions from the positions of reefs and inter-reef areas and assign levels of uncertainty dependent on the distance to the nearest survey site where data were collected. An aggregate MCART analysis for all reef organisms was then run using the membership of each site in different hard coral, soft coral, fish and benthic assemblages as the response variables (De'Ath 1999).

Separate two-day workshops were then convened for a panel of reef experts and a panel of inter-reef experts to interpret data and analyses and define and justify regionalisations that explained the dominant patterns in fauna, flora, habitats and processes throughout the Great Barrier Reef World Heritage Area.

The groups were provided with defined objectives and terms of reference and the results of the MCART analyses were explained by the consultant biostatistician, then reviewed, discussed and generally endorsed by the expert panels. Almost all data and analyses were mapped in ArcView and ARCINFO GIS and provided to the panels as large, A0 sized paper maps and reports that included maps, metadata and descriptions of all the data sets collected.

[1] i.e. x = (distance of each point from coast) / (total distance between coast and 200 m isobath).

[2] i.e. y = (distance of each point from north end of reef) / (total distance along longest axis of the Great Barrier Reef)

Table 3.2. Physical and biological data sets mapped and documented for the GBRMPA Representative Areas Program.

Physical	Biological
Regionalisations	Regionalisations
1. Depth, slope, exposure & substrate overlays	48. Interim Marine and Coastal Regionalisation of Australia
2. Regionalisation of reef morphology	
3. Numeric regionalisation of reef morphology	49. Australian coastal regionalisation
4. Galloway coastal classes	
Bathymetry	50. Delphic reef regionalisation
5. Depth & elevation model	Plants
6. Gridded bathymetry (15 and 30 arc second)	51. Inter-reef algae
7. Seafloor aspect	52. *Halimeda*-bed coverages
8. Slope	53. Inshore seagrasses
9. Exposure	54. Deepwater seagrasses
10. Queensland coastline	55. Mangroves
11. Intertidal areas	56. Reef macro algae
Sediment	Corals
12. Sediment grain size	57. Soft coral surveys
13. *Halimeda* sediments	58. Hard coral surveys
14. Percent mud, carbonate, sand, gravel and rock	59. Long-term monitoring reef surveys
15. Biological facies	
16. Past shorelines and river valleys	60. Surveys of reef biota
Estuaries	61. Museum collections
17. Coastal rivers	
18. Australian drainage basins	Echinoderms
Islands	62. Museum specimen data
19. Islands	63. Echinoderms from Cairns Section
20. Cays	
21. Island inventory	Epibenthos
22. Classification of islands in GBR	64. Cross transects off Townsville
Reefs	
23. Reefs	65. Far Northern Section effects of trawling survey
24. Drying reefs	
25. Named rocks	66. GBR seagrass and intereef surveys
26. Reef inventory	
27. Classification of reef morphology	Urochordates
28. Reef size	67. Museum collections
29. Reef shape	Molluscs
30. Cross shelf position	68. Museum collections
31. Long shelf position	Sponges
Oceanography	69. Northeast Australia surveys
32. Biological oceanography	70. Museum collections
33. Secchi depth	Fishes
34. Extents of flood plumes from rivers	71. Baitfish
35. Water quality sector model of GBR lagoon	72. Pelagic fish
36. Regional seasonal ocean maps	73. Reef fish surveys
37. Australian region oceanography dataset	74. Long term monitoring
38. Exposure to wind	75. Reef biota surveys
Sea temperature	76. Fisheries catch reporting
39. 10 year mean temperature fields	77. Spawning sites
40. Sea surface temp effects on coral bleaching	78. Pelagic fish - Billfish & Marlin
Tides and currents	
41. Regional hydrodynamics & dispersal project	79. Museum collections
42. Coral reef and mangroves: modelling & management project	Reptiles
	80. Turtle nesting and movements
43. Tidal ranges	
44. Surface and oceanic currents	81. Sea snake database
Waves	Birds
45. Australian region wave dataset	82. Seabird atlas
Cyclones	Mammals
46. Cyclone atlas of GBR reef region	83. Whales
47. Australian region cyclone dataset	84. Dolphins
	85. Dugong

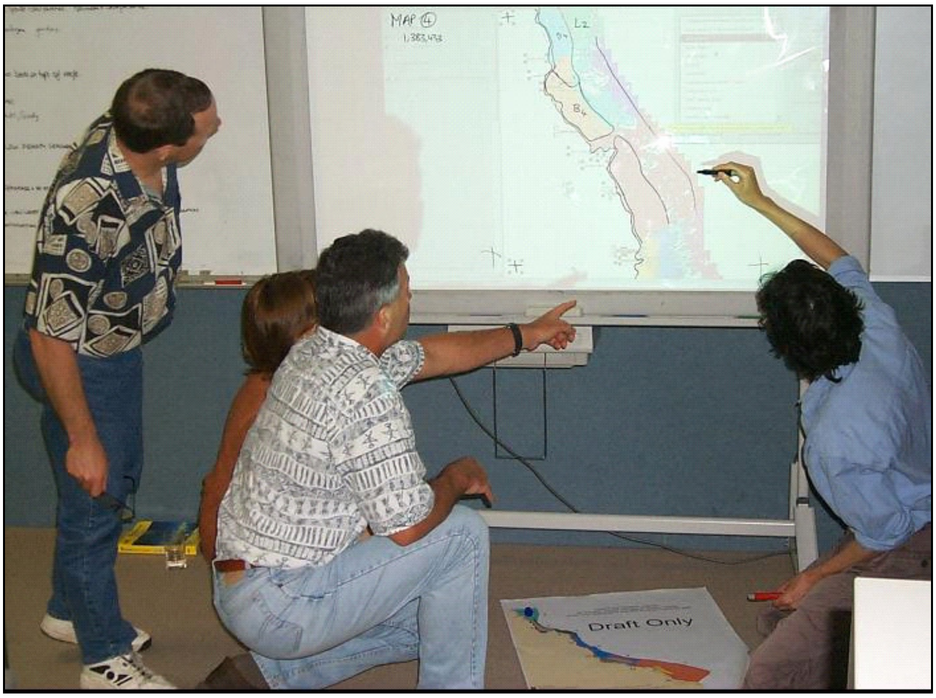


Figure 3.14. Scientists defining bioregions on an image of ArcView GIS projected on a whiteboard photocopier in a workshop for the GBRMPA Representative Areas Program.

All GIS data were preformatted and projected onto a photocopy whiteboard during workshops. Additional ArcView extensions were used to synchronise views for different data sets, record and return to defined extents, and rapidly record, edit and annotate the regions defined by the group. The expert panels were able to interactively edit and refine regions and provide descriptions and justifications for different boundaries and regions. This resulting bioregionalisations were recorded as they evolved and updated maps were provided to the panels for checking the following day.

A third, joint workshop of the reef and inter-reef panels was held to consolidate bioregions where possible and confirm the draft boundaries of the new joint bioregionalisation (Figure 3.15 and Figure 3.16, Kerrigan *et al.* 1999). Gap analyses indicated that most of the new bioregions were clearly under-represented in the existing network of highly protected areas (e.g. Figure 3.15). Participants were also able to identify sites of special significance for diversity, uniqueness, productivity, feeding, breeding and migration. The regionalisations were then reviewed externally and a number of changes made to different boundaries.

The expert groups also developed a set of reserve design guidelines or 'biophysical operating principles.' These included minimum specifications for size, shape, representation, configuration and replication of no-take areas in each bioregion. A workshop was then held to review reserve planning tools and two new tools, Marxan (based on the terrestrial software Spexan, Ball and Possingham 1999b, 2000) and Trader (De'Ath 1999), were commissioned for the project.

The bioregionalisation and supporting data were then used with Marxan, Trader and social, economic and cultural information to plan and consult for a new representative zone plan for the marine park (Figure 3.17). The biodiversity classification process for the Representative Areas Program was only one stage of the zone plan review (Day *et al.* 2002). The subsequent reserve selection processes, tools, consultation, negotiations, assessments and mapping took a large team several more years to complete (Fernandes *et al.* 2005). However, the use of a systematic, scientifically justified process, the best available information and advice, and the support of the scientific community, provided substantial support for zoning decisions and a more effective basis for planning.

The process was remarkable for the synthesis of ideas that occurred among scientists from different disciplines and institutions at the workshops. In many cases, boundaries emerged with input from several individuals using data from different sources and from conceptual models of the likely responses of organisms to their environment. The situation was relatively unique in the way that data, experience and intuition were used with graphic tools to address specific tasks in a systematic and cooperative manner.

From a broader perspective, the program increased the awareness of many existing and new data sets and the value of using science to support conservation management. The benefits of these systematic techniques extend beyond the Great Barrier Reef Marine Park. Such tools and techniques are also being used to assist planning for MPAs in Moreton Bay (Buxton 2005) and elsewhere in Queensland (Banks *et al.* 2005), South Australia (Stewart *et al.* 2002, Stewart and Possingham 2003, 2005), Florida (Leslie *et al.* 2003), California (Airame *et al.* 2003), New England (Cook and Auster 2005), Wales (Richardson *et al.* in press), Fiji (D. Breen, unpublished data), New Zealand (D. Breen, unpublished data). and NSW (Breen *et al.* 2002, 2004, 2005, 2006).

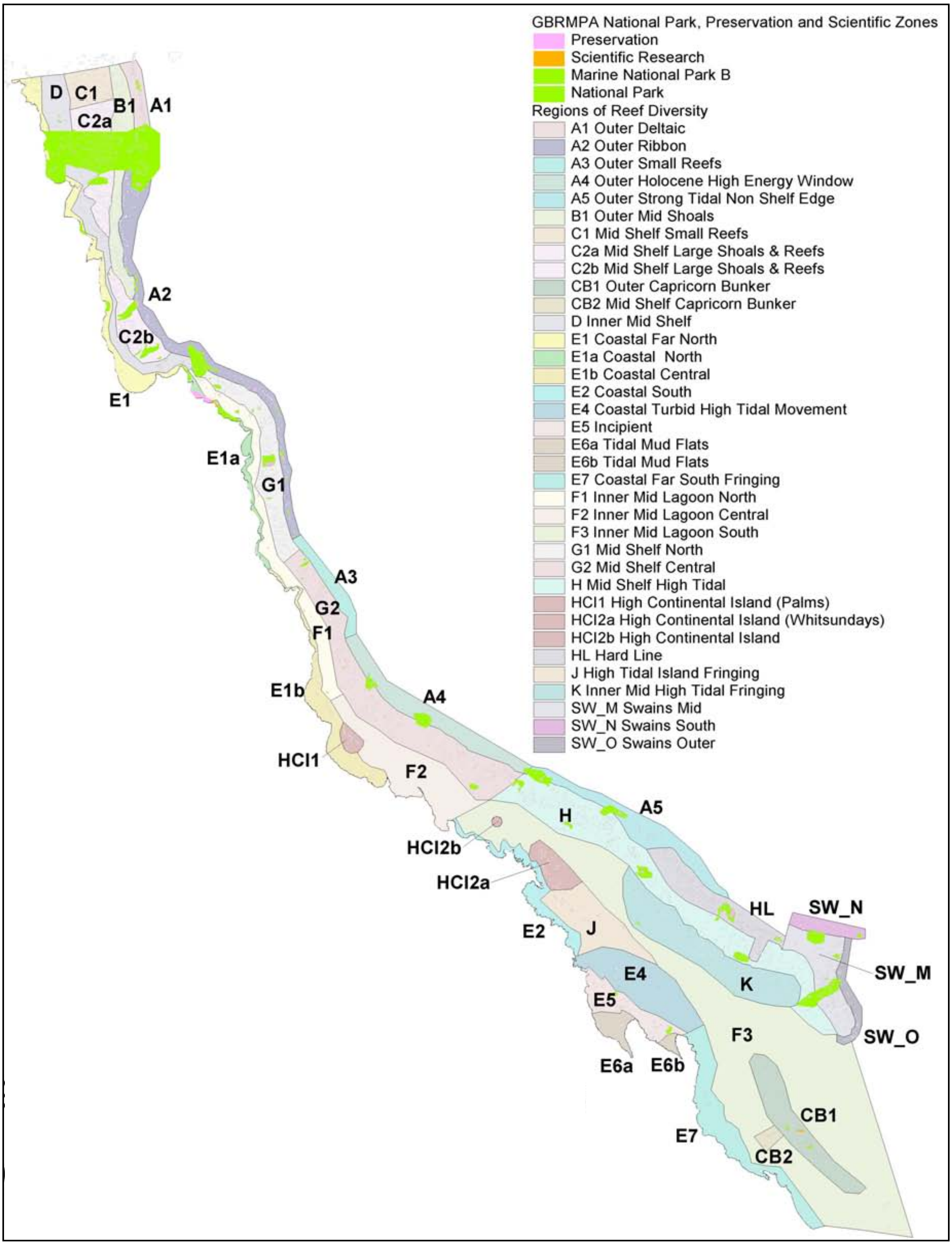


Figure 3.15. Draft reef regionalisation from the reef expert workshop for the GBRMPA Representative Areas Program and highly protected no-take zones from the previous zone plan for the Marine Park.

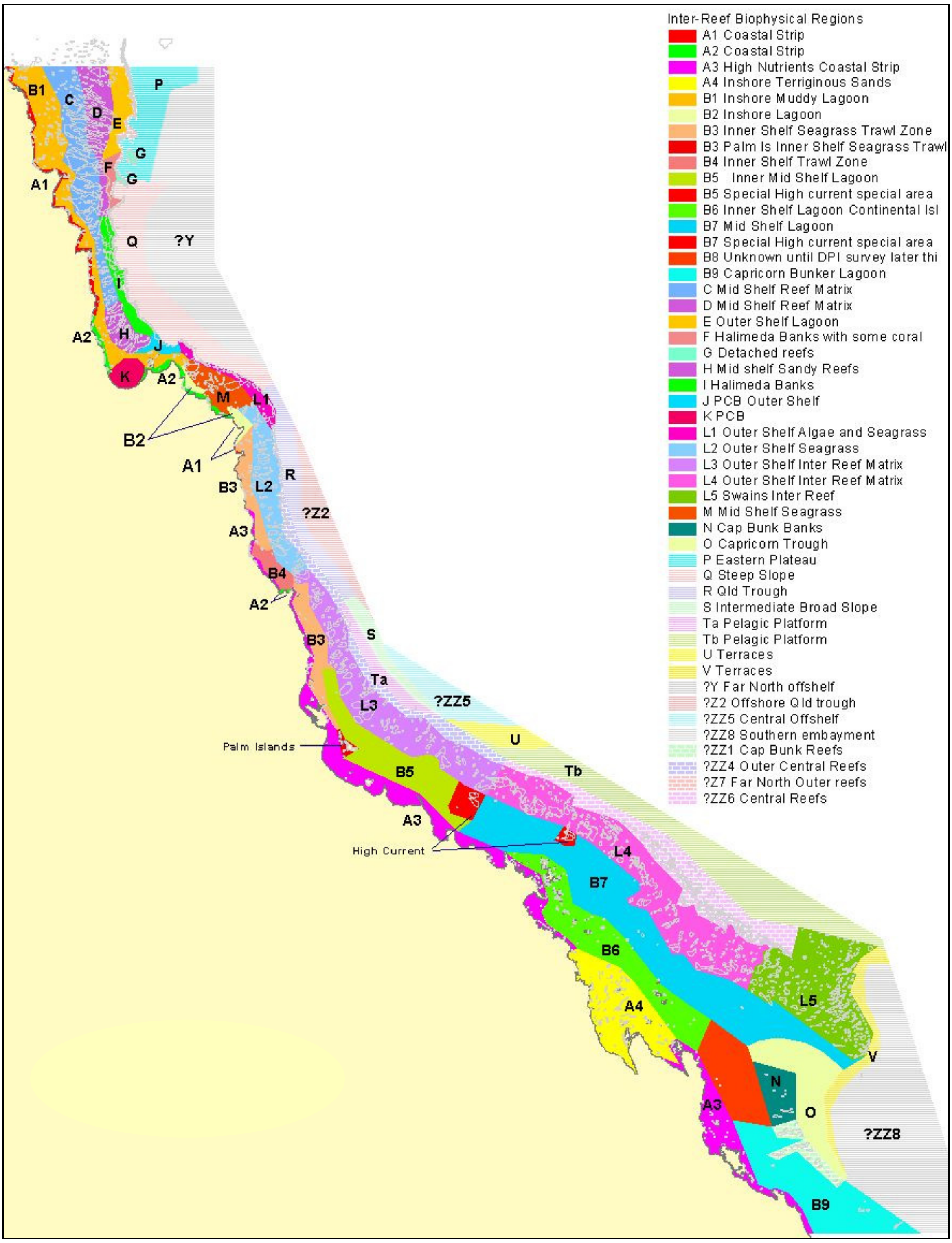


Figure 3.16. Draft inter-reef regionalisation from the expert workshop for the GBRMPA Representative Areas Program.

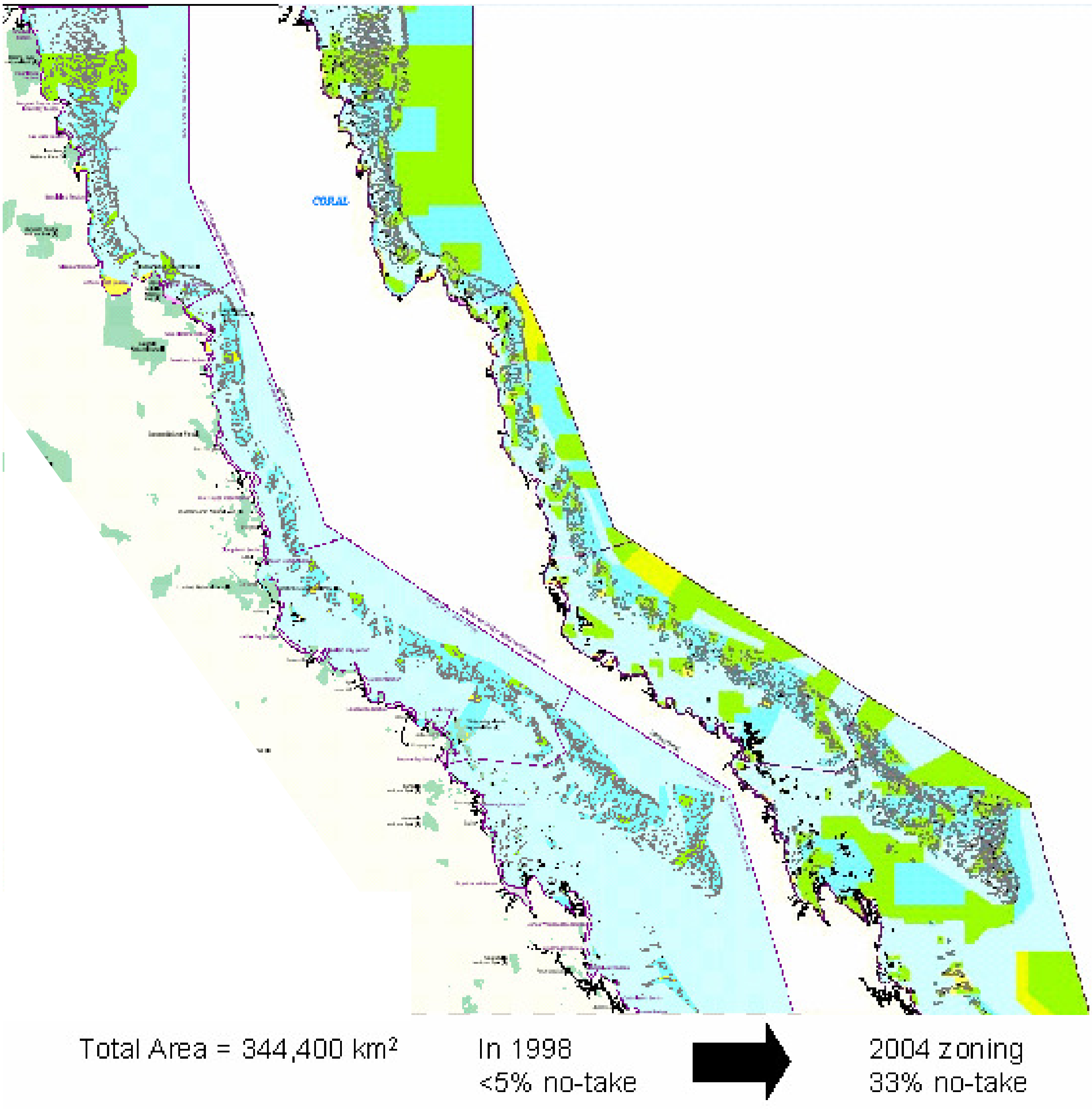


Figure 3.17. Distribution of no-take zones (green) in the Great Barrier Reef Marine Park before and after the Representative Areas Program and the new zone plan in 2004 (Maps from www.gbrmpa.gov.au).

Statement of the contribution of others in Chapter 4.

Ron Avery and I together reviewed legislation, objectives and the application of MPAs in NSW and this is reflected in the content of the following chapter.

4 Marine Protected Areas in NSW

The earliest marine protected areas in NSW were, arguably, sections of terrestrial National Park that extended below mean high tide (McNeill 1995) and several of these were declared between 1967 and the early 1980s. However, it took some time before protected areas dedicated solely to marine conservation were created. Pollard (1997) provides a comprehensive account describing the background, history and justification for these MPAs and parts of this are summarised below.

The first proposal for a protected area dedicated to marine conservation was made in 1969 for parts of the Solitary Island group, north of Coffs Harbour on the northern NSW coast. However, it took over 20 years for a reserve to be declared at this site. Other early proposals for marine protected areas were made at Julian Rocks in 1972 (proposed by William Sylvester), at Long Reef in 1974 (Isobel Bennett), at Fly Point-Halifax in 1974 (D. Harris) and at North Sydney Harbour in 1979 (David Stead). In 1971, the NSW government extended Bouddi State Park over an area of inshore water to be managed jointly by the NSW National Parks and Wildlife Service and NSW Fisheries. The unique management arrangement at this site persists today with NSW Fisheries (NSW Department of Primary Industry) providing protection from fishing through closures which must be renewed each five years.

In 1980, Pollard notes that "NSW State Fisheries has for a number of years been carrying out a program of investigation into the suitability of areas along the NSW coastline as potential sites for marine and estuarine reserves…resulting in the identification of some 40 or so potential sites. Preliminary surveys of some 30 or so of these specific sites have since been carried out and 15 have now been surveyed in considerable detail."

After amendments to the *Fisheries and Oyster Farms (Amendment) Act 1979*, the first Aquatic Reserve in NSW was declared at Long Reef (1980), shortly followed by declarations at Julian Rocks (1982), North Sydney Harbour (1982), Bushrangers Bay (1982), Shiprock (1982) and Fly Point / Halifax (1983). In 1987, a relatively large area (1400 ha) of mangrove, seagrass, saltmarsh and estuary in Botany Bay was protected in Towra Point Aquatic Reserve. In 1991, a large 100,000 ha MPA was declared in State and Commonwealth waters around the Solitary Islands, 22 years after the original proposal.

After the formation of the NSW Marine Parks Authority, large, multiple use marine parks were established at the Solitary Islands in 1997, at Jervis Bay in 1998, around Lord Howe Island in 1999 and then at Cape Byron in 2002. Additional small aquatic reserves were also established by NSW Fisheries at Cook Island in 1998, and at Barrenjoey Head, Narrabeen Head, Cabbage Tree Bay, Bronte-Coogee, Cape Banks and Boat Harbour in 2002. Many additional areas of national park and nature reserve now also include marine habitats, but only the Bouddi marine extension has any direct protection from fishing.

According to the definition adopted by the NSW Government (IUCN 1994), three types of marine protected areas now exist in NSW:

- **marine parks** – managed under the *Marine Parks Act 1997* by the NSW Marine Parks Authority. The Authority comprises the Director-General of the Premier's Department, the Director-General of Department of Environment and Conservation and the Director-General of NSW Fisheries, Department of Primary Industry.
- **aquatic reserves –** managed by NSW Fisheries under the *Fisheries Management Act 1994*
- the marine components of **national parks and nature reserves** – managed by NSW National Parks (Department of Environment and Conservation) under the *National Parks and Wildlife Act 1974.*

The locations of marine parks, aquatic reserves, and those sections of national parks and nature reserves established up until 2006 are shown in Figure 4.1. Since the completion of the assessments described in this thesis an additional two large marine parks were established in 2006 in the Port Stephens and Batemans Bay regions.

Prior to these assessments, legislation for the three types of MPAs was assessed for its ability to meet the goals and criteria described in Chapter 2. All three MPA types had significant powers to conserve biodiversity and ecological processes, but differed in how this could be achieved. It was apparent that under the right circumstances the different MPA types could complement each other in a network of MPAs.

Large, multiple use marine parks could be used to create extensive networks of no-take areas embedded within areas of sustainable, integrated management at key locations. Aquatic reserves could be used to address local issues, species and habitats at specific sites; and national parks and nature reserves could provide extensive protection for shorelines, catchments, wetlands and, with additional legislation adjoining areas of open water. The following section describes the objectives of the different types of MPA in NSW and how they are applied. Further information on MPAs in NSW is found in "*Developing a representative system of marine protected areas - an overview*" (NSW Marine Parks Authority MPA Strategy Working Group 2001) and in reviews by Parker (1995) and Pollard (1997).

4.1 Marine parks

The *Marine Parks Act* aims to conserve marine biological diversity, habitats and ecological processes in marine parks. Where consistent with these objectives, it also aims to provide for the ecologically sustainable use of fish and marine vegetation (including commercial and recreational fishing) and provide opportunities for public appreciation, understanding and enjoyment of marine parks. Integrated management of these marine parks also aims to assist in managing pollution, visitor use, activities on adjacent lands, marine pests and a wide range of human activities, environments and species.

Four marine parks were declared in NSW before the assessments described in the following chapters (Figure 4.1). These are large, multiple use MPAs, ranging from approximately 200 km^2 to 700 km^2 in area. These marine parks are zoned to allow for a range of human activities, including commercial and recreational fishing. They also include sanctuary zones where plants and animals are fully protected. Approximately 12% of the Solitary Islands, 20% of the Jervis Bay, 27% of Lord Howe and 27.5% of the Cape Byron Marine Park are zoned as highly protected, 'no-take' sanctuary.

As well as zoning and other forms of regulation, marine parks use permits, impact assessments, education, consultation, research, monitoring and best practices to manage not just what activities occur, but how activities can be carried out sustainably.

Large marine parks attempt to include a range of interconnected ecosystems and habitats, and aim to provide protection from external threats, protection for mobile or widely dispersed populations and have the capacity to manage a wide range of impacts. Including many features within a large marine park also provides for greater flexibility in multiple use zoning, with more opportunities to meet community and stakeholder requirements, while still meeting conservation goals.

4.2 Aquatic reserves

Aquatic reserves also aim to conserve the biodiversity of fish and marine vegetation, but may also be established for specific objectives including the protection of fish habitat, protection of threatened species, populations and ecological communities, and conservation for educational activities and scientific research.

There are currently 13 aquatic reserves in NSW. Most are relatively small (2–150 ha), and with the exception of Towra Point (1,400 ha) and North Sydney Harbour (250 ha), mainly protect rocky intertidal shores and inshore reefs. They have a role in complementing the range of ecosystems found in other MPAs, and in addressing specific local issues and ecological features.

4.3 National parks and nature reserves

Marine protected areas also occur where national parks and nature reserves are specifically gazetted over subtidal or intertidal areas. In NSW, there are around 50 national parks or nature reserves with recognised marine components. These areas can protect animals, vegetation and substrata, but cannot directly protect fish or aquatic invertebrates as defined in the *Fisheries Management Act 1994.* National parks and nature reserves differ substantially from aquatic reserves and marine parks in that there is no zoning or regulation for 'multiple use.'

Conservation of marine species can be enhanced through the protection of habitat and the general management of use including control over moorings, motor vessel access and the construction of marinas and other structures, and by protecting adjacent terrestrial habitat.

Direct protection for fish and other marine life can be achieved through arrangements with NSW Fisheries. MPAs within national parks and nature reserves exist as components of a broader terrestrial reserve system. Generally, they include large areas of intertidal and subtidal estuarine habitat and smaller areas of intertidal and subtidal coastal habitat. Offshore ecosystems have not been included within these MPAs, and are not currently targeted for protection.

As a part of an integrated system of MPAs, national parks and nature reserves make a complementary contribution to comprehensiveness, particularly in coastal and estuarine areas. The number and area of MPAs in national parks and nature reserves is substantial and several are large enough to include a range of marine habitats and ecosystem processes. For example, Myall Lakes National Park extends over 97 km^2 of estuary and ocean coast, although this area is now included in the newly declared Port Stephens - Great Lakes Marine Park.

Because of their relationship with terrestrial reserves, MPAs in national parks and nature reserves bridge gaps in protection for saltmarsh, mangrove, rocky shore, beach and other coastal transition areas. The associated terrestrial reserves also provide protection for catchment and coastal ecological processes that critically affect biodiversity in the land and sea. In particular, the protection of shoreline and catchment from habitat clearing, development and pollution provides an important buffer for near shore environments. Agreements with other management agencies (e.g. NSW Fisheries) can provide direct protection for fish in MPAs and assist in integrating conservation strategies for marine and terrestrial environments.

The *National Parks and Wildlife Act* requires a plan of management to be prepared for national parks and nature reserves, as soon as is practicable after reservation. However, these plans do not usually deal specifically with the management of marine protected areas or the aquatic biodiversity present. Current issues for NSW National Parks in this area include the control of vehicles and dogs on shores and intertidal areas and the effects of these threats on seabirds, waders and other biodiversity.

4.4 Commonwealth MPAs

The NSW state jurisdiction includes only sea within 3 nautical miles of the coast and islands. MPAs beyond the three nautical mile limit of state territorial waters are managed for the Federal Government by the Department of Environment and Heritage. These areas include important habitats and ecological gradients across the shelf, shelf break and slope associated with a distinct but largely undescribed diversity of organisms and processes of widespread importance to oceanic ecosystems. Dramatic changes in depth and sea floor topography here create unique habitats for benthic invertebrates and demersal fishes and produce unique oceanographic conditions. Currents and up-welling in these areas have important roles in the feeding and migration patterns of many fishes, invertebrates, birds, reptiles and mammals.

Currently the state Solitary Islands and Lord Howe Island Marine Parks are declared out to the three nautical mile state limit but have complementary Commonwealth MPAs established further offshore. A small section of bay inside Bowen Island at the southern headland of Jervis Bay is also managed as an MPA 'in sympathy' with the adjoining Commonwealth National Park. A Commonwealth Marine Reserve has also been declared at the Cod Grounds, off Laurieton on the NSW north coast to protect the endangered Grey Nurse Shark (*Carcharias taurus*).

Systematic planning for the Commonwealth sections of Australia's marine bioregions is currently underway through the Department of Environment and Heritage (www.deh.gov.au).

Statement of the contribution of others in Chapter 5.

Ron Avery developed the original environmental classification with the NSW Marine Parks Scientific Committee and provided much of the research to justify the environmental categories chosen and identify available sources of data. Ron also developed and implemented the methods to digitise near shore environments from aerial photographs.

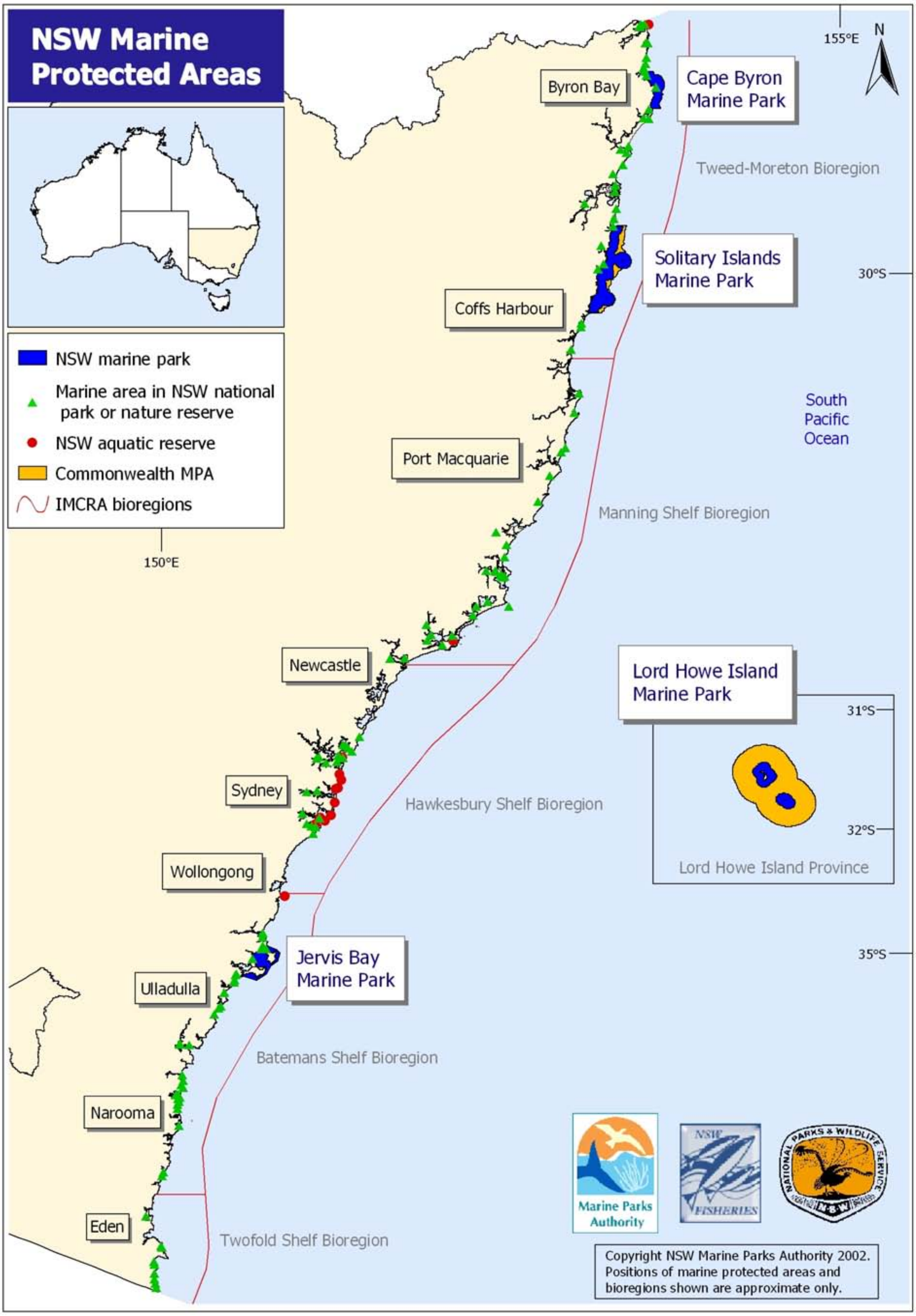


Figure 4.1 Marine protected areas in NSW before 2006 (map provided by Rodney James, Department of Environment and Conservation).

5 Methods to identify MPAs in NSW

This chapter describes the methods used to assess broad scale patterns in marine biodiversity and identify potential sites for MPAs in NSW. More detailed accounts can be read in Breen *et al*. (2003, 2004, 2005, 2006), Creese and Breen (2003) and Appendix 1. The approach used in NSW differs substantially from the process used for the Great Barrier Reef Marine Park Representative Areas Program in the amount of detailed biological information available and the level of public and scientific consultation.

The mapping methods used in the following assessments are derived from those adopted by Avery (2001) for a marine protected area assessment of the Tweed-Moreton bioregion. Mapping was based largely on the modification of existing data into an appropriate GIS format. The major exceptions were maps of near shore reefs and rocky shores digitised by Ron Avery from high resolution aerial photography. A major constraint for the assessments was the scarcity of biological data at the community and species level for large areas, and the absence of detailed maps of subtidal seabed beyond the near shore zone. The assessments focused on mapping broad scale variation as coarse scale 'ecosystem' and 'habitat' surrogates supplemented with available species data and derived measures of condition and vulnerability.

Options for marine protected areas in each bioregion were identified according to three major criteria: comprehensiveness, representativeness and adequacy. These broad criteria were applied in the assessment through the many, more detailed sub-criteria described in Chapter 2. While data were available to assess most measures for comprehensiveness as defined in Figure 2.2, much less information was available to assess representativeness at the community and species level (Figure 2.3).

To assess adequacy, quantitative measures of the potential level of human impact were calculated as general indicators of the likely condition and vulnerability of different areas (Figure 2.4). These measures were based largely on patterns of adjacent land use, as little information was available to consistently measure disturbance of marine environments at broad spatial scales.

Ultimately, the location of MPAs will be strongly influenced by meeting criteria for comprehensiveness and representativeness. However, the ability of reserves to adequately protect biodiversity and ecosystem processes will also be influenced by reserve designs that consider biological characteristics such as home range, migration, habitat complexity, disturbance and connectivity among species, habitats and processes. Criteria to address these factors were conceptually grouped under criteria for reserve design and adequacy in Figure 2.4 and include consideration of the size, shape, configuration and replication of reserves in a MPA network. Although these factors were not assessed analytically, guidelines summarised from the scientific literature were compiled by Ron Avery and are presented in Appendix 1. The decision support tools used in Chapters 6 and 10 provide ways to explore and implement these principles.

Criteria were first assessed as a function of measures for individual criteria and then combined in irreplaceability and multiple criteria analyses. Each information source, the criteria addressed and the derived measures are described in Chapters 6-8 with an assessment of the degree to which different planning units met those criteria.

The methods reflect the paucity of marine biological data for large areas and a significant by-product of this work is the identification of gaps in our knowledge of marine biodiversity in NSW. However, by basing the assessment on a broad scale environmental classification, the project avoids many of the biases inherent in examining only those areas where detailed research information is available. The ecological classification presented here lays the foundations for future research and is general enough to incorporate new information as it becomes available. The information used to identify MPAs in following three chapters can be summarised as:

- MPA goals and identification and selection criteria (Chapter 2)
- an environmental classification of marine ecosystems, habitats and communities
- available broad scale surveys of marine communities and species
- derived measures from related conservation assessments, and
- maps created of existing marine protected areas.

The methods used to help identify candidate MPA locations from this information include:

- summary statistics displayed in graphs and tables
- Geographical Information System (GIS) maps and spatial analyses
- irreplaceability analyses in C-Plan (NPWS 2001) and Marxan (Ball and Possingham 2000)
- multiple criteria analyses, and
- reviews of literature.

5.1 A marine environmental classification for NSW

The broad scale assessments are based primarily on an environmental classification developed in conjunction with Ron Avery and the NSW Marine Parks Research Committee. The surrogate biodiversity measures in this classification were used to represent progressively finer scales of biological variation in marine environments. Levels in the hierarchy were:

- IMCRA bioregions (IMCRA 1998)
- ‘ecosystem’ units - estuary types and cross-shelf depth zones (Figure 2.2 and Figure 6.2)
- ‘habitat’ units - seagrass, saltmarsh, mangrove, reef, rocky shore, beach, island and sediment (Figure 2.2 and Figure 6.8)
- finer scale ‘community’ units from other physical predictors, dominant biota and species assemblages (Figure 2.3)
- estimated distributions and abundances of species and populations (Figure 2.3).

Categories in the classification are described in the following section with a brief justification based on a review of the marine research literature researched mainly by Ron Avery. More detailed descriptions are available in Breen *et al*. (2003, 2004, 2005, 2006).

5.1.1 Estuary ecosystem classes

Coastal water bodies from the NSW Waterways GIS coast coverage were classified on the basis of coastal morphology, entrance type and tidal exchange according to Roy *et al*. (2001) who associates these differences with characteristic ecosystem processes and related assemblages of organisms. The estuary classes are:

I. Ocean embayments. These semi-enclosed bays are transitional zones between estuaries and the ocean and include communities of both environments. They generally have low turbidity, ocean tidal ranges and salinities, and include sandy areas with seagrass beds in protected locations (e.g. Botany Bay, Jervis Bay, Batemans Bay and Twofold Bay).

II. Tide dominated, drowned river valleys. These are tidal, generally deep, narrow estuaries with rocky sides, and sometimes with large, submerged, sand deltas extending up the estuary (e.g. Port Stephens, Sydney Harbour, Hawkesbury River and the Clyde River estuary).

III. Wave dominated, barrier estuaries. Young barrier estuaries in the early stages of infilling have large shallow lagoons with dense seagrass beds away from the main tidal channels (e.g. Wallis Lake, Lake Macquarie, St Georges Basin and Tuross Lake). Mature estuaries in the late stages of infilling form a riverine estuary with extensive flood plains and coastal wetlands. They often have narrow, elongated entrance channels and broad barrier sand flats (e.g. Tweed, Richmond, Clarence, Macleay, Hastings, Manning and Shoalhaven Rivers).

IV. Intermittent lagoons and creeks. These water bodies are intermittently open to the ocean, are usually associated with small catchments and small fluvial inputs, and are often non-tidal and brackish. Mangroves are generally absent, with sea rush (*Juncus kraussi*) often dominant. Benthic species diversity is often low, but there are sometimes extreme variations in abundance (e.g. Durras Lake, Narrabeen Lakes, and Smiths Lake).

V. Brackish barrier lakes. These bodies of fresh to brackish water have only a tenuous connection to the sea and are dominated by freshwater species. They are relatively rare in NSW (e.g. Myall Lakes).

5.1.2 Ocean ecosystem classes

Oceanic ecosystem types were derived from depth contours digitised by NSW Waterways from Australian Hydrographic Office nautical charts. The contours were used to divide the shelf into four broad depth zones between 0-20 m, 20-60 m, 60-200 m and waters deeper than 200 m. These zones aim to account for biotic and abiotic variation across the shelf in algae (Womersley 1984), sponges (Roberts and Davis 1996), benthic fauna (Coleman *et al*. 1997, Gray *et al*. 1997), fish assemblages (Andrew *et al*. 1997), light, wave action, sediments, currents, temperature, salinity and water chemistry (Rochford 1975, Godfrey *et al*. 1980, Colwell *et al*. 1981, Chapman *et al*. 1982, Skene and Roy 1986, Short 1993).

5.1.3 Seagrass, mangrove and saltmarsh habitats

The distributions of seagrass, mangrove and saltmarsh habitats were estimated from a GIS coverage digitised by the National Parks and Wildlife Service[3] from paper maps produced by West *et al*. (1985). Mangrove and salt marsh communities contribute to estuaries through nutrient cycling, trapping of sediments and detritus and providing habitat for characteristic and highly diverse assemblages of fish, birds and invertebrates (Hutchings and Recher 1982, Saenger 1999). Seagrass beds are widely recognised for their role in providing habitat for diverse assemblages of flora and fauna (Bell and Pollard 1989, Howard and Edgar 1999, Hannan and Williams 1998). The maps are now being updated through digital GIS classifications of orthorectified high resolution aerial photographs (1:10,000-1:25,000, R. Williams and G. West pers. comm. Fisheries, NSW Department of Primary Industry).

5.1.4 Subtidal reef habitats

Areas of shallow near shore reef systems and intervening sediment patches were estimated from GIS coverages mapped to a depth of 10-20 m by Ron Avery (NSW Department of Environment and Conservation, DEC) using 1:10,000 – 1:25,000 scale aerial photographs provided by the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR). Shallow areas of reef and shoal further offshore were digitised from Australian Hydrographic Office nautical charts.

Subtidal rocky reef areas in NSW provide habitat for distinctive assemblages of invertebrates, algae and fishes (Underwood *et al.* 1991, Andrew 1999). However, the use of aerial photographs to map subtidal habitats is limited to near shore areas and hydrographic charts focus only on those reefs and shoals that approach the sea surface and pose a hazard for shipping. It is recommended that a more comprehensive assessment of existing seabed data is made and that, where required, additional seabed surveys are carried out to accurately characterise these environments.

5.1.5 Island habitats

Areas of islands and emergent rocks were estimated from a GIS coverage generated for the Australian Maritime Boundary Information System (AMBIS) held by Geoscience Australia (Commonwealth of Australia 2001). Islands, emergent rocks and surrounding waters provide unique and important habitats for seabirds, marine mammals, fish, invertebrates and other species. Fronts, wakes and other oceanographic features that extend beyond rocks and islands (Cresswell *et al*. 1983) are important for the feeding ecology of many species and the transport

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[3] now within the NSW Department of Environment and Conservation (DEC)

and retention of larvae (Kingsford and Choat 1986, Kingsford 1990, Kingsford and Suthers 1994, 1996, Wolanski 2000).

5.1.6 Subtidal sediment habitats

Areas of near shore subtidal sediments were estimated from the GIS coverage described above for subtidal reef. Benthic fauna are known to vary significantly with depth and grain size (Poore *et al*. 1985 in Ward and Blaber 1994, Coleman *et al*. 1997), but for many areas there is currently little compiled information on the distribution of sediments that can be easily accessed. While cross shelf variation in sediment distribution is at least partly represented by ocean depth zones, further research and collation of existing data is required.

5.1.7 Intertidal beach habitats

Topographic maps (1:25,000) and the calculated area between the high and low water lines in the Digital Cadastre database from the Land and Property Information Division (LPI) of the NSW Department of Lands were used to produce a GIS shape file of intertidal areas and estimate areas of intertidal beach habitat. Justification for the classification of beaches in NSW is provided by Hacking (1997, 1998) based on relationships described in McLachlan and Hesp (1984), McLachlan (1985, 1990), Brown and McLachlan (1990) and McLachlan *et al.* (1996).

5.1.8 Intertidal rocky shore habitats

The intertidal GIS coverage described in section 5.1.7 for beach habitats was also used to estimate the area of intertidal rocky shore habitats. Field surveys by Otway (1999) and Otway and Morrison (in prep.) were used to score sections of rocky shore for the presence of five ‘community’ level substrata (platform, boulder, cobble, pool, and crevice) that were correlated with the number of species present for a given shore. Other previous conservation assessments (Quint 1982, Short 1995) also provided information on rocky shores.

5.2 Data for individual species

Information available for some communities and species included surveys of estuarine vegetation (West *et al.* 1985 and more recent surveys, R. Williams and G. West pers. comm.), juvenile fish biodiversity in estuaries (R. Williams pers. comm.), intertidal rocky shores (Griffiths 1982, Short 1995, Otway 1999, Otway and Morrison, in prep.), wetlands (ANCA 1996), birds (NPWS 1999abc, 2000bcd), mammals (Allen and Moller, 1999 Allen *et al.* 2000) and threatened Grey Nurse Shark (Otway and Parker 2000, Otway *et al.* 2003).

Other, data sources for species included analyses of commercial fish catch data (Pease 1999), and sightings databases kept by the NSW Department of Primary Industry, the NSW Department of Environment and Conservation and the Commonwealth Department of Environment and Heritage. Data from museum collections were not available at the time of the assessments, although they had been previously reviewed for these projects (Avery 2001).

5.3 Condition, vulnerability and previous assessments

There was little direct information available on condition, threat or vulnerability for marine environments across whole bioregions. However, data sets indicative of condition, potential threats and vulnerability were available for adjoining terrestrial areas. These included GIS maps of national parks and nature reserves, state forest, wetlands, wilderness, land capability, built-up areas, acid sulphate soils, and the Australian river and catchment condition database (Stein *et al*. 2000). Indices of the percentage area of these features along shorelines and in catchments were calculated for estuaries and sections of coast.

The results of previous conservation assessments for wetlands (ANCA 1996), estuaries (Bell and Edwards 1980, Digby *et al.* 1998, Frances 2000, Healthy Rivers Commission 1998, 1999, 2002ab), and rock platforms (Short 1995, Otway 1999) were also summarised and related to MPA identification and selection criteria along with descriptive information from coastal management plans (NPWS 1995ab, 1998ab).

5.4 Systematic methods to identify MPA options in NSW

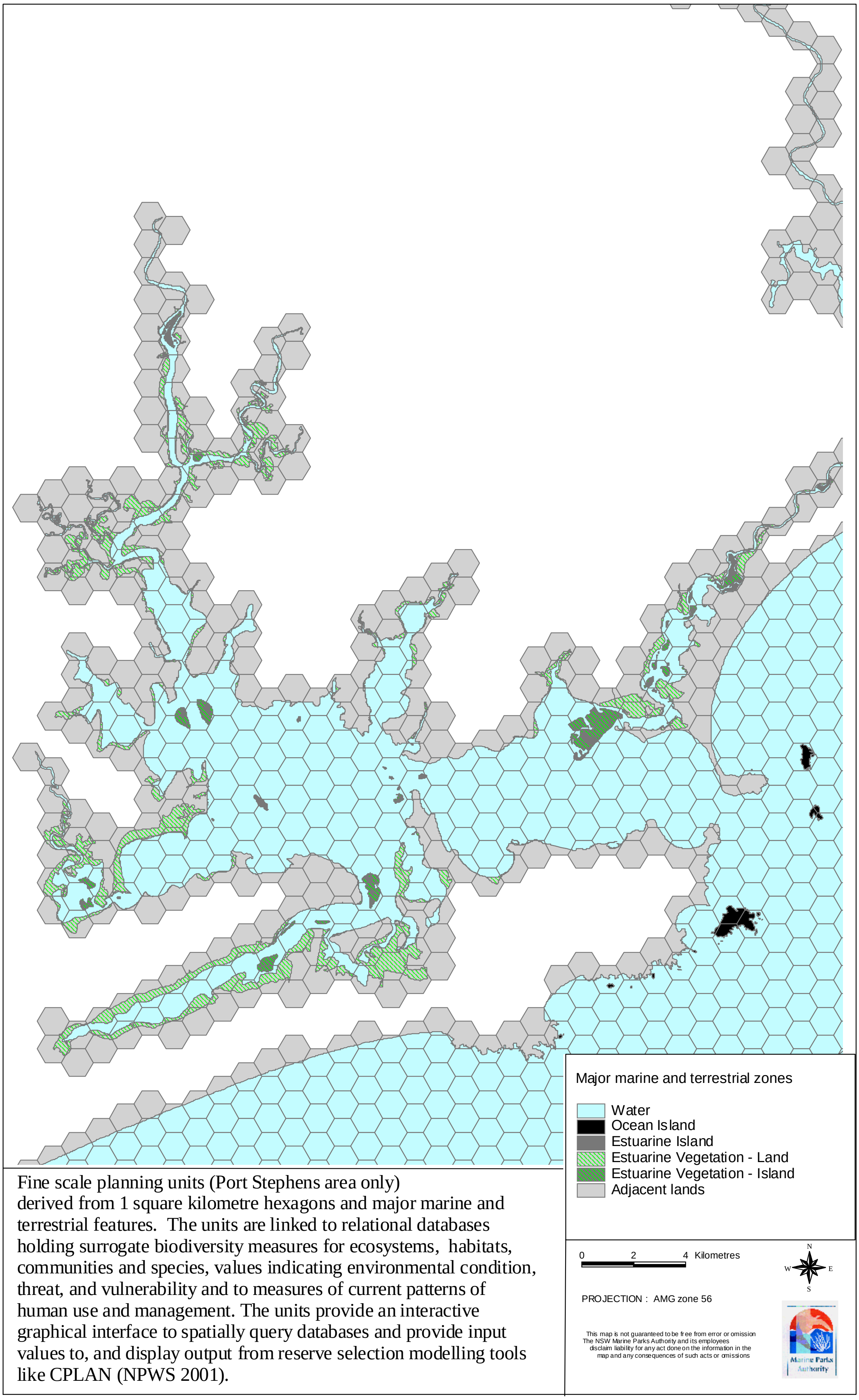
A systematic approach was used to document the conservation values of alternatives, and interpret the many criteria and sources of information used to assess options for MPAs. The methods used included summary statistics, Geographical Information System (GIS) maps and spatial analyses, irreplaceability analyses and reviews of literature and existing conservation plans.

5.4.1 Planning units

Two types of spatial planning units were used to summarise information: fine scale (1 to 4 km^2) hexagonal plan units (Figure 5.1, Figure 6.37, Figure 7.24 and Figure 8.33) and relatively large, broad scale units representing whole estuaries and sections of coast and shelf (Figure 6.2, Figure 7.4 and Figure 8.6). The small planning units were useful for summarising local patterns, and for identifying small scale planning options. The large planning units were more useful for summarising broad scale regional patterns, analysing patchy data and identifying MPA options at wider scales.

5.4.2 Graphical summaries and qualitative scores

Broad scale planning units were used to summarise regional patterns in the number and size of different ecosystems, habitats, communities and populations. These and other measures were graphed, mapped and summarised in tables with the results of related conservation assessments. Each information source, the criteria addressed, the derived assessment measures used and values for broad scale planning units are presented in Chapters 6-8.



Fine scale planning units (Port Stephens area only) derived from 1 square kilometre hexagons and major marine and terrestrial features. The units are linked to relational databases holding surrogate biodiversity measures for ecosystems, habitats, communities and species, values indicating environmental condition, threat, and vulnerability and to measures of current patterns of human use and management. The units provide an interactive graphical interface to spatially query databases and provide input values to, and display output from reserve selection modelling tools like CPLAN (NPWS 2001).

Figure 5.1. Fine scale planning units derived from 1 km^2 hexagons and coastal features.

5.4.3 Irreplaceability

A number of computer-assisted techniques take into account the 'complementarity' (Pressey *et al*. 1994) of different areas in jointly achieving targets for a range of conservation features. These targets are usually defined in terms of a desired area or proportion of a habitat, or representation of a given number of occurrences of a species.

The complementary value of a site to a reserve network is not only related to how many features (e.g. species or habitats) it includes, but also, to how that site complements the range of features already represented in protected areas. While an area may include many species and habitats, it may not be able to add anything to an existing network if conservation goals have been met for those features. However, a site with one feature not found elsewhere may be virtually irreplaceable and be an essential requirement if a system of reserves is to meet a particular conservation goal.

Including new locations in a reserve continually alters the potential value of remaining areas in meeting overall goals, and a site's value is affected by the order in which new areas are included. These changing values are difficult to quantify within a static measure, but a statistical estimate can be made of each site's 'irreplaceability'. This measure represents "the likelihood that an area will be required as part of a conservation system that achieves the set of targets" or "the extent to which the options for achieving the set of targets are reduced if the area is unavailable for conservation"' (Pressey *et al.* 1994).

Statistical estimators for irreplaceability can be computed relatively quickly (Ferrier *et al.* 2000). Other goal seeking algorithms such as integer linear programming (Cocks and Baird 1989; Underhill 1994), iterative heuristic algorithms (Margules *et al.* 1988, Nicholls and Margules 1993, Pressey *et al.* 1997) or simulated annealing (Possingham *et al*. 1999a) may have longer computing times, particularly where there are many sites and criteria.

The NSW National Parks (DEC) reserve selection software 'C-Plan' (NPWS 2001) was used in the assessments to compute irreplaceability for the following data sets:

- ecosystem types (estuary type and ocean depth zone)
- habitat types (seagrass, mangrove, saltmarsh, rocky intertidal shore, beach, subtidal reef and islands)
- juvenile estuarine fish and invertebrate survey data (Fisheries, NSW DPI)
- commercial fish catch data for estuaries and ports of landing (Fisheries, NSW DPI)
- bird sightings data (NSW National Parks (DEC))
- threatened species data (NSW National Parks (DEC))
- surveys of species presence on rock platforms (Griffiths 1982).

Hypothetical conservation targets of 20% of the total area of each ecosystem and habitat in the bioregion were used to calculate and map irreplaceability indices. C-Plan requires a conservation target to be set as a computational necessity. For the species data sets, a hypothetical target to represent each species at least once in an MPA system was used to calculate relative irreplaceability values. For area targets, 20% goals were set as arbitrary targets to allow the calculation of relative irreplaceability values. If targets are set at 100%, all planning units are irreplaceable; if set at 0% no locations are required. Setting a target between these extremes allowed the relative merits of alternative MPA systems to be assessed for a range of scenarios. However for presentation in print, only a few representative scenarios will be shown.

Two different irreplaceability measures, *site* irreplaceability and *summed* irreplaceability, were calculated for the broad scale and fine scale planning units. Site irreplaceability is a measure of the overall likelihood that an area will be required as part of a conservation system to achieve a set of conservation targets. Irreplaceability values can range from totally irreplaceable (1.0) to zero irreplaceability (0.0).

In explaining this concept, Pressey *et al*. (1994) state: “If an area is totally irreplaceable, then no matter how a system of conservation areas is designed for a region, it will have to include that area. Put the other way, if that area loses its conservation values, one or more of the conservation targets for the study area will become unreachable. Areas with progressively lower irreplaceabilities have progressively more replacements in the region, less likelihood of being required as part of a system of conservation areas, and less impact on the achievement of targets if destroyed or unavailable for conservation. Areas with zero irreplaceability contain only features that have already had their conservation targets met in existing protected areas.”

While a *site* irreplaceability of 1.0 may indicate that a planning unit is irreplaceable for one or perhaps several conservation targets, *summed* irreplaceability is also related to how many conservation targets a planning unit is likely to contribute to. It is derived by summing the individual site irreplaceabilities estimated separately for each conservation target and can therefore range from 0 to greater than 1.

For most data sets, site irreplaceability values indicated that many options were available for meeting feature targets and only a few planning units were totally irreplaceable for some targets. In general, we present results for summed irreplaceability of the broad scale plan units as these provided the most easily summarised, general interpretations of the data. However, for resolving small-scale pattern and building detailed reserve networks, the fine scale units and a variety of diagnostic measures and tools can be used.

Links between C-Plan and ArcView GIS allow operators to quickly map the results of analyses and include or exclude potential sites from MPA networks while assessing the consequences of alternative decisions. These rapid display and analysis capabilities of C-Plan make it a useful tool for exploring potential scenarios during decision-making.

5.4.4 Multiple Criteria Analyses

Criteria, data and options identified in the assessments were also used in multiple criteria analyses (Criterium Decision Plus, InfoHarvest 2000) to assess options for MPAs as a function of the combined scores for many criteria and priorities. These methods have been widely applied elsewhere in management, environmental impact assessment (Edwards 1977, www.expertchoice.com), fisheries (Mardle and Pascoe 1999) and in the selection and management of reserve networks (Fernandes 1996, Rothley 1997, Villa *et al.* 2002). The techniques allow for the weighting of criteria, calculation of trade offs, representation of uncertainty, sensitivity analyses of the relative influence of criteria, and the ability to combine and assess alternative models, data and sources of opinion.

In the Manning Shelf assessment, the Simple Multi Attribute Rating Technique (SMART) was used to assess goals and criteria for each individual estuary and section of coast and ocean. In the Hawkesbury, Batemans and Twofold Shelf assessments, the technique was used to compare nine different options for large marine parks.

Statement of the contribution of others in Chapter 6.

Ron Avery was a partner in the Manning Shelf bioregional assessment and in developing a systematic approach to researching and assessing data, mapping the environmental classification and mapping a range of other data sets, including existing marine protected areas and other management sites. Ron also mapped near shore reefs for all of NSW and rocky shores for the Manning Shelf bioregion from aerial photograph and assisted in identifying options for MPAs.

6 MPA assessment of the Manning Shelf bioregion

6.1 Introduction

The Manning Shelf bioregional assessment is one of several projects to systematically assess broad scale patterns of biodiversity within each of five NSW marine bioregions and identify where additional MPAs may be required (Figure 6.1). Scientists and conservation managers have identified 65 Australian marine bioregions and provinces (IMCRA 1998) to help plan a national system of marine protected areas. Including the characteristic biodiversity of each bioregion within a system of MPAs aims to ensure that marine ecosystems are effectively managed for the conservation of biodiversity and sustainable use.

National guidelines and criteria have been developed to identify and select MPAs within each bioregion (ANZECC 1998ab, 1999) in accordance with international, national and state strategies (Commonwealth of Australia 1992ab, UNEP 1994, Commonwealth of Australia 1996, NSW Government 1997, NSW Marine Parks Authority 2001).

This chapter describes the broad scale assessment used to identify options for new MPAs in the Manning Shelf bioregion on the basis of ecological criteria alone. Broad scale (10's of km^2) and fine scale (4 km^2) planning units are used to assess potential locations for MPAs against over 50 specific criteria derived from state and national guidelines. Assessments were assisted by mapped displays and analyses in a Geographic Information System (GIS) and irreplaceability analysis using C-Plan reserve selection software (NPWS 2001).

Possible areas for large, multiple use marine parks are identified and important locations and conservation values within each are described (Section 6.5.1 and Appendix 2). Given the uncertainty involved in assessing biodiversity and the issues involved, a strong emphasis is placed on presenting information and methods to examine a range of options. Information used for the assessment is derived from:

- national criteria for the identification of MPAs (Chapter 2)
- a broad scale atlas of marine ecosystems and habitats in NSW
- existing broad scale scientific surveys of habitats, communities and species
- existing data, maps, aerial photographs and literature
- new data coverages and analyses generated for this study
- ecological guidelines for reserve design (Appendix 1) and
- preliminary discussions with scientists, managers and the community.

A separate selection process is required for more detailed site assessment, consultation and consideration of social, economic and cultural values. The information, criteria and methods applied here should also assist in ongoing assessment, selection and management of MPAs and other strategies to conserve marine ecosystems in NSW.

6.2 Geographic extent

The Manning Shelf bioregion is defined in the Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998) from recommendations provided in an assessment by Pollard *et al.* (1997). It includes estuaries, the open coast and offshore waters out to the continental shelf break at a depth of about 200 m.

The northern boundary of the bioregion is defined by a line of latitude (30°39′S) just north of the Nambucca River mouth. The southern boundary is defined by a line of latitude (32°54′S) just north of the Hunter River mouth at Stockton (Figure 6.1). This assessment focuses on waters managed by the NSW Government that lie within three nautical miles of the NSW coast and islands as defined by the Australian Maritime Boundaries Information System (AMBIS 2001, Geoscience Australia). Although not strictly within the defined Manning Shelf bioregion, the Hunter River estuary was included in this assessment as it was a major estuary with important conservation values occurring on the southern boundary of the bioregion.

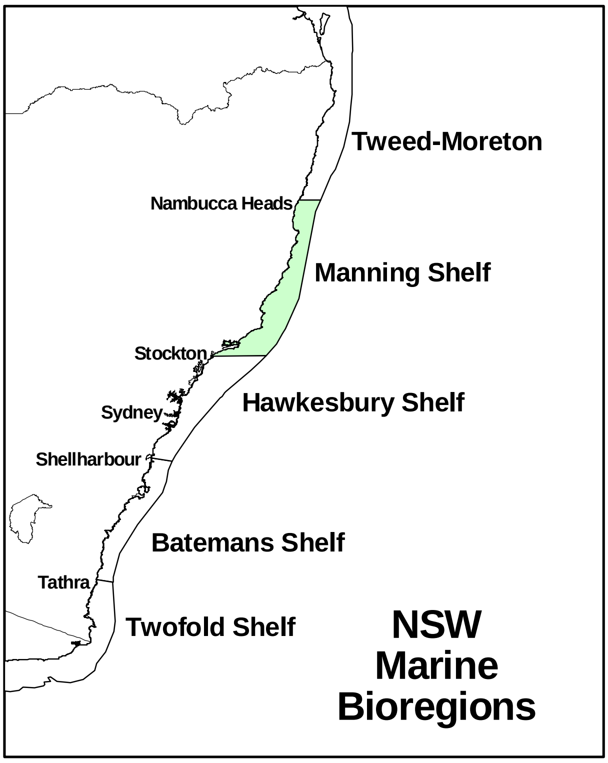


Figure 6.1. Manning Shelf marine bioregion (IMCRA 1998).

6.3 MPAs in the Manning Shelf bioregion

At the time of this assessment the Manning Shelf bioregion (Figure 6.2a) included:

- no marine parks
- one aquatic reserve at Fly Point/Halifax Park, Port Stephens (~0.8 km^2)
- eleven national parks and nature reserves recognised as having marine components (~130 km^2) but having no direct protection for fish or aquatic invertebrates.

Table 6.1. MPAs in the Manning Shelf bioregion before 2005.

MPA type	Name	Area (km^2)
Marine parks	None	0
Aquatic reserves	Fly Point / Halifax Park	0.8
A total area of 0.8 km^2 representing 0.03% of NSW marine waters in the bioregion.		
National parks and nature reserves	Hat Head NP	0.2
	Limeburners Creek NR	2.2
	Lake Innes NR	5.4
	Crowdy Bay NP	13.5
	Khappinghat NR	1.3
	Darawank NR	0.3
	Myall Lakes NP	102.9
	Corrie Island NR	0.0
	Karuah NR	1.3
	Tilligerry NR	0.3
	Worimi NR	2.0
	Grand Total	129.5
A total area of 129.5 km^2 representing 4.9% of NSW marine waters in the bioregion.		

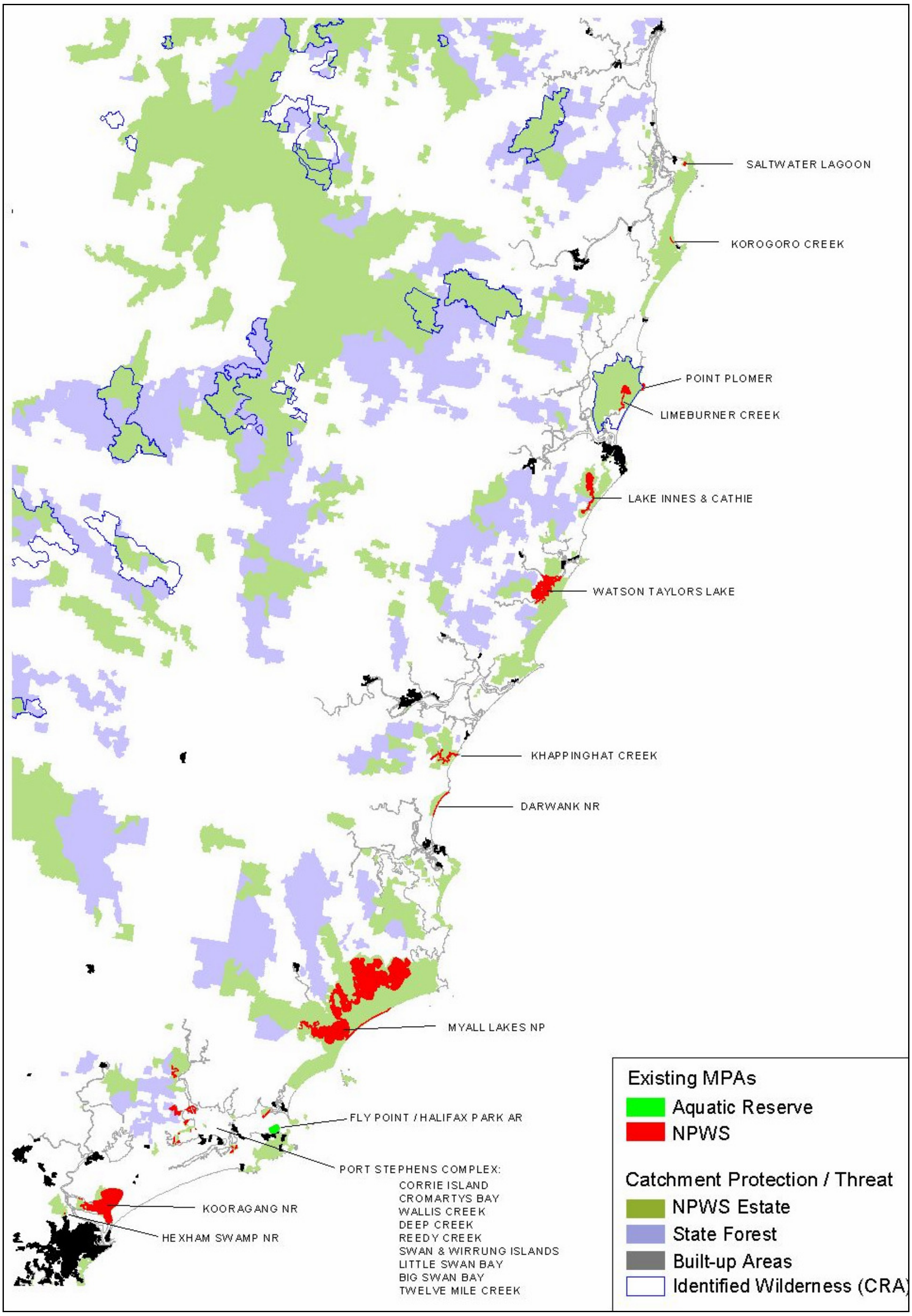


Figure 6.2a. Protected areas in the Manning Shelf bioregion before 2005 (Map by Ron Avery. Data from NSW Fisheries, State Forests of NSW, Geoscience Australia and NSW National Parks, Department of Environment and Conservation (formerly National Parks and Wildlife Service).

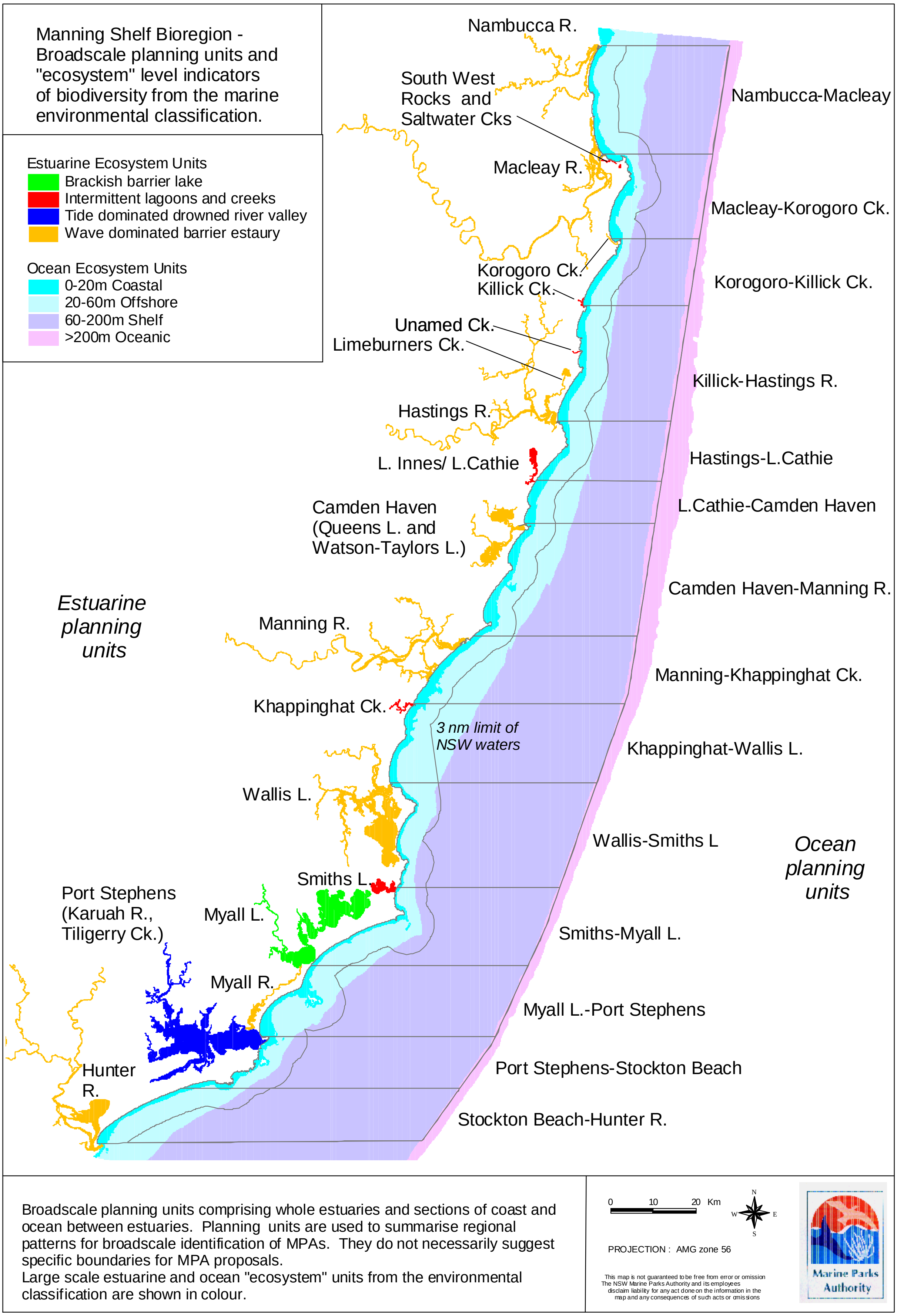


Figure 6.2b. Broad scale planning units and 'ecosystem' level indicators of biodiversity.

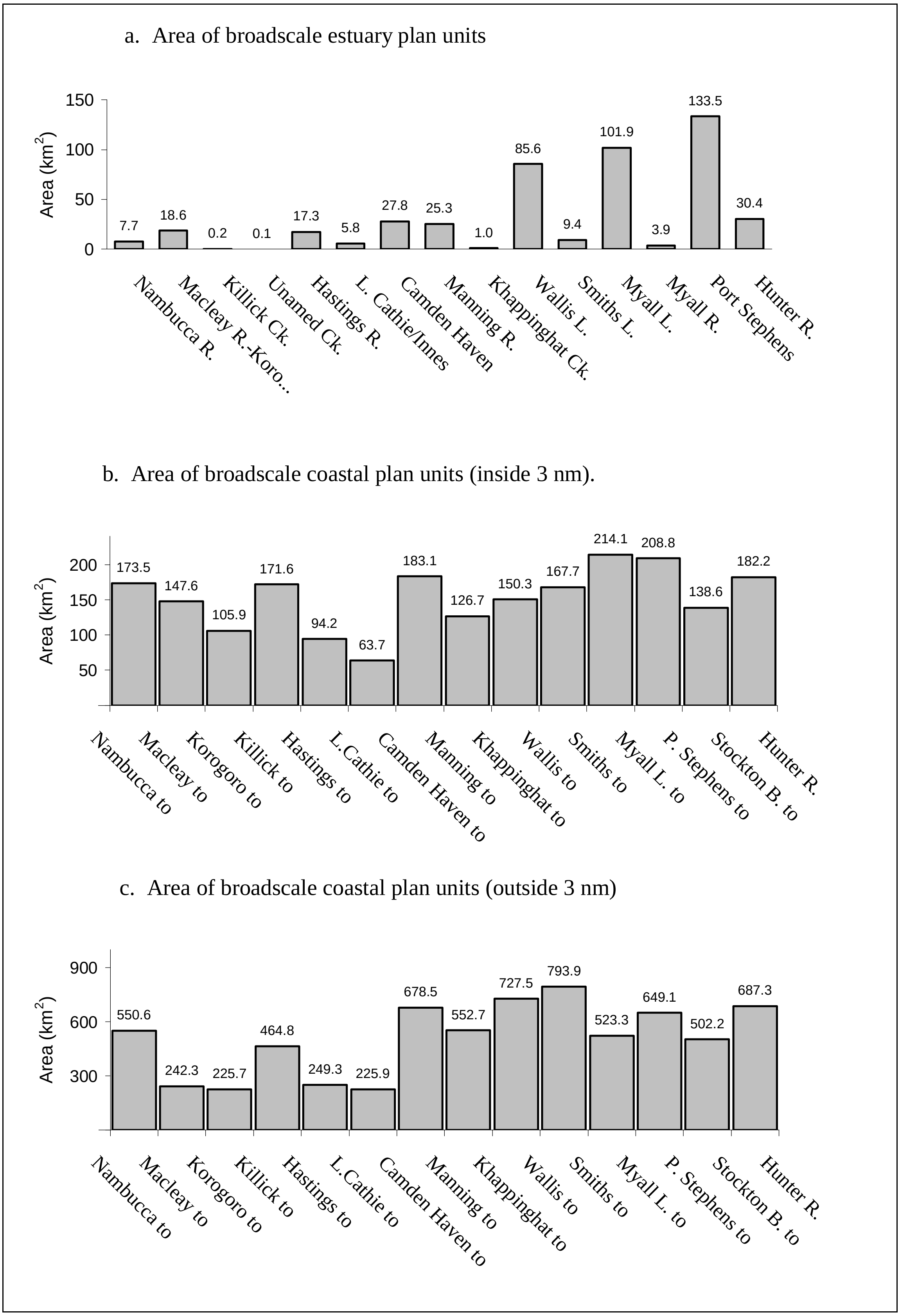


Figure 6.3. Open water area of broad scale planning units in the Manning Shelf bioregion for estuaries (a), and latitudinal sections of exposed coast and ocean within NSW territorial waters inside 3 nautical miles of coast (b) and beyond 3 nautical miles in Commonwealth waters (c).

6.4 Systematic assessment

6.4.1 Estuarine ecosystems

Data source

Roy *et al*. (2001), "Structure and function of south-east Australian estuaries."

Data description

A GIS data layer of estuaries from NSW Waterways was classified by estuary type according to Roy *et al.* (2001). The classification describes five estuary types for NSW: ocean embayment; tide dominated drowned river valley; wave dominated barrier estuary; intermittent coastal lagoons and creeks; and brackish barrier lake. Roy *et al*. describe differences among these estuary types in evolution and physical processes and corresponding responses in biota and biological processes.

Criterion

Comprehensiveness

Assessment measures

Area and number of estuaries in each estuarine ecosystem class.

Assessment

Options for representing brackish barrier lakes and tide-dominated drowned river valleys are restricted, but there are several ways to represent barrier and intermittent estuaries in MPAs (Figure 6.4). Of the 18 waterways assessed in the bioregion, there were 9 wave-dominated barrier estuaries, 6 intermittent creeks and lagoons, but only one major system of brackish barrier lakes and one tide-dominated drowned river valley (Figure 6.5). With the possible exception of Saltwater Lake on Limeburners Creek in the Hastings estuary system, the Myall Lakes are the only major examples of brackish barrier lakes in the bioregion and the largest (102 km^2, Figure 6.5c) of their kind in NSW. Myall Lakes are included within Myall Lakes National Park (Figure 6.2a) but the *National Parks and Wildlife Act* does not directly protect fishes or aquatic invertebrates from fishing.

Port Stephens is the only major drowned river valley in the bioregion (Figure 6.5d) and the largest estuary (133 km^2) of any type in NSW. Fly Point/Halifax (Figure 6.2a) is the only aquatic reserve in the bioregion and protects approximately 0.8 km^2 of estuarine rocky shore, beach, subtidal reef and soft sediments. Corrie Island, Tilligerry, Worimi and Karuah Nature Reserves (Figure 6.2a) also protect areas of mangrove, saltmarsh, estuarine beach, intertidal flat and some adjacent waters under the *National Parks and Wildlife Act*.

There are more alternatives for wave dominated barrier estuaries and intermittent creeks and lagoons (Figure 6.5ab). Wallis Lake is the largest wave-dominated estuary (86 km^2) in the region and the 3rd largest estuary of this type in the state. However, the Nambucca (8 km^2), Macleay (18 km^2), Hastings (17 km^2), Camden Haven (28 km^2), Manning (25 km^2) and Hunter (30 km^2) Rivers are also significant barrier estuaries. The Myall River (4 km^2) is unique in that it links the brackish Myall Lakes with the Port Stephens tide dominated estuary. Korogoro Creek (0.2 km^2) is the smallest estuary of this type in the bioregion (Figure 6.5a).

There are currently no marine protected areas within Wallis Lake or the Nambucca, Macleay, Manning or Myall River barrier estuaries. Most of Watson Taylors Lake in Camden Haven (Crowdy Bay National Park), the upper reaches of Limeburners Creek in the Hastings estuary (Limeburners Creek Nature Reserve), and Korogoro Creek (Hat Head National Park) are included in national park or nature reserve but have no direct protection from fishing. In the Hunter River, a large area of wetland and estuary (24.6 km^2) is protected in Kooragang Nature Reserve with a smaller area included in Hexham Swamp Nature Reserve (Figure 6.2a).

There are two relatively large intermittent lagoons (Lake Innes/Cathie – 5.8 km^2 and Smiths Lake – 9.4 km^2) in the bioregion and five much smaller intermittent creeks (South West Rocks, Saltwater, Killick, Unnamed and Khappinghat Creeks), the largest being Khappinghat Creek (1 km^2; Figure 6.5b).

Almost all of the upper reaches of Lake Innes and Lake Cathie are within Lake Innes Nature Reserve, but Smiths Lake is not protected within any form of MPA. Almost all of Khappinghat Creek is included within Khappinghat Nature Reserve. The Saltwater Lagoon section of Saltwater Creek near South West Rocks falls inside Hat Head National Park (Figure 6.2a). but South West Rocks, Killick and Unnamed Creeks are not included in any form of MPA.

In summary, 23% of the bioregion’s wave dominated barrier estuary, 43% of intermittent lagoon and creek, 100% of brackish lake and 2.7% of the area of tide dominated drowned river valley are included within nature reserves or national parks. However, only the 0.06% of the tide dominated estuary within the Fly Point/Halifax Aquatic Reserve (Figure 6.2a) has protection for fish and aquatic invertebrates, representing less than 0.02% of the total area of estuary in the bioregion.

Representation of each of these ecosystem types in the Manning Shelf bioregion would require adequate MPAs for the Myall Lakes brackish lake system, the Port Stephens/Karuah River system and adequate MPAs in at least one of the barrier estuaries and intermittent lagoons or creeks.

6.4.2 Ocean ecosystems

Data source

NSW Waterways and Australian Hydrographic Office (AHO) depth contour data.

Data description

Four depth zones (0–20 m, 20–60 m, 60–200 m and >200 m) were derived from AHO hydrographic chart depth contours digitised by NSW Waterways. These zones reflect general gradients in light, wave energy and corresponding differences in biota and ecological processes.

Criterion

Comprehensiveness

Assessment measure

Area of depth zones within planning units.

Assessment

Options for representation of the defined ocean ecosystem zones are spread evenly throughout the latitudinal extent of the bioregion if both Commonwealth and State waters are considered (Figure 6.6). However, if only NSW waters within the 3 nm limit are considered, representation of the 60–200 m depth zone can only be achieved in the north (Nambucca–Hastings) or south (Smiths L.–Hunter R.) of the bioregion (Figure 6.7c).

Small areas of the 0–20 m depth zone are protected in Limeburners Creek and Darawank Nature Reserves and Myall Lakes National Park (Figure 6.2a), representing a total of 0.1% (45 ha) of the area of this habitat and the only representation of exposed coast or ocean within a MPA in this bioregion.

a. Nambucca River
b. Macleay River and
c. South West Rocks Creek
d. Saltwater Creek & Lagoon
e. Korogoro Creek
f. Killick Creek
g. Hastings River
h. Lake Innes
i. Camden Haven
j. Manning River
k. Khappinghat Creek
l. Wallis Lake
m. Smiths Lake
n. Myall River
o. Karuah R. & Port Stephens
p. Port Stephens
q. Port Stephens (Tomaree)
r. Hunter River

Figure 6.4a–r Oblique aerial photographs of major estuaries in the Manning Shelf bioregion (provided by the NSW DIPNR).

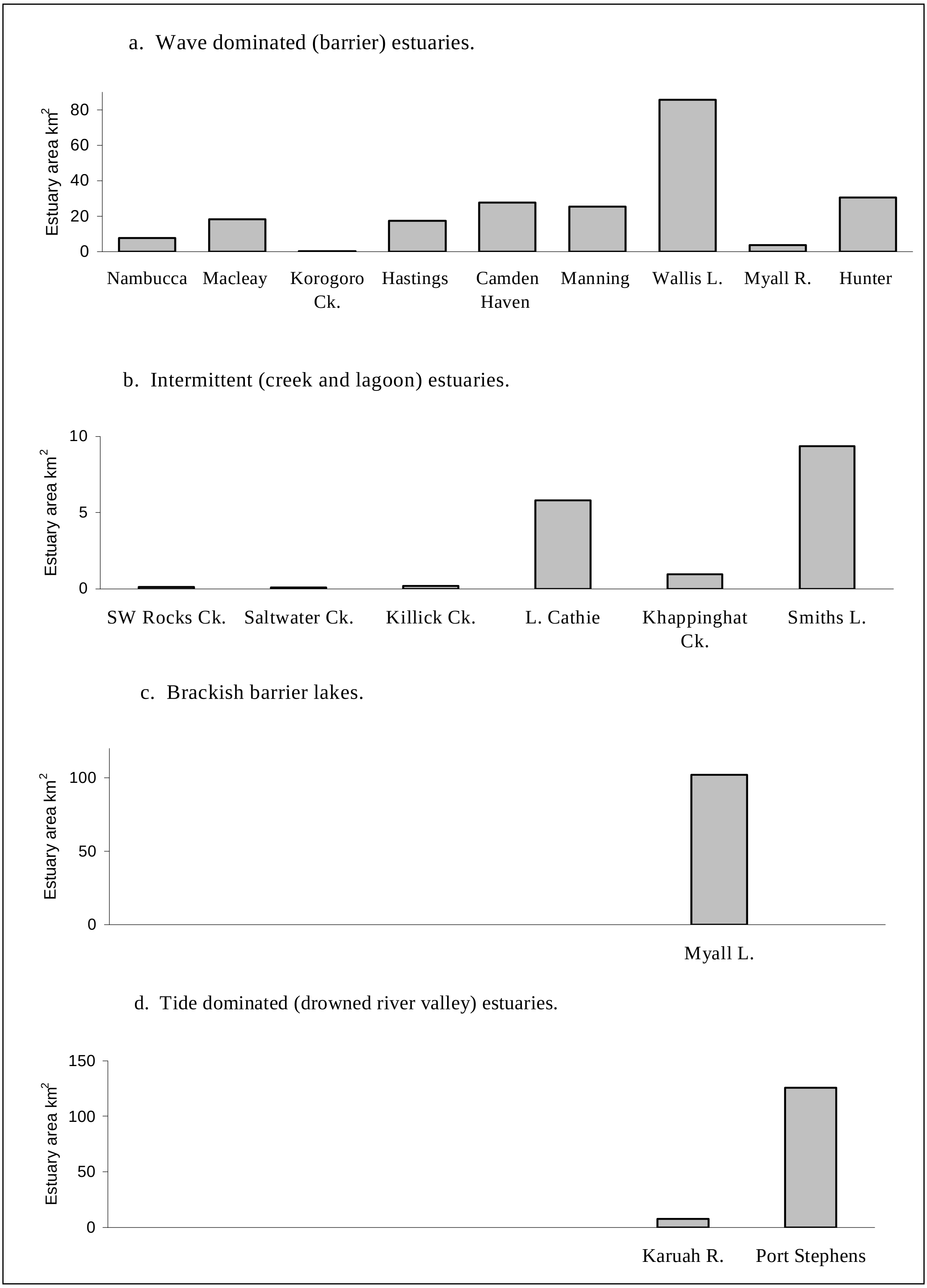


Figure 6.5 a–d. Open water area (km^2) of Manning Shelf estuarine ecosystems (values from West *et al.* 1985).

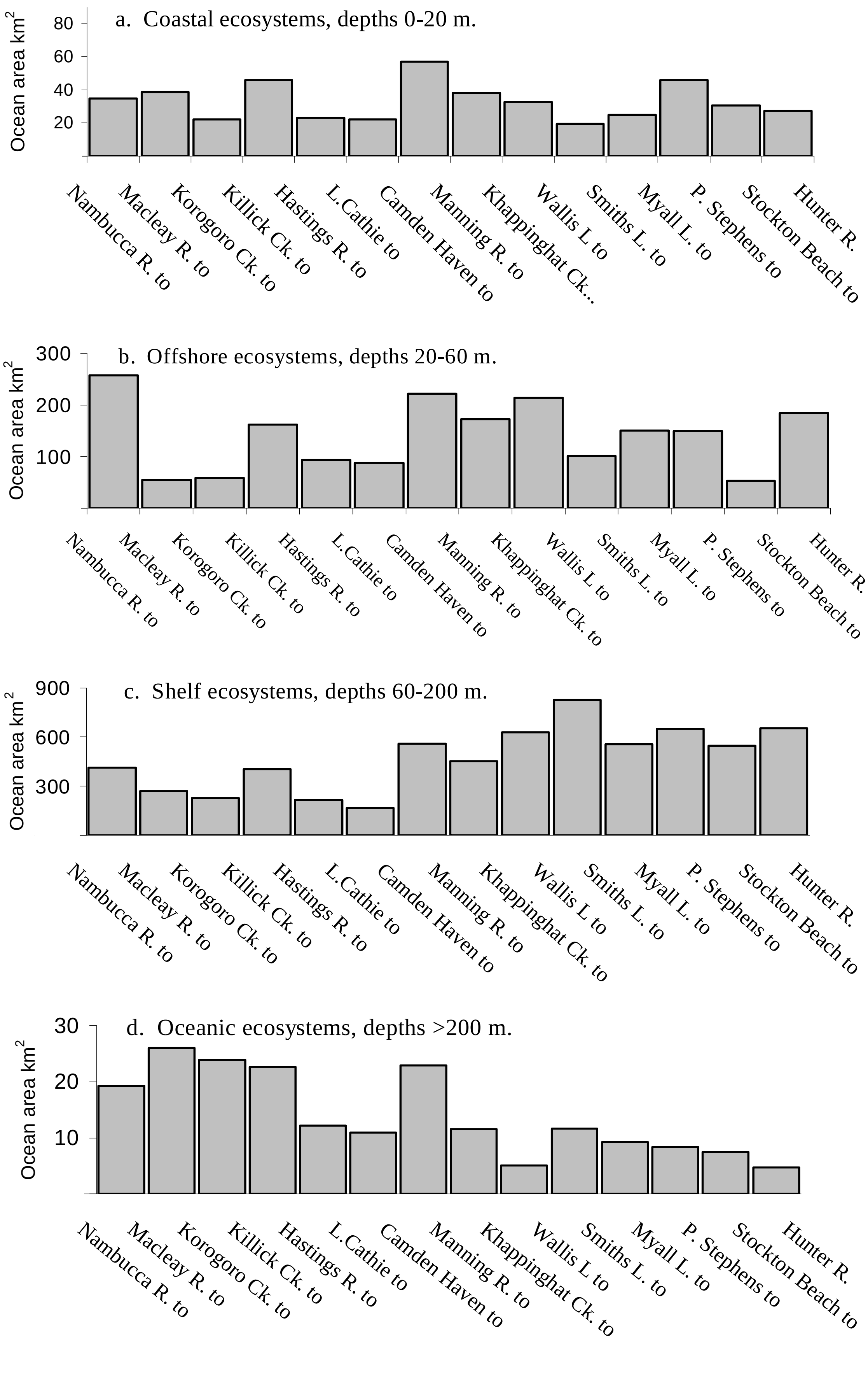


Figure 6.6 a–d Estimated areas of Manning Shelf ocean ecosystems in four depth zones within State and Commonwealth waters of the bioregion (derived from AHO nautical charts digitised by NSW Waterways).

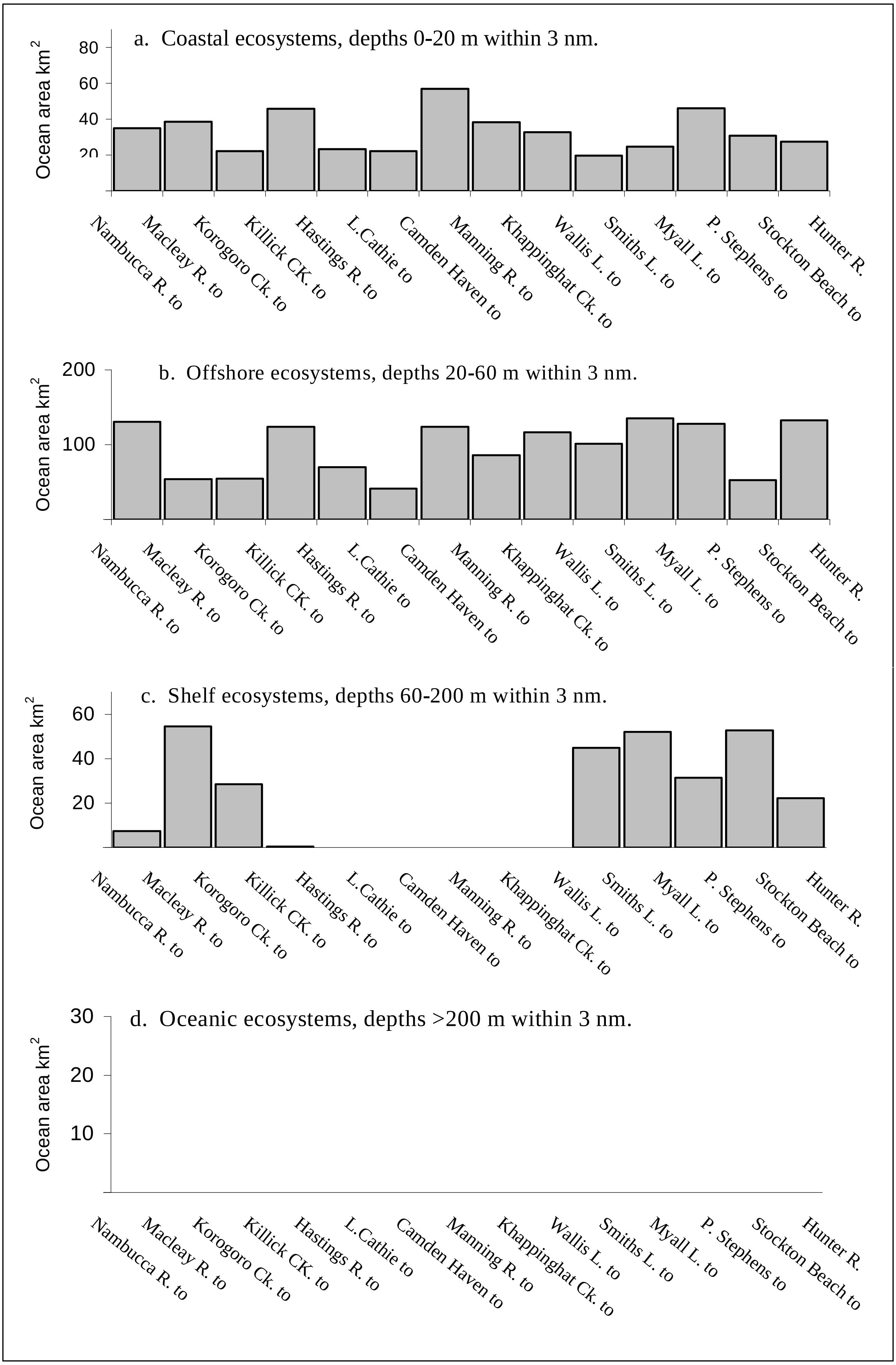


Figure 6.7. a–d Estimated areas of Manning Shelf ocean ecosystems in four depth zones within the 3 nm NSW State limit (derived from AHO nautical charts digitised by NSW Waterways).

6.4.3 Seagrass, mangrove and saltmarsh habitats

Data source

Estuarine vegetation mapping from West *et al.* (1985), digitised by NSW National Parks.

Data description

Estuarine plant communities were mapped by hand between 1981 and 1984 (West *et al*. 1985) from 1:25,000 scale aerial photographs and a 1:25,000 scale topographic map base. Vegetation types identified in the digitised GIS data layer include saltmarshes, mangroves and seagrasses. Estuarine vegetation has been mapped more recently by Greg West (NSW Fisheries) from orthorectified aerial photographs but this work was not available in time for this assessment. While changes in vegetation between these surveys are likely, broad patterns among estuaries are likely to be similar.

Criterion

Comprehensiveness

Assessment measures

Area and number of habitats and their mean, maximum and proportional size (only area is graphed here).

Assessment

Significant mangrove, seagrass and saltmarsh habitats occur in most estuaries in the region (Figure 6.8 and Figure 6.9). With the exception of Myall Lakes, the area of these habitats is strongly related to the overall size of each estuary (Figure 6.10). Port Stephens is the largest estuary in NSW and has the largest areas of mangroves (27 km^2) and saltmarshes (12 km^2) in the state. Wallis Lake is the largest barrier estuary in the bioregion and has the largest area of seagrass (31 km^2) in the state. Port Stephens and Wallis Lake also have the largest number of mangrove, saltmarsh and seagrass habitats and the biggest individual patches of mangrove forest and seagrass. Lake Cathie has the largest individual patch of saltmarsh and the highest mean saltmarsh size. Port Stephens has the largest mean patch size for mangrove forest and the Myall River has the largest mean patch size for seagrass.

If the area of habitat is standardised as a proportion of the overall estuary size, South West Rocks Creek (67%) and Korogoro Creek (36%) score highest for mangroves, the Myall River scores highest for seagrass (71%), and Lake Cathie/Innes (51%) and the Karuah River (30%) score highest for saltmarsh.

Mangrove, seagrass and saltmarsh habitats are included within the recognised marine components of 13 different national parks and nature reserves. Mangroves and saltmarshes are also found in 12 other national parks and nature reserves inland of the mapped coastline. The latter areas occur in a transition zone between marine and terrestrial environments that can occupy many square kilometres above the mapped mean high tide mark.

In total, 29% of the area of mangrove habitats in the Manning Shelf bioregion is represented in currently recognised marine components of national parks and nature reserves. This percentage increases to 43% of the bioregion's mangrove habitat when all areas of national park or nature reserve are considered (i.e. including those areas inland of the mapped coastline).

For saltmarsh, 4% of the total area in the bioregion is located in national parks and nature reserves seaward of the mapped coastline, but this value increases to 47% if all areas of national park and nature reserve are considered.

Almost half of the area of mapped mangrove and saltmarsh habitat, therefore, already lies within national parks or nature reserves but has no direct protection for fish or aquatic invertebrates from fishing. Most of the protected mangrove habitat is found in Kooragang (24.6% of the total area of mangrove habitat in the bioregion), Worimi (8%) and Karuah Nature Reserves (4.6%). Most of the protected saltmarsh habitat is found in Lake Innes (20.5% of the total area of saltmarsh) and Kooragang Nature Reserves (10.9% of the total saltmarsh area).

National parks and nature reserves include only 2% of the bioregion's seagrass mapped by West *et al*. (1985). No mapped areas of mangrove, seagrass or saltmarsh habitat in the Manning Shelf bioregion are protected within aquatic reserves or marine parks.

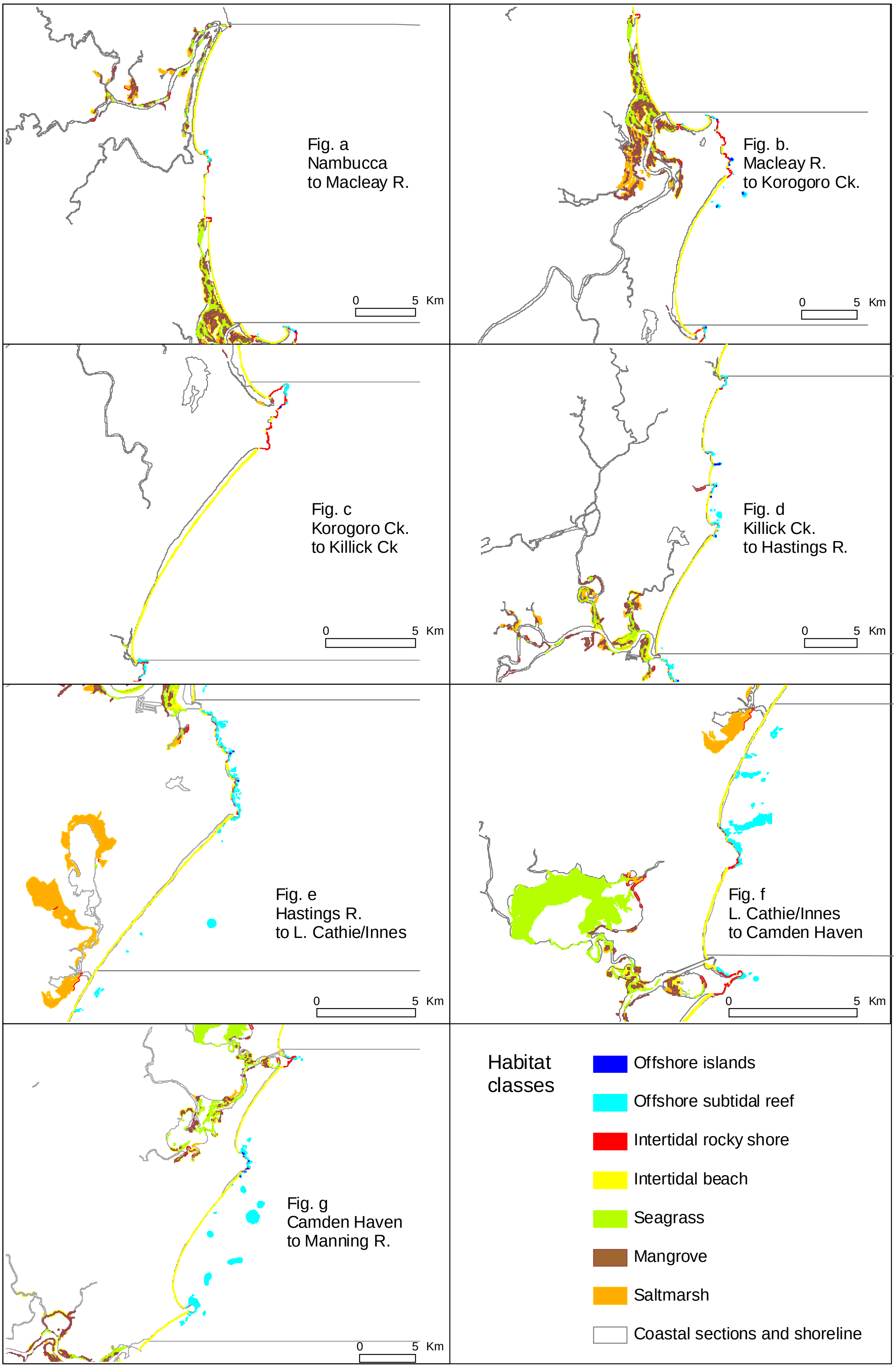


Figure 6.8a–g. Habitat classes for estuaries and sections of exposed coast and ocean in the Manning Shelf bioregion.

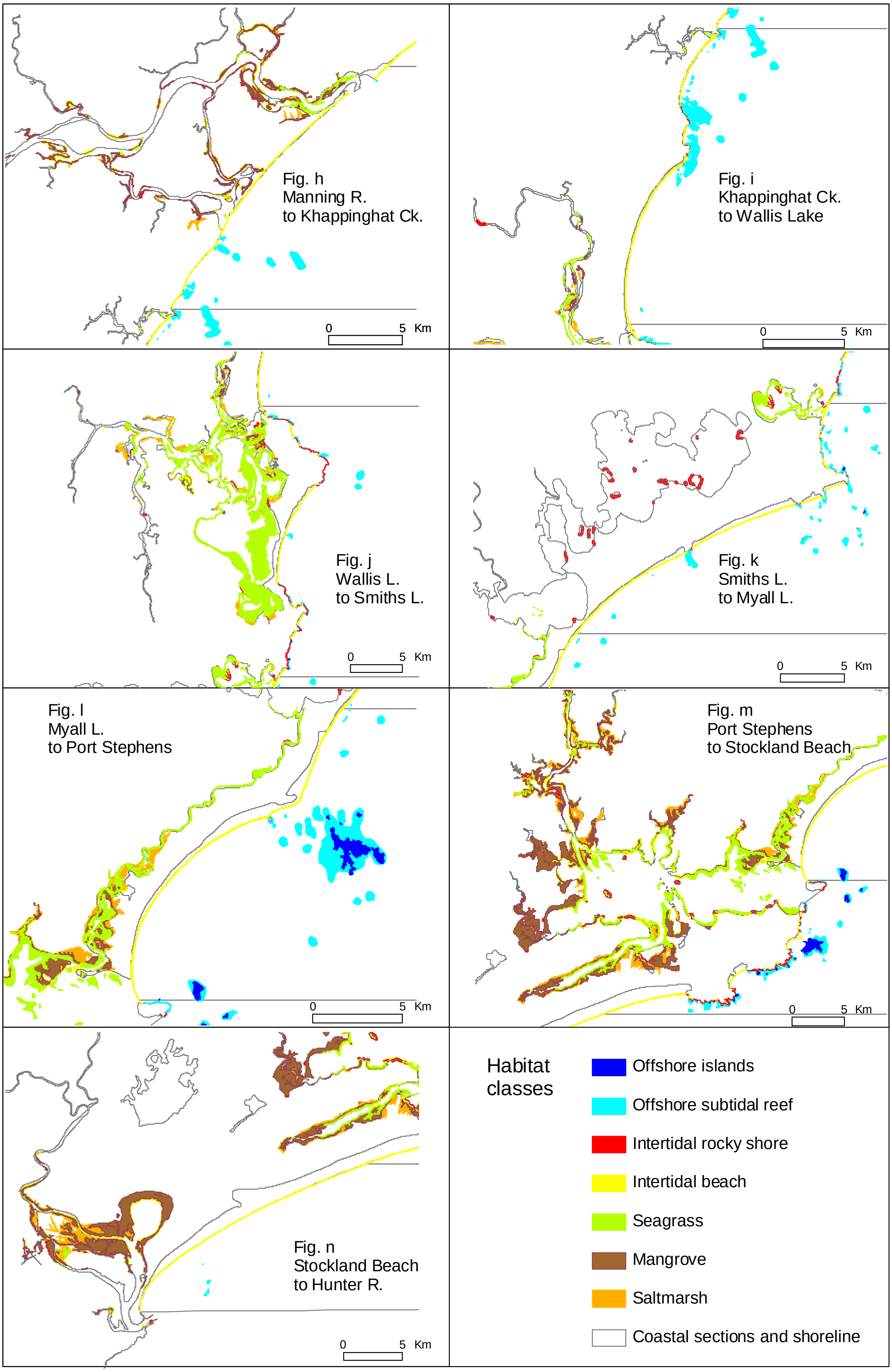


Figure 6.9 h–n. Habitat classes for estuaries and sections of exposed coast and ocean in the Manning Shelf bioregion.

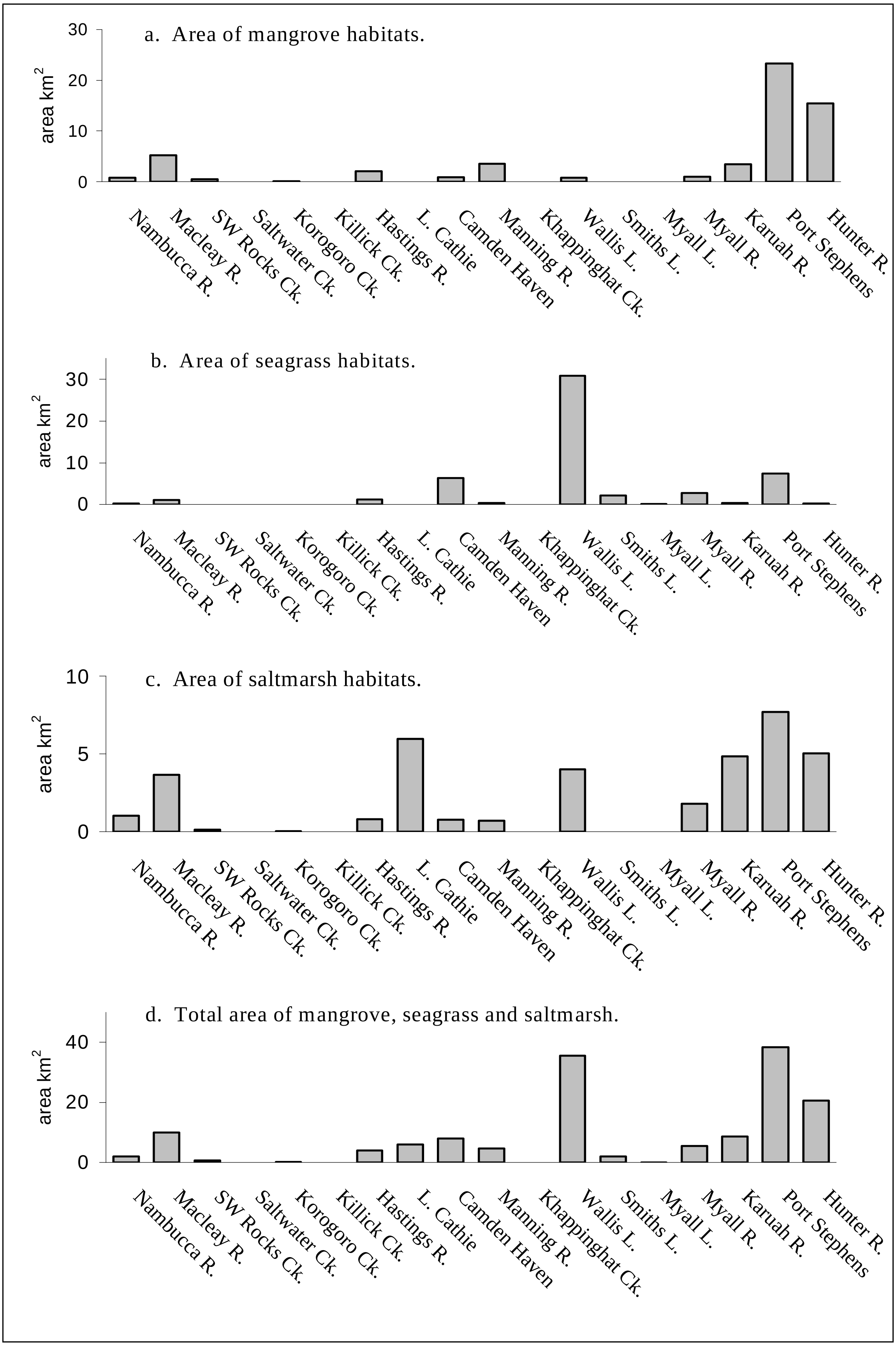


Figure 6.10a–d. Area of mangrove, seagrass and saltmarsh habitats for major estuaries in the Manning Shelf bioregion (derived from West *et al.* 1985).

6.4.4 Subtidal reefs and shoals

Data sources

1:10,000–25,000 aerial photographs provided by the NSW Department of Infrastructure Planning and Natural Resources (DIPNR).

Near shore reefs digitised by Ron Avery (NSW National Parks).

NSW Land and Property Information Centre 1:25,000 topographic maps.

Digital Australian Hydrographic Office charts.

Data description

The outlines of near shore reefs were hand drawn from aerial photographs onto 1:25,000 maps by Ron Avery using camera lucida and then digitised. Offshore reefs and shoals were digitised from AHO charts. Reefs were classified by their distance offshore (more or less than 1 km) as a community level surrogate for differences in environments and biota. While aerial photography provided detailed maps of inshore reefs, the majority of deeper offshore areas in NSW remain unmapped as the hydrographic charts only show areas of reef that are hazardous to shipping.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Number and area of reefs in broad scale plan units (sections of exposed coast and ocean).

Assessment

The largest total area of mapped subtidal reef (9 km^2) occurred in the Myall L.–Port Stephens section followed by the Port Stephens–Stockton Beach, Khappinghat–Wallis L. and Camden Haven–Manning R. sections. The least area of mapped subtidal reef occurred in the Nambucca–Macleay and Korogoro–Killick Ck sections (Figure 6.11a).

The Port Stephens–Stockton Beach section included the most area of reef within 1 km of shore, while the Myall L.–Port Stephens section included the most area of reef over 1 km from shore (Figure 6.11bc).

The Hastings–L. Cathie section included the greatest number of reefs (Figure 6.11d). These occurred mostly within 1 km of the coast and on average were relatively small. On average, the largest reefs occurred in the Port Stephens–Stockton Beach section. The highest number of reefs more than 1 km offshore occurred in the two sections between Smiths Lake and Port Stephens and their average size was greatest in the Myall L.–Port Stephens section.

There is currently no offshore subtidal reef represented in a nature reserve or national park but an unmapped area of subtidal estuarine reef is found within the 80 ha of the Fly Point/Halifax Aquatic Reserve in Port Stephens.

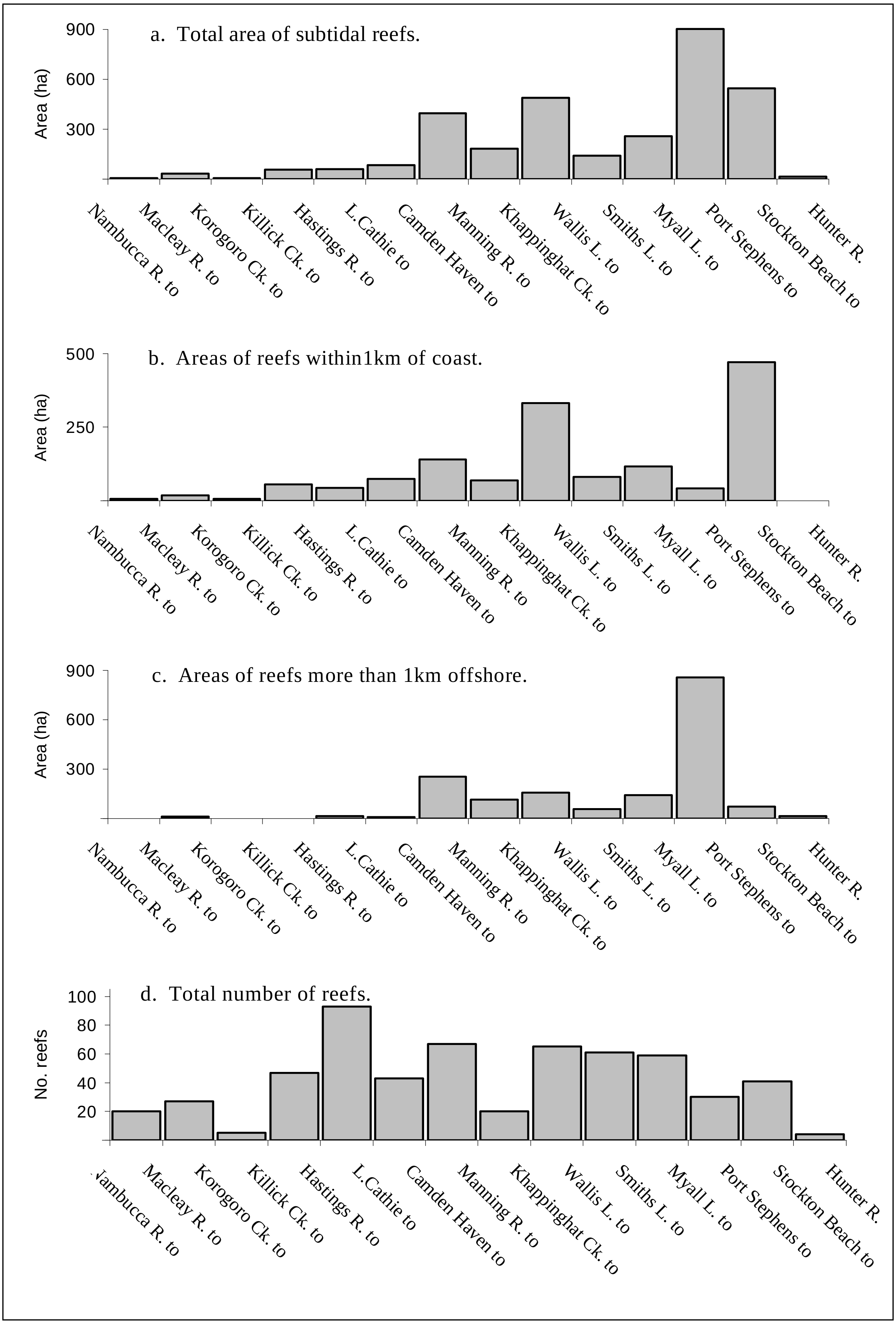


Figure 6.11a–d. Areas and numbers of reefs mapped for sections of coast and ocean in the Manning Shelf bioregion.

6.4.5 Islands

Data source

GIS data layer of islands and emergent rocks from the Australian Maritime Boundary Information System (Geoscience Australia).

Data description

This GIS layer is an extensive coverage of islands and rocks exposed at low tide. Arbitrary 100 m buffers extending out from the low water mark of oceanic islands and exposed rocks were also used to represent the influence of islands on adjacent waters. Islands were classified by distance offshore (more or less than 1 km) as an indicator of environmental differences within this habitat category.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Number and area of islands and the area of island buffers within plan units.

Assessment

The greatest number of islands and rocks (77) occurred along the Port Stephens–Stockton Beach section of exposed coast. This section also included more islands within 1 km of the mainland (56), and the second highest number of islands over 1 km offshore (21) after the Myall Lakes–Port Stephens section (30 islands). Otherwise, islands over 1 km from shore occurred only in the Macleay–Korogoro section (2 islands), Hastings–L. Cathie section (1 island) and between Smiths L. and Myall L. (2 islands).

The greatest area of water within 100 m of islands occurred in the Myall L.–Port Stephens and Port Stephens–Stockton Beach sections (Figure 6.12). The former section had the greatest area around islands more than 1 km offshore, while the latter had the greatest area around islands less than 1 km offshore.

Currently a total of 0.01% (0.9 ha) of waters within 100 m of islands is represented in Limeburners Creek and Darawank Nature Reserves and no island waters are represented in aquatic reserves.

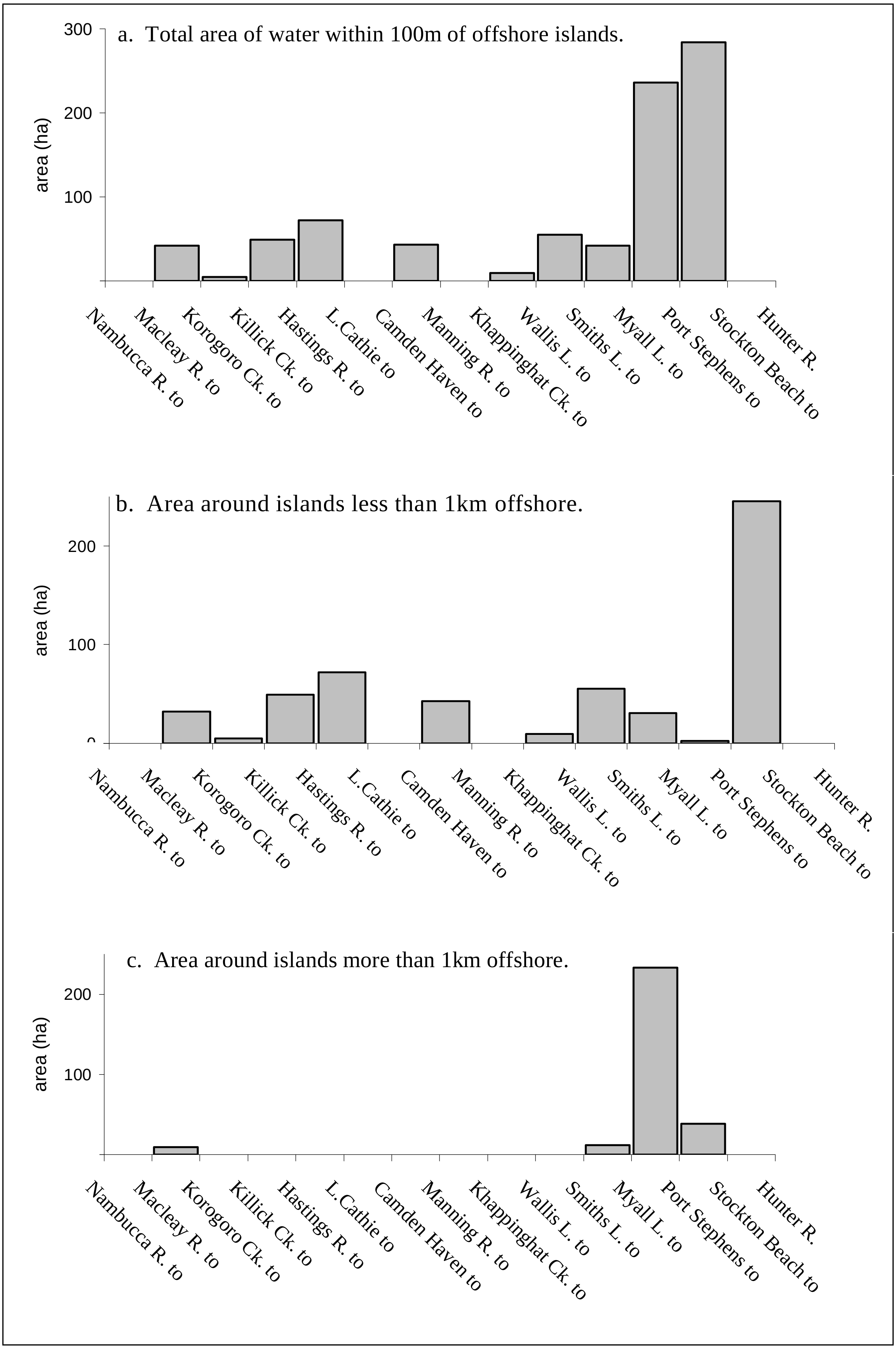


Figure 6.12a–c. Area within a 100 m buffer of islands for sections of exposed coast and ocean in the Manning Shelf bioregion.

6.4.6 Beaches

Data sources

AMBIS (Geoscience Australia) high water mark (length of coastline).

Land and Property Information Centre 1:25,000 topographic maps.

Area between the AMBIS high and low tide coastlines.

1:10,000–25,000 aerial photographs from the DIPNR.

Data description

The limits of exposed beaches were identified on 1:250,000 topographic maps and digitised and measured along a GIS line coverage of the high tide mark provided by AMBIS. Areas of beach between the AMBIS high and low tide marks were identified from aerial photographs and categorised as either intermediate or reflective according to Hacking (1997, 1998). Areas of estuarine beach and intertidal flat were identified from acid sulphate soil risk maps from the NSW DIPNR.

Criteria

Comprehensiveness and representativeness.

Assessment measure

Length and area of shore for broad and fine scale plan units.

Assessment

The total length of beach in each section of exposed coast ranged from 29 km for the Camden Haven–Manning and Smiths–Myall sections down to 9.3 km for the L. Cathie–Camden Haven section (Figure 6.15). The greatest number of beaches occurred in the Hastings–L. Cathie and Port Stephens–Stockton Beach sections but these beaches tended to be shorter in length than in other sections.

The Myall L.-Port Stephens and Stockton Beach–Hunter R. sections included the largest area of intermediate beach while the Wallis L.–Smiths L. and Macleay–Korogoro sections included the largest areas of reflective beach. Reflective beaches were not found in the Hastings R.-Khappinghat Ck, Myall L.–Port Stephens or the Stockton Beach–Hunter R. sections (Figure 6.13b and c).

The largest area of mapped estuarine beach, intertidal flat, supra-tidal flat and offshore island beaches occurred in Port Stephens (Figure 6.13 and Figure 6.14). However, the use of the acid sulphate soil risk maps to assess these habitats may underestimate the area of beach for other estuaries in the bioregion.

Currently a total of 7.1% (114 ha) of the bioregion's ocean beach is represented in Limeburners Creek and Darawank Nature Reserves and Myall Lakes National Park, with another 300 m length of estuarine beach included in Fly Point/Halifax Aquatic Reserve.

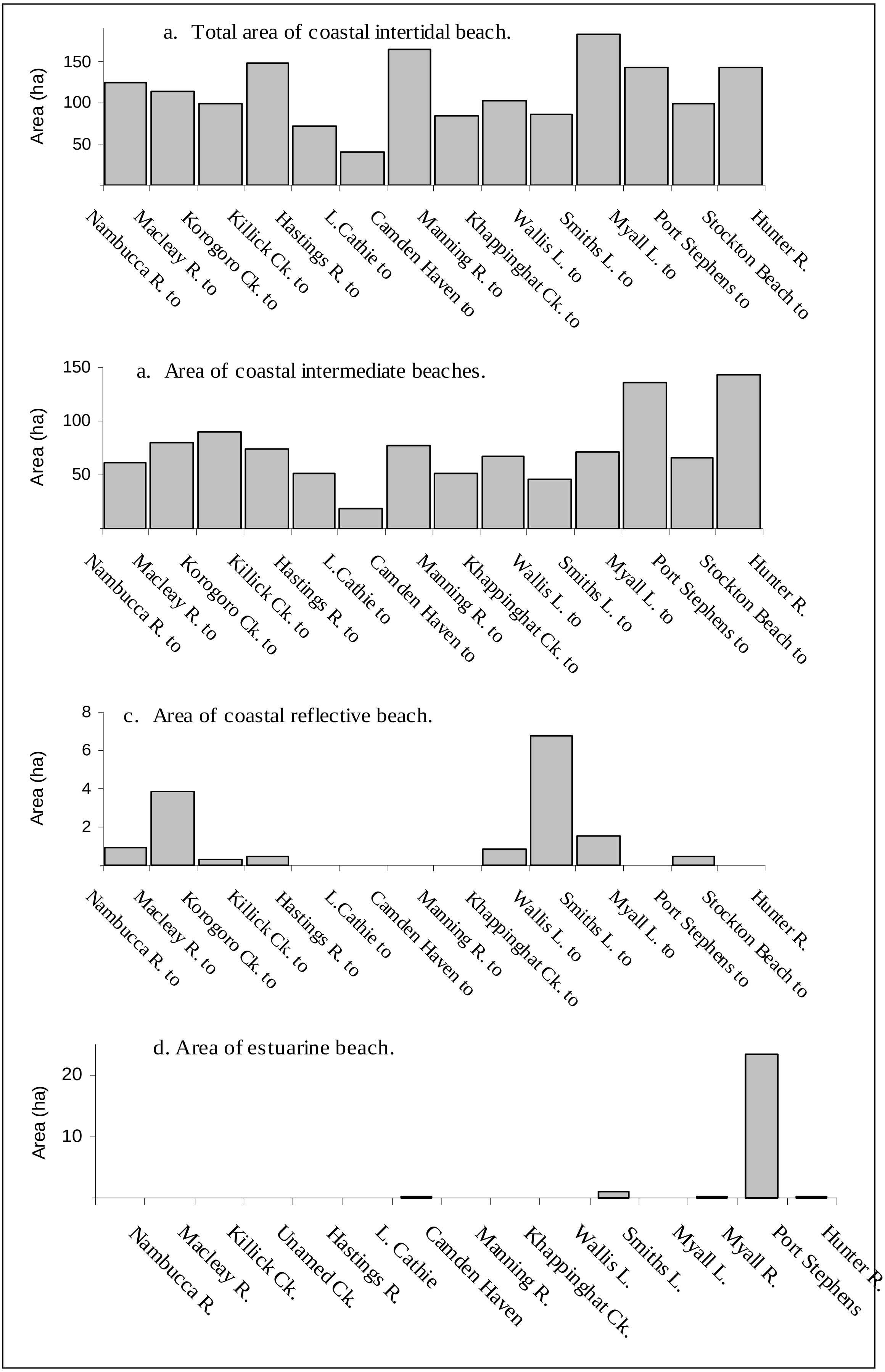


Figure 6.13a–d. Area (ha) of intertidal beach habitat mapped for sections of ocean coast and for estuaries in the Manning Shelf bioregion.

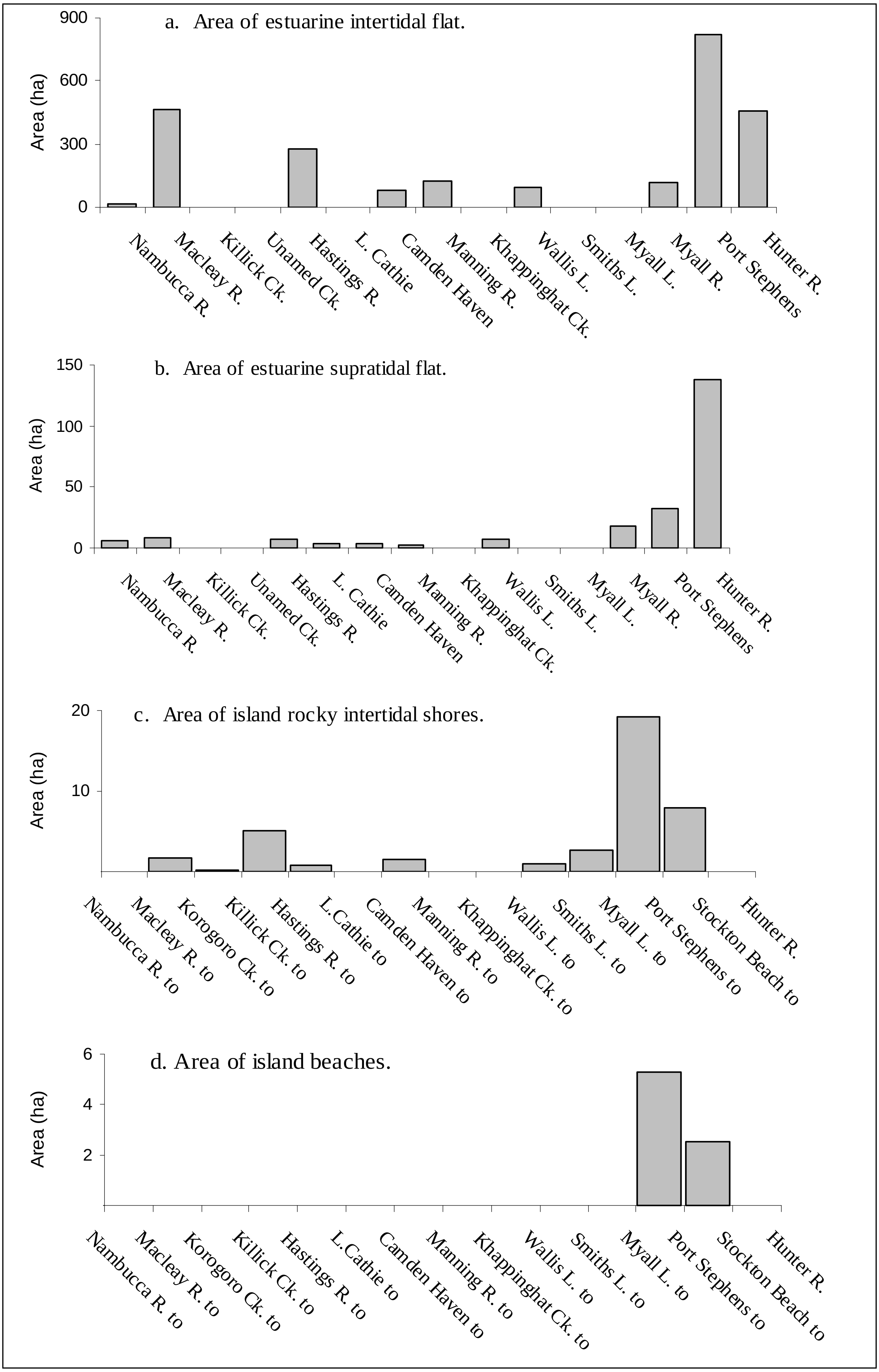


Figure 6.14 a–d. Area of intertidal habitat mapped for estuaries and offshore islands in the Manning Shelf bioregion.

6.4.7 Intertidal rocky shore

Data sources

AMBIS (Geoscience Australia) high water coast (length of coastline).

NSW Land and Property Information Centre 1:25,000 topographic maps.

Otway and Morrison (in prep.).

Area calculated between AMBIS high and low tide coastlines.

1:10,000–25,000 scale aerial photographs from DIPNR.

Data description

The limits of exposed, intertidal, rocky shores were identified on 1:250,000 topographic maps and digitised and measured along a GIS line coverage of the high tide mark provided by AMBIS. Areas of rocky intertidal shores were estimated from a GIS polygon coverage created between the AMBIS high and low water tide marks. Ron Avery used aerial photographs to categorise shores as either platform or cobble, wherever the intertidal zone was greater than 5 m wide. At accessible sites, Otway and Morrison (in prep.) conducted field surveys to score shores for the presence of platform, boulder, rubble, pool and crevice communities.

Criteria

Comprehensiveness and representativeness.

Assessment measure

Length, area and number of rocky intertidal shores within plan units.

Number and area of bedrock and cobble shores.

Presence of platform, boulder, rubble, pool and crevice communities.

Assessment

The Port Stephens–Stockton Beach section (33 km) and the Wallis L.–Smiths L. section (20 km, Figure 6.15b) include the longest total length of intertidal rocky shore. The L. Cathie–Camden Haven, Manning–Khappinghat, Myall L.–Port Stephens, and Stockton Beach–Hunter R. sections are distinct in that they include less than 2 km of rocky coast.

The greatest number of individual intertidal rocky shores are found in the Hastings–L. Cathie section (17 shores) and Port Stephens–Stockton Beach section (17 shores), but the average length of these shores is greater for the latter section. The total area of intertidal rocky shore is highest for the Wallis L.–Smiths L. section (Figure 6.16a) and the largest areas of rock platform and boulder beach are found there (Figure 6.16bc).

Otway and Morrison (in prep.) assessed the presence of platform, crevice, pool, cobble and boulder communities on rocky shores in the bioregion as a surrogate measure for ‘community’ level biodiversity. The Port Stephens–Stockton Beach section included the highest number of rocky shores (5 shores) containing all five ‘communities’. Other sections with shores containing all five community types were the Killick–Hastings (2 shores), Hastings–L. Cathie (1 shore), L. Cathie–Camden Haven (1 shore), Camden Haven–Manning (3 shores), Khappinghat–Wallis (3 shores) and the Wallis–Smiths L. (1 shore) sections of ocean coast (Figure 6.17).

Currently a total of 4.7% (9.4 ha) of exposed rocky intertidal shore in the bioregion is represented in Limeburners Creek and Darawank Nature Reserves and in Myall Lakes National Park, with another 2 km length of estuarine rocky shore represented in the Fly Point/Halifax Aquatic Reserve.

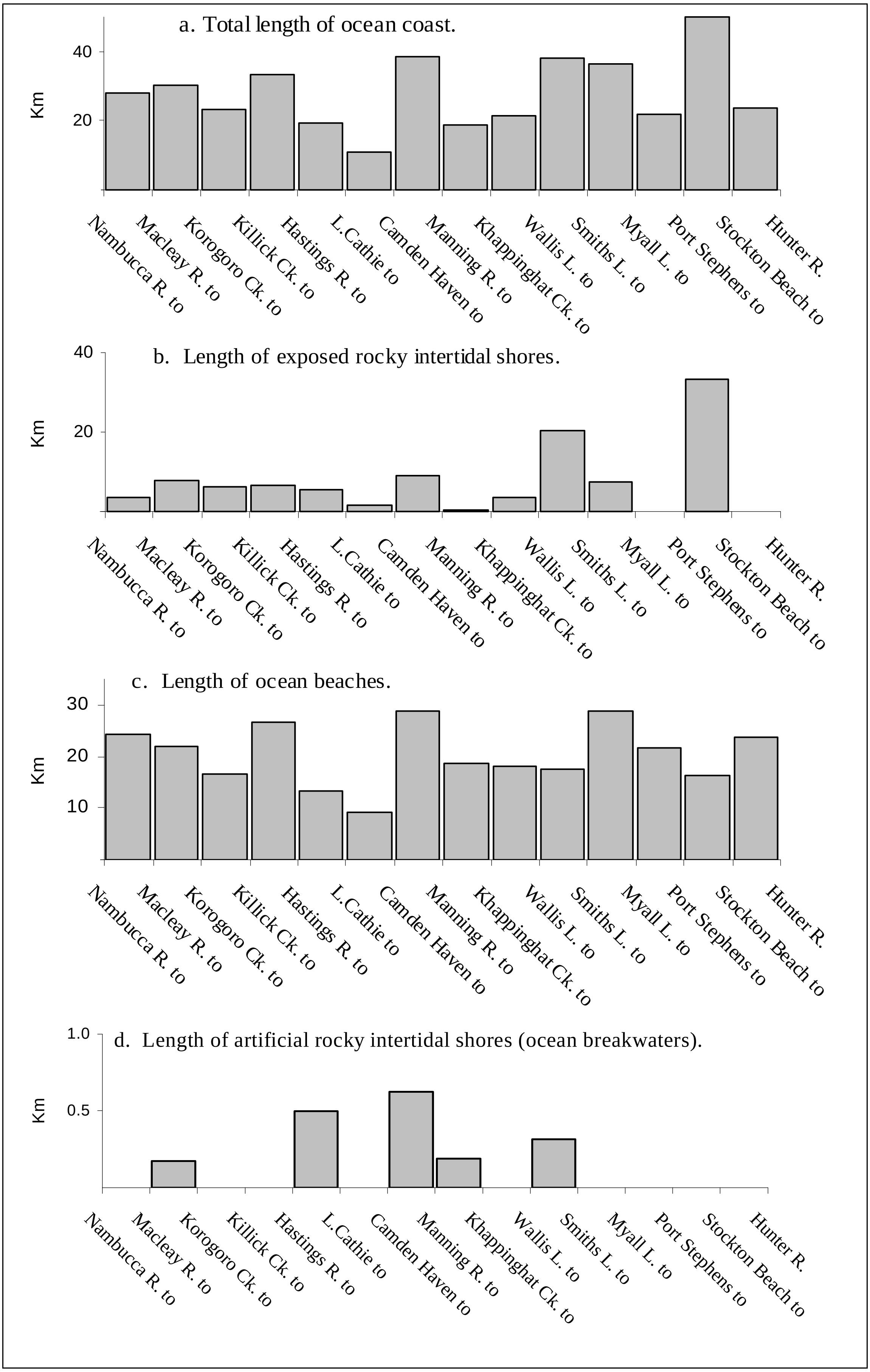


Figure 6.15a–d. Lengths (km) of intertidal habitats mapped for sections of ocean coast in the Manning Shelf bioregion.

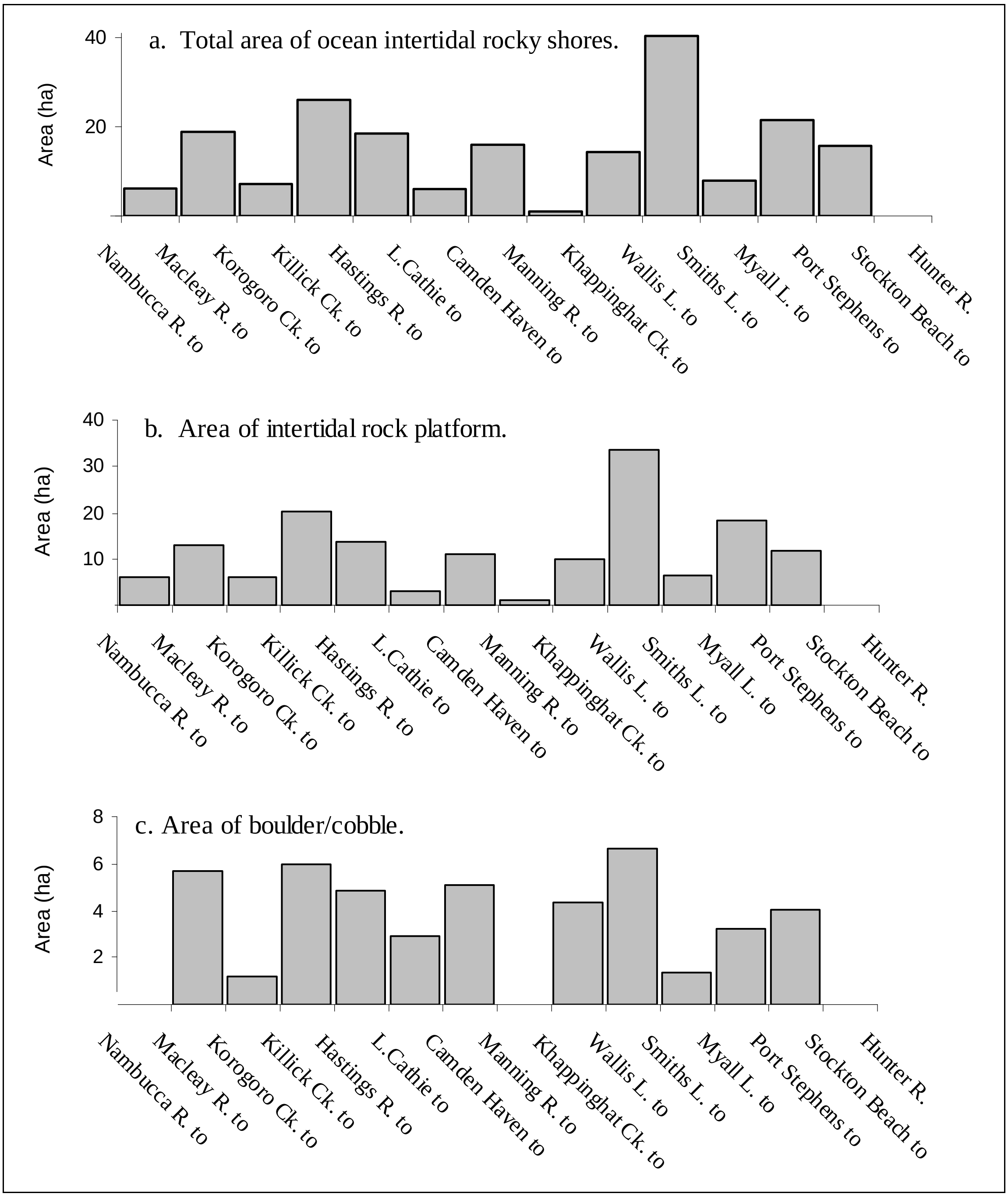


Figure 6.16a–c. Area (ha) of rocky intertidal habitats for sections of ocean coast in the Manning Shelf bioregion.

6.4.8 Coastal rock platforms (Total Environment Centre)

Data source

Short J.M. (1995). “Protection of coastal rock platforms in NSW.”

Data description

This database of ‘significant rock platforms’ identifies 198 separate rock platforms in NSW, 33 of which lie in the Manning Shelf bioregion.

Criterion

Representativeness

Assessment measures

The database includes attributes relating to: location, access, platform dimensions, physical characteristics, geology, biology, impacts, existing management, other data and recommendations for management.

Assessment

Based on an assessment of the characteristics described above, Short (1995) recommended 15 of the 33 headlands investigated in the Manning Shelf bioregion for protection (Figure 6.17).

6.4.9 Intertidal platform survey (Griffiths 1982)

Data sources

Quint G. (1982) “Headland Survey.” In “Coastal Headlands Survey Parts 1–3.”

Data description

The coastal headlands survey (Parts 1–3) provides a detailed summary of the vegetation and geology of 193 headlands in NSW, 35 of which are in the Manning Shelf bioregion. Parts 4–5 provide a geomorphological investigation of 185 rock platforms, 32 of which are in the Manning Shelf bioregion. Of these 185 platforms, a detailed biological survey was conducted on 45 platforms, five of which occur in the bioregion.

Criterion

Representativeness

Assessment measures

The biological surveys of rock platforms sampled over 100 species from a range of taxa including gastropods, cephalopods, crustacea, annelids, echinoderms, coelenterates, sponges and algae. Identification measures included the survey assessment, number of species and summed irreplaceability.

Assessment

Bald Head (north of Smiths Lake) was the only site recommended for protection in the Manning Shelf bioregion (Figure 6.17). Species data from the survey were analysed in C-Plan for the five sites in the Manning Shelf bioregion for which there was detailed biological information. Bald Head had most species and the highest summed irreplaceability value for representation of at least one of each species.

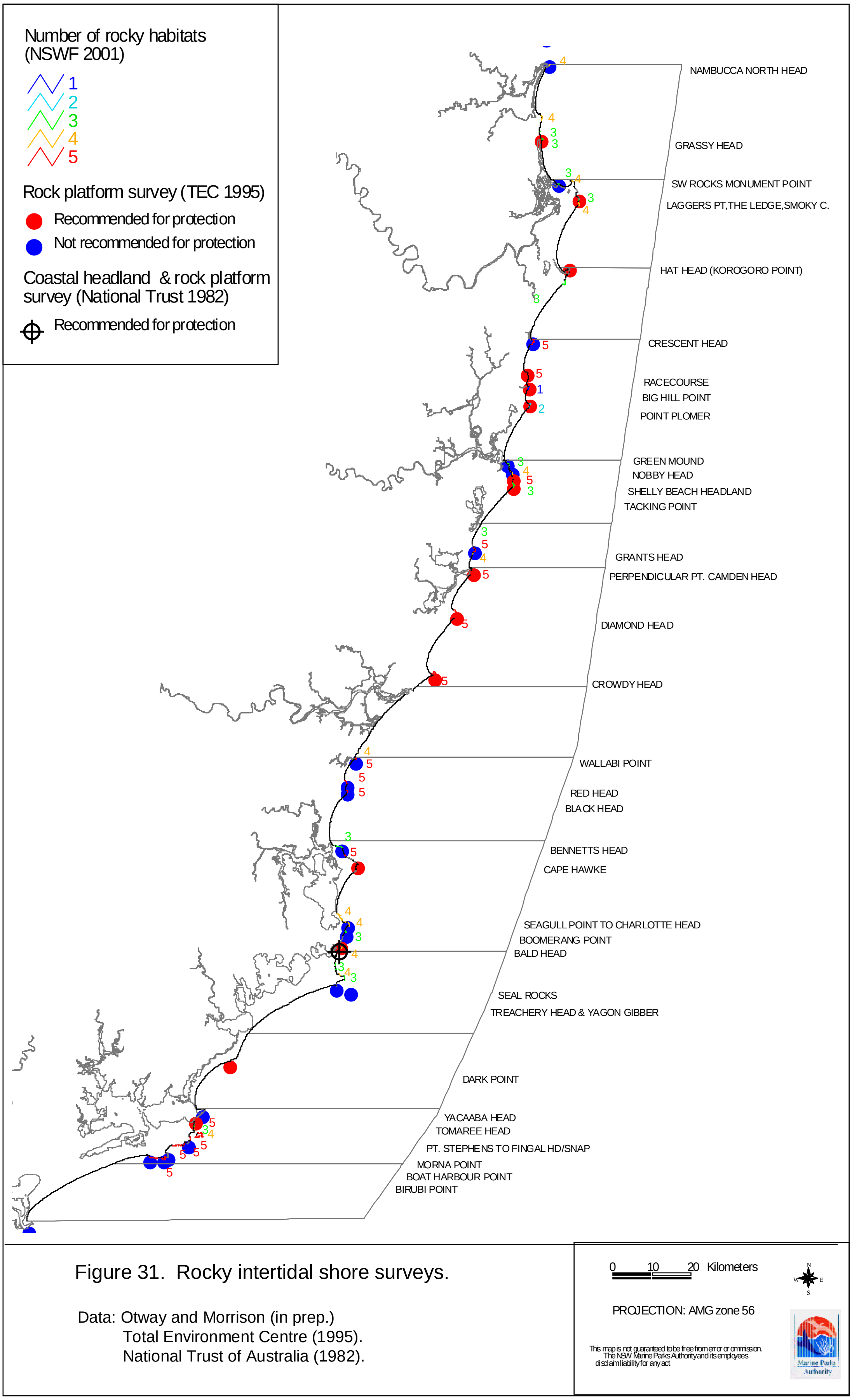


Figure 6.17. Rocky intertidal shores identified in previous assessments (Map by Ron Avery).

6.4.10 Estuarine juvenile fish and invertebrates

Data source

Estuarine fish biodiversity project undertaken by the NSW Fisheries[2] Office of Conservation and funded by the Natural Heritage Trust (R.J. Williams, pers. comm.)

Data description

The data set includes counts of estuarine juvenile fish and invertebrates sampled by seine nets hauled along shores in estuaries throughout NSW. Habitats sampled include vegetated and bare substrata, and 2–3 zones between the estuary mouths and riverine habitats. At the time of the assessment, 500,000 fish from 176 taxa had been collected although the project had not yet sampled or analysed data for all estuaries.

For this assessment, all available data were mapped in ArcView GIS and sites and estuaries assessed for species richness and summed irreplaceability using C-Plan reserve planning software (NPWS 2001). However, only a subset of all estuaries were sampled and temporal variation in fish populations may easily confound patterns. There were also differences in the number of sites sampled in each estuary and these differences were correlated with overall species richness and irreplaceability scores for each estuary. These differences make it difficult to make unbiased comparisons among different estuaries. However, a more detailed analysis of this data is warranted as these systematic surveys of species diversity and abundance have the potential to provide a more direct assessment of marine biodiversity.

Criterion

Representativeness

Assessment measures

Number of species and summed irreplaceability to represent at least one of each species.

Assessment

The number of fish and invertebrate species caught in seine net surveys along estuary shores is shown in Figure 6.18. Differences in species richness are evident between seagrass and bare habitats and although there is variation within estuaries, species richness for some locations such as the Manning River estuary appears to be higher.

When data for all sites sampled in each estuary are pooled (n = 4–12 sites), or pooled for a limited, but even number of sites per estuary (n = 4), species richness is similar for most estuaries but lower for Smiths Lake and the Hunter River (Figure 6.19 and Figure 6.20). When all sites sampled are considered, summed irreplaceability for representation of each species is highest for Port Stephens (Figure 6.19c). However this location was sampled most frequently and is more likely to record additional species. If an equal number of sites are analysed (n = 4), summed irreplaceability is similar for most estuaries but highest for Port Stephens, the Manning River and Wallis Lake (Figure 6.20c).

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[2] now within the NSW Department of Primary Industry.

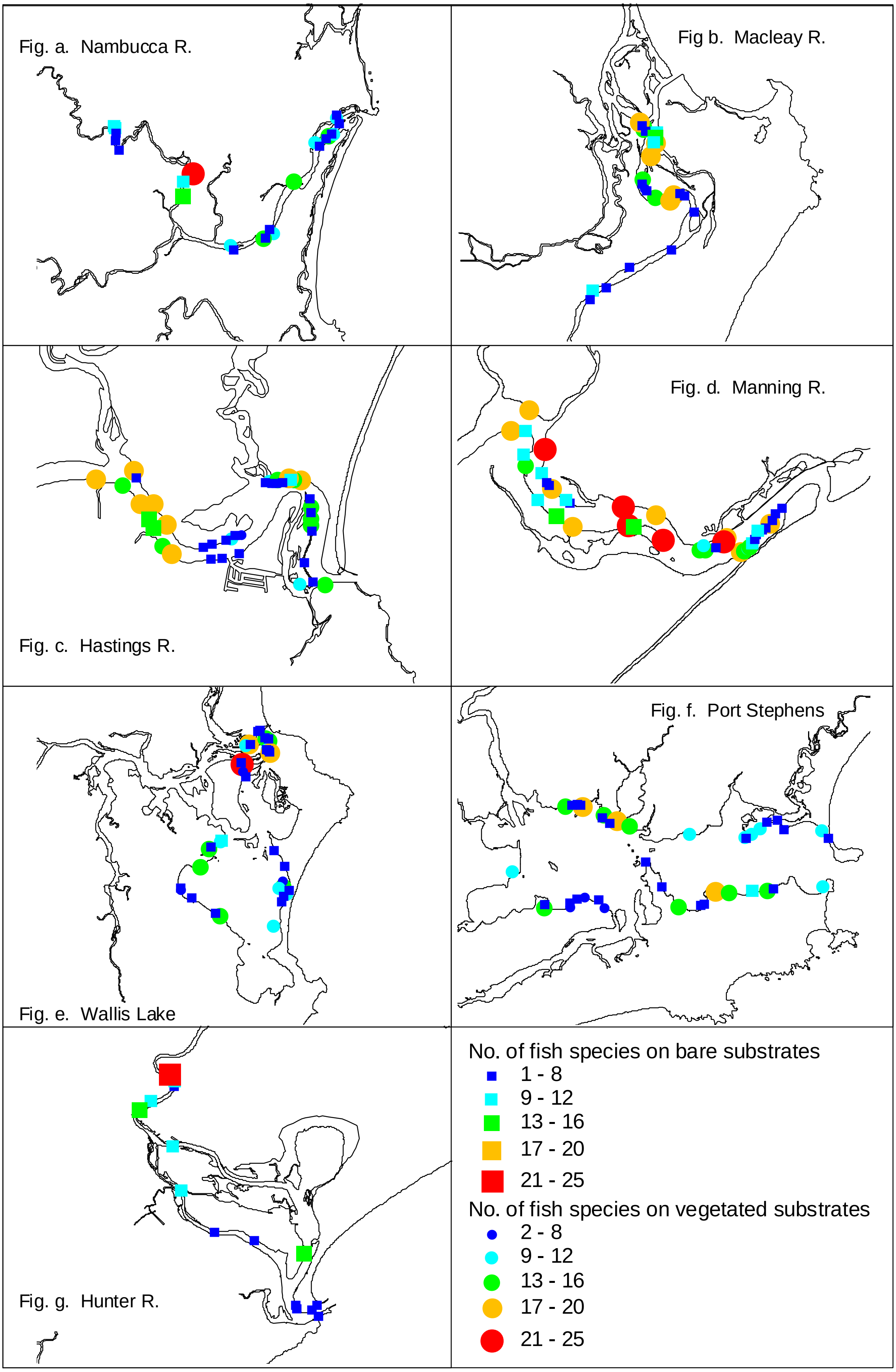

Figure 6.18a–g. Number of species of juvenile fish and invertebrates sampled by seine net along estuary shores (n=5 hauls per site) in the Manning Shelf bioregion. Data provided by NSW Fisheries[2] (pers. comm. R.J. Williams).

[2] now within the NSW Department of Primary Industry.

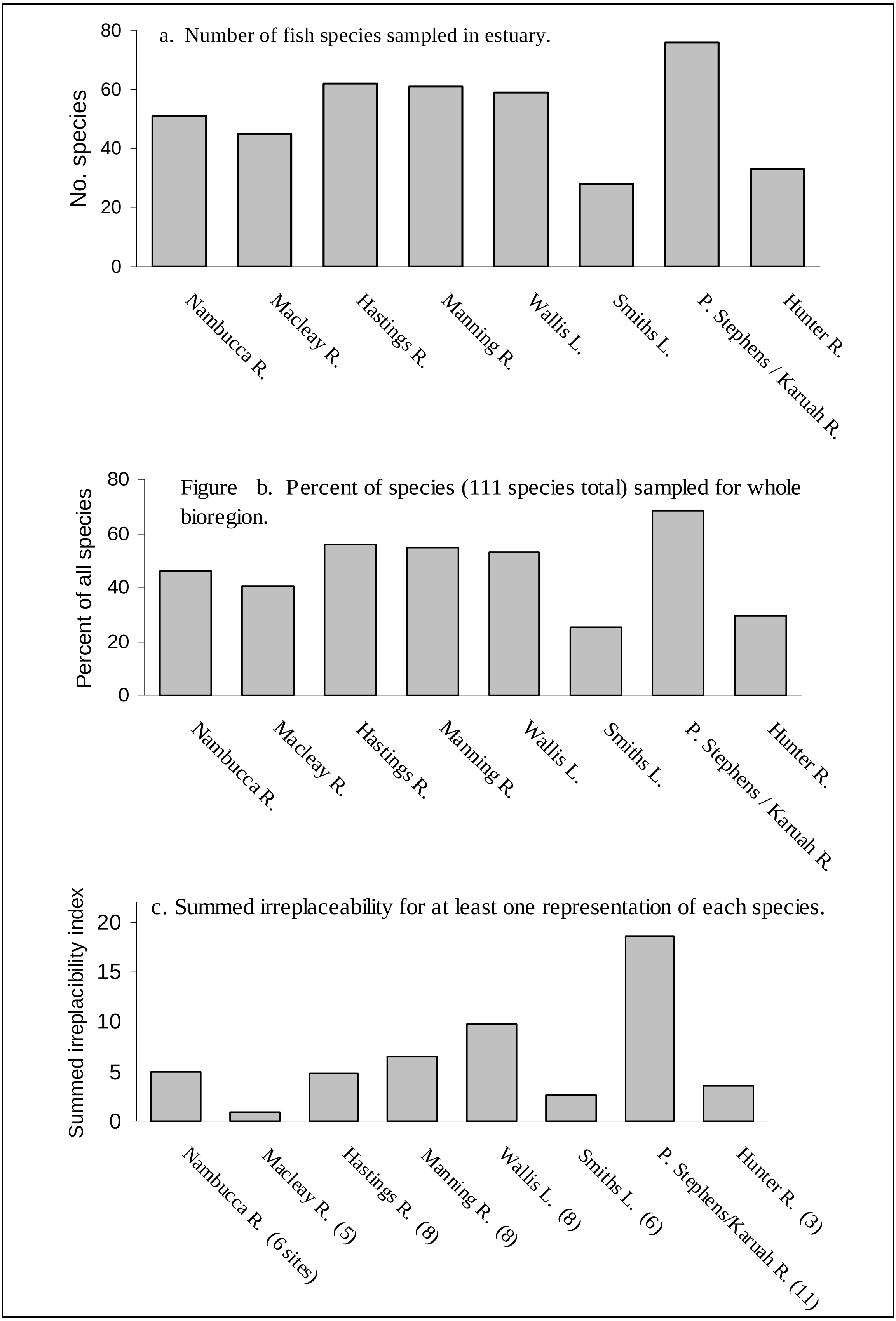

Figure 6.19a–c. Total number of species, percentage contribution to bioregional species total and summed irreplaceability for juvenile fish and invertebrate species sampled at varying numbers of sites along estuary shores in the Manning Shelf bioregion during 1999–2000. Data provided by NSW Fisheries (pers. comm. R.J. Williams).

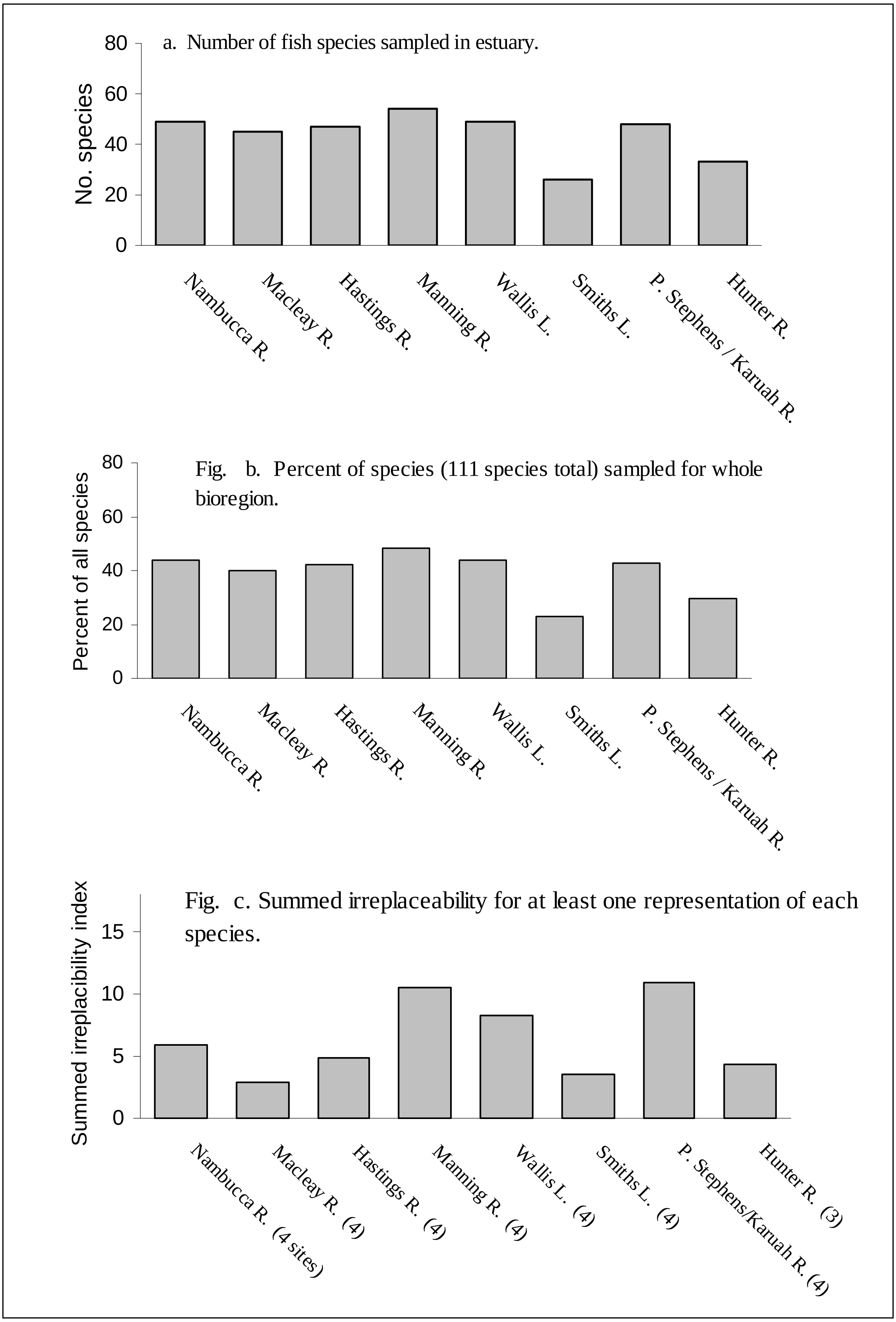

Figure 6.20a–c. Total number of species, percentage contribution to bioregional species total and summed irreplaceability for juvenile fish and invertebrate species sampled at a reduced (but equal) number of sites along estuary shores in the Manning Shelf bioregion during 1999–2000. Data provided by NSW Fisheries (pers. comm. R.J. Williams).

6.4.11 NSW Fisheries commercial catch data

Data sources

NSW Fisheries Commercial Catch Returns database, Tanner and Liggins (1999).

NSW Commercial Fisheries Statistics 1993–94 to 1997–98.

Data description

Commercial fish and invertebrate catch, effort and value ($) data were assigned to GIS locations for the port or estuary where the catch was landed. Data is derived from mandatory catch return forms submitted to NSW Fisheries by commercial fishers.

Criteria

Representativeness, productivity, potential threats and human use.

Assessment measures

Number of species and summed irreplaceability for representation of each species and catch.

Assessment

The number of species represented in commercial estuarine fish and invertebrate catches was highest for Myall Lake/Port Stephens and Wallis Lake, high for most other estuaries, but lower for Lake Innes/Cathie and Smiths Lake (Figure 6.21a). Summed irreplaceability for representation of each species at least once was also highest for Myall Lake/Port Stephens and Wallis Lake, and these areas also recorded the highest catch (Figure 6.21bc).

The number of species in commercial catch recorded for ocean ports of landing and summed irreplaceability for representation of at least one species was highest for Port Stephens and Newcastle. Catch was also high for these areas but similar to that for Crowdy Head, Tuncurry and South West Rocks (Figure 6.22).

These data should be interpreted cautiously. Possible problems in their use are a bias in species richness towards ports receiving more catch, misreporting of catch and difficulties in determining exactly where catch was caught as opposed to landed. The data presented here also only represents catch returns from one of many years. More detailed analyses of catch data have been made by Pease (1999).

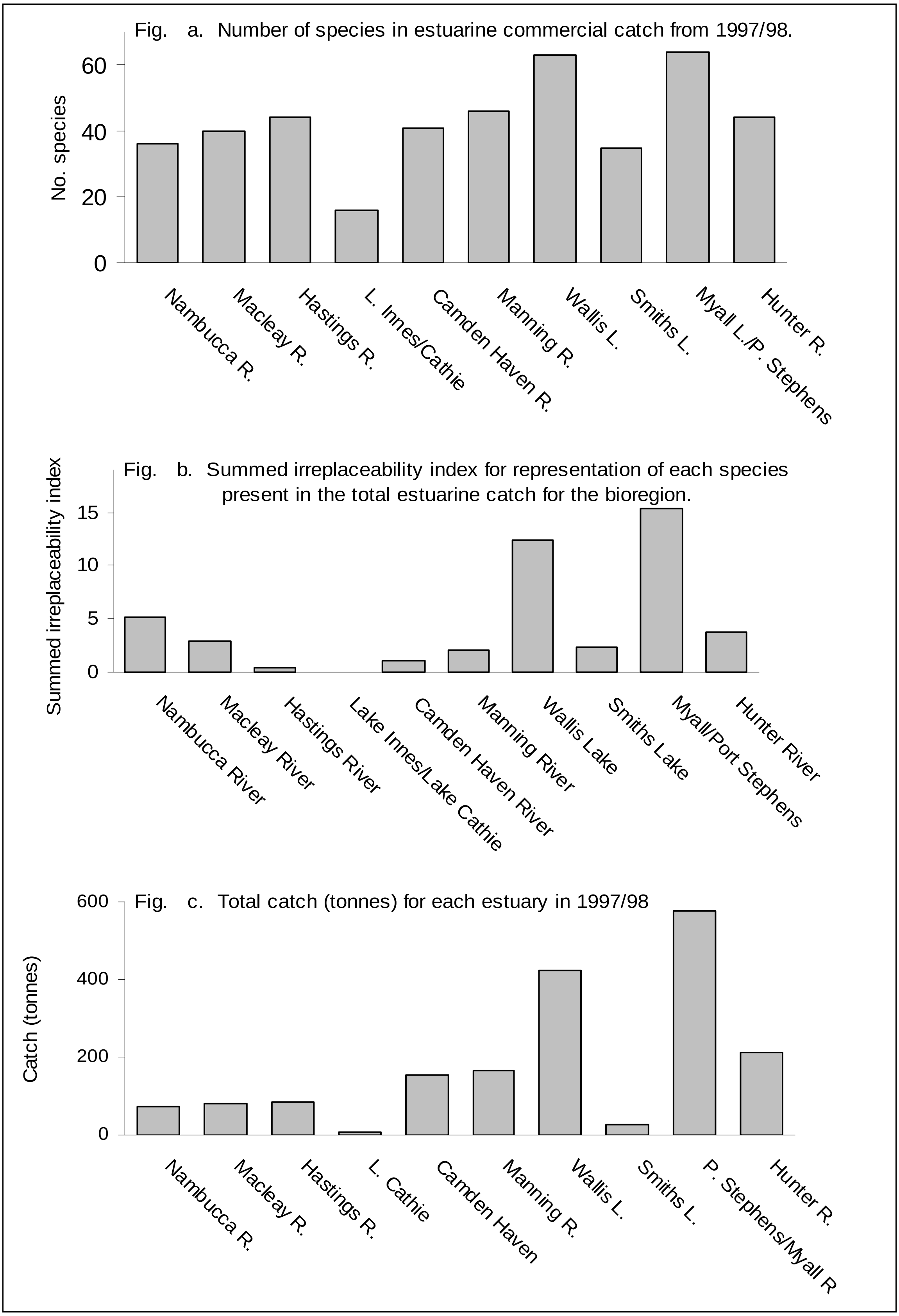

Figure 6.21a–c. Number of species, summed irreplaceability and size (tonnes) of commercial fishing catch for estuaries in the Manning Shelf bioregion during 1997–98. Data provided by NSW Fisheries Catch Records Section and Tanner and Liggins (1999).

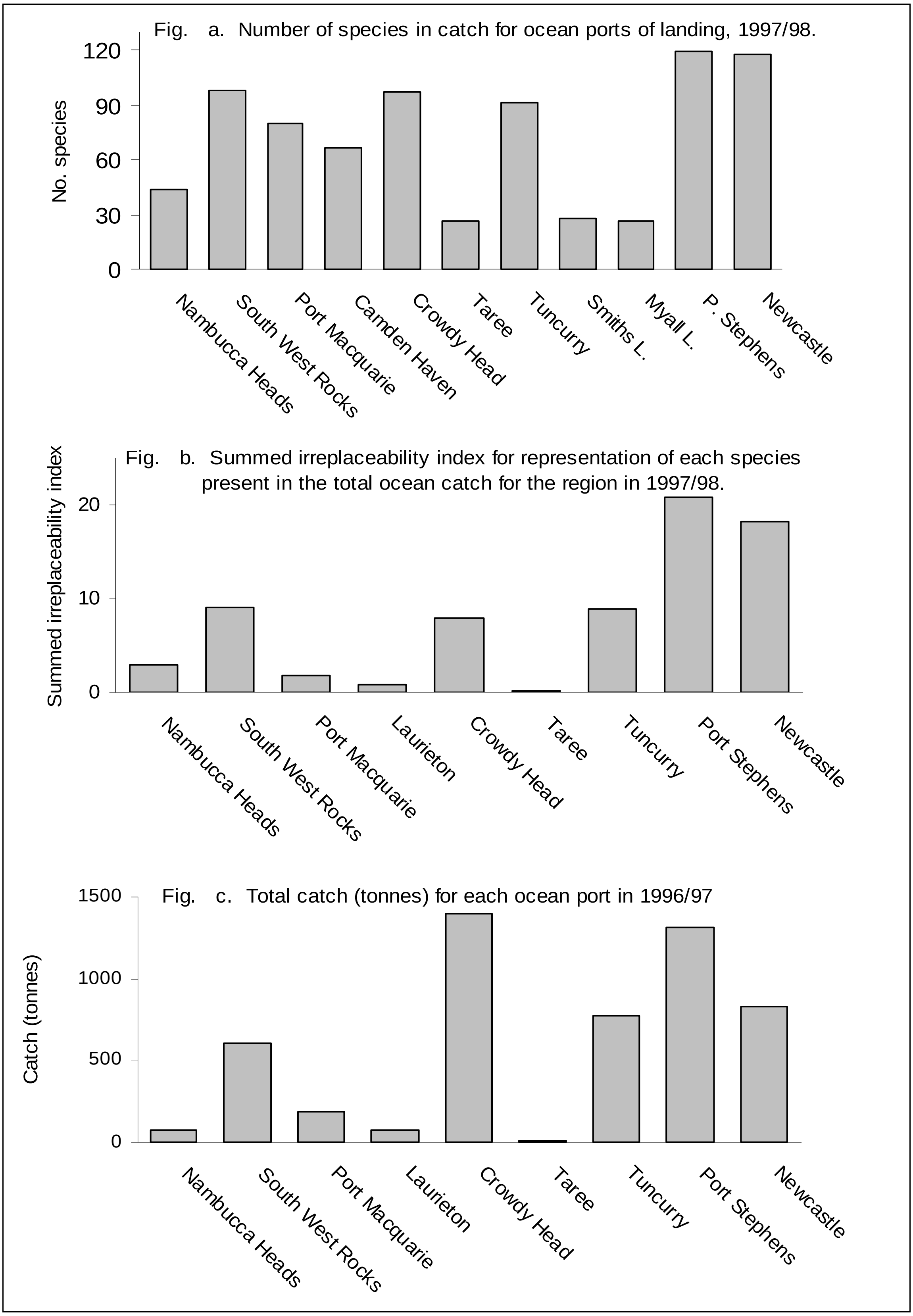

Figure 6.22a–c. Number of species, summed irreplaceability and size (tonnes) of commercial fishing catch for ocean ports in the Manning Shelf bioregion in 1997–98 and 1996–97. Data provided by NSW Fisheries Catch Records Section and Tanner and Liggins (1999).

6.4.12 Birds of International Importance

Data source

"NSW Oil Spill Response Atlas" version 2.2 (CD-ROM) from the Australian Maritime Safety Authority (AMSA).

Data description

This GIS database includes compiled sightings of sea and shore birds as well as important areas of habitat for threatened birds, birds protected under JAMBA/CAMBA[4] international treaties and for other native birds. For this assessment, sightings and areas of habitat were classified by estuarine and ocean plan units.

Criteria

Representativeness.

Assessment measures

Number of species, summed irreplaceability and area of bird habitat.

Assessment

The number of bird species sighted near estuaries was highest for the Hunter River, but also high for other estuaries including Wallis Lake and the Nambucca, Macleay, Hastings, and Manning Rivers (Figure 6.23a). Summed irreplaceability for representation of at least one of each species was also highest for the Hunter River (Figure 6.23b).

The numbers of bird species sighted near exposed coast and ocean were equally high for several sections between Smiths Lake and Port Stephens, and between Stockton Beach and the Hunter River (Figure 6.23c). However summed irreplaceability for at least one representation of each species was highest for the section of coast between the Hastings River and Lake Innes/Cathie (Figure 6.23d).

The area of important habitat near estuaries for threatened and JAMBA/CAMBA bird species was highest for the Hunter River and also high for Port Stephens, Hastings River, Macleay River and Lake Cathie (Figure 6.24a). There was a similar pattern for habitat of other bird species with Wallis Lake and Camden Haven also supporting large areas of important bird habitat (Figure 6.24b).

The sections of exposed coast between Wallis Lake and the Hunter River supported the most area of important habitat for threatened and JAMBA/CAMBA species and other bird species (Figure 6.24cd).

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[4] Japan/China and Australian Agreements for the protection of migratory and endangered birds and their environments.

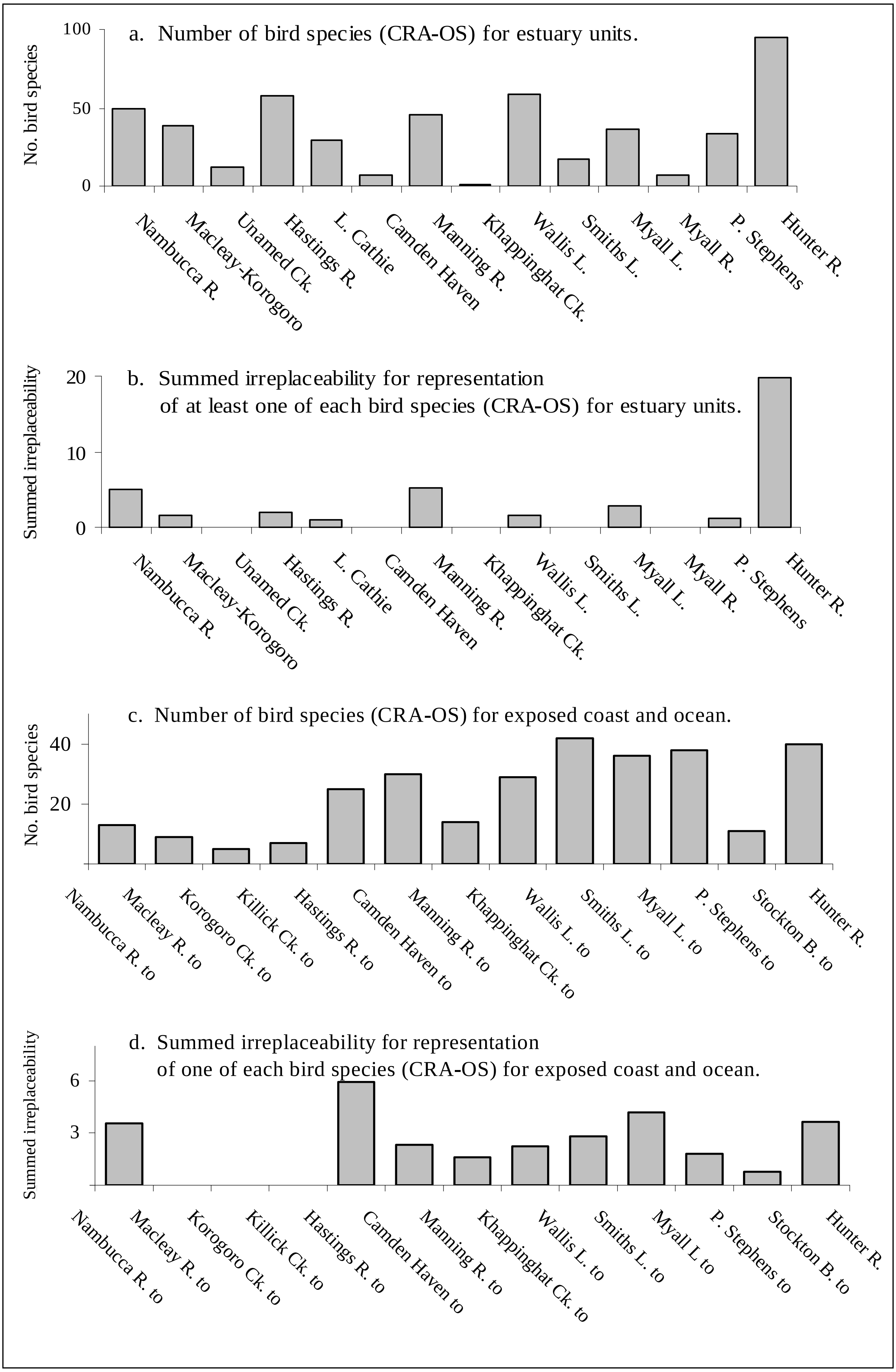

Figure 6.23a–d. Number of species and summed irreplaceability for sea and shore birds in the Manning Shelf bioregion. Data derived from NSW Oil Spill Response Atlas version 2.2 provided by the Australian Maritime Safety Authority (2000).

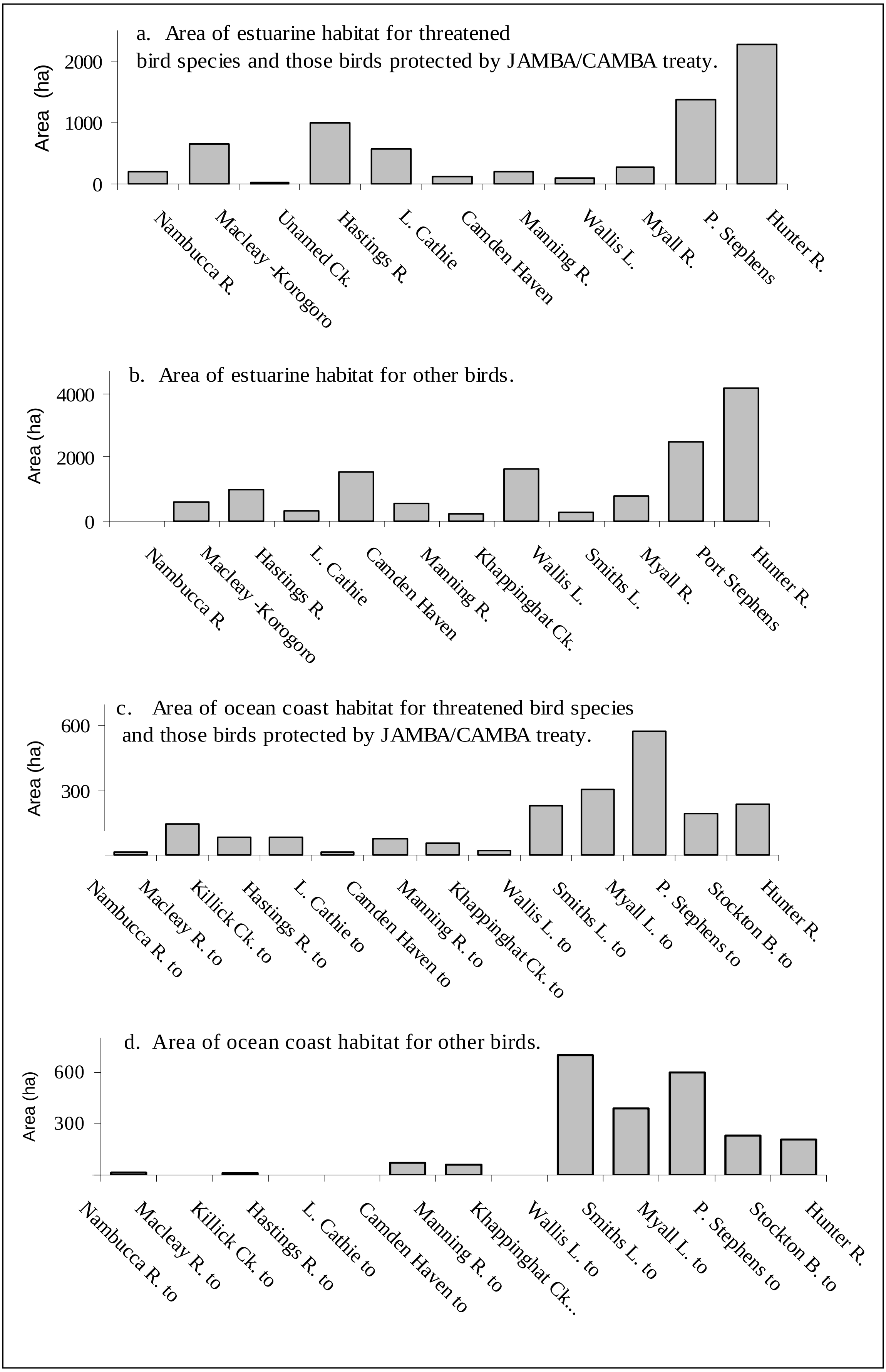

Figure 6.24a–d. Areas of important estuary and ocean coast for birds protected by international treaties or the *Threatened Species Conservation Act 1995* and for other native birds. Data derived from NSW Oil Spill Response Atlas version 2.2 provided by the Australian Maritime Safety Authority (2000).

6.4.13 Threatened birds – NSW National Parks

Data sources

NSW National Parks Wildlife Atlas.

Little Tern and Gould's Petrel Draft Recovery Plans (NPWS 2000cd).

Data description

The NSW Wildlife Atlas records sightings of fauna and flora declared as threatened under the *NSW Threatened Species Conservation Act 1995*. Sightings of threatened species were extracted from the database of the atlas, mapped in ArcView GIS and their records assigned to the nearest estuary or section of coast. Estuaries and sections of coast were assessed for the number of threatened species sighted and the summed irreplaceability to represent each species at least once.

Of the 32 species of intertidal wader and sea birds in NSW listed as threatened, 24 occur in the Manning Shelf bioregion (Table 6.2), and three of the 24 species are listed as endangered. Two of the endangered species have significant nesting sites in the Manning Shelf bioregion.

Endangered	
Beach Stone-curlew *Esacus neglectus*	Little Tern *Sterna albifrons*
Gould's Petrel *Pterodroma leucoptera*	
Vulnerable	
Australasian Bittern *Botaurus poiciloptilus*	Little Shearwater *Puffinus assimilus*
Black Bittern *Ixobrychus flavicollis*	Osprey *Pandion haliaetus*
Black-browed Albatross *Diomedea melanophrys*	Painted Snipe *Rostratula benghalensis*
	Pied Oystercatcher *Haematopus longirostris*
Black-tailed Godwit *Limosa limosa*	Providence Petrel *Pterodroma solandri*
Broad-billed Sandpiper *Limicola falcinellus*	Sanderling *Calidris alba*
Bush Stone-curlew *Burhinus grallarius*	Shy Albatross *Diomedea cauta*
Flesh-footed Shearwater *Puffinus carneipes*	Sooty Oystercatcher *Haematopus fuliginosus*
Greater Sand Plover *Charadrius leschenaultii*	Sooty Tern *Sterna fuscata*
Grey Ternlet *Procelsterna cerulea*	Terek Sandpiper *Xenus cinereus*
Lesser Sand Plover *Charadrius mongolus*	White Tern *Gygis alba*

Table 6.2 Threatened intertidal waders and sea birds recorded in the Manning Shelf bioregion.

Criterion

Representativeness.

Assessment measures

Number of threatened species, summed irreplaceability and location of significant nesting sites.

Assessment

Gould's Petrel

Gould's Petrel (*Pterodroma leucoptera leucoptera*) is Australia's rarest endemic seabird and only breeds on Cabbage Tree and Boondelbah Islands off Port Stephens. Threats to this species include: predation by currawongs and ravens, habitat degradation through the grazing of rabbits, entanglement in the sticky fruits of the bird-lime tree, disturbance from jet aircraft, and inappropriate recreational use by day visitors (NPWS 2000c).

Gould's Petrel feeds primarily on surface fish, small squid and krill. It has been suggested that oceanic events such as the 1995–96 pilchard die-off have led to a decrease in food availability, leading to decreased body condition and otherwise unexplained breeding failures (Priddell and Carlile 1997). The terrestrial components of Cabbage Tree and Boondelbah Islands are protected within John Gould Nature Reserve and Boondelbah Nature Reserve.

Little Tern

Little Terns (*Sterna albifrons* subspecies *sinensis*) nest in NSW during spring near the entrances of estuaries on sand spits, sand islands and beaches, and feed in nearby waters (NPWS 2000d). A migratory Asian population that does not breed in NSW also occurs here but does not nest and is not the focus of threatened species management in NSW.

Prey species recorded from NSW include the Port Jackson perchlet (*Ambassis jacksoniensis*), Striped Gudgeon (*Gobiomorphus australis*), Empire Gudgeon (*Hypseleotris compressa*), Sandy Sprat (*Hyperlophus vittatus*), Sand Mullet (*Myxus elongatus*), Sea Mullet (*Mugil cephalus*), Silver Sweep (*Scorpis lineolatus*), Trumpeter Whiting (*Sillago maculata*), Surf Fish (*Tropidostethus rhothophilus*) and juvenile Flying Fish (references in NPWS 2000d).

Nests are highly vulnerable, and are generally located on open sand within 150 m of the water and less than 1.5 m above the high tide mark. Threats include nest disturbance by recreational beach users, nest flooding, foreshore development and predation and disturbance by silver gulls (*Larus novaehollandiae*), ravens, kestrels, falcons, whimbrels, foxes, dogs, ghost crabs and ants (NPWS 2000d).

While no areas of habitat have been listed as critical under the *Threatened Species Conservation Act*, a number of significant nesting sites have been identified in the region including at: Nambucca Heads, Harrington and Farquhar Inlet (Old Bar) on the Manning River, and at Wallis Lake near Forster. The Little Tern has also been sighted in Lime Burners Creek Nature Reserve, Myall Lakes National Park, Port Stephens and Kooragang Nature Reserve on the Hunter River.

Beach Stone-curlew

The Beach Stone-curlew (*Esacus neglectus*) is at the southern extent of its range and no significant or critical sites (including nesting/breeding sites) have been identified within the region.

Other species

Sightings for threatened species (not graphed) occurred for all estuaries, with the greatest number of species recorded for the Hunter River (15 species), followed by the Manning, Macleay and Hastings Rivers, Wallis Lake, Port Stephens and the Nambucca River (6-9 species). Summed irreplaceability for representation of each species was highest for the Hunter River (3) followed by the Nambucca and Manning Rivers and Port Stephens (~1).

Sightings for threatened species occurred for all sections of exposed coast with the highest number of species recorded for the Nambucca–Macleay, Wallis L.–Smiths L. and Khappinghat–Wallis L. sections (8-9 species). Summed irreplaceability however was highest for the Hastings–L. Cathie section (3). Sightings are provided voluntarily and should be interpreted cautiously as they may be biased towards areas where there is more sighting effort.

6.4.14 Threatened Grey Nurse Shark (Carcharias taurus)

Data source

A GIS point coverage of significant Grey Nurse Shark aggregation sites prepared from survey data provided by Otway and Parker (2000) and Otway *et al.* (2003).

Data description

The Grey Nurse Shark is listed as endangered under the *Fisheries Management Act 1994*. NSW Fisheries staff and volunteer SCUBA divers surveyed approximately 65 sites within a four-week long survey period in each season (Summer, Autumn, Winter, Spring) between November 1998 and October 2000. The maximum count of sharks from multiple dives during each 4 week survey period were taken as the sample estimate for each site and season.

Criterion

Representativeness

Assessment measures

Maximum number of sharks, % of observed sightings, mean maxima and percent occurrence.

Assessment

Between Summer 1998 and Spring 2000, an average of 65% of Grey Nurse Sharks (maximum counts) in NSW were counted in the Manning Shelf bioregion. Over 11% were sighted at Fish Rock and Green Island near South West Rocks, 14% at the Cod Grounds and Mermaid Reef near Laurieton, 16% at the Pinnacle and Latitude Rock near Forster, 12% at Seal Rocks near Sugar Loaf Point and 10% at Broughton Island near Port Stephens (Figure 6.25). None of these sites were included within marine protected areas at the time of the assessment, although most have been declared as critical habitat for the shark under the *Fisheries Management Act*.

A similar pattern among these sites can be seen for the overall maxima, mean maxima for each season and percent occurrence at each site (Figure 6.25 and Figure 6.26). Initial research indicates that the male and female sharks have specialised patterns of migration and that most of the above sites are important at some time. For example, 50% of the sharks sighted during the Spring 2000 survey were sighted at one site, the Cod Grounds, and seasonal peaks in the number of male sharks occurred near South West Rocks. If the sharks do migrate between sites, threats to these animals will need to be considered at all sites involved. Subsequent tagging studies (Otway pers. comm. NSW Fisheries) have now indicated that seasonal migrations do occur among these and other sites in NSW. Recent data imply that the same sharks may be at risk at each location from accidental capture through recreational and commercial line fisheries.

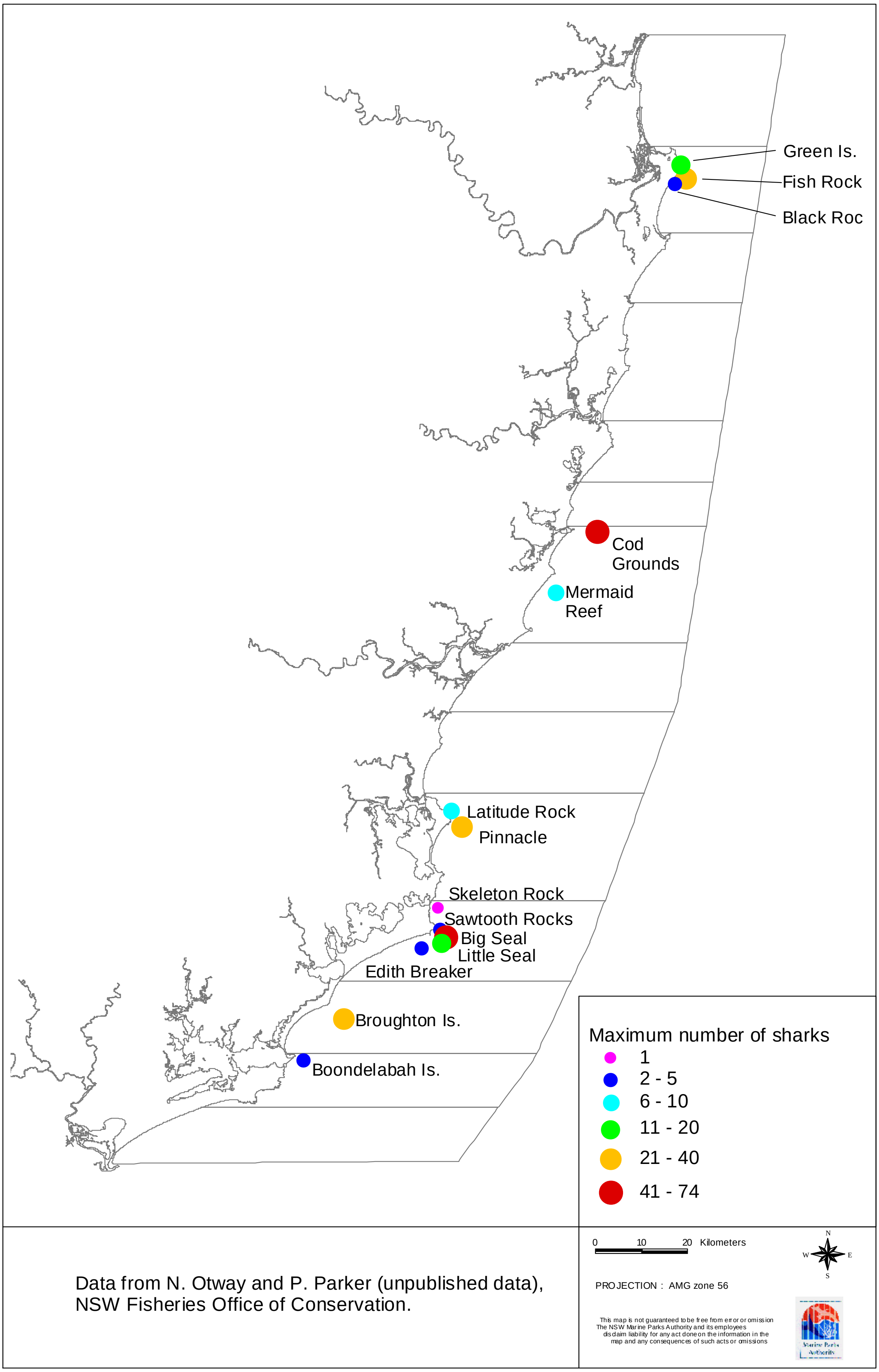

Figure 6.25. Maximum numbers of Grey Nurse Shark (*Carcharias taurus*) observed at dive sites in the Manning Shelf bioregion during eight survey seasons between 1998 and 2000 (published and unpublished data from Otway and Parker (2000) and Otway *et al.* (2003)).

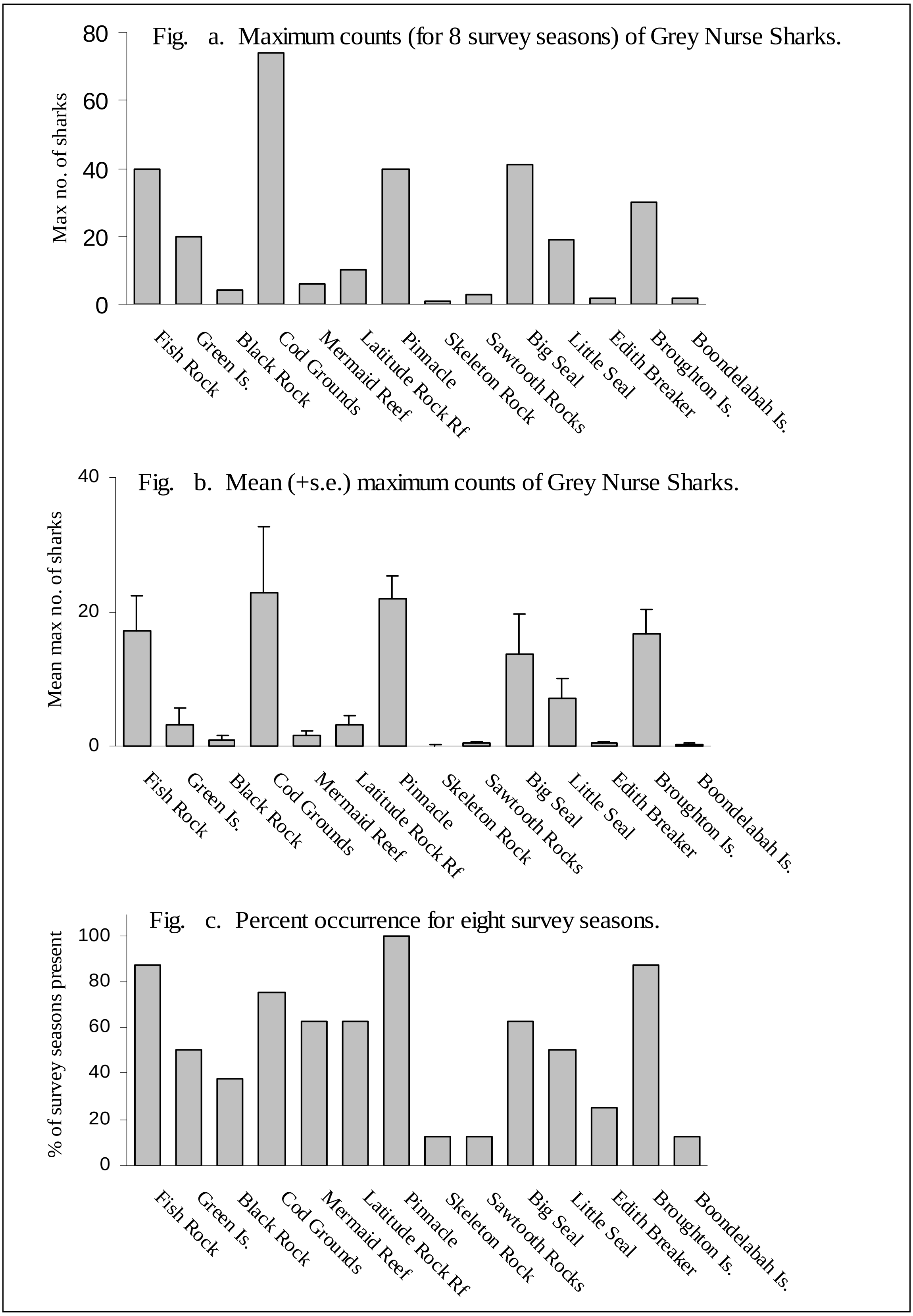

Figure 6.26a–c. Maximum, mean maximum (+ s.e.) and percent occurrence of Grey Nurse Shark (*Carcharias taurus*) for dive sites in the Manning Shelf bioregion for eight survey seasons between 1998 and 2000 (published and unpublished data from Otway and Parker (2000) and Otway *et al*. (2003)).

6.4.15 NSW Fisheries threatened species database

Data source

Voluntary reports of sightings held in the NSW Fisheries threatened species database.

Data Description

The *NSW Fisheries Management Act* includes provisions to declare threatened species of fish and marine vegetation, and to declare endangered populations and ecological communities and key threatening processes. At the time of the assessment, the threatened species database was limited to 75 records for the Manning Shelf bioregion. These data are too sparse for quantitative analysis, however they provide descriptive, site-specific information.

Four marine species have been declared threatened:

- Great White Shark (*Carcharodon carcharias*)
- Grey Nurse Shark (*Carcharias taurus*)
- Black Cod (*Epinephelus daemelii*)
- Green Sawfish (*Pristis zijsron*).

Seven other marine species are protected in NSW waters:

- Ballina Angelfish (*Chaetodontoplus ballinae*)
- Bleeker's Devil Fish (*Paraplesiops bleekeri*)
- Common Sea Dragon (*Phyllopteryx taeniolatus*)
- Elegant Wrasse (*Anampses elegans*)
- Estuary Cod (*Epinephelus coioides*)
- Herbsts Nurse Shark (*Odontaspis ferox*)
- Queensland Groper (*Epinephelus lanceolatus*).

Other species are protected from commercial fishing, these include:

- Black Marlin (*Makaira indica*)
- Blue Marlin (*Makaira nigricans*)
- Striped Marlin (*Tetrapturus audax*)
- Blue Groper (*Achoerodus viridis*).

Criteria

Representativeness.

Assessment measure

Descriptive summary.

Assessment

Sightings include: Ballina Angel Fish at Cattie Creek; Black Cod near Seal Rocks, Taree and Fish Rock; Bleeker's Devil Fish at Nambucca Heads; Elegant Wrasse at Broughton Island and Lake Cathie; Queensland Groper at Fish Rock and Nambucca Heads; Estuary Cod at Lake Cathie, Harrington, Fish Rock, Manning River, Nambucca Heads and Wallis Lake; Great White Shark at Green Island, the Pinnacle and Edith Breaker; and Grey Nurse Shark near Nambucca Heads, South West Rocks, Forster, Seal Rocks, Broughton Island and Nelson Bay.

6.4.16 Marine mammals and reptiles

Data sources

Environment Australia – Species of National Environmental Significance database.

"NSW Oil Spill Response Atlas" version 2.2 (CD-ROM June 2000) from the Australian Maritime Safety Authority (AMSA).

Data Description

The database held by Environment Australia holds maps of broad scale species distributions and taxonomic, ecological and management information about Species of National Environmental Significance as listed under the Commonwealth *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*. The "NSW Oil Spill Response Atlas" includes sightings data for marine mammals in NSW.

Criterion

Representativeness

Assessment measure

Descriptive summary.

Assessment

Marine mammal species of national significance with mapped distributions within the Manning Shelf bioregion include the Humpback Whale (*Megaptera novaeangliae*), Southern Right Whale (*Eubalaena australis)*, Sei Whale (*Balaenoptera borealis)*, Fin Whale (*Balaenoptera physalus*), Blue Whale (*Balaenoptera musculus*) and the Dusky Dolphin (*Lagenorhynchus obscurus*). Marine reptile species of national significance with mapped distributions that include the bioregion are the Green Turtle (*Chelonia mydas*), Leatherback Turtle (*Dermochelys coriacea),* Elegant Sea Snake (*Hydrophis elegans*) and Yellow Bellied Sea Snake (*Pelamis platurus*). The distributions of these species extend well beyond NSW and several species are at the limit of their range (Gill *et al*. 2000).

The "NSW Oil Spill Response Atlas" includes 284 sighting records of marine mammals in the bioregion (851 in all NSW) including the Humpback Whale, Bryde's Whale (*Balaenoptera edeni*), False Killer Whale (*Pseudorca crassidens*), Killer Whale (*Orcinus orca*), Long-finned Pilot Whale (*Globicephala melas*), Melon-head Whale (*Peponocephala electra*), Minke Whale (*Balaenoptera acutorostrata*), Pygmy Sperm Whale (*Kogia breviceps*), Sperm Whale (*Physeter macrocephalus*), Short-finned Pilot Whale (*Globicephala macrorhynchus*), Southern Right Whale, Straptooth Beaked Whale (*Mesoplodon layardii*), Bottlenose Dolphin (*Tursiops truncatus*), Common Dolphin (*Delphinus delphis*), Fraser's Dolphin (*Lagenodelphis hosei*), Risso's Dolphin (*Grampus griseus*), Spotted Dolphin (*Stenella attenuata*), Striped Dolphin (*Stenella coeruleoalba*), Dugong (*Dugong dugon*), Leopard Seal (*Hydrurga leptonyx*) and

Australian Fur Seal (*Arctocephalus pusillus*). Again, the distributions of these mammals extend well beyond the bioregion and several are at the extreme limit of their range.

A number of species are relatively common throughout the bioregion. Humpback Whales are regularly observed off the NSW coast in June and July migrating to winter breeding grounds off Queensland and returning south between October and November to summer, cold water feeding areas. This east Australian population of humpbacks was estimated to have declined from 10,000 to 500 whales during the first half of the 20th century but is increasing slowly each year (Baker 1983, Paterson and Paterson 1989, Smith 1997). These whales often pass relatively close to the coast, particularly near prominent headlands, and whale watching tourism is established in several coastal ports including Port Stephens, Forster and Port Macquarie.

Allen and Moller (1999) and Allen *et al.* (2000) conducted surveys of inshore Bottlenose Dolphins (*Tursiops truncatus aduncus)* in Port Stephens. They identified 122 individuals from photographs, made observations of dolphin interactions with some of the 14 listed dolphin-watching vessels and made recommendations for management of these activities.

6.4.17 RAMSAR sites – Nationally and internationally important wetlands

Data source

A GIS coverage of RAMSAR sites in this bioregion was mapped by Ron Avery from the official descriptions for their designation (Figure 6.2a).

Data description

The RAMSAR Convention on Wetlands is an intergovernmental treaty signed by 123 parties for the conservation and wise use of wetlands. Contracting parties designate wetlands for inclusion in a "List of Wetlands of International Importance." Criteria for identifying RAMSAR sites include representativeness and uniqueness of wetlands, the flora and fauna present (including 'fish habitat values') and specific criteria for waterfowl.

Criterion

Representativeness and international or national importance.

Assessment measures

Presence and area of RAMSAR sites.

Assessment

Two RAMSAR internationally important wetlands are located in the Manning Shelf bioregion:

- Kooragang Nature Reserve (including Fullerton Cove, Hexham Swamp and Kooragang Island). This site was identified for its representative wetlands, general flora and fauna, and for its significance as a feeding and roosting site for migratory waders and waterbirds
- Myall Lakes National Park including:
  - Myall Lakes
  - Broughton Island and Little Broughton Island Nature Reserve
  - the northern headland (Yaccaba) of Port Stephens

- Fame Cove and Corrie Island Nature Reserve in Port Stephens
- the southern shores of Smiths Lake
- most of the ocean coast between Smiths Lake and Port Stephens.

The Myall Lakes RAMSAR site is known for its coastal brackish lake systems which are not greatly modified by human activities and for its floristic diversity (over 600 species of plants) and complex variety of habitats. Wetland types include rocky marine shores; sand, shingle or pebble beaches; estuarine waters; intertidal mud, sand and salt flats; intertidal marshes; intertidal forested wetlands; brackish to saline lagoons and marshes with one or more narrow connections to the sea; freshwater lagoons and marshes in the coastal zone; and permanent inland saline/brackish lakes.

6.4.18 Directory of Important Wetlands in Australia

Data source

A GIS coverage of extent of important wetlands in this bioregion was mapped by Ron Avery using the descriptions provided by the Directory (Figure 6.2a).

Data description

The ‘Directory of Important Wetlands’ (ANCA 1996, NPWS 2000a) is a cooperative project coordinated by Environment Australia to identify nationally important wetlands for the Commonwealth, State and Territory Governments of Australia. The wetlands listed in the directory are those which meet the criteria of national importance as revised by the ANZECC Wetlands Network in August 1994. All wetlands which meet the criteria have been listed, not just the best representatives of a wetland type. The criteria used to assess important wetlands require that the area:

- be a good example of a wetland type occurring in the bioregion
- be a wetland that plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex
- be a wetland that is important as habitat for animal taxa at a vulnerable stage of their life cycles, or provide refuge when adverse conditions such as drought prevail
- support 1% or more of the national population of any plant or animal taxa
- support native plant or animal taxa or communities which are considered endangered or vulnerable at the national level
- be a wetland of outstanding historical or cultural significance.

Criterion

Representativeness and international or national importance.

Assessment measure

Presence and area of nationally important wetlands.

Assessment

Nine important wetlands are listed in the Manning Shelf bioregion, ranging in size from 1,817 ha in the Clybucca Creek estuary to over 30,000 ha in Port Stephens and Myall Lakes (Table 6.3). Detailed descriptions of wetland geomorphology and community ecology were used to support the options for MPAs described in Section 6.5 and Appendix 2.

Table 6.3 Important wetlands in the Manning Shelf bioregion.

Wetland name	Location and description	Area (ha)
Clybucca Creek Estuary	Macleay estuary delta including Macleay Arm, Macleay River down river of Pelican Reach, Clybucca Creek down from Clybucca township	1,817
Swan Pool/Belmore Swamp	Coastal floodplain swamp (i.e. fresh meadows, seasonal fresh swamps, and reef swamps) on the Upper Macleay River west of Hat Head	6,350
Crowdy Bay National Park	Coastal plains including dune wetland systems (i.e. sand dunes, wet heath, sedgeland and forested swamp)	9,519
Limeburners Creek Nature Reserve	Subcatchment of the Hastings River system incorporating natural dunal wetland system and brackish lake	9,123
Wallis Lake and adjacent estuarine islands	Tidal waters wetlands of Wallis Lake extending up Coolongolook River to Minimbah Creek, and to the mouth of the Wallamba River	8,556
Myall Lakes	Myall Lakes NP coastal plains including coastal lagoon complex and low lying dunal wetland complex	31,777
Port Stephens Estuary	Tidal waters and intertidal wetlands up the Myall River to Myall Lakes NP, up the Karuah River to Karuah, and including all of Tilligerry Creek and Twelve Mile Creek	30,253
Kooragang Nature Reserve	Tidal and intertidal wetlands on the north side of the Hunter River	3,000
Hexham Swamp	Small brackish marsh on lower Hunter River	–

6.4.19 Independent inquiry into coastal lakes

Data source

"Classification of coastal lakes" from the Healthy Rivers Commission's "Independent Inquiry into Coastal Lakes – Final Report" (2002a).

Data description

Classifications of coastal lakes were assigned to GIS plan units for each estuary. The classifications draw on 'data collected, analysed and collated by the NSW DIPNR in its 'Estuary Inventory' and on information collated for the Commonwealth Government's 'National Land and Water Audit.' Within the classification system the following broad factors influence the class to which a lake is assigned:

- natural sensitivity to human activities (e.g. potential nutrient inflow, flushing capacity)
- existing condition of catchment and lake (e.g. land clearing, land use and water quality)
- 'recognised' natural and resource conservation values (e.g. presence of threatened species, ecological uniqueness, representativeness and commercial values, reserves).

Criteria

Representativeness and adequacy.

Assessment measures

Qualitative ranks for natural sensitivity, existing catchment and lake condition, recognised conservation value, potential to improve and orientation for management.

Assessment

The assessment examined ten coastal lake systems in the Manning Shelf bioregion (Table 6.4).

Table 6.4. Classification of coastal lakes in the Manning Shelf bioregion (Healthy Rivers 2002).

Coastal lake	Natural sensitivity	Existing condition		Recognised conservation value	Lake classification
		Catchment	Lake		
Saltwater Lagoon	Extreme	Severely modified	Moderately affected	Low	Healthy modified condition
Goolawah	Extreme	Largely unmodified	Slightly affected	High	Significant protection
Saltwater Lake	Extreme	Near pristine	Slightly affected	Moderate	Comprehensive protection
Innes	Extreme	Largely unmodified	Severely affected	High	Significant protection
Cathie	High	Unknown	Slightly affected	Moderate	Healthy modified condition
Queens	High	Largely unmodified	Slightly affected	High	Significant protection
Watson Taylor	High	Modified	Moderately affected	High	Healthy modified condition
Wallis	High	Modified	Slightly affected	High	Healthy modified condition
Smiths	Very High	Largely unmodified	Slightly affected	Moderate	Significant protection
Myall	Extreme	Largely unmodified	Severely affected	High	Significant protection

6.4.20 Environmental inventory of estuaries and coastal lagoons

Data source

Bell and Edwards (1980). "An inventory of estuaries and coastal lagoons in NSW."

Data description

Bell and Edwards (1980) conducted inventories of estuaries in NSW including a description of recreation and tourism significance, degree of disturbance, area, mean annual rainfall, mean annual runoff and conservation features. While these data may not be current in regards to coastal development and catchment use, they provide a relative measure of differences among estuaries and a useful check against more recent inventories. Inventory scores were assigned to GIS plan units for estuaries.

Criteria

Representativeness and adequacy.

Assessment measures

Qualitative scores from 1–4 for shore/water disturbance and for catchment disturbance.

Verbal description of conservation and human-use values and threats.

Assessment

Scores for disturbance of shore and water range from very low for Myall Lakes and the Myall River to very high for the Macleay, Hastings and Hunter Rivers. Scores for catchment disturbance range from low for the Nambucca River, Lake Cathie/Innes, and Killick and Limeburners Creeks to high for the Macleay River and Wallis Lake.

6.4.21 Australian Estuarine database

Data source

Digby *et al*. (1998). "Australian Estuarine database."

Data description

Data were available for 11 estuaries in the Manning Shelf bioregion (Nambucca R., Macleay R., Hastings R., L. Cathie, Camden Haven R., Manning R., Khappinghat C., Wallis L., Smiths L., Port Stephens, Hunter R.). For the assessment, GIS point data in the database were reassigned to GIS plan units for whole estuaries.

Criterion

Representativeness and adequacy.

Assessment measures

Qualitative scores for conservation value and threat, fisheries value and threat, ecological status and water quality.

Assessment

Conservation value ranged from high for Wallis Lake, Port Stephens and the Hunter River to low for Khappinghat Creek and moderate for all other estuaries rated. Conservation threat ranged from 'none' for the Hastings River, Lake Cathie/Innes, Camden Haven and Khappinghat Creek, to perceived for the Manning River and 'real' for the Macleay and Hunter Rivers.

Fisheries value ranged from high for the Macleay, Hastings and Manning Rivers and Camden Haven, Wallis Lake and Port Stephens to low for Lake Cathie/Innes and Khappinghat Creek. Fisheries threat ranged from high for the Macleay and Hunter Rivers to low for the Hastings River, Lake Cathie/Innes, Camden Haven and Khappinghat Creek.

Ecological status was 'slightly affected' for most estuaries, 'moderately affected' for the Macleay and Hastings Rivers, and 'considerably affected' for the Hunter River. For most estuaries there were no data available for water quality, but the Macleay and Hunter Rivers were rated as 'poor' (significant effect on the ecology of the estuary) and the Hastings River was rated as 'moderate' (effect on biota not substantial).

6.4.22 National parks and nature reserves

Data source

GIS data layer of estate managed by the NSW National Parks and Wildlife Service[5].

Data description

Data include the boundaries of existing national parks, nature reserves, state recreation areas, historic sites, Aboriginal areas and regional parks declared under the *National Parks and Wildlife Act 1997*. National parks and nature reserves are generally declared on the basis of their high conservation values and high natural condition. Their declaration ensures long-term protection of those values, and provides an important permanent buffer for estuaries and coastal environments against the effects of inappropriate land use. Many coastal national parks and natures extend below mean high and low tide marks and include large areas of open estuary and ocean shore. These areas are regarded as marine protected areas, but additional regulations are required to protect fish and invertebrates from fishing.

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measures

Percentage of adjacent lands managed as national park or nature reserve within 1 km of each estuary (classed by subcatchment) and within 1 km of the high water mark for sections of exposed coast.

These and the following vulnerability measures were also calculated for lands within 5 km of the high water mark and as a percentage of all lands within each estuarine subcatchment. The latter measures provided similar information and so all results are not reported here.

Areas of national park and nature reserve in the Manning Shelf bioregion extending below mean high tide were mapped in detail by Ron Avery (NSW National Parks) and used to assess the comprehensiveness of the current system of marine protected areas in the bioregion.

Assessment

For estuaries, the highest percentage of adjacent lands managed as national park or nature reserve occurred for Korogoro, Limeburners and Khappinghat Creeks and the Myall Lakes and Myall River (all >50% national park or nature reserve within 1 km, Figure 6.27a). The lowest percentages of adjacent national park and nature reserve occurred for the Nambucca, Macleay, Hastings, Manning and Hunter Rivers.

Sections of exposed coast between the Macleay River and Killick Creek, between Camden Haven and the Manning River, and between Smiths Lake and Port Stephens all had over 50% of lands within 1 km of the coast managed as national park or nature reserve. Nambucca–Macleay R., Lake Cathie–Camden Haven, Manning–Khappinghat and Stockton Beach–Hunter R. all had less than 5% of lands within 1 km managed as national park or nature reserve (Figure 6.28a).

6.4.23 State forest

Data source
GIS data layer of areas managed as NSW state forest.

Data description
The data identify the location and extent of lands managed as state forest.

Assessment measure
Percent of adjacent lands managed as state forest within 1 km of each estuary (classed by subcatchment) and within 1 km of high water for sections of exposed coast.

Criteria
Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment
Most state forest was found around the upper reaches of the Nambucca River and around Watson Taylor Lake and Port Stephens (4–8%, Figure 6.27b). There were no areas of State Forest within 1 km of the coast.

6.4.24 SEPP 14 wetlands

Data source
GIS data layer provided by the NSW DIPNR.

Data description
The data identify coastal wetlands protected under State Environmental Planning Policy No. 14 (SEPP 14) of the NSW *Environmental Planning and Assessment Act 1979* mapped at a scale of 1:25,000.

Criteria
Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure
Percent of adjacent lands managed under SEPP 14 within 1 km of each estuary (classed by subcatchment) and within 1 km of high water for sections of exposed coast.

Assessment
Estuaries with the highest percentage of SEPP 14 wetland within 1 km were Limeburners Creek (70%) and Lake Cathie (55%), followed by Korogoro Creek, Maria River (Hastings), Khappinghat Creek, Wallis Lake, Myall River and Port Stephens (all with 15–20%) (Figure 6.27c).

Sections of coast between the Macleay and Hastings Rivers and between Camden Haven and the Manning River all had over 25% of lands within 1 km managed under SEPP 14 (Figure 6.28b).

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[5] now within the NSW Department of Environment and Conservation

6.4.25 Wilderness

Data source

NSW National Parks – Comprehensive Regional Assessment (CRA).

Data description

Wilderness identified through the Lower North East Comprehensive Regional Assessment process.

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed as wilderness within 1 km of each estuary (classed by subcatchment) and within 1 km of high water for sections of exposed coast.

Assessment

Limeburners Creek (51%), Unamed Creek (40%) and the Maria River (1.6% for the Hastings River estuary) were the only estuaries with wilderness within 1 km (Figure 6.27d).

The Killick–Hastings R. section was the only section to have wilderness within 1 km of the exposed coast (48%, Figure 6.29a).

6.4.26 SEPP 26 littoral rainforest

Data source

GIS data layer produced by the NSW DIPNR.

Data description

The data identify littoral rainforest protected under State Environmental Planning Policy No. 26.

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed under SEPP 26 within 1 km of high water for sections of exposed coast.

Assessment

Small areas of littoral rainforest (1–4%) occurred within 1 km of all coastal sections except Korogoro–Killick Ck, Myall L.–Port Stephens and Stockton Beach–Hunter R. (Figure 6.28c).

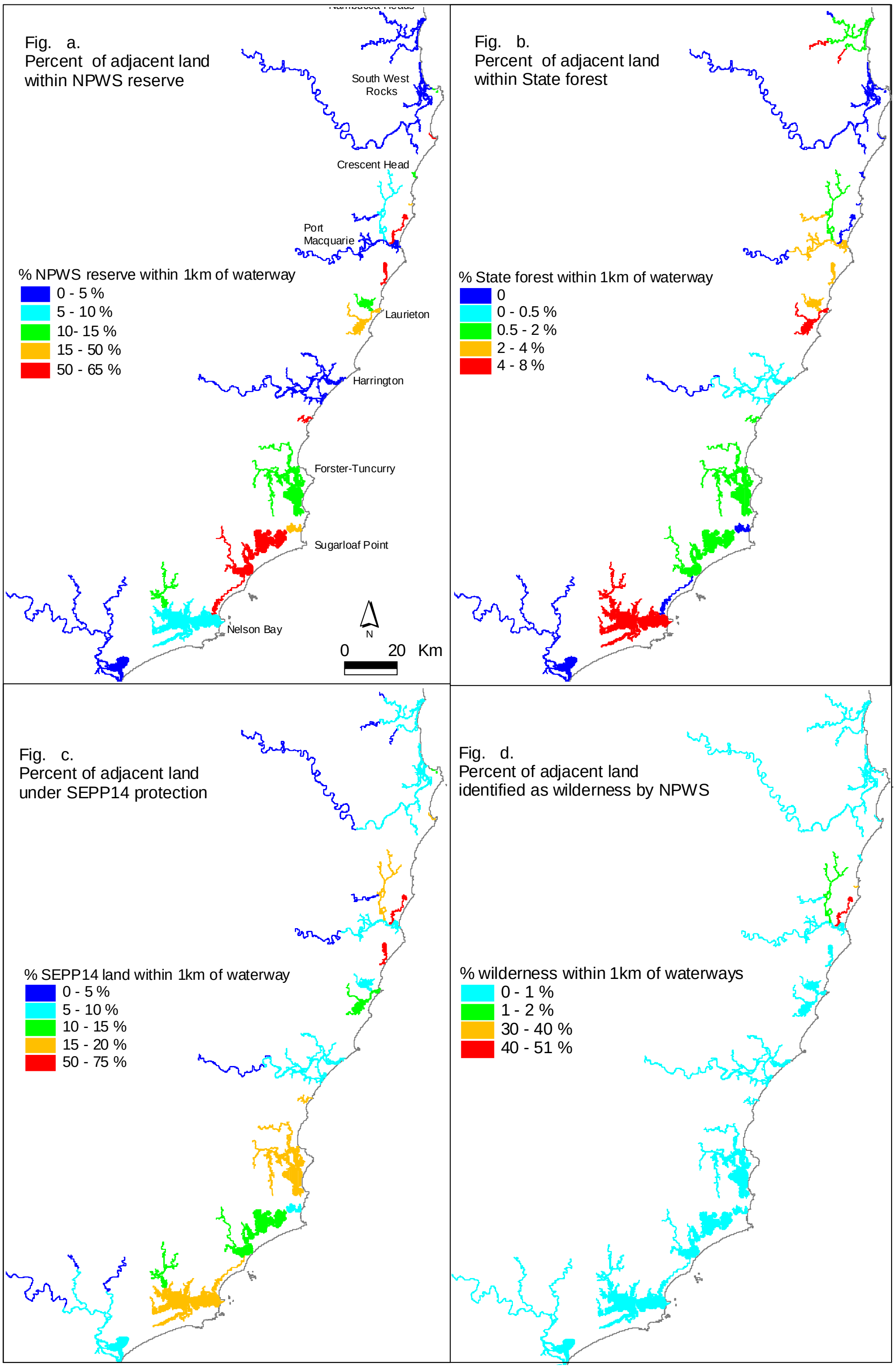


Figure 6.27a–d. Percentage area of land adjacent (within 1 km) to waterways with NSW Government protection. (Data provided by NSW National Parks, State Forests and DIPNR).

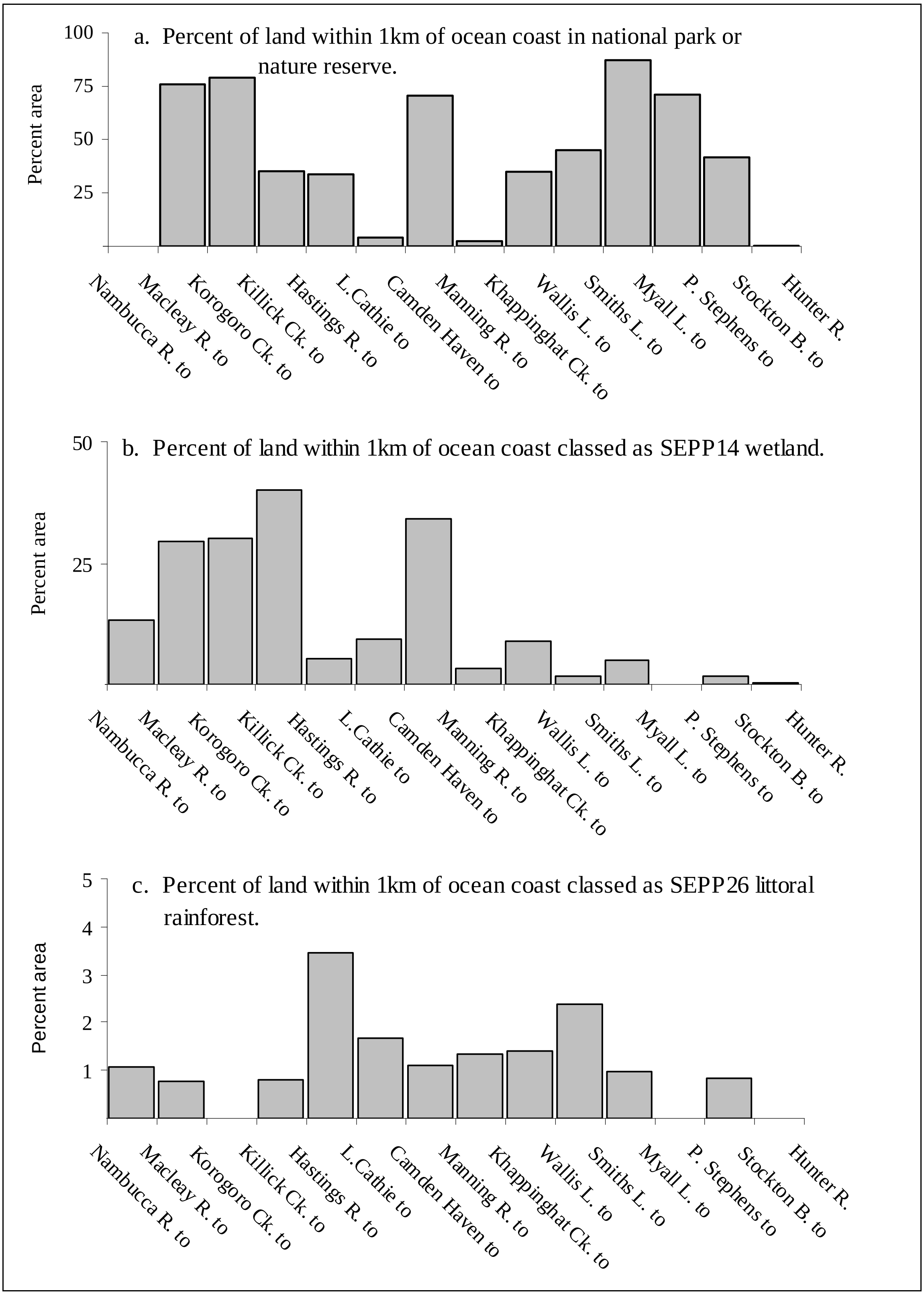


Figure 6.28a–d. Percentage area of land within 1 km of ocean coast with NSW Government protection (derived from data provided by NSW National Parks and DIPNR).

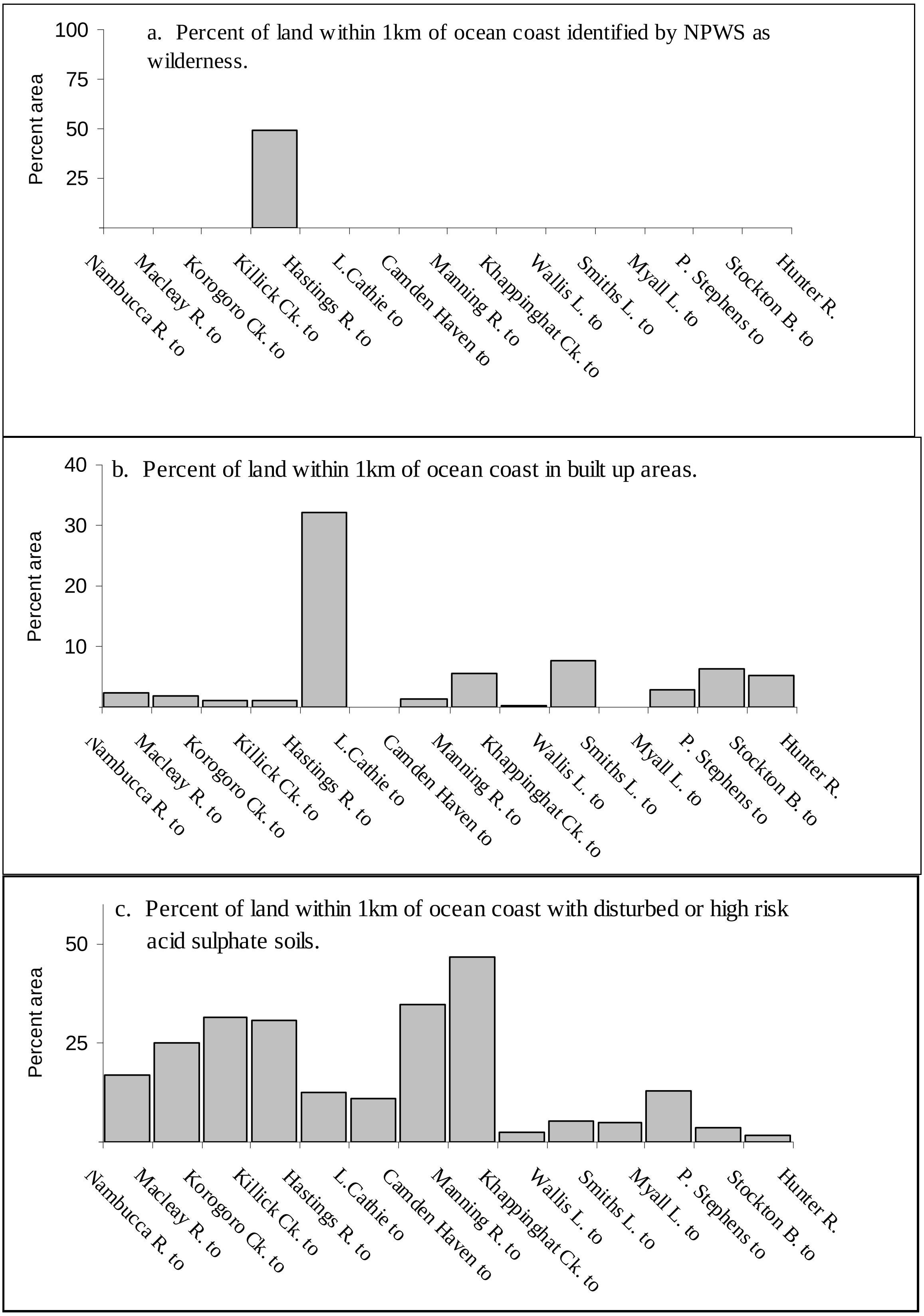


Figure 6.29a–c. Percentage of land within 1 km of ocean coast: as wilderness; in built-up areas; or with disturbed or high risk acid sulphate soils (derived from data provided by NSW National Parks, Geoscience Australia and DIPNR).

6.4.27 Land capability

Data source

GIS data from 'Land capability mapping', Soil Conservation Service, NSW DIPNR.

Data description

This data layer classifies different soils and terrains for lands in NSW according to their ability to support 8 main categories of land use. These categories were summarised into three broader classes: suitable for cultivation (1–3), suitable for grazing (4–6), or suitable for forest or to be left with natural vegetation (7–8).

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percentage of adjacent lands for each land capability group within 1 km of each estuary (classed by subcatchment) and within 1 km of high water for sections of exposed coast.

Assessment for estuaries

Land capability for forest or land to be left under natural vegetation (6.30a)

South West Rocks Creek (40%), Saltwater Creek (36%) and Lake Cathie/Innes (54%) had the highest percentage of land within 1 km classed most suited for forestry or being left as natural vegetation. Korogoro Creek (26%), Wallis Lake (22%), Smiths Lake (20%) and Port Stephens (25%) also had a large proportion of adjoining areas suitable for forestry or suitable for being left as natural vegetation. Less than 2% of land adjoining the Hastings River was classed as suitable for this purpose.

Land capability for cultivation (6.30b)

The Macleay (42%), Nambucca (24%), Hastings (31%), Manning (29%) and Hunter (33%) Rivers had the highest percentage of land within 1 km suitable for cultivation. Most other estuaries had less than 5% of adjacent lands suitable for cultivation.

Land capability for grazing (6.30c)

Most estuaries, particularly in the upper catchments, had a high percentage (20–90%) of adjacent land suitable for grazing. South West Rocks (16%) and Korogoro Creeks (7%) were the only estuaries classed as having less than 20% of their adjoining land within 1 km suitable for grazing.

Assessment for sections of exposed coast

Land capability for forest or land to be left under natural vegetation (Figure 6.31c)

The Port Stephens–Stockton Beach and Stockton Beach–Hunter River sections of coast had the highest percentage of land within 1 km suitable for forestry or natural vegetation. Nambucca–Macleay and Lake Cathie–Khappinghat also had a high percentage of adjacent land in this class.

Land capability for cultivation (Figure 6.31a)

Less than 2% of lands within 1 km of coast were classed suitable for cultivation in the Nambucca–Macleay, Hastings–Lake Cathie, and Manning–Khappinghat sections.

Land capability for grazing (Figure 6.31b)

The Khappinghat–Wallis, Nambucca–Macleay, Killick–Hastings, and L. Cathie–Camden Haven coastal sections all had over 30% of adjacent lands within 1 km suitable for grazing.

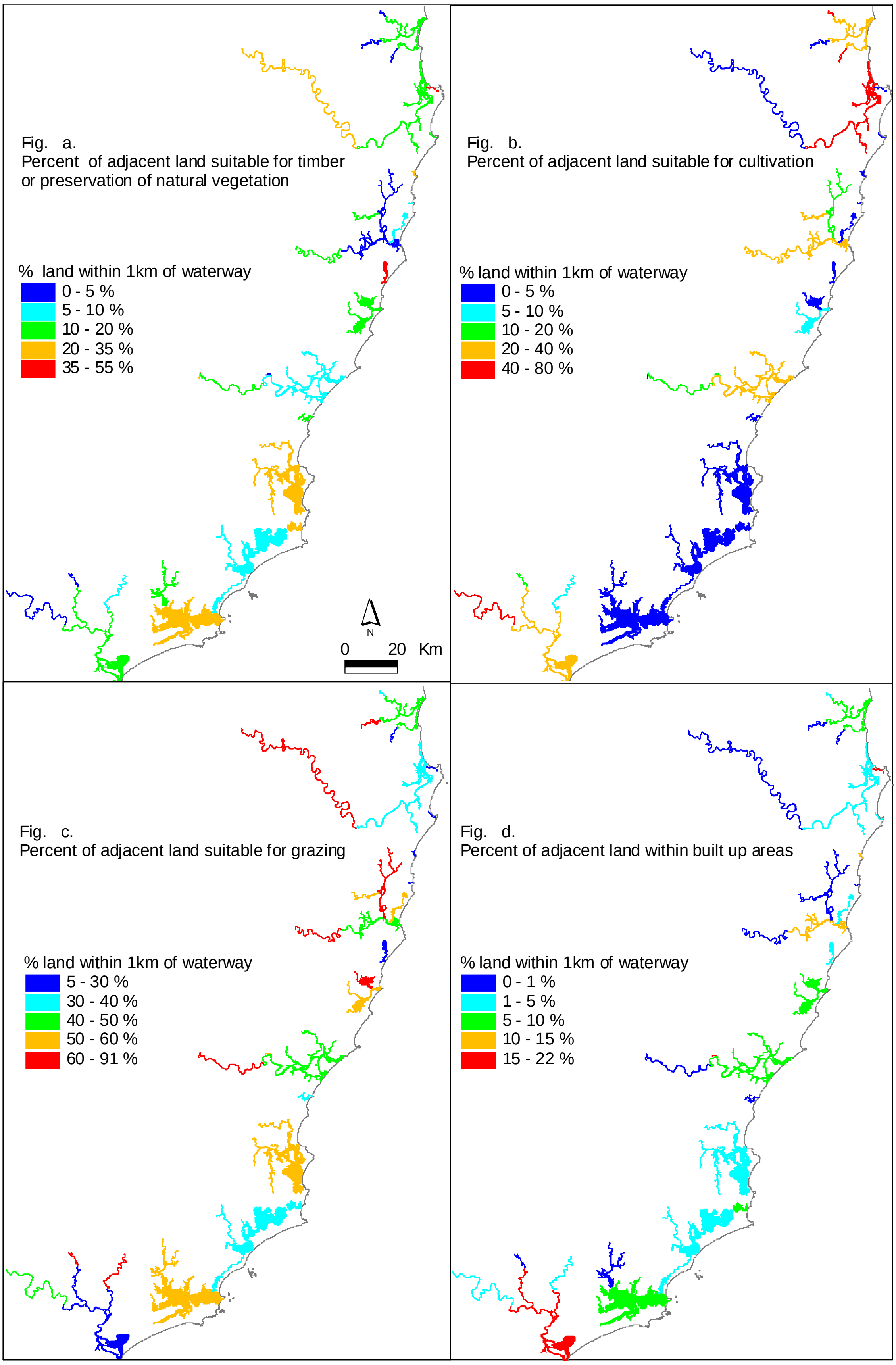


Figure 6.30a–d. Percentage of land within 1 km of waterways classed by land capability.

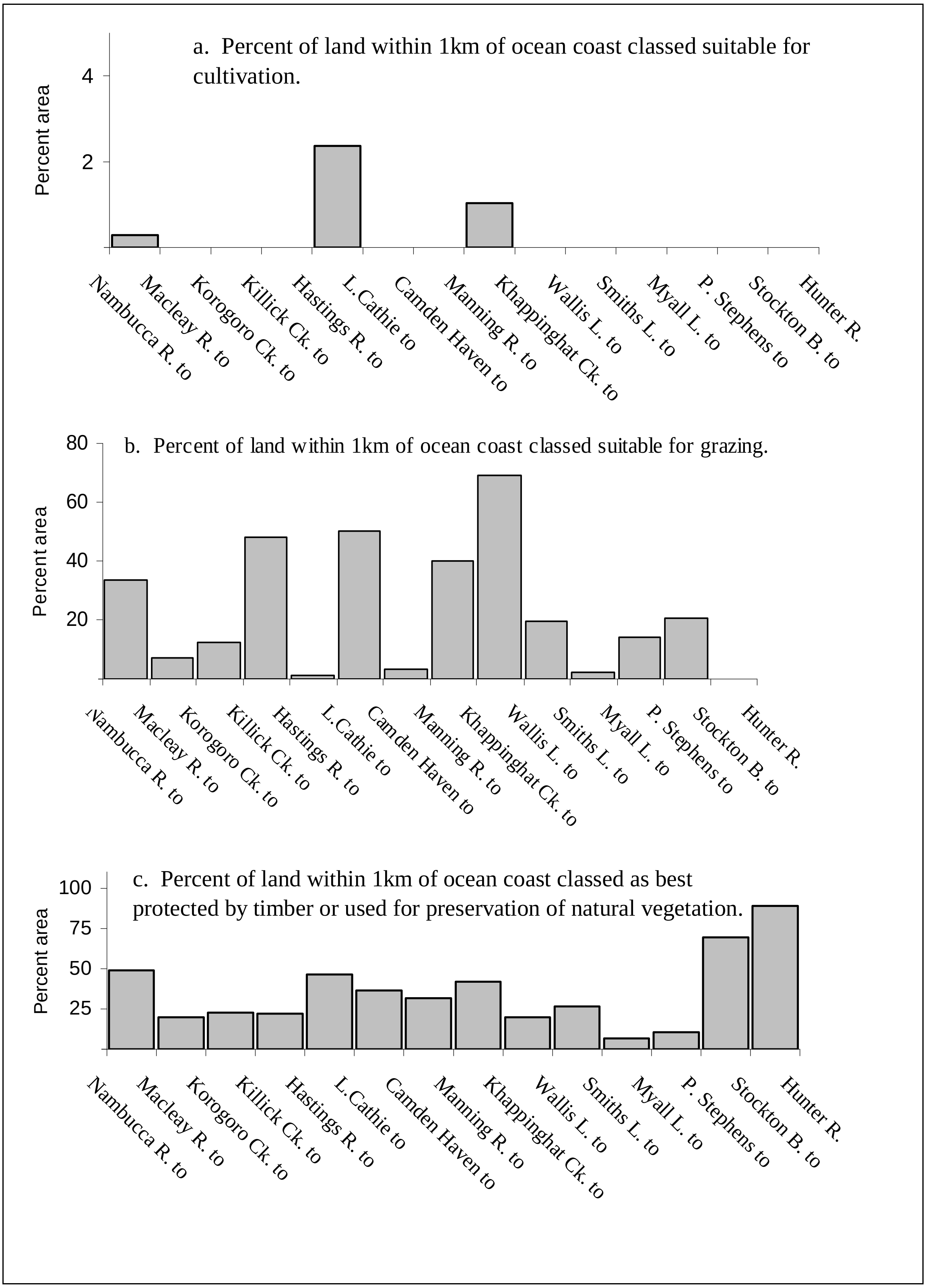


Figure 6.31a–c. Percentage of land within 1 km of ocean coast classed by land capability.

6.4.28 Built-up areas

Data source

Geoscience Australia 1:250,000 topographic database.

Data description

GIS layer of built-up, urban areas.

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands in built-up areas within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

South West Rocks Creek (20%), Saltwater Creek (15%) and the Hunter River (16%) had the highest percentage of built-up areas within 1 km. The Maria River (Hastings), Khappinghat Creek and the Karuah River had less than 1% and the Macleay River, Limeburners Creek, Lake Cathie, Wallis Lake and Myall Lakes had less than 5% of land in built-up areas (6.30d).

Built-up areas occupied over 30% of lands within 1 km of the coast in the Hastings–L. Cathie section of exposed coast. For all other sections, built-up areas occupied less than 10% of the 1 km coastal buffer and for L. Cathie to Camden Haven, Khappinghat–Wallis L. and Smiths L.–Myall L. built-up areas occupied less than 1% of lands within 1 km of the coast (6.29b).

6.4.29 Acid sulphate soils

Data source

Acid sulphate soil risk maps provided by the NSW DIPNR.

Data description

The acid sulphate soil risk maps predict the distribution of acid soils based on 1:25,000 scale aerial photograph interpretation and field and laboratory soil analysis. These soils occur naturally, particularly on coastal flood plains and in and around estuaries. They become a threat to the environment if exposed to the air when either the water table is lowered or sediments are excavated. The threat of acid release is related to the occurrence of inappropriate land use and development, not just the presence of the sediments.

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands with high risk or disturbed acid sulphate soils within 1 km of each estuary (classed by subcatchment) and within 1 km of high water for sections of exposed coast.

Assessment

Lake Cathie (55%), Limeburners Creek (35%) and the Macleay (55%), Maria (Hastings 59%) Hunter (57%), Manning (46%) and Myall (46%) Rivers had the highest percentages of high risk or disturbed acid sulphate soils within 1 km. Smiths Lake and Korogoro, Unamed and Khappinghat Creeks had less than 10% acid sulphate soils within 1 km (Figure 6.33a).

Manning–Khappinghat, Camden Haven–Manning and Macleay–Hastings had the highest percentages of high risk or disturbed acid sulphate soils within 1 km of the coast (Figure 6.29c).

6.4.30 Australian river and catchment condition database (ARCCD)

Data source

Australian river and catchment condition database produced by the Australian Heritage Commission. "The identification of wild rivers: methodology and database development. Australian Heritage Commission" (Stein *et al*. 2000).

Data description

GIS grid coverage with a cell size of 250 m for seven catchment and flow disturbance indices calculated from a wide range of distance weighted topographic features (e.g. land use, roads, mines, weirs, levees, vegetation, pollution sources) (e.g. Figure 6.32).

Criteria

Adequacy, ecological importance, naturalness (condition) and vulnerability.

Assessment measure

The average grid value (weighted by the number of cells) for each measure was estimated for each estuarine subcatchment and for lands within 5 km of each section of exposed coast.

Assessment for estuaries

Mean total river disturbance (Figure 6.33b):

- highest for the Hunter and Macleay Rivers and Limeburners Creek
- lowest for the Maria River, Camden Haven, Khappinghat Creek, Wallis Lake, Myall Lakes, and the Myall River.

Mean Catchment disturbance (Figure 6.33c):

- highest for the Nambucca, Macleay, Manning and Hunter Rivers
- lowest for Maria River, Camden Haven, Khappinghat Creek, Myall Lakes and the Myall River.

Mean flow disturbance (Figure 6.33d):

- highest for the Hunter and Macleay Rivers and Limeburners Creek
- lowest for Camden Haven, Khappinghat Creek, Wallis Lake, Smiths Lake, Myall Lakes and the Myall River.

Mean settlement factor (Figure 6.34a):

- highest for the Hunter, Hastings and Manning Rivers and Lake Cathie
- low for most other estuaries.

Mean land use factor (Figure 6.34b):

- highest for the Macleay, Manning, Hunter, Nambucca and Hastings Rivers
- lowest for Limeburners Creek.

Mean infrastructure factor (Figure 6.34c):

- highest for the Hunter, Macleay and Hastings Rivers
- lowest for the Maria River, Limeburners Creek, Wallis Lake, Smiths Lake, Myall Lakes, the Myall River and Port Stephens.

Mean extractive industry/pollution point source factor (Figure 6.34d):

- highest for the Nambucca and Hunter Rivers
- lowest for the Maria River, Limeburners Creek, Camden Haven, the Manning River and Khappinghat Creek.

Assessment for exposed coast

Mean total river disturbance (Figure 6.35a):

- highest for Stockton Beach–Hunter River, Port Stephens–Stockton Beach
- lowest for L. Cathie–Camden Haven and Wallis L.–Port Stephens.

Mean catchment disturbance (Figure 6.35b):

- highest for Stockton Beach–Hunter River, Port Stephens–Stockton Beach, Hastings–L. Cathie
- lowest for Killick–Hastings, L. Cathie– Manning and Wallis L.–Port Stephens.

Mean settlement factor (Figure 6.35c):

- highest for Hastings–L. Cathie and Stockton–Hunter River
- low for all other sections.

Mean land use factor (Figure 6.36a):

- highest for Stockton Beach–Hunter River, Manning–Khappinghat Creek and Korogoro–Killick Creek
- lowest for Killick–Hastings and Wallis L.–Myall L.

Mean extractive industry/pollution point source factor (Figure 6.36b):

- highest for Port Stephens–Stockton Beach
- lowest for Killick–Hastings, Manning–Khappinghat and Wallis L.–Smiths Lake.

Mean infrastructure factor (Figure 6.36c):

- highest for Hastings–L. Cathie and Stockton Beach–Hunter River
- lowest for Killick–Hastings and Wallis L.–Port Stephens.

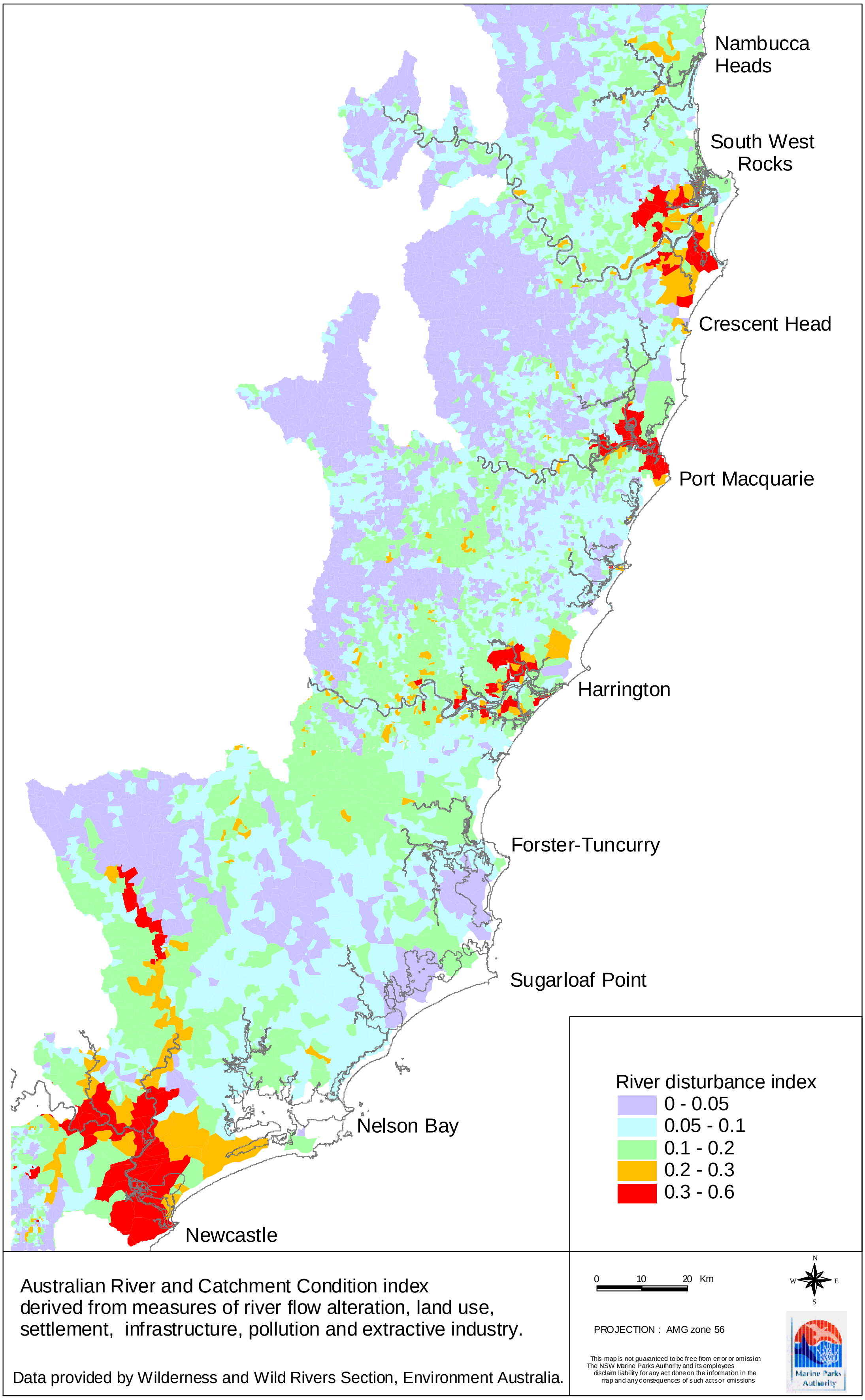


Figure 6.32. Australian river and catchment condition index for overall river disturbance in the Manning Shelf bioregion (data from Stein *et al.* 2000).

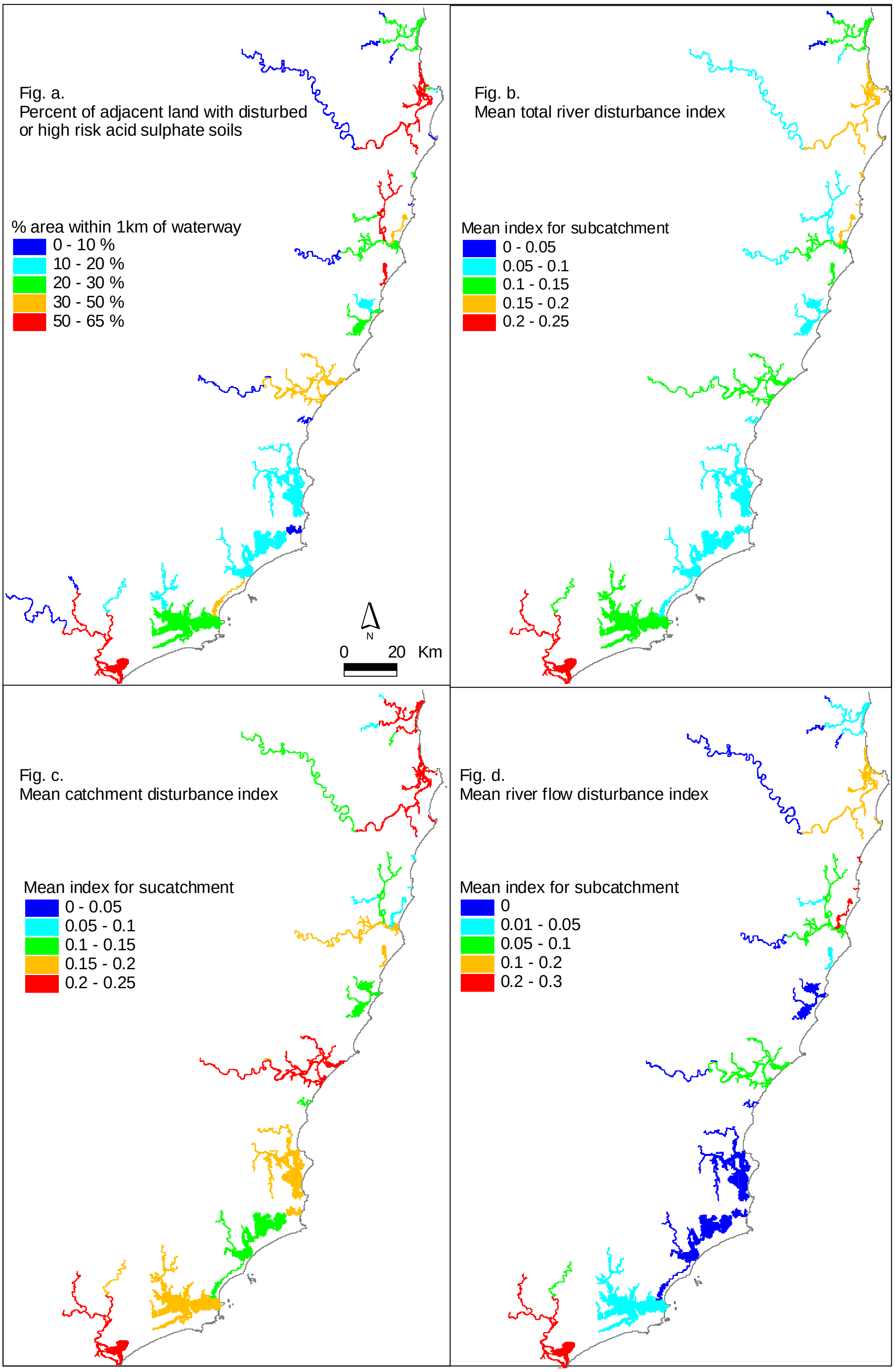


Figure 6.33a–d. Percentage of land within 1 km of estuaries with disturbed or high risk acid sulphate soils; and mean Australian river and catchment condition indices for estuarine subcatchments (derived from data provided by the DIPNR and the Australian Heritage Commission).

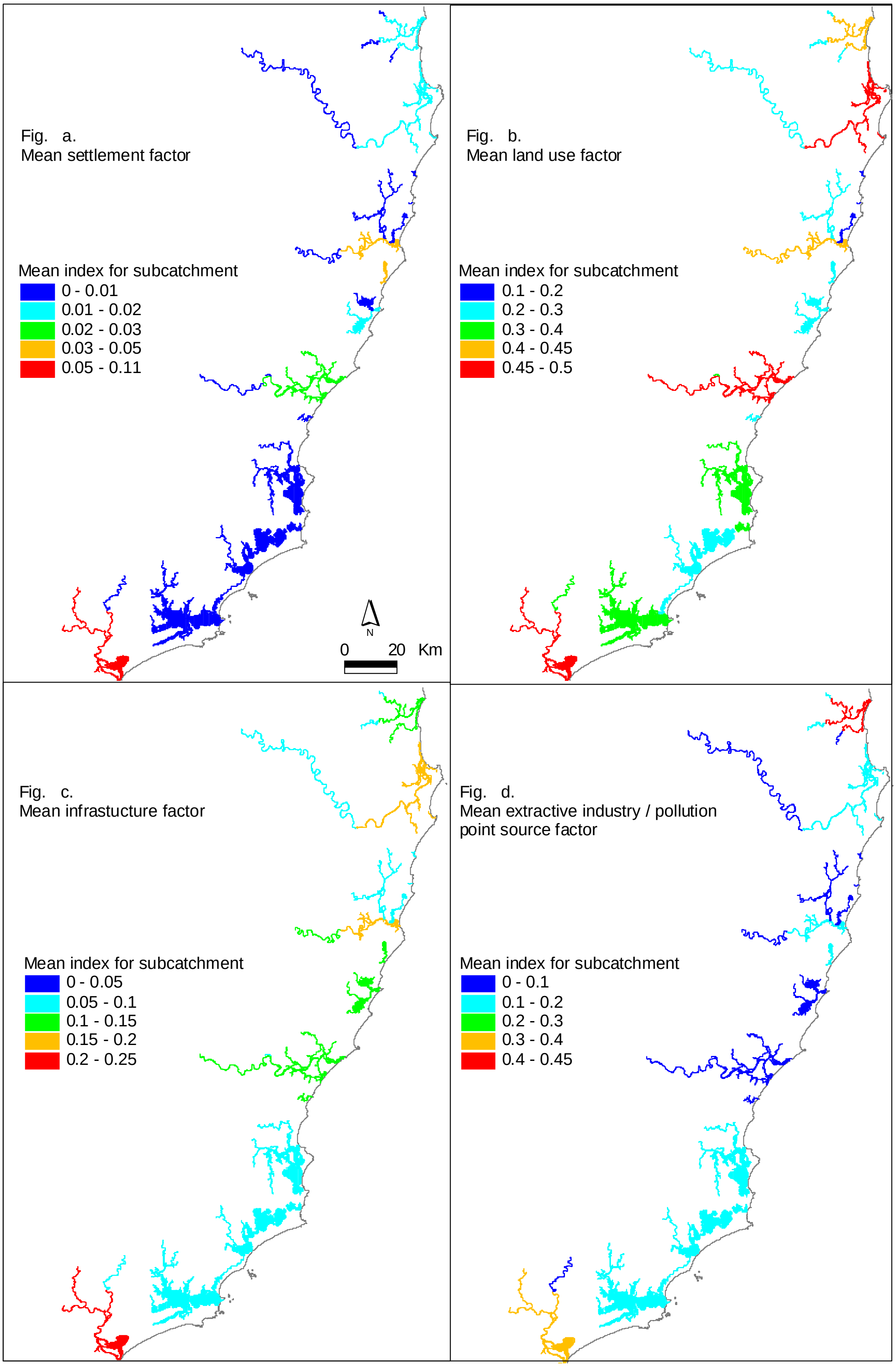


Figure 6.34a–d . Australian river and catchment condition indices for estuarine subcatchments (derived from data provided by the Australian Heritage Commission).

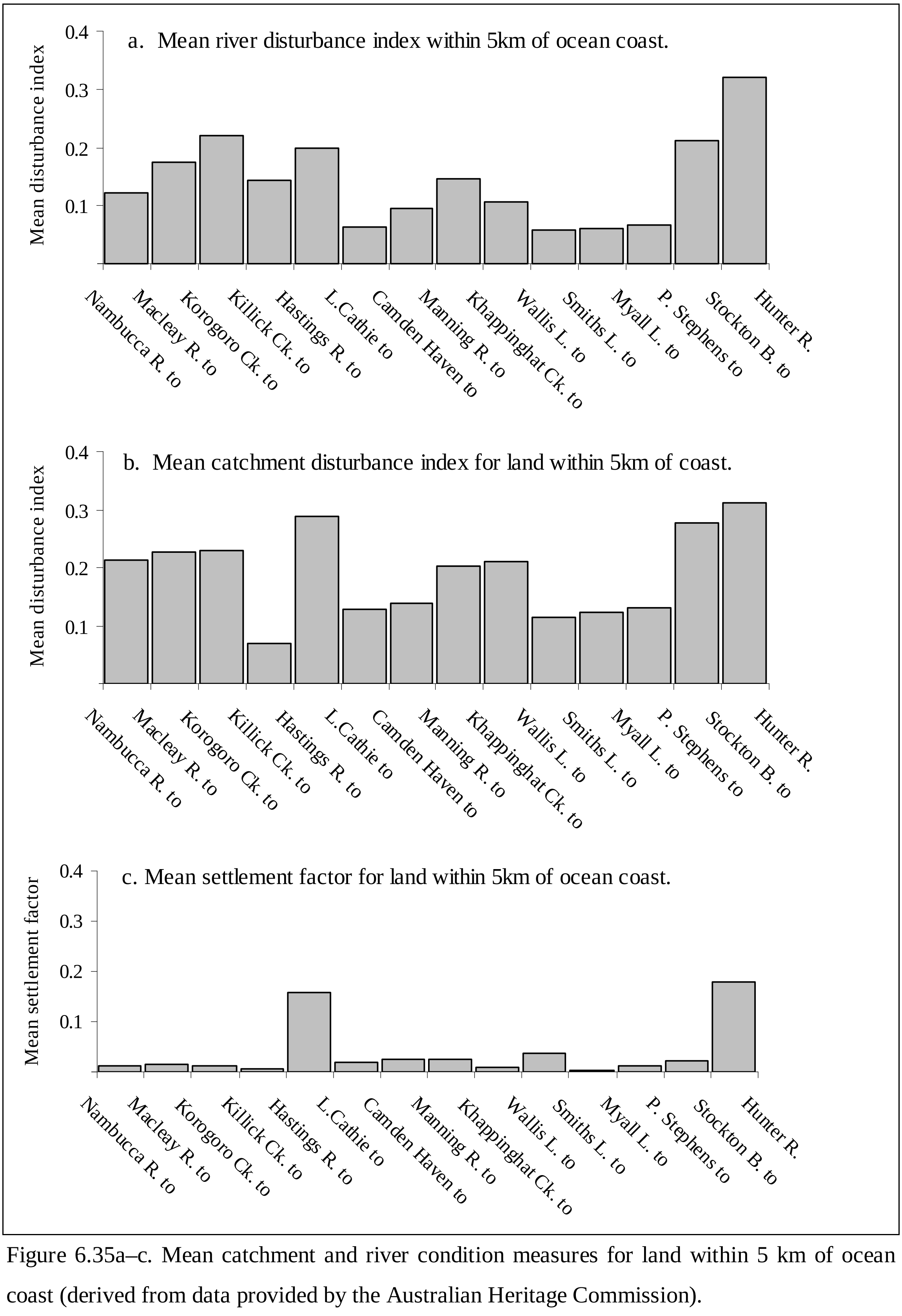


Figure 6.35a–c. Mean catchment and river condition measures for land within 5 km of ocean coast (derived from data provided by the Australian Heritage Commission).

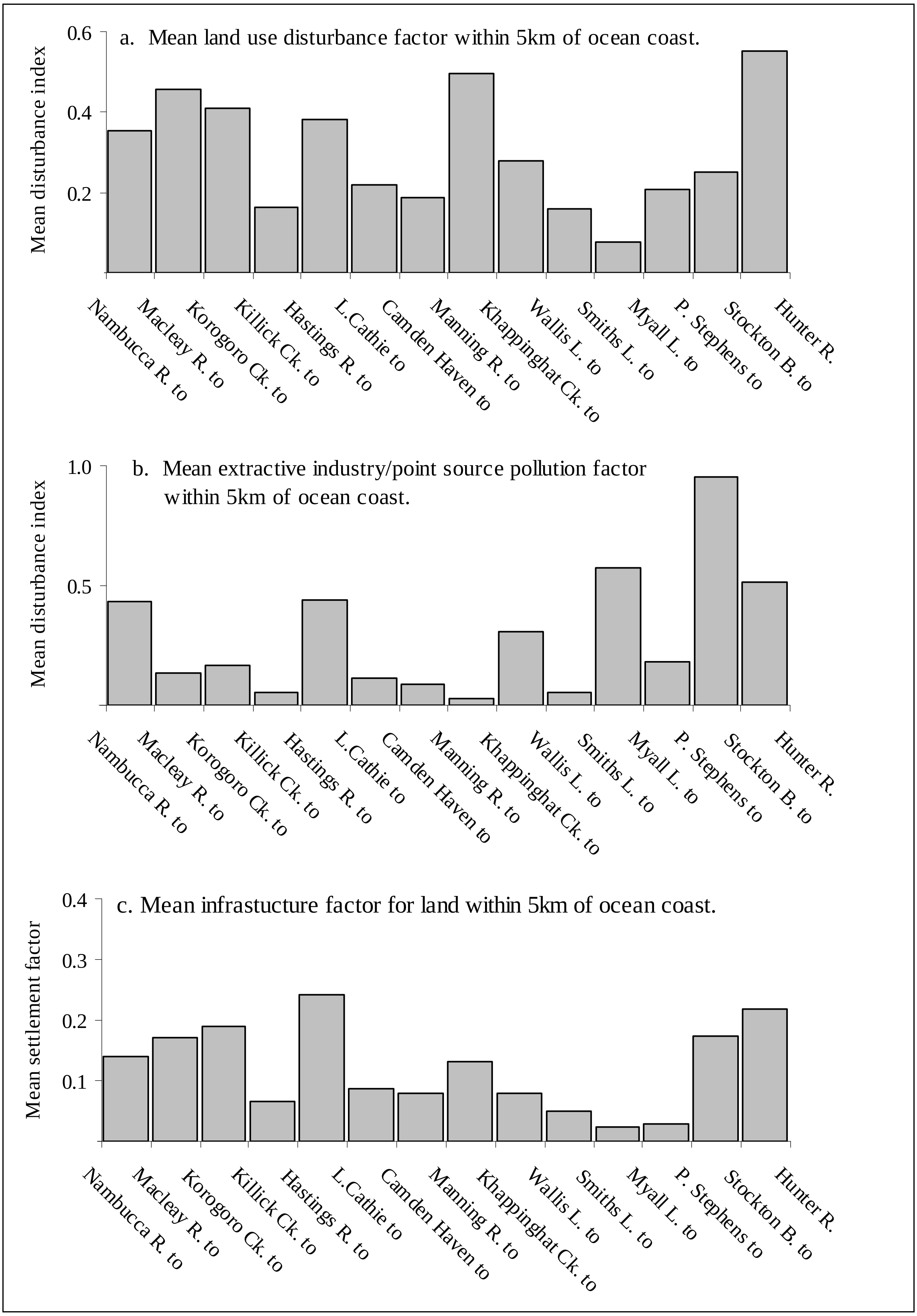


Figure 6.36a–d. Mean river and catchment condition measures for land within 5 km of ocean coast (derived from data provided by the Australian Heritage Commission).

6.4.31 Irreplaceability analysis for ecosystem and habitat units

Irreplaceability is a measure of a site or planning unit's ability to contribute a range of biodiversity to a proposed network of protected areas. It estimates the likelihood of a site being required for the network to meet a range of different conservation targets. The targets are usually defined as areas, numbers or percentages of different habitats, species or other features of interest.

Figure 6.37 shows *site* irreplaceability calculated for fine scale planning units and a hypothetical goal of 20% of the area of each ecosystem (estuary types and ocean depth zones) and habitat feature (seagrass, mangrove, saltmarsh, rocky intertidal, beach, reef, island). Arbitrary targets of 20% of the area of each feature were used. In practice, scenarios for a range of different targets can be assessed interactively and scores will vary as potential sites are included or excluded from a hypothetical reserve system. However, for this assessment, a 20% target provides a useful measure to display the relative contribution that different sites could provide.

Site irreplaceability ranges between zero and one, where a value of one means the site must be included if targets are to be met. In Figure 6.37, irreplaceability for most sites is less than 0.6 (green and blue plan units) and there are no sites where irreplaceability equals one. This indicates that for these plan units and targets, many alternative sites could substitute for each other in a reserve system and still meet goals for a range of ecosystem and habitat features.

However, higher site irreplaceabilities ranging between 0.6 and 0.9 (yellow and orange) indicate that options are more restricted for some areas. In the estuaries, these areas include Fullerton Cove and Kooragang Island in the Hunter River, various bays around upper Port Stephens, the southern Myall River, much of south eastern Wallis Lake, northern Camden Haven and Lake Innes and Lake Cathie. These are all areas with high densities of a mangrove, saltmarsh and seagrass habitats.

In coastal waters, high irreplaceabilities occur off Port Stephens, Broughton Island, Khappinghat Creek, Port Macquarie and Smoky Cape (South-West Rocks). These are all areas with high densities of reef, offshore islands and rocky shores.

A slightly different index, s*ummed* irreplaceability, is calculated by adding the individual irreplaceabilities for all the features in a site. Figure 6.38 shows summed irreplaceability for the same features, plan units and hypothetical goal, and indicates those sites (ranked by percentile) likely to contribute to targets for more habitats and ecosystems. High values indicate that a site is important for achieving conservation goals for many different features.

Again estuarine areas such as Fullerton Cove and Kooragang Island in the Hunter River, bays in Port Stephens, the lower Myall River, Wallis Lake, Camden Haven, Lake Innes and Lake Cathie score highly as do coastal waters near Port Stephens, Broughton Island, Khappinghat Creek, Port Macquarie and Smoky Cape.

The broad scale plan units in Figure 6.39 and Figure 6.40 show summed irreplaceabilities for entire estuaries and sections of exposed coast and ocean calculated for a goal of 20% of each mapped ecosystem and habitat. Myall Lakes and Port Stephens score the highest summed irreplaceability for estuarine ecosystems (Figure 6.39a) as they are the only estuaries of their type in the bioregion. Wallis Lake and Port Stephens score highest for representation of estuarine habitats (seagrass, mangrove and saltmarsh, Figure 6.39b). Summed irreplaceability combined across all estuarine ecosystem and habitat features was highest for Port Stephens, Wallis Lake and Myall Lakes (Figure 6.39c).

To represent 20% of ocean ecosystems (depth zones), summed irreplaceability was similar for most sections of exposed coast but highest for the Myall L.–Port Stephens, Camden Haven–Manning River and Port Stephens–Stockton Beach sections (Figure 6.40a). To represent 20% of ocean habitats (rocky intertidal, beach, island and reef), summed irreplaceability was highest for Port Stephens–Stockton Beach and Myall Lakes–Port Stephens (Figure 6.40b). These sections also scored highest for summed irreplaceability measured across all ocean ecosystems and habitats (Figure 6.40c).

If the aim is to include large areas of all defined marine ecosystems and habitats within a limited number of broad scale planning units then this is most readily achieved at the southern end of the bioregion between Wallis Lake and Stockton Beach.

This choice would be driven primarily by a need to include Port Stephens and Myall Lakes as respectively, the only examples of a drowned river valley and a brackish barrier lake in the bioregion. However, this section of coast also includes the most extensive examples of other ecosystems and habitats in the bioregion including the largest intermittent estuary (Smith's Lake) and the largest areas of mangrove, saltmarsh, seagrass, reef, islands and rocky shore.

It would therefore be possible for a large multiple use marine park in this region to include all ecosystem types and many extensive examples of each habitat type. By including replicate examples of these habitats, such a park might include a greater range of finer scale patterns in biodiversity, provide for connectivity, allow for disturbance and provide for a variety of sustainable human activities within different zones.

However, irreplaceability analysis using the fine scale planning units demonstrates that there are many alternative options for building a system of marine protected areas, which might include large multiple use marine parks as well as other, perhaps smaller MPAs. It also shows that there are significant conservation values distributed throughout the bioregion, that might not be successfully protected within a single, localised MPA.

It is also arguable whether a single large MPA at one end of the bioregion will provide any substantial benefits to environments and communities throughout the rest of the bioregion. This indicates that what may be required to comprehensively conserve marine ecosystem values is a network of interconnected MPAs that includes not only large marine parks but smaller, targeted reserves with specific local objectives.

Given our inexperience in designing and testing ecologically functional networks of MPAs, it is difficult to specify exactly what this network should look like. However the objectives in Chapter 2, guidelines given in Appendix 1 and the tools and information used here and in Chapter 9 and 10 (e.g. Marxan) provide a good basis for comparing alternative systems.

There are also mathematical approaches developed to assess reserve networks and other patchy environments (e.g. graph analysis) that could be used with the models developed here to explore the effect of adding and removing areas on network connectivity and other attributes. There also now exists a reasonable understanding of the life histories of a range of marine organisms and their habitat requirements, migration, dispersal, recruitment, survivorship and reproduction.

This knowledge together with exploratory models of reserve systems built using realistic seascapes could do much to improve the way these marine protected areas are implemented. The use of C-Plan and Marxan planning tools is explored further in Chapters 9 and 10 but additional research incorporating the biology of the region's marine organisms could provide an even better approach to designing MPA networks for this coast.

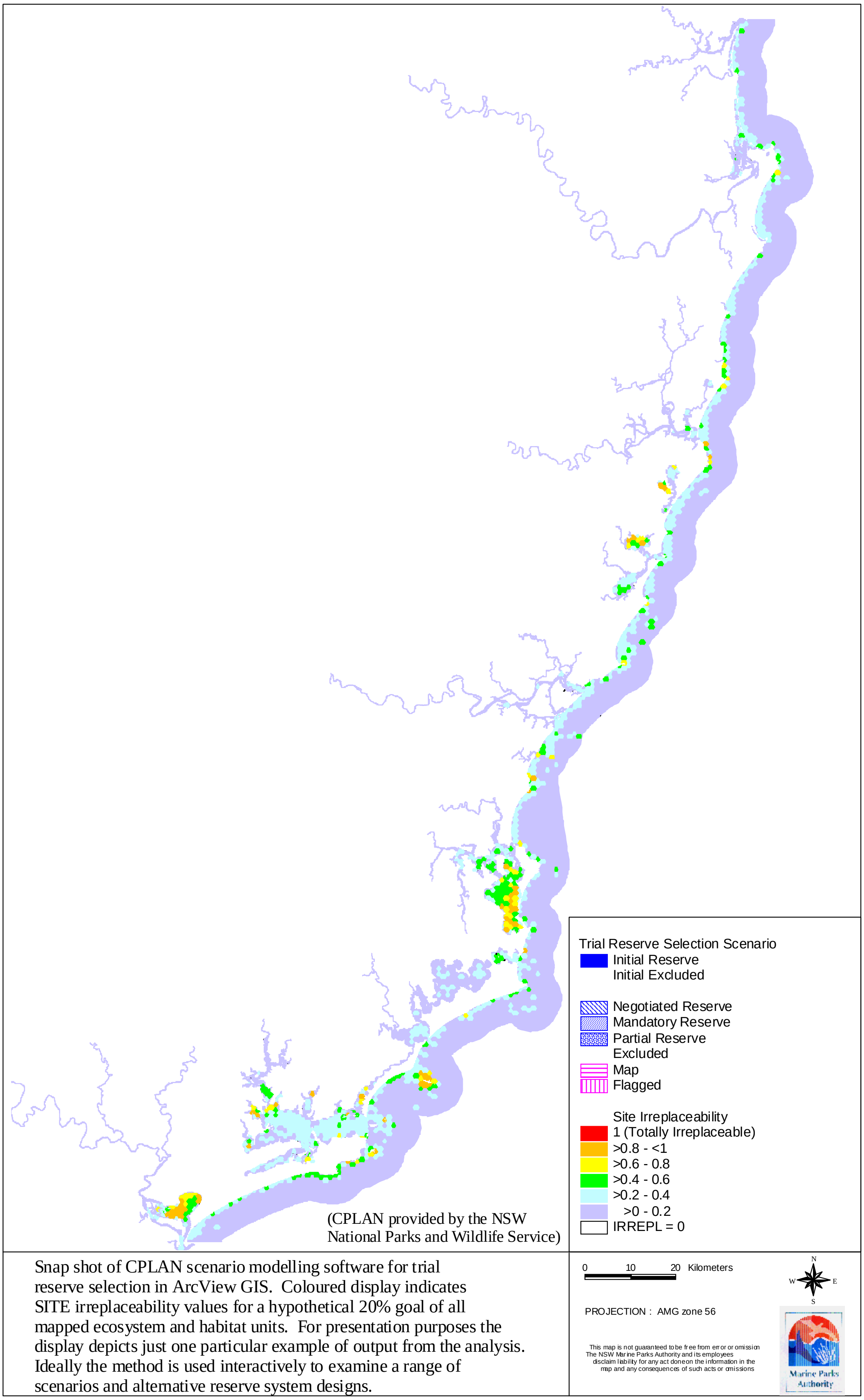


Figure 6.37. Site irreplaceability of fine scale planning units for ecosystem and habitat units (C-Plan 2001).

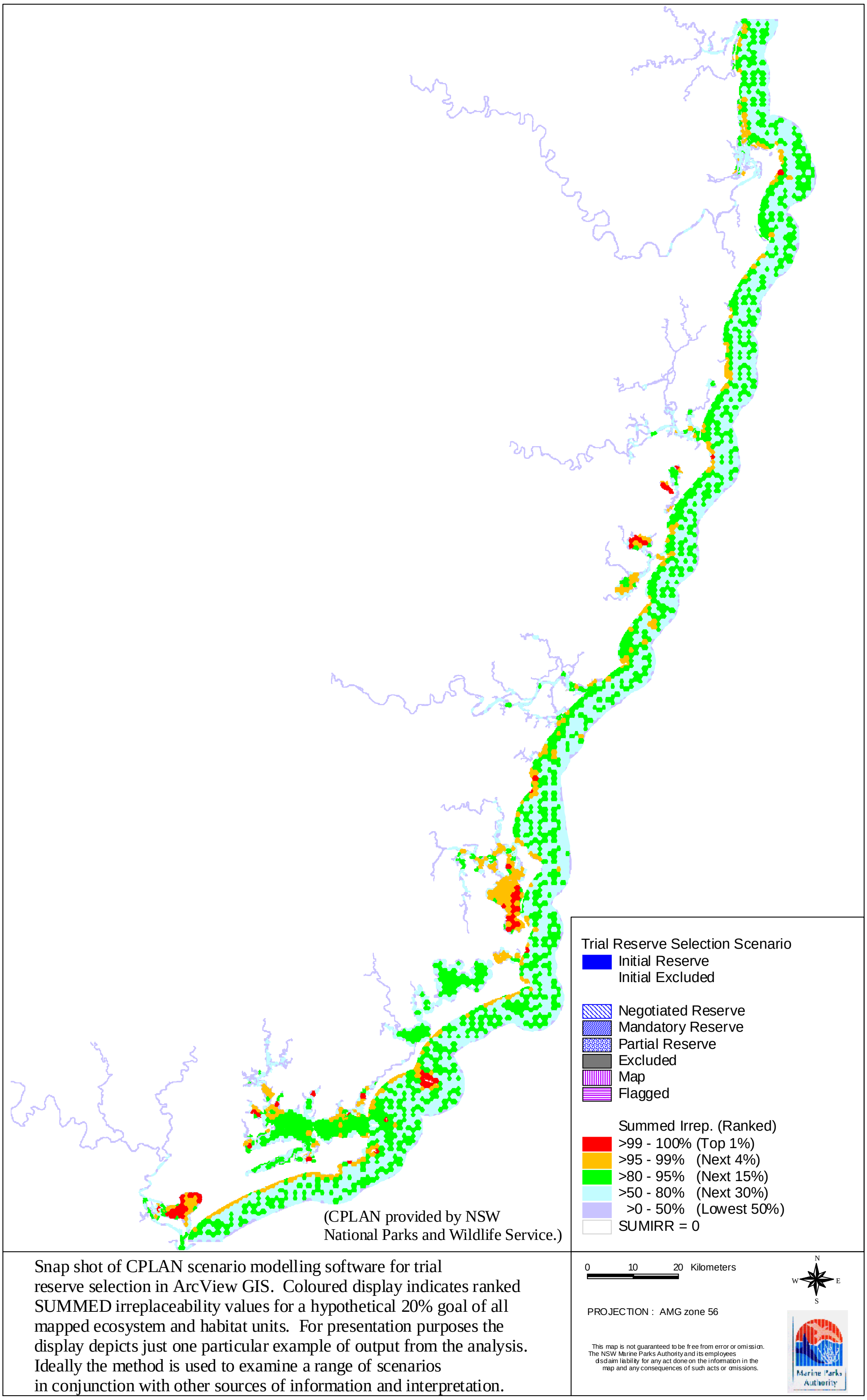


Figure 6.38. Summed irreplaceability of fine scale planning units for ecosystem and habitat units. Values from C-Plan (NPWS 2001).

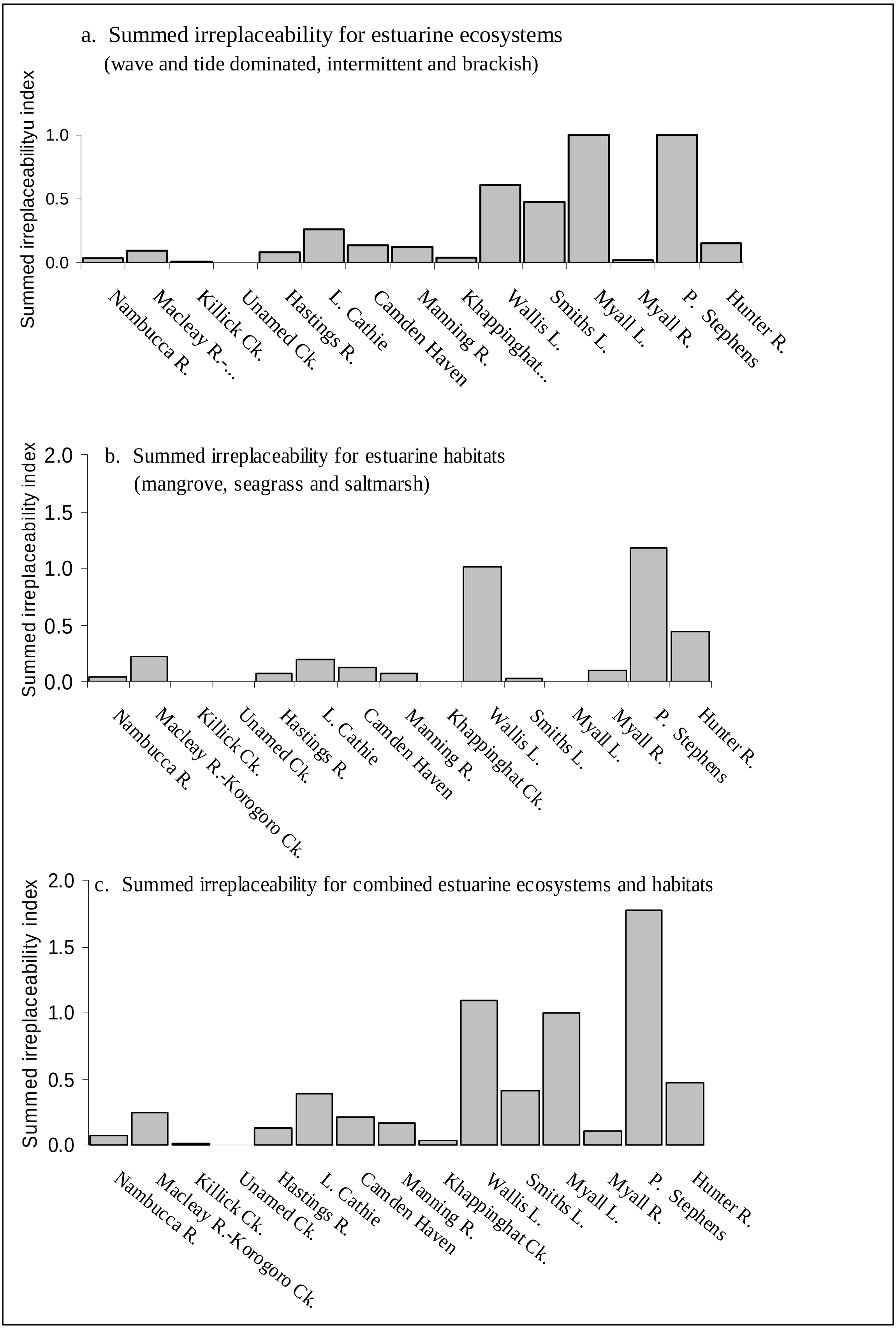


Figure 6.39a–c . Summed irreplaceability for broad scale estuarine planning units. Values from C-Plan (NPWS 2001).

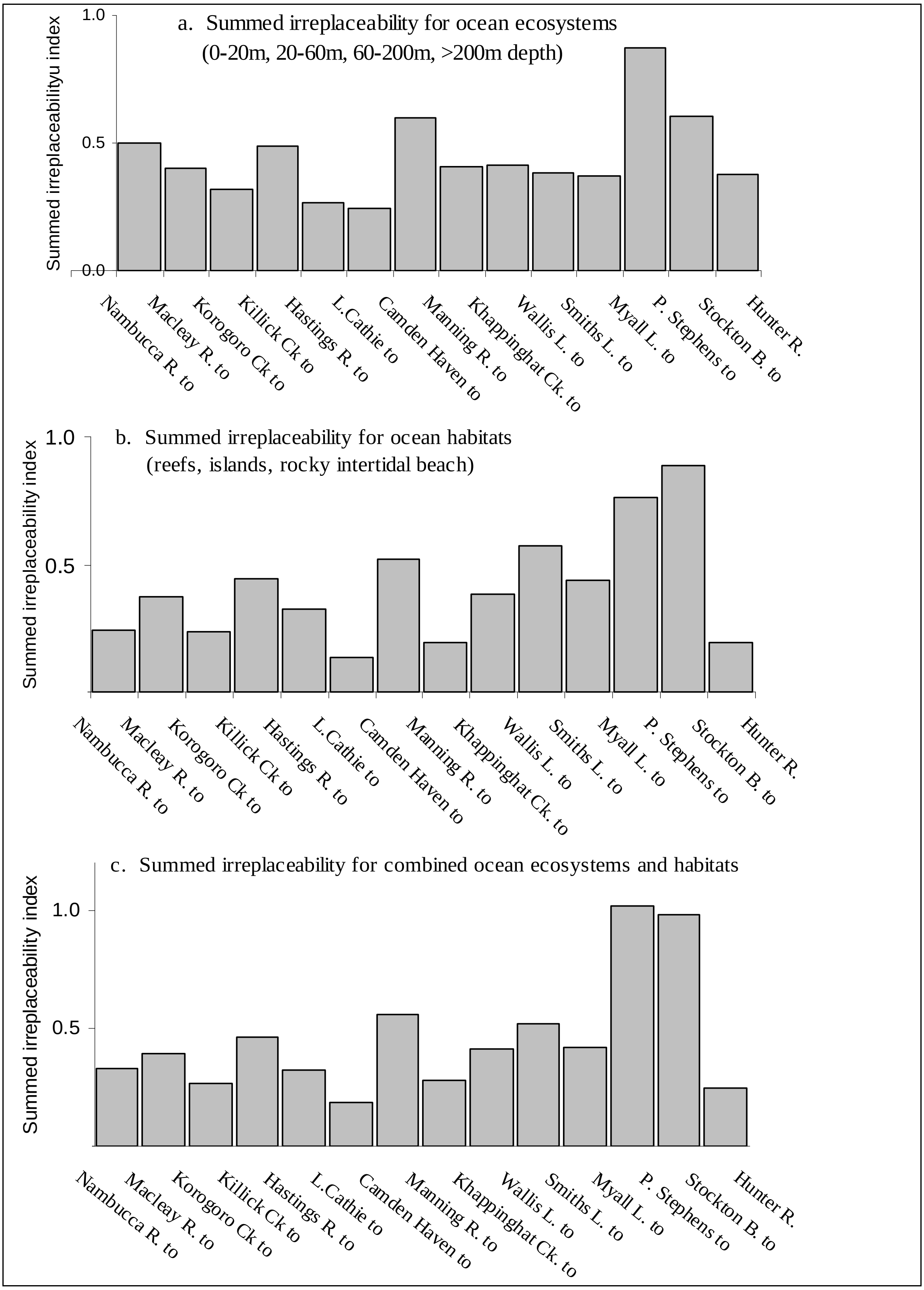


Figure 6.40a–c . Summed irreplaceability of broad scale sections of exposed coast and ocean. Values from C-Plan (NPWS 2001).

6.4.32 Multiple criteria decision analysis

The assessment scores for the broad scale planning units described in sections 6.4-6.430 are summarised in Table 6.5 to Table 6.8. The dots summarise scores on each assessment measure with more dots reflecting greater suitability for candidate MPAs. These symbolic measures were assigned to the highest, lowest and intermediate quantitative scores for each measure. However, these tables are difficult to interpret for so many measures and the dot format oversimplifies responses for each measure. This simple scoring format also ignores the way that measures overlap or may duplicate each other and ignores the possibility that criteria may not be of equal priority.

However the hierarchical, multiple criteria models used in Chapter 2 to describe conceptual goals and criteria for MPAs can be adapted to address these limitations and quantify the overall performance of alternative sites in meeting the conceptual goals using scores for detailed criteria. The quantitative models are not identical to the conceptual models as data for all conceptual criteria were not readily available. The conceptual models still provide an important role in indicating what criteria have been addressed and where more information is required.

Figure 6.41 shows a multiple criteria tree built in Criterium Decision Plus 3.0 that models the general goals of ‘comprehensiveness’ and ‘representativeness’ in terms of several levels of finer scale criteria. At each level, the finer scale ‘child’ criteria ‘inherit’ the general characteristics of the broader ‘parent’ criteria but are defined by more detailed specifications.

At the lowest level in the tree, the most detailed criteria are evaluated for each site (in this case, each estuary) in terms of the standardised scores for each assessment measure. Scores are standardised to a comparable scale, in this case, between 0 and 100. Where scores are already rank or percentage scales, the relative scaling is maintained. However for unscaled interval measures such as hectares or number of animals, scores are scaled between the minimum and maximum values for each variable. The scales can be transformed to reflect positive or negative slopes, logarithmic gradients or custom built functions. In most cases a simple positive linear function was used, except where factors considered unsuitable for MPAs warranted a negative slope or where counts of many organisms (e.g. bird sightings) indicated that a logarithmic function was appropriate.

For each criteria, at each level in the tree, a weighted average score for each estuary is calculated from the scores and the weights of the criteria lower in the tree. The criteria at each level in the hierarchy can be individually weighted according to policy, reliability or subjective importance. In these examples, all criteria are weighted equally under an initial assumption that all criteria are important. Weights may also be manipulated in the software program to reflect different scenarios and their effect on how alternative sites perform under different priorities can be assessed interactively through graphic displays.

Broad scale planning units are listed on the right hand side of Figure 6.41a with their overall score against the main goal, calculated as a function of scores for each assessment measure and the relative weights (indicated to the left of each criterion) assigned at each level in the tree. In this example, 'adequacy' and 'human use' are weighted to zero, in order to differentiate the effects of these main criteria.

The resulting scores for comprehensiveness and representativeness are ranked from highest to lowest in Figure 6.41b. Port Stephens, the Hunter River and Wallis Lake score highest, followed by Myall Lake, the Hastings River and the Myall River.

Modelling the 'adequacy' of estuarine plan units as a function of disturbance, protection and the results of previous conservation assessments (Figure 6.42a and Figure 6.42b) ranks Limeburners Creek, Unamed Creek, the Myall River, Myall Lake, Killick Creek, Khappinghat Creek, Warrell Creek and Lake Innes as the most appropriate candidate sites for this criterion. At the other end of the scale, the Hunter River (a major shipping, industrial and agricultural area) is ranked as the least appropriate site for this criterion.

Figure 6.43a shows a multiple criteria tree model of the 'comprehensiveness' and 'representativeness' of sections of coast and ocean as a function of the area and length of different ecosystems, habitats and communities and the number of sites where different endangered species are found. With criteria all equally weighted, the Myall L.–Port Stephens section of coast, followed by the Wallis L.–Smiths L., Port Stephens–Stockton Beach, Camden Haven-Manning R. and Smiths L. – Myall L. sections best meet goals for 'comprehensiveness' and 'representativeness' (Figure 6.43b).

Figure 6.44a models 'adequacy' for sections of coast and ocean as a function of vulnerability to external threats and protection by various forms of conservation management. With criteria weighted equally, the Killick–Hastings R., Smiths L.–Myall L., Camden Haven–Manning R. and Myall L.-Port Stephens sections score highest against the overall goal for 'adequacy' (Figure 6.44b).

In addition to these basic scenarios, a range of 'what if' situations can be explored using different models, data inputs, and priorities (weights) to represent alternative opinions and differences in data reliability. One benefit of this modelling is to test how 'sensitive' a given decision may be to adding, removing, or changing the relative influence (weight) of different criteria and measures. A potential MPA site that consistently scores well, regardless of how criteria are weighted, may represent a more widely accepted outcome or at least a compromise among conflicting goals and objectives. This method provides a way to simultaneously assess data from a wide range of formats while documenting the information, rules and priorities used to reach a decision. However the full value of this technique is realised when subjective priorities and other criteria for social, economic and cultural values are used to explore a range of different scenarios.

Table 6.5 Summary of measures assessing estuarine plan units for comprehensiveness and representativeness.

	Suitability for MPA • Low •• ••• Medium •••• ••••• High	Nambucca R.	- Warrell Ck	Macleay R.	Macleay Arm	- SW Rocks Ck	- Saltwater Ck	- Korogoro Ck	Killick Ck	Unamed Ck.	Hastings R.	- Limeburners Ck	- Maria R.	L. Cathie/Innes	Camden Haven	- Queens L.	-Watson Taylors L.	Manning R.	Khappinghat Ck.	Wallis L.	Smiths L.	Myall L.	Myall R.	Karuah R.	Port Stephens	Hunter R.
Comprehensive	Wave dominated estuary	•••		•••				••			•••				•••			••••		•••••			•••			••••
	Tide dominated estuary																							••	•••••	
	Intermittent creeks & lagoons					••	••		••	••				••••					•••		•••••					
	Brackish barrier lake																					•••••				
	Ecosystem irreplaceability	•		•					•		•			•••	•			•	•	•••	•••	•••••	•		•••••	•
	Mangrove habitat	•		••		•		•		••				•	•			••		•				••	•••••	••••
	Seagrass habitat	•		•		•					•				•••			•		•••••	••	•	••	•	•••	•
	Saltmarsh habitat	••		•••		•		•	•		••			••••	•			•		•••			••	•••	•••••	••••
	Habitat irreplaceability	•		••							•			•	••			•		•••••	•		•		••••	••
	Summed irreplaceability	•		••					•	•	••			•••	••				•	••••	•••	••••	•		•••••	•••
Representative	No. juvenile fish spp.	•••		•••							•••							•••		•••	••				•••	••
	Juvenile fish irreplaceability	•••		•••							•••							••••		••••	•••				••••	•••
	No. commercial fish spp.	•••		•••							•••			•	•••			•••		••••	••	••••	••••		••••	
	Com. fish irreplaceability	••		••							•			•	•			•		••••	•			••••	••••	••
	Threatened & JAMBA CAMBA bird habitat	••		•••						•	••••			•••	••			••		••			••		••••	•••••
	Other bird habitat	•		••							••			••	•••			••	••	•••	••		••		••••	•••••
	Shore/Seabird species	•••		•••						•	••••			•••				••••	•	••••	•	•••	•		•	•••••
	Bird species irreplaceability	•••		••						•	••			•	•			•••	•	••	•	••	•		••	•••••
	Threatened fish species	•••												•••				•							•	
	Threatened Little Tern	•••••																•••••		••••						
	Significant bird sites (EA)										•••••														•••••	•••••
	RAMSAR wetlands																					•••••	•••••			•••••
	Important wetlands			•••••				•••••				•••••					•••••			•••••		•••••	•••••	•••••	•••••	•••••

Table 6.6. Summary of measures assessing estuarine plan units for adequacy

Condition, Threat, Vulnerability and Conservation value

Suitability for MPA • Low •• ••• Medium •••• ••••• High	Nambucca R.	- Warrell Ck	Macleay R.	Macleay Arm	- SW Rocks Ck	- Saltwater Ck	- Korogoro Ck	Killick Ck	Unamed Ck.	Hastings R.	- Limeburners Ck	- Maria R.	L. Cathie/Innes	Camden Haven	- Queens L.	-Watson Taylors L.	Manning R.	Khappinghat Ck.	Wallis L.	Smiths L.	Myall L.	Myall R.	Karuah R.	Port Stephens	Hunter R.
Coastal lakes inquiry																									
- Natural sensitivity						•••••					•••••		•••	•••					••••	••••	•••••				
- Catchment condition						•					•••••		•••						••	•••	•••				
- Lake condition						••					••••		•	•••					••••	••••	•				
- Conservation value						•					••••		•••••	•••••					•••••	••••	•••••				
- MPA recommendation						••					•••••		•••	•••					••	••••	••••				
Bell and Edwards (1980)																									
- Shore & water	••	••••	•	•••				•••		•	••••	••	••••		•••	••	••	•••	••	•••	•••••	•••••		•••	•
- Catchment	••••	•••	••	••				••••		•••	••••	•••	••••		•••	•••	•••	•••	••	•••	•••	•••		•••	•••
Aust. Estuaries Database																									
- Conservation value	•••		•••							•••			•••	•••			•••	•	•••••	•••				•••••	•••••
- Conservation threat	•••		•							•••••			•••••	•••••			•••	•••••	•••	•••				•••	•
- Fisheries value	•••		•••••							•••••			•	•••••			•••••	•	•••••	•••				•••••	•••
- Fisheries threat	•••		•							•••••			•••••	•••••			•••	•••••	•••	•••				•••	•
- Ecological status	•••••		•••							•••			•••••	•••••			•••••	•••••	•••••	•••••				•••••	•
- Water quality			•							••															•
% NPWS estate within 1km	•	•	•		•••	•••	•••••	•••	••••	•	•••••	••	•••••		•••	••••	•	•••••	•••	••••	•••••	•••••	•••	••	•
% State forest within 1km	•••	•••	•		•	•	•	•	•	•••••	•	•••	••••		••••	•••••	••	•••	•••	•	•••	•	•••••	•••••	•
% SEPP14 within 1km	••	••	••		•••	•••	••••			••	•••••	••••	•••••		••	•••	••	••••	••••	••	•••	••••	••	••••	••
% Wilderness within 1km											•••••	•													
% Urban areas within 1km	•••	•••	••••		•	•	••••	••	•••••	••	••••	•••••	••••		•••	•••	•••	•••••	••••	•••	••••	••••	••••	•••	•
% Acid sulphate soils 1km	•••	•••	•		•••	••••	•••••	•••	•••••	•••	••	•	•		••••	•••	••	•••••	••••	•••••	••••	••••	••••	•••	•
Land capability- Culitvation	••	••	•		•••••	•••••	•••••	•••••	•••••	••	•••••	•••	•••••		•••••	••••	••	•••••	•••••	•••••	•••••	•••••	•••••	•••••	••
Land Capability- Grazing	•••	•••	••••		•••••	•••••	•••••	•••••	•••••	•••	••	•	•••••		•	••	•••	••••	••	••••	••••	••••	••	••	•••••
Land Capability- Forest	•••	•••	•••		•••••	•••••	•••	••••	••	•	••	•	•••••		•••	•••	••	•••	••••	••••	••	••	•••	••••	•••
ARCCD - River disturb	•••	•••	••					••	••	•••	••	••••	•••		••••	••••	•••	••••	••••	••••	••••	••••	•••	•••	•
- Catchment disturb	•	•	•					••••	••••	••	••••	•••	••		•••	•••	•	•••	••	••	•••	•••	••	••	•
- Flow disturbance	••••	••••	••					•	•	•••	•	•••	••••		•••••	•••••	•••	•••••	•••••	•••••	•••••	•••••	••••	••••	•
- Settlement	••••	••••	••••					•••••	•••••	••	•••••	•••••	••		•••••	••••	•••	•••••	•••••	•••••	•••••	•••••	•••••	•••••	•
- Land use	••	•	•					•••••	•••••	••	•••••	••••	••••		••••	••••	•	••••	•••	•••	••••	••••	•••	•••	•
- Infrastructure	•••	•••	••					••••	••••	••	••••	••••	•••		•••	•••	•••	•••	••••	••••	••••	••••	••••	••••	•
- Point source/Extractive	•	•	••••					•••••	•••••	••••	•••••	•••••	••••		•••••	•••••	•••••	•••••	••••	••••	••••	••••	••••	••••	••

Table 6.7. Summary of measures assessing ocean plan units for comprehensiveness and representativeness.

	Suitability for MPA • Low •• ••• Medium •••• ••••• High	Nambucca R. to…	Macleay R. to	Korogoro Ck. to	Killick Ck. to	Hastings R. to	L.Cathie to	Camden Haven to	Manning R. to	Khappinghat Ck. to	Wallis L to	Smiths L. to	Myall L. to	Port Stephens to	Stockton B. to…	Hunter R.
Comprehensive	Coastal, depths 0-20m within 3nm	•••	•••	••	•••	••	••	•••••	•••	•••	••	•••	••••	•••	•••	
	Offshore depths 20-60m within 3nm	•••	••	••	•••	••	••	•••	•••	•••	•••	•••	•••	•••	••	
	Shelf depths 60-200m within 3nm	••	•••••	••••	••	•	•	•	•	•	•••••	•••••	••••	•••	•••••	
	Oceanic depths >200m within 3nm	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
	Summed irreplaceability - ocean ecosystems	•••	•••	•••	•••	••	••	••••	•••	•••	•••	•••	•••••	••••	•••	
	Area within 100m of Islands	•	•••	••	•••	•••	•	•••	•	••	•••	•••	•••••	•••••	•	
	Area of subtidal reef	•	••	•	••	••	••	••••	•••	••••	•••	•••	•••••	••••	•	
	Area of intertidal rocky shore	••	•••	••	••••	•••	••	•••	•	••	•••••	••	•••	••••	•••	
	Area of intertidal beach	•••	•••	•••	••••	••	•	••••	•••	•••	•••	••••	••••	•••	••••	
	Length of intertidal rocky shore	••	••	••	••	••	•	••	•	••	•••	••	•	••••	•	
	Length of beach	•••	•••	•••	•	•	•	•••	•	••	•••	••	•	••••	•	
	Summed irreplaceability - ocean habitats	••	•••	••	•••	••	•	••••	••	•••	••••	•••	•••••	•••••	••	
	Summed irreplaceability - ecosystems + habitats	•••	•••	•••	•••	•••	•••	••	•••	•••	•••	•••	•••	•••••	•••••	
Representative	Area around Islands <1km offshore	•	•••	••	•••	•••	•	•••	•	••	•••	•••	••	•••••	•	
	Area around Islands >1km offshore	•	••	•	•	•	•	•	•	•	•	••	•••••	•••	•	
	Area around reefs >1km offshore	•	•	•	••	••	••	•••	••	••••	••	••	••	•••••	•	
	Area around reefs <1km offshore	•	••	•	•	••	••	•••	•••	•••	•••	•••	•••••	•••	•	
	Area of platform intertidal shore	••	•••	••	••••	•••	••	•••	•	•••	•••••	••	•••	•••	•	
	Area of boulder intertidal shore	••	•••	••	•••	•••	•	••	•	••	•••••	••	•••	•••	•	
	Area of intermediate beach	•••	•••	••••	•••	••	•	•••	•••	•••	•••	•••	•••••	•••	•••••	
	Area of reflective beach	•••	••••	••	••	•	•	•	•	••	•••••	•••	•	••	•	
	No. rocky shores with 5 sub-habitats	•	•	•	•••	••	••	••••	•	••••	••	•	••	•••••	•	
	No. rocky intertidal recommended by TEC (1995)	••	••	••	•••••	•••	•	•••••	•	•	•••	•	••	••	•	
	Intertidal recommended by National Trust (1982)										•••••					

Table 6.8. Summary of measures assessing ocean plan units for adequacy.

Suitability for MPA

- • Low
- ••
- ••• Medium
- ••••
- ••••• High

	Suitability for MPA	Nambucca R. to...	Macleay R. to	Korogoro Ck. to	Killick Ck. to	Hastings R. to	L.Cathie to	Camden Haven to	Manning R. to	Khappinghat Ck. to	Wallis L to	Smiths L. to	Myall L. to	Port Stephens to	Stockton B. to	Hunter R.
Representative	Threatened Grey Nurse Shark sites		•••••					•••••			•••••	•••••	•••••			
	Threatened Little Tern	•••••							•••••		•••••					
	Threatened Gould's Petrel												•••••	•••••		
	RAMSAR areas											•••••	•••••			
	Directory of Important wetlands (NPWS)	•••••			•••••							•••••	•••••			
	Significant seabird breeding islands		•••		•••							•••	•••••	•••••		
	Important bird habitat- JAMBA/CAMBA & threatened	•	•••	••	••	••	•	••	••	•	••••	••••	•••••	•••	•••	
	Important bird habitat- other spp.	••	•	•	••	•	•	••	••	•	•••••	•••	•••••	•••	•••	
	No.bird species- CRA-OS	••	••	•	•	•••	•	••••	••	••••	•••••	•••••	•••••	••	•••••	
	Irreplaceability bird species- CRA-OS	•••	•	•	•	••••••	••	••	••	••	••	••••	••	••	•••	
	No. threatened bird, mammal, reptile species sights	•••••	•••	••	•••	•••	••	•••	••	••••	•••••	••	•••	•••	•••	
	No. threatened shark and fish species sights	•••••	•••••						•••		•••	•••	•••			
	No. species - commercial fish, port of landing '97/'98***	••	••••			•••		•••	••••		••••	•	•	•••••	•••••	
	Irreplaceability to represent each commercial fish species	••	•••			••		•	•••		•••			•••••	••••	
Condition, threat and vulnerability	Total catch ocean ports '96/'97	•	•••			••		•	•••••		•••			•••••	•••	
	% NPWS reserve within 1km	•	•••••	•••••	•••	•••	••	••••	••	•••	•••	•••••	•••••	•••	•	
	% SEPP14 within 1km	•••	••••	••••	•••••	••	••	••••	••	••	••	••	•	•	•	
	% SEPP26 within 1km	••	••	•	••	•••••	•••	•••	•••	•••	••••	••	•	••	•	
	% Wilderness within 1km	•	•	•	•••••	•	•	•	•	•	•	•	•	•	•	
	% Urban area with 1km	••••	••••	••••	••••	•	•••••	••••	•••	••••	•••	•••••	•••	•••	•••	
	% High risk acid sulphate within 1km	•••	•••	••	••	•••	•••	•	•	•••••	•••••	•••••	••••	•••••	•••••	
	% Land capability- Cultivation within 1km	••••	•••••	•••••	•••••	••••	•••••	•••••	••••	•••••	•••••	•••••	•••••	•••••	•••••	
	% Land capability - Grazing within 1km	•••	••••	••••	••	•••••	••	•••••	••	•	•••	•••••	••••	•••	•••••	
	% Land capability - Forest within 1km	••••	••	••	••	••••	•••	•••	•••	••	••	•	•	•••••	•••••	
	Mean ARCCD river disturbance within 5km	•••	••	••	•••	••	•••••	•••	•••	•••	•••••	•••••	•••••	••	•	
	Mean catchment disturbance within 5km	••	••	••	•••••	•	••••	••••	••	••	••••	••••	••••	•	•	
	Mean settlement factor within 5km	••••	••••	••••	•••••	•	••••	••••	••••	•••••	••••	•••••	••••	••••	•	
	Mean land use factor within 5km	•••	••	••	•••••	••	••••	••••	•	••••	••••	•••••	••••	••••	•	
	Mean extractive industry/pollution source within 5km	•••	••••	••••	•••••	•••	••••	••••	•••••	•••	•••••	••	••••	•	••	
	Mean infrastucture factor within 5km	•••	••	••	••••	•	••••	••••	•••	••••	••••	•••••	•••••	••	•	

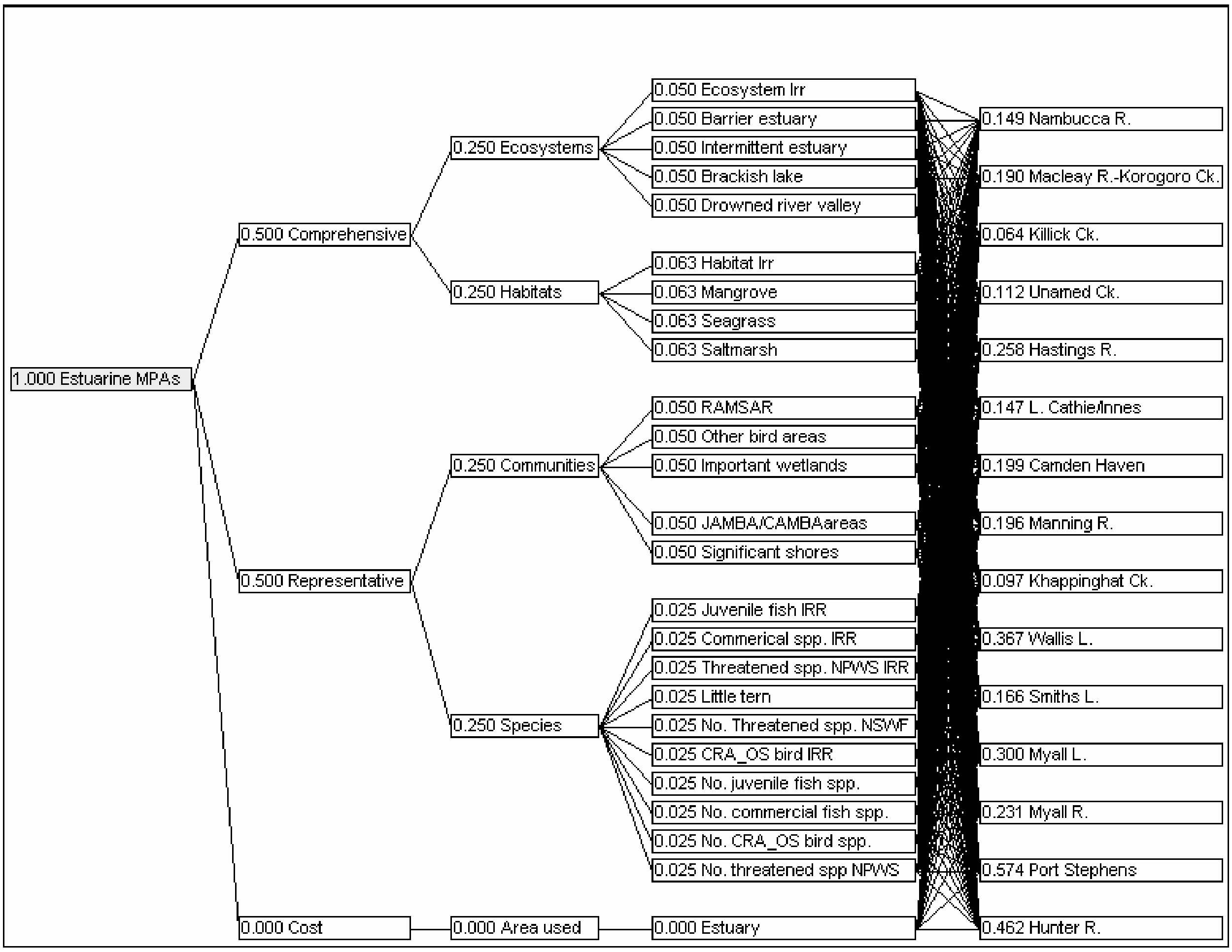


Figure 6.41a. General goals (on the left) are defined by more detailed weighted criteria (centre) with scores for plan units (far right and below) calculated from the scores for individually weighted criteria. In this particular example, all criteria for comprehensiveness and representativeness are weighted equally. Criteria for adequacy and human use are not included. (Irr = irreplaceability).

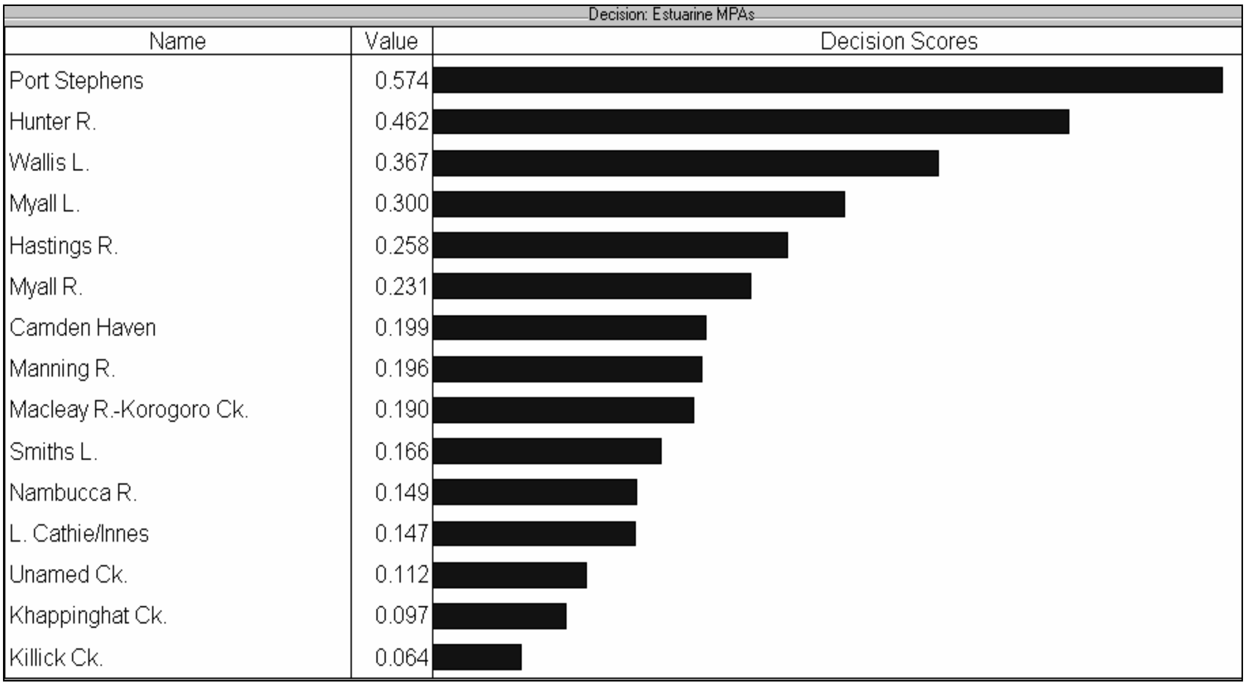


Figure 6.41b. Multiple criteria model and ranked scores for whole estuary plan units assessed for comprehensiveness and representativeness.

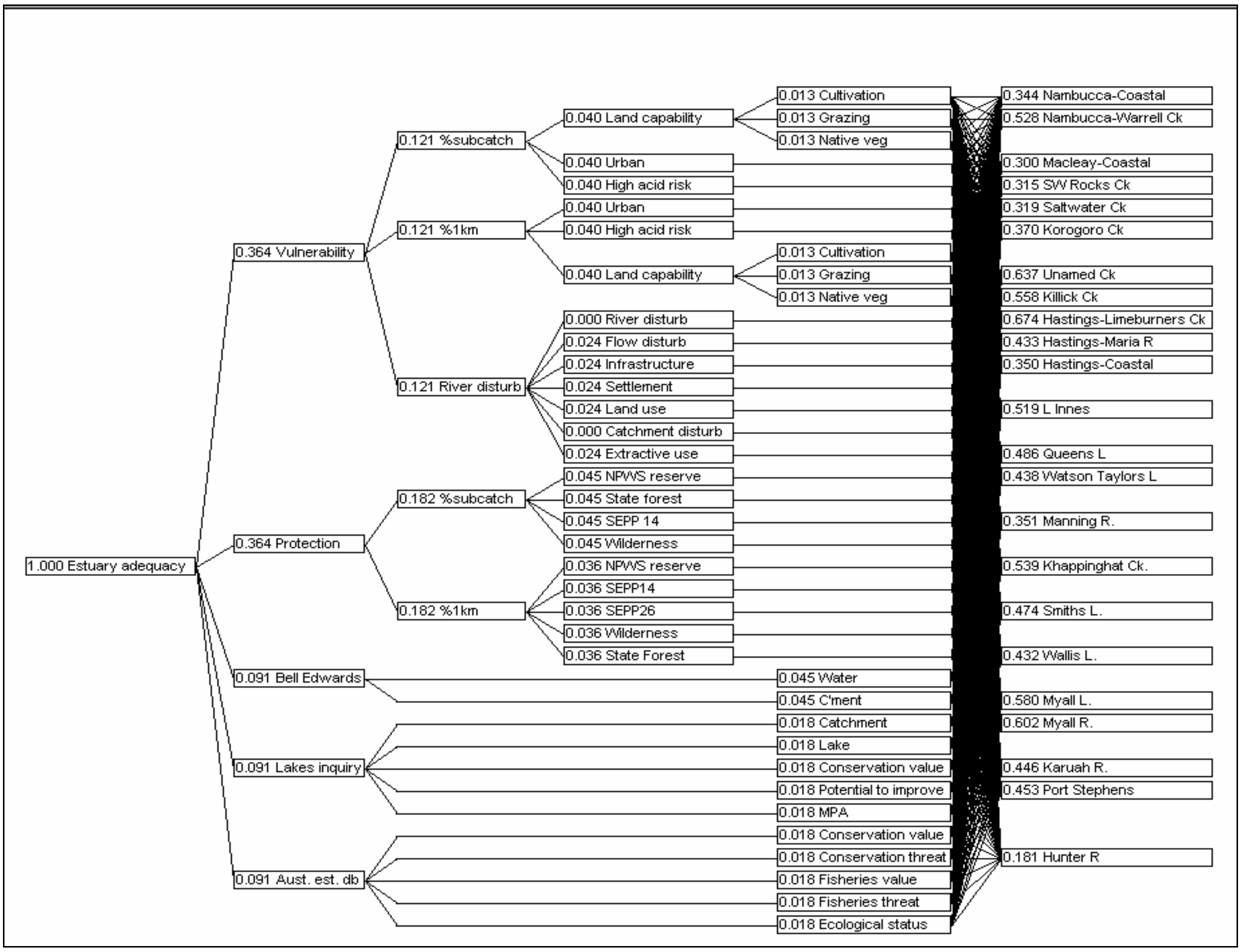


Figure 6.42a. General goals (on the left) are defined by more detailed weighted criteria (centre) with scores for plan units (far right and below) calculated from individually weighted criteria. In this example, all available criteria for adequacy are weighted equally.

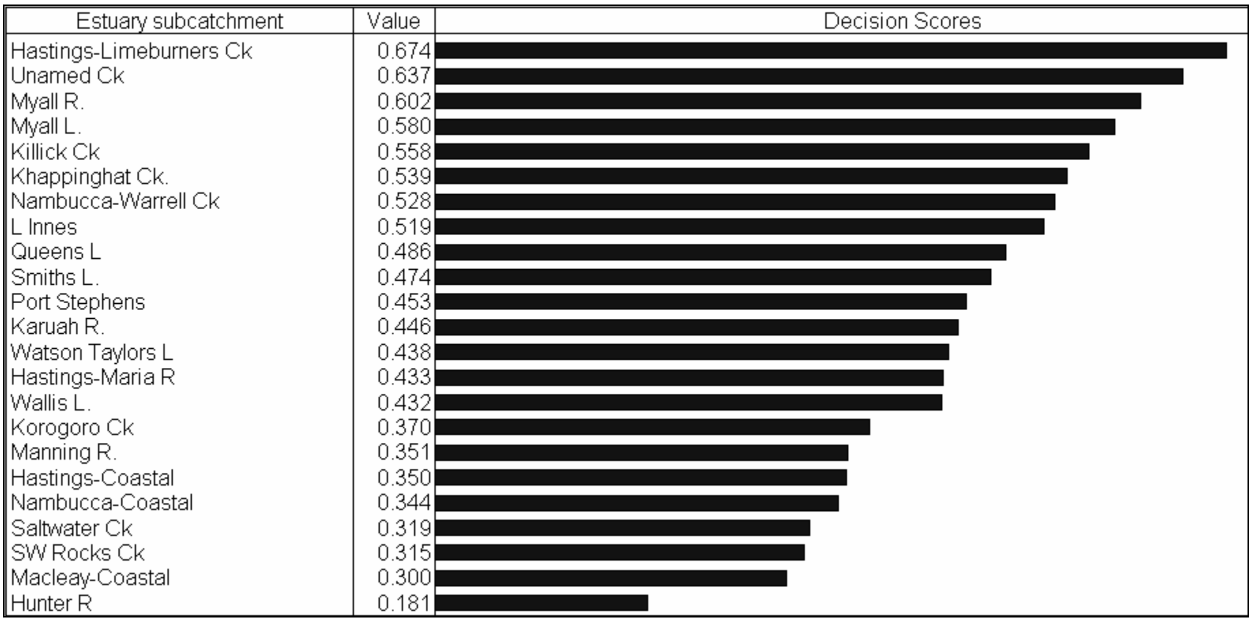


Figure 6.42b. Multiple criteria model and ranked decision scores for estuaries assessed for adequacy.

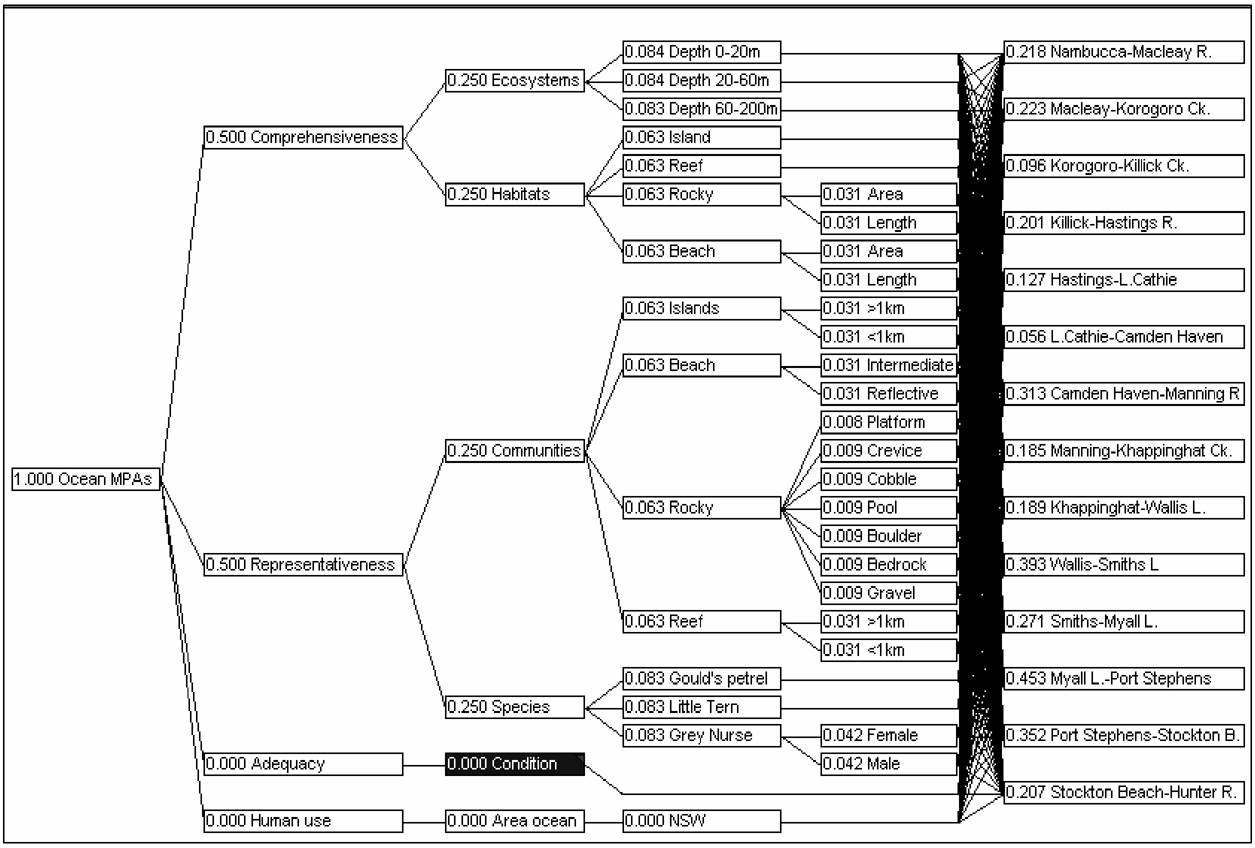


Figure 6.43a. General goals (on the left) are defined by more detailed weighted criteria (centre) with scores for plan units (far right and below) calculated from individually weighted criteria. In this example, all criteria for comprehensiveness and representativeness are weighted equally. Criteria for adequacy and human use are not included.

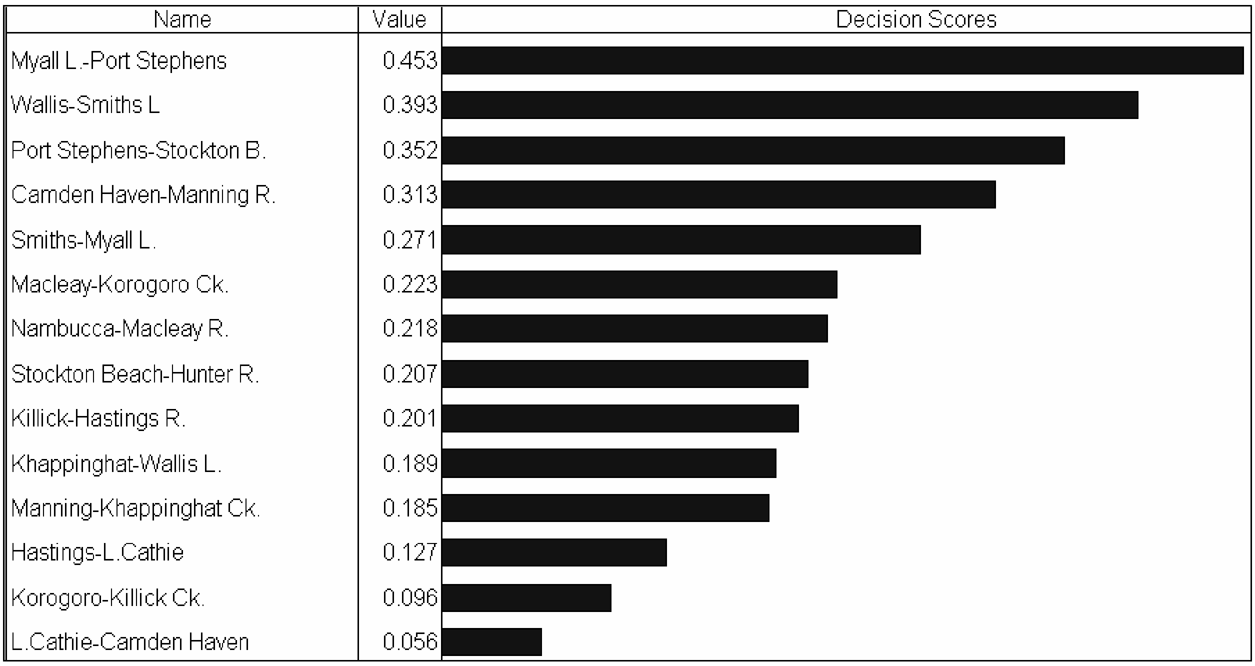


Figure 6.43b. Multiple criteria model and ranked scores for ocean plan units assessed for comprehensiveness and representativeness.

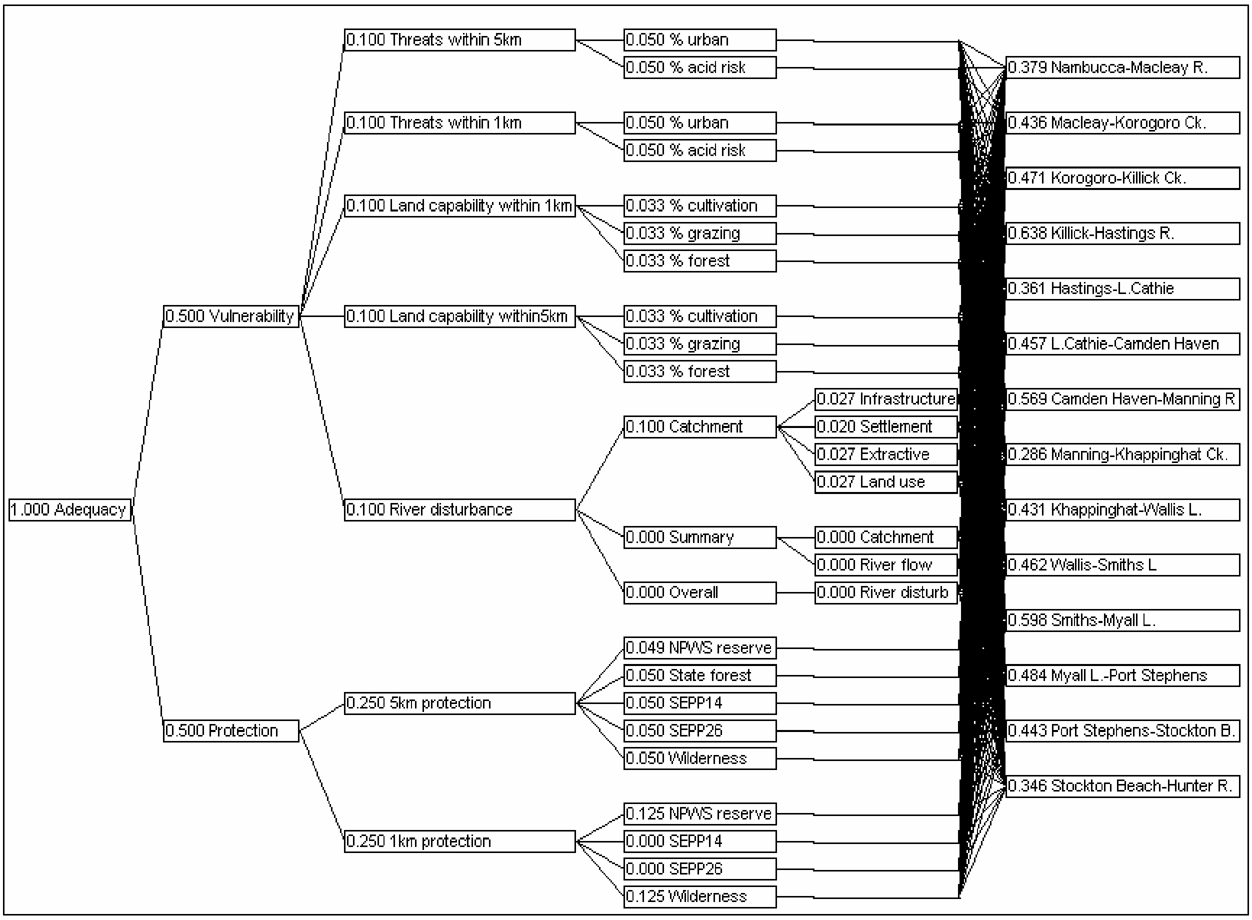


Figure 6.44a. General goals (on the left) are defined by more detailed weighted criteria (centre) with scores for plan units (far right and below) calculated from individually weighted criteria. In this example, all available criteria for adequacy are weighted equally.

Strip label	Value	Decision Scores
Killick-Hastings R.	0.638	
Smiths-Myall L.	0.598	
Camden Haven-Manning R.	0.569	
Myall L.-Port Stephens	0.484	
Korogoro-Killick Ck.	0.471	
Wallis-Smiths L	0.462	
L.Cathie-Camden Haven	0.457	
Port Stephens-Stockton B.	0.443	
Macleay-Korogoro Ck.	0.436	
Khappinghat-Wallis L.	0.431	
Nambucca-Macleay R.	0.379	
Hastings-L.Cathie	0.361	
Stockton Beach-Hunter R.	0.346	
Manning-Khappinghat Ck.	0.286	

Figure 6.44b. Multiple criteria model and ranked scores for ocean plan units assessed for adequacy.

6.5 Discussion – Manning Shelf Assessment

This study provides the basic information to help plan a representative system of marine protected areas in the Manning Shelf bioregion and methods to systematically examine options for the Manning Shelf and other areas of NSW. Even at the broad scale of this study, a number of patterns were evident. Clearly the current system of marine protected areas for the Manning Shelf does not provide comprehensive, adequate or representative protection for biodiversity or ecological processes.

There are no marine parks in the bioregion and only one aquatic reserve protecting just 0.8 km^2 of estuarine reef, beach, subtidal sediments and rocky shore at Fly Point/Halifax Park in Port Stephens. This represents the total area in the bioregion where fish and marine invertebrates are protected within MPAs from fishing. As a percentage, this translates to 0.03% of the marine bioregion within NSW waters, or to 0.008% of the bioregion's waters if Commonwealth waters beyond 3 nm of the coast are considered.

Large areas of fringing saltmarsh, mangrove and open water in several estuaries are included in nature reserves or national parks, but these areas do not on their own, provide direct protection for fish or marine invertebrates from fishing. A few small areas of intertidal ocean beach and rocky shore are also included in national parks or nature reserves, but ocean areas beyond the shore are virtually unrepresented.

While nature reserves and national parks include a reasonably comprehensive selection of estuarine areas, their locations are biased towards the terrestrial and freshwater fringes of estuaries. The area of ocean ecosystems and habitats represented in MPAs is almost negligible and the need for improvement is urgent, given the rapid increases in population and coastal development in the region.

A number of different areas of high conservation value were identified using currently available information. These options are described briefly in the following section but discussed in detail in Appendix 2. These areas were those that tended to best meet criteria for representing a range of ecosystems, habitats and species in locations with protected foreshores and catchments and waters relatively unaffected by human impacts.

The options for exactly where MPAs are established are relatively flexible for all but a few criteria. There is, therefore, the potential to apply reserve design criteria to achieve more effective management and to accommodate, and even promote, a range of sustainable human activities while still meeting conservation objectives.

6.5.1 MPA options in the Manning Shelf bioregion

Ecological options for MPAs in the Manning Shelf bioregion were derived from

- national criteria developed for the identification of MPAs
- a broad scale atlas of marine ecosystems and habitats in NSW
- existing broad scale scientific surveys of habitats, communities and species
- existing data, maps, aerial photographs, literature and conservation assessments
- new data coverages and analyses generated for this study
- ecological guidelines for reserve design
- preliminary discussions with scientists, managers and the community.

Broad scale (10’s km^2) and fine scale (1 km^2) planning units were used to assess locations for MPAs against over 50 criteria from state and national guidelines. Assessments were assisted by mapped displays in a Geographic Information System (GIS), irreplaceability analysis in C-Plan reserve selection software, and multiple criteria analysis. Data analyses and background research and discussions with Ron Avery from the NSW National Parks and Wildlife, who co-authored the assessment, were used to identify a possible location for a large, multiple use marine park and other areas with important conservation values that might be included in a state-wide network of MPAs. The criteria, methods and information in the assessment provide a basis for more detailed research, consultation and management of these areas. Some options for MPAs in the Manning Shelf bioregion are as follows.

1. A candidate marine park at the southern end of the bioregion, within the area between Stockton Beach and Forster

This area was identified for the many outstanding ecosystems, habitats and species occurring within one region. It meets criteria for comprehensiveness and representativeness for all mapped ecosystem and habitat units. It has a high degree of naturalness and catchment protection. It includes areas recommended from previous conservation assessments and consistently scores highest in quantitative analyses for a range of criteria. The area also complements existing MPAs and other conservation management strategies. While no specific boundaries are proposed, some of the features that could be incorporated within the marine park are:

- *Port Stephens and the Karuah River estuary,* including the largest areas of mangrove and saltmarsh in NSW and the only tide dominated drowned river valley in the bioregion
- *Myall Lakes*, the largest system of coastal brackish lakes in the state and the only major example of this ecosystem type in the bioregion
- *Smiths Lake*, the largest intermittent lagoon in the state
- *Wallis Lake*, including the largest area of seagrass in the state and the largest example of a wave dominated barrier estuary in the bioregion, and
- *the adjacent exposed coast and ocean to 3 nm offshore*, which includes a range of ocean depth zones and the greatest area, number and diversity of mapped island, subtidal reef, intertidal rocky shore and beach habitats in the bioregion.

2. Other areas of high conservation value

Other locations within the bioregion also have high conservation values. These locations (listed under various categories below) could be used to develop MPA proposals to represent geographic variation in biodiversity throughout the bioregion, and assist in fulfilling the principles of comprehensiveness, adequacy and representativeness. Where possible, these options should aim to include neighbouring habitats to increase the range of biodiversity represented and accommodate the movements of organisms between habitats.

A. Small, relatively unimpacted estuaries:

Each of these estuaries adjoins a national park or nature reserve, represents geographic variation in biodiversity and may help maintain connectivity among a range of coastal habitats.

- *Khappinghat Creek*, the largest intermittent creek in the bioregion and one of the few estuaries with relatively unimpacted waters and catchment
- *Lakes Innes and Lake Cathie*, including the largest single area of saltmarsh in the bioregion and a relatively high degree of catchment protection
- *Camden Haven* estuary including the third largest area of seagrass in the bioregion (after Wallis Lake and Port Stephens) and a high degree of catchment protection
- *Korogoro Creek* and adjacent beach and rocky shores for its connection with extensive freshwater wetlands, coastal dune habitats and an extensive protected catchment
- *South West Rocks Creek* for the high proportion of this small creek occupied by mangrove, saltmarsh and seagrass in close proximity to built-up areas
- *Saltwater Creek* and *Saltwater Lagoon* for their high natural sensitivity, surrounding wetlands and proximity to built-up areas.

B. The least impacted subcatchments of the major estuaries:

These estuarine areas remain in a reasonable condition within large catchments otherwise disturbed by land use, flood mitigation, or urban and industrial development.

- *Limeburners Creek* and *Saltwater Lake* in the Hastings River for the low degree of disturbance and high level of subcatchment protection in an estuary otherwise disturbed by flood mitigation works and adjoining land use
- *Kooragang Island* and *Fullerton Cove* in the Hunter River for their large areas of mangrove and saltmarsh, importance to migratory wading birds, and the wetlands remaining despite significant modifications to the surrounding area
- *Macleay River delta* and the *Macleay Arm* in the Macleay River for the large areas of mangrove, saltmarsh and seagrass, adjacent wetlands and importance to migratory waders and other bird life
- *Warrell Creek* in the Nambucca River for the adjacent wetlands, importance to bird fauna (including the Little Tern) and the low degree of disturbance to this arm of the estuary
- *Farquhar Inlet* and the *Manning River Channel* in the Manning River for the remaining estuarine vegetation and nesting areas for Little Tern.

C. Intertidal rocky shores, beaches and inshore reefs:

Surveys by Otway and Morrison (*in prep.*) mapped 52 shores and scored the number of 'community' types (platform, boulder, cobble, pool, crevice) present on each shore in the bioregion. Twenty one shores included all five community types, 15 shores included four community types and 15 shores included three community types. The National Trust Headland and Rock Platform survey in 1982 identified one rock platform, Bald Head, for protection in the Manning Shelf bioregion. Another survey carried out by the Total Environment Centre in 1995, identified 19 rock platforms in the Manning Shelf bioregion for protection. Consideration should be given to these options as currently no exposed rocky shores are protected in MPAs.

D. Offshore reefs and islands at:

- Fish Rock and Green Island near South West Rocks
- the Cod Grounds near Laurieton
- the Pinnacles and Latitude Rock near Forster
- Big Seal and Little Seal Rocks near Sugar Loaf Point
- Broughton Island near Port Stephens.

These sites were identified for:

- conservation of the threatened Grey Nurse Shark (Environment Australia 2000, Otway and Parker 2000, NSW Fisheries 2002 and Otway *et al.* 2003).
- sightings of other threatened species
- their high productivity
- their potential as sources of larvae for areas downstream
- a high diversity and abundance of fish and invertebrates
- the influence of the East Australian Current
- their vulnerability to existing and future levels of use.

Extensive areas of subtidal reef were also mapped offshore of the coast between:

- Crowdy Head and Diamond Head
- Hallidays Point, Khappinghat Creek and the Manning River.

Many other offshore areas of reef and sediment on the NSW shelf have not been mapped in detail and little is known of broad scale patterns in the distribution of many offshore biota. There may be many areas in deeper water with significant conservation values and these require further investigation.

6.6 Conclusion

The large marine park identified in the previous section has now been established, with some modifications. It extends from Cape Hawke Surf Life Saving Club, near Forster, south to Birubi Beach Surf Life Saving Club, at the northern end of Stockton Beach. This 975 km^2 multiple use marine park includes all the features recommended in the assessment except for Wallis Lake and its adjacent coast. Wallis Lake includes the largest areas of seagrass in the state and is the most northern location where *Posidonia* seagrass occurs. It is also a major area for the aquaculture of oysters and for commercial and recreational fisheries. The NSW Department of Primary Industry has indicated that it will investigate the use of aquatic reserves in this area to provide protection for important seagrass habitats and associated biota. Similar MPAs may also be appropriate for many other areas in the bioregion where high marine conservation values are threatened.

The NSW Marine Park Authority has since completed more detailed surveys of the new marine park using multibeam geoswath sonar (Alan Jordan, unpublished data), aerial photograph interpretation to describe estuarine vegetation (Greg West, unpublished data), social and economic maps of commercial fishing and recreation and an economic impact assessment. The ecological data (Figure 6.45) and surveys of commercial fishing and recreation were used to develop options, assist in community consultation, evaluate Marxan and C-Plan models (D. Breen unpublished data) and assess a multiple use, draft zone plan.

After over 130 meetings to consult with communities and stakeholders and the distribution of 50,000 public surveys, 43,000 draft zone plans and analysis of 4,400 submissions a final zone plan was released in December 2006 (Figure 6.46). The plan came into effect in March 2007. The zone plan includes 17.75% of the marine park's area (175 km^2) in 27 'no-take' sanctuary zones (pink), 38.45% of the park in habitat protection zones where recreational fishing and some commercial fishing activities are permitted and 43.7% of the park in general use zones where most commercial fishing is permitted.

The marine park partly fulfils a commitment by the NSW Government to establish at least one large marine park in each bioregion. Given the selection criteria to represent a range of ecosystem and habitat types the nomination of this area is not unforeseen. However the detailed information in this assessment provides assurance that management of this area is warranted and confidence that the decision was not made without consideration of available information. The corroboration of many independent sources of information for ecosystems, habitats, species, processes and condition indicates that even where detailed information is not available, coarse scale surrogates can provide a useful way to prioritise locations for MPA management. The multiple use design of the park is ideally suited to a scientifically assisted approach to adaptive management that aims to improve our understanding of how MPAs can be best used. Biological baseline and monitoring programs are now needed to test these predictions and evaluate the benefits and impacts of the new marine park.

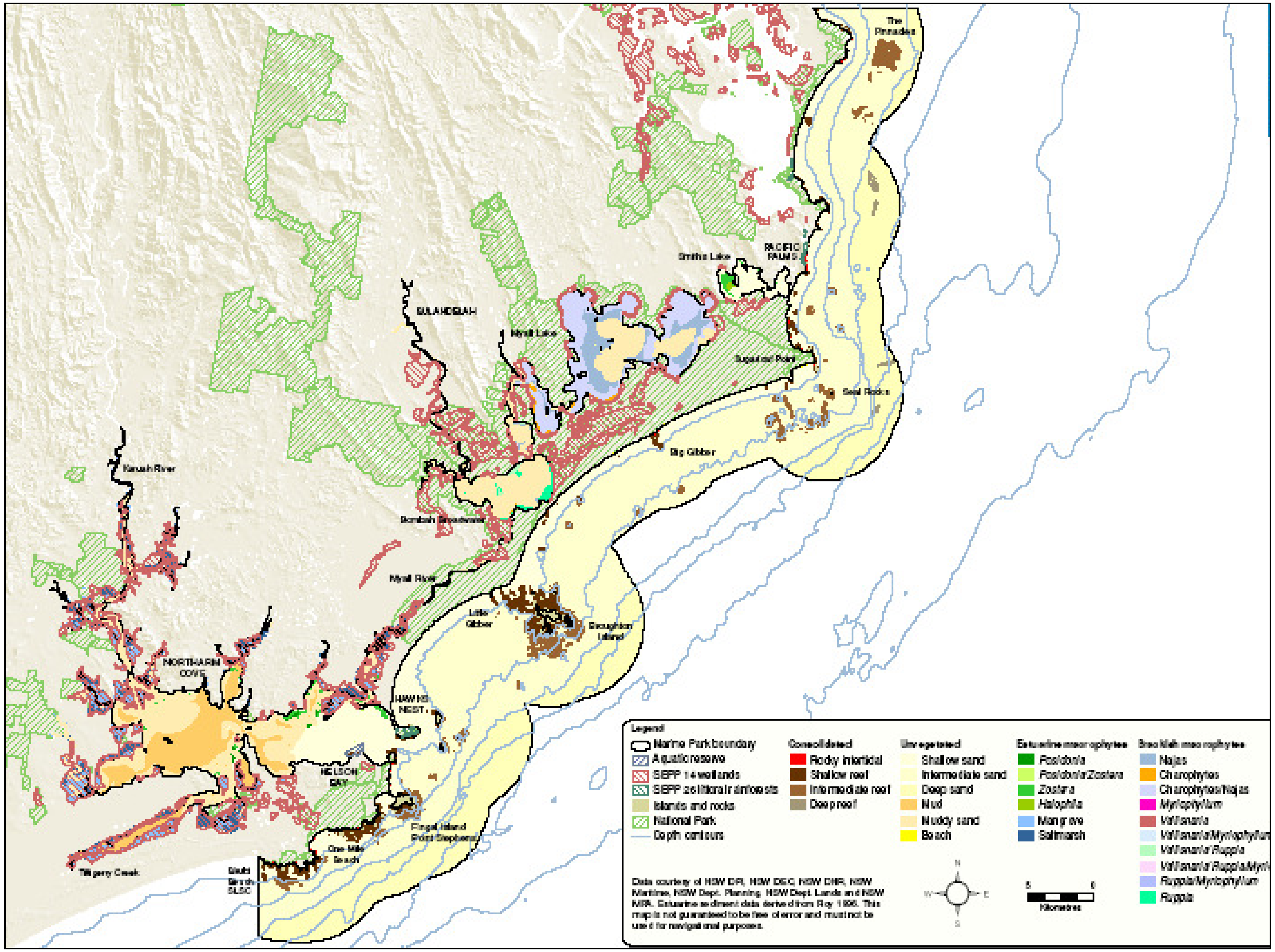


Figure 6.45. Fine scale habitat map of the Port Stephens - Great Lakes Marine Park built from NSW Marine Parks multibeam geoswath sonar and drop video data (Alan Jordan pers. comm. NSW Marine Parks), aerial photo interpretation of inshore reef (Ron Avery), estuarine vegetation (Greg West) and intertidal shores derived from NSW Land Information Centre cadastre (D. Breen and R. Avery). Map and GIS coverage by Vanessa Mansbridge, NSW Marine Parks Authority. www.mpa.nsw.gov.au.

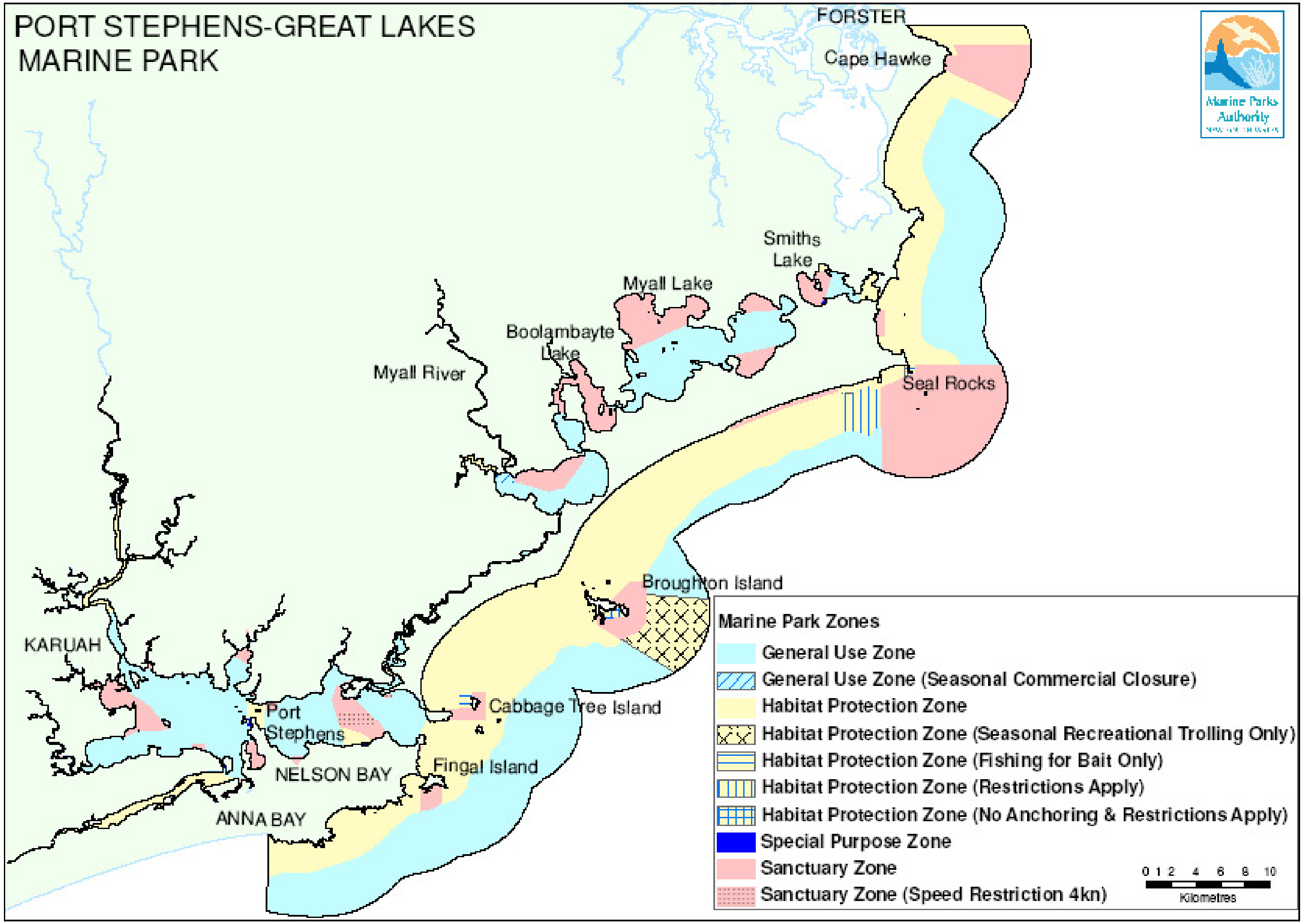


Figure 6.46. Final zone map of the Port Stephens - Great Lakes Marine Park (97, 200). Pink denotes highly protected ‘no-take’ Sanctuary Zone, yellow is Habitat Protection Zone and light blue is General Use Zone. Map and GIS layer by Vanessa Mansbridge, NSW Marine Parks Authority.

7 MPA assessment of the Hawkesbury Shelf bioregion

7.1 Introduction

The NSW Marine Parks Authority aims to establish and manage a comprehensive, adequate and representative system of marine protected areas (MPAs) to help conserve marine biodiversity and maintain marine ecosystem processes (NSW Marine Parks Authority 2001). The Hawkesbury Shelf bioregional assessment is one of several projects to systematically assess broad scale patterns of biodiversity within each of five NSW marine bioregions and identify where additional MPAs may be required (Figure 7.1).

This chapter summarises the broad scale information and methods used to identify some options for new MPAs on the basis of ecological criteria alone. Possible areas for large, multiple use marine parks are identified and important locations and conservation values within each are described (Section 7.5 and Appendix 3). Given the uncertainty involved in assessing biodiversity and the complex issues involved, a strong emphasis is placed on presenting information and methods to examine a range of options.

A separate selection process is now required for more detailed site assessments, consultation with communities and consideration of social, economic and cultural values. The information, criteria and methods applied here should also assist in ongoing assessment, selection, and management of MPAs and in other strategies to conserve marine ecosystems in NSW.

7.2 Geographic extent

The Hawkesbury Shelf bioregion was defined in the Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998) from recommendations provided by Pollard *et al.* (1997). The bioregion includes estuaries, coast and offshore waters out to the continental shelf break (approximately the 200 m depth contour) from the Hunter River at Stockton (32^{o} 54’ S) south to Shellharbour (34^{o} 35’ S, Figure 7.1). This report focuses on NSW state waters within 3 nautical miles of the coast as defined by Australian Maritime Boundary Information System (AMBIS) data provided by Geoscience Australia (Commonwealth of Australia 2001).

The 1:100,000 map sheets for the bioregion are:

Newcastle	9232	Penrith	9030
Lake Macquarie	9231	Port Hacking	9129
Gosford	9131	Wollongong	9029
Sydney	9130	Kiama	9028

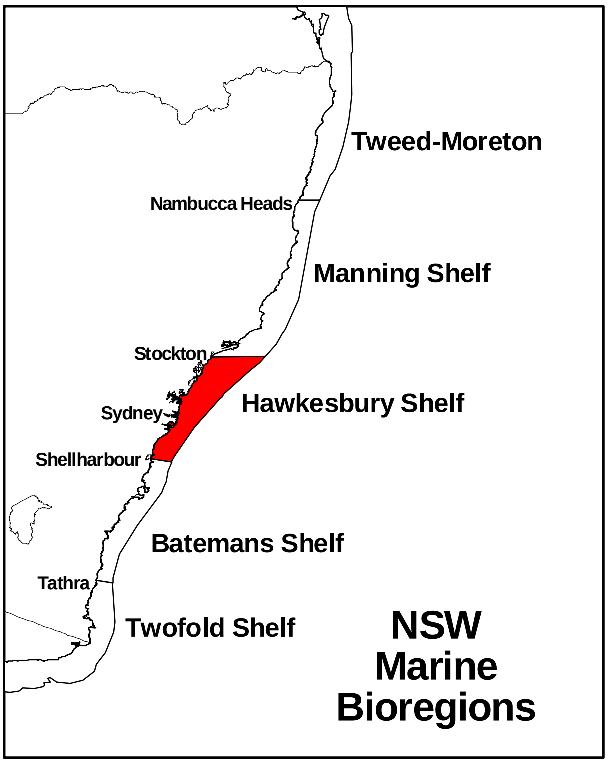


Figure 7.1. Hawkesbury Shelf marine bioregion (IMCRA 1998).

7.3 MPAs in the Hawkesbury Shelf bioregion

At the time of this assessment, there are no marine parks in the bioregion. Eight aquatic reserves protect relatively small (2 - 80 ha) sections of intertidal rocky shore, beach and shallow inshore reef. North Sydney Harbour Aquatic Reserve includes 2,600 ha of outer harbour rocky shore, reef, beach, sand and seagrass. Towra Point includes a larger (1400 ha) area of seagrass, mangrove, saltmarsh and estuary on the southern shore of Botany Bay (Table 7.1, Figure 7.2).

Complete protection from fishing for finfish in these aquatic reserves is only provided at Cabbage Tree Bay (Manly), Shiprock (Port Hacking) and within a 500 ha sanctuary zone in the Towra Point Aquatic Reserve. Line and spear fishing is allowed within all other aquatic reserves in the bioregion except in part of the Bronte - Coogee Aquatic Reserve where spear fishing and line fishing for Eastern Blue Groper (*Achoerodus viridis)* is prohibited.

It is however, prohibited to collect cunjevoi (commonly used as bait) and invertebrates (dead or alive), including anemones, barnacles, chitons, cockles, crabs, mussels, octopus, pipis, sea urchins, starfish, snails and worms, and empty shells from the rocky shore MPAs. All of these aquatic reserves are located on the shores of the Sydney metropolitan area. There are no aquatic reserves between the Hawkesbury and Hunter Rivers to the north, or south of Port Hacking to Shellharbour.

At the time of this assessment, there are eleven national parks and nature reserves that include areas declared below mean high tide (Table 7.1, Figure 7.2). These MPAs, with the exception of Bouddi National Park help to protect areas of estuary and associated mangrove, seagrass, saltmarsh, wetland and sediment habitats. Bouddi National Park is the only MPA of this type in the bioregion to protect coastal rocky shore, reef and inshore reef and the only one which provides protection for fishes and invertebrates from fishing (through a fisheries closure managed by the Department of Primary Industry).

Fisheries closures also include nine intertidal protected areas (IPAs, Figure 7.3) in the Sydney metropolitan area. These extend from the mean high water mark to 10 metres seaward of the mean low water mark. Collecting of invertebrates including crabs, snails, cunjevoi, octopus, sea urchins, anemones, pipis, cockles, mussels, oysters, and nippers in these areas is prohibited.

Table 7.1. MPAs in the Hawkesbury Shelf bioregion.

MPA type	Name	Area (km^2)
Marine parks	None	0
Aquatic reserves	Barrenjoey	0.3
	Narrabeen	0.1
	Long Reef	0.8
	Cabbage Tree Bay	0.2
	North Sydney Harbour	2.6
	Bronte-Coogee	0.4
	Cape Banks	0.2
	Towra Point	14
	Boat Harbour	0.7
	Shiprock	0.02
A total area of 19.3 km^2 representing 0.96% of NSW marine waters in the bioregion.		
National parks and nature reserves	Kooragang Nature Reserve	17.4
	Hexham Swamp Nature Reserve	0.02
	Wamberal Lagoon Nature Reserve	0.5
	Bouddi National Park	2.6
	Pelican Island Nature Reserve	0.05
	Brisbane Water National Park	0.04
	Ku-ring-gai Chase National Park	10.9
	Muogamarra Nature Reserve	0.4
	Lane Cove National Park	0.03
	Towra Point Nature Reserve	1.3
	Royal National Park	1.1
A total area of 34.4 km^2 representing 1.7% of NSW marine waters in the bioregion.		

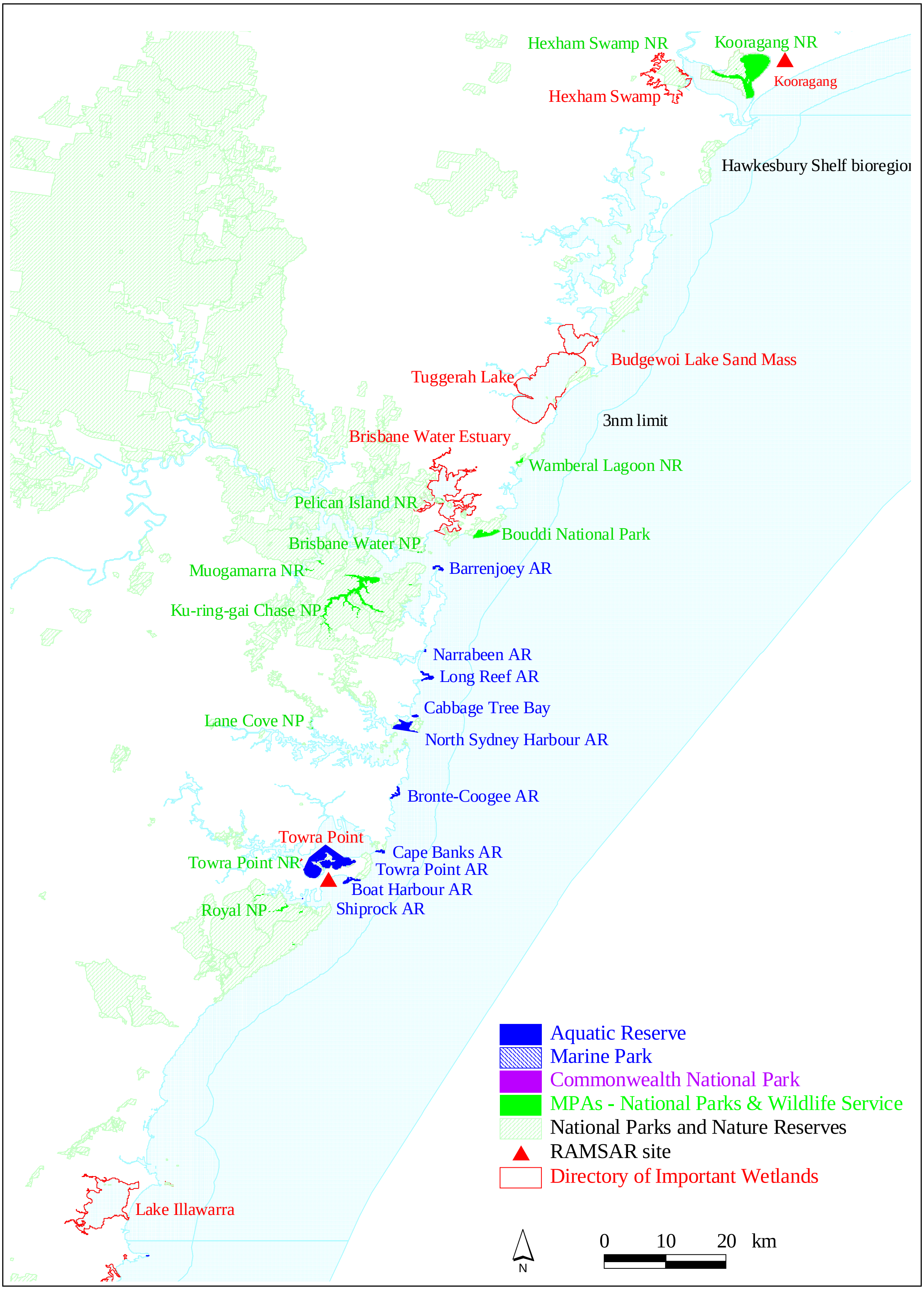


Figure 7.2. Marine protected areas (aquatic reserves and marine components of national parks and nature reserves), RAMSAR sites and important wetlands in the Hawkesbury Shelf bioregion. Data from D. Breen and Danielle Morrison, Fisheries, Department of Primary Industry (DPI) and Rodney James, National Parks, NSW Department of Environment and Conservation (DEC).

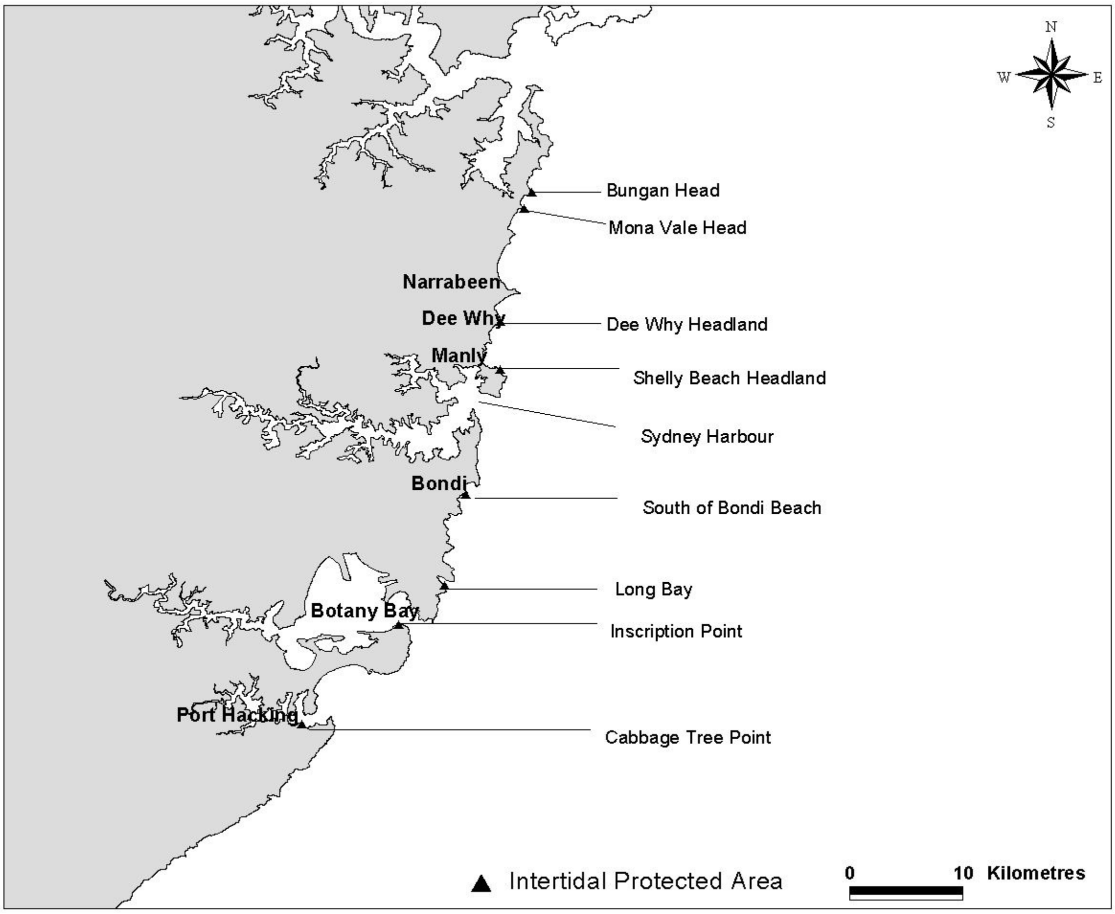


Figure 7.3. Intertidal protected areas in the Sydney region. Map by Danielle Morrison, Fisheries, NSW Department of Primary Industry.

7.4 Systematic assessment

7.4.1 Estuarine ecosystems

Data sources

Roy *et al*. (2001). "Structure and function of southeast Australian estuaries."

GIS coverage of estuaries from NSW Waterways.

Oblique aerial photos from the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR).

Data description

GIS cover of estuaries from NSW Waterways classified by estuary type from Roy *et al.* (2001).

Criterion

Comprehensiveness.

Assessment measures

Area and number of different estuary types represented in marine protected areas.

Assessment

Of the 22 major estuaries in the Hawkesbury Shelf bioregion, there is only one ocean embayment, but there are five tide dominated drowned river valleys, six wave dominated barrier estuaries and ten intermittent coastal lagoons or creeks (Figure 7.4, Figure 7.5 and Figure 7.6). Botany Bay is the only example of an ocean embayment in the bioregion with 14 km^2 of the estuary included in Towra Point Aquatic Reserve and Towra Point Nature Reserve. This represents 26% of the total area of this ecosystem type in the Hawkesbury Shelf bioregion (Figure 7.5a).

The Hawkesbury River is the largest of the drowned river valleys, but Port Jackson, Pittwater, Port Hacking and the Georges River are also substantial estuaries of this kind (Figure 7.5b). Approximately 15 km^2 or 7% of the total area of drowned river valleys in the bioregion is included in MPAs in the Hawkesbury River (Ku-ring-gai Chase and Brisbane Water National Parks and Muogamarra Nature Reserve), Pittwater (Ku-ring-gai Chase National Park), Port Jackson (North Sydney Harbour Aquatic Reserve and Lane Cove National Park) and Port Hacking (Shiprock Aquatic Reserve and the Royal National Park).

Lake Macquarie is the largest wave dominated barrier estuary in NSW, but Tugggerah Lakes, the Hunter River, Brisbane Waters and Lake Illawarra are also substantial examples of this estuary type (Figure 7.5c). Approximately 17 km^2 or 5% of the total area of barrier estuaries in the Hawkesbury Shelf bioregion is included in Kooragang Nature Reserve on the Hunter River with smaller areas also found in Hexham Swamp and Pelican Island Nature Reserves and Brisbane Water National Park.

Narrabeen Lagoon is the largest intermittent estuary in the bioregion followed by Avoca Lake, Wamberal Lagoon, Terrigal, Cockrone, Dee Why, Harbord and Manly Lagoons and Towradgie and Bensons Creeks (Figure 7.5d). Wamberal Lagoon is included in Wamberal Lagoon Nature Reserve and represents 11% of the total area of intermittent estuaries in the Hawkesbury Shelf.

In summary, aquatic reserves include 26% of the bioregion's ocean embayment and 1.2% of the area of drowned river valley in the bioregion. However aquatic reserves do not include any areas of barrier estuary or intermittent estuary. In total, aquatic reserves include 2.8% of all estuarine waters in the bioregion.

The marine components of national parks and nature reserves include 2.4% of the bioregion's ocean embayment, 5.7% of the area of drowned river valley, 5.4% of the area of barrier estuary and 11% of the area of intermittent estuarine ecosystems. In total, the marine components of national parks and nature reserves include 5.4% of all estuarine waters in the bioregion, but these MPAs do not protect fish or aquatic invertebrates from fishing.

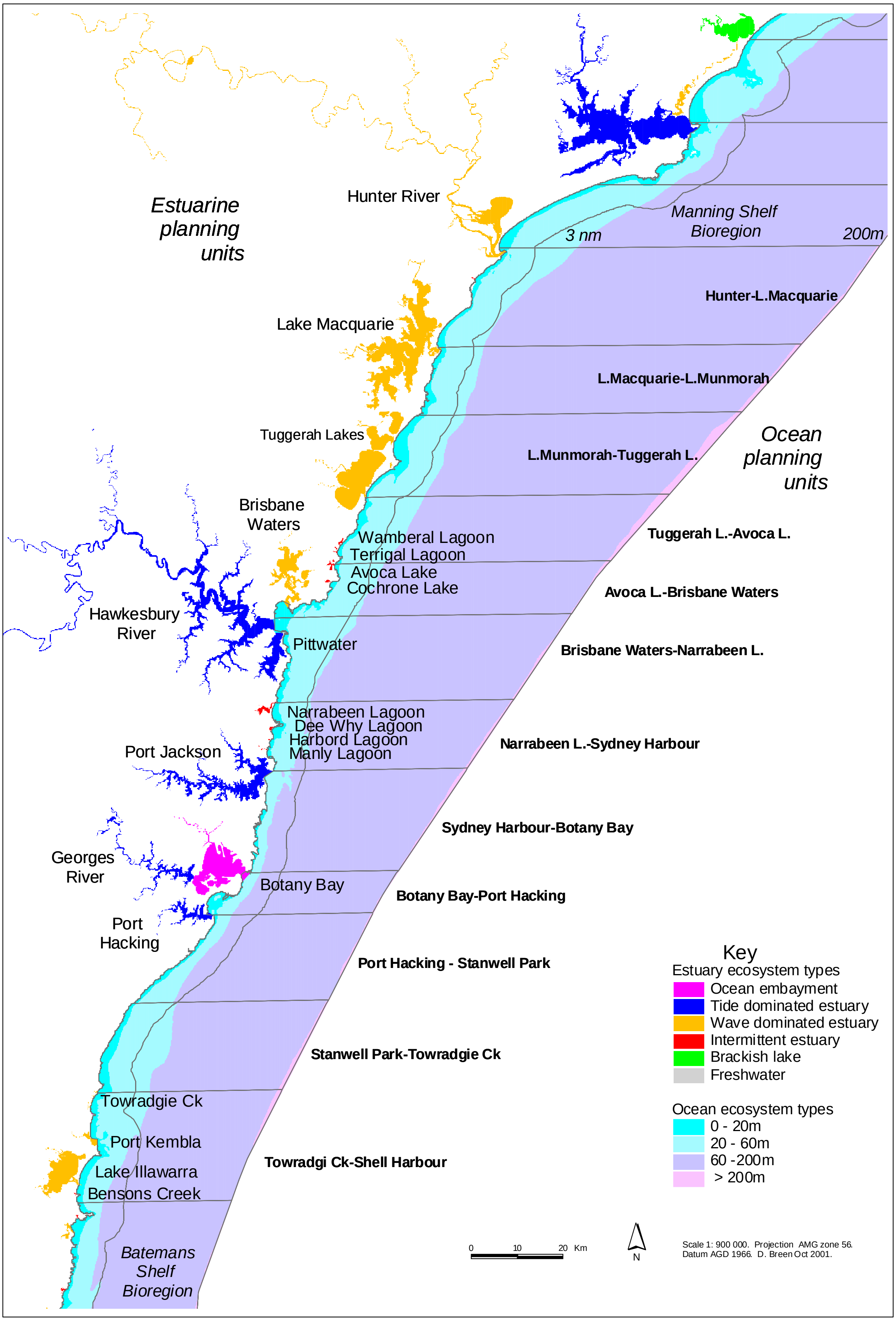


Figure 7.4. Large scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types.

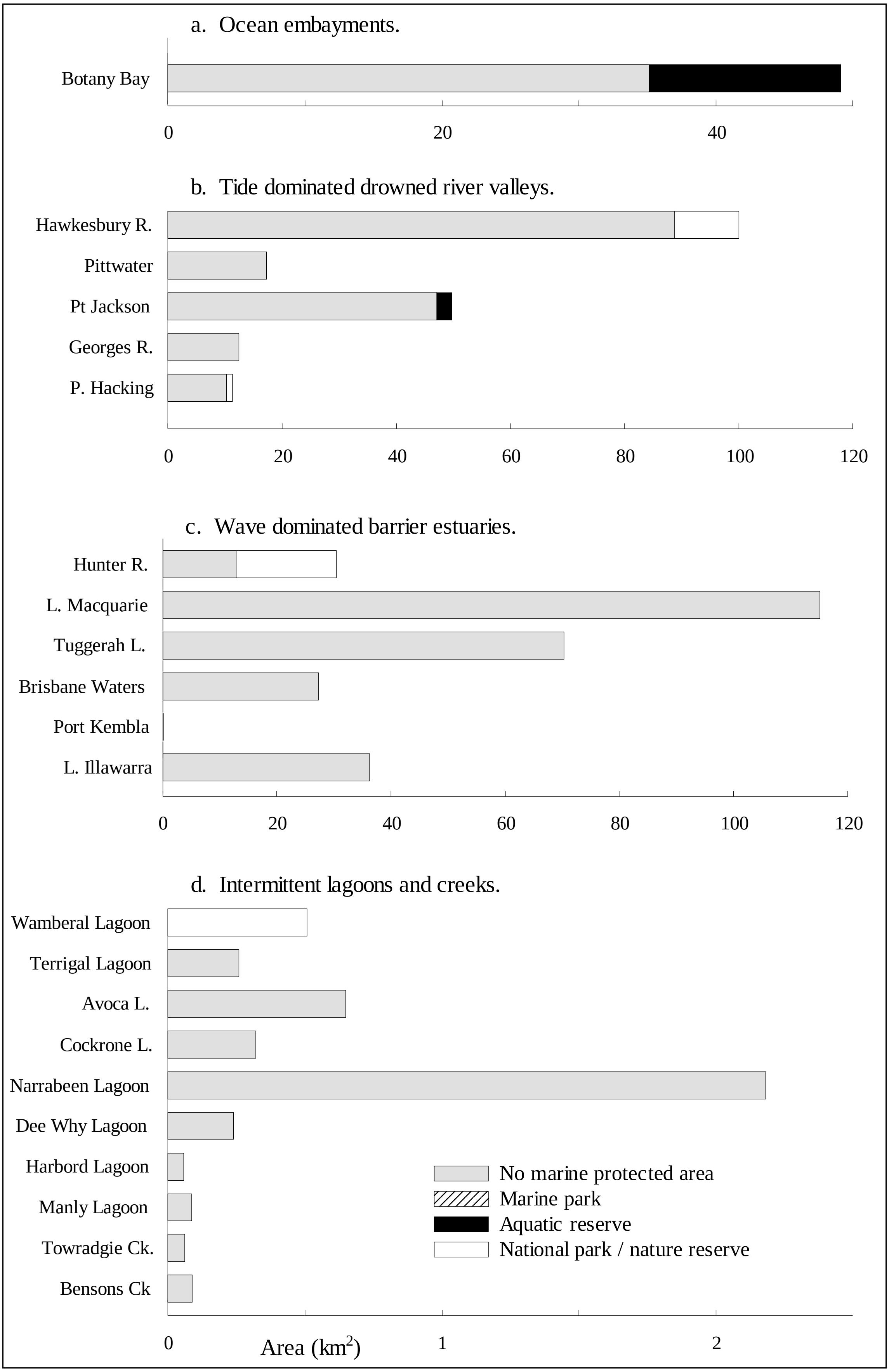
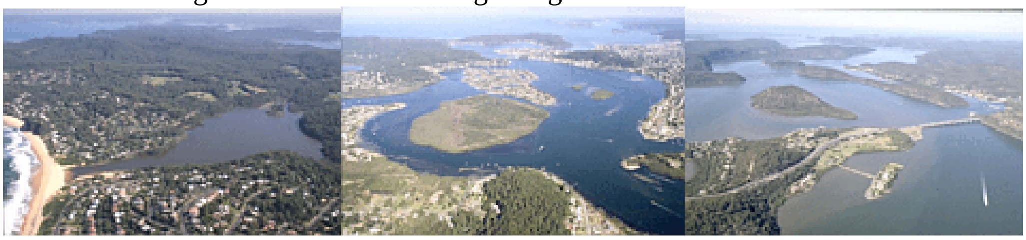


Figure 7.5a-d. Area (km^2) of open water for different estuarine ecosystem types in the Hawkesbury Shelf bioregion within marine protected areas. Data from West *et al.* (1985), estuaries classified according to Roy *et al.* (2001).

a. Hunter River b. Lake Macquarie c. Tuggerah Lakes

d. Wamberal Lagoon e. Terrigal Lagoon f. Avoca Lake



g. Cochrone lake h. Brisbane Waters i. Hawkesbury River

j. Pittwater k. Narrabeen Lagoon l. Dee Why Lagoon

m. Harbord Lagoon n. Manly Lagoon o. Sydney Harbour p. Botany Bay

q. Georges River r. Port Hacking s. Lake Illawarra

Figure 7.6a-s. Oblique aerial photographs of major estuaries in the Hawkesbury Shelf bioregion (provided by the NSW Department of Infrastructure, Planning and Natural Resources).

7.4.2 NSW Fisheries[2] assessment of wave dominated and intermittent estuaries

Data source

Frances, J. (2000) “Identification of candidate sites for aquatic reserves in the Hawkesbury Shelf and Batemans Shelf ecosystems.”

Data description

The estuary classification of Roy *et al.* (2001) was used as a surrogate to assess comprehensiveness and representativeness together with criteria for ecological importance, uniqueness, national and international importance, productivity, vulnerability and naturalness. An expert panel was used to assist in considering collated data, provide ‘delphic’ ratings for criteria and prioritise sites for declaration as aquatic reserves.

Criterion

Comprehensiveness, representativeness, ecological importance, uniqueness, national and international importance, productivity, vulnerability and naturalness.

Assessment measures

Area and number of different estuary types represented in marine protected areas.

Assessment

Table 7.2 describes sites short-listed for the assessment, their delphic ratings and their priority for declaration as MPAs. A more detailed description of these sites is given in Appendix 3. Sites in Lake Macquarie, Fullerton Cove, Dee Why Lagoon and Wamberal Lagoon (Figure 7.7 and Figure 7.8) were selected as priority candidate aquatic reserves but, after public consultation, a decision on their declaration was deferred until after completion of this assessment.

[2] now within the NSW Department of Primary Industry

Table 7.2. Delphic ranking and priorities for estuarine aquatic reserve candidates.

Type	Estuary	Ecological importance	Uniqueness	Naturalness	Vulnerability	Priority
Youthful Wave dominated	L. Macquarie	High	No data	Medium	High	1
	Brisbane W.	High	High	Medium	Medium	2
	L. Illawarra	High	No data	Low	High	3
	L. Budgewoi	Medium	No data	Medium	Low	
	Tuggerah L.	Medium	No data	Medium	Medium	
	L. Munmorah	Low	No data	Medium	Low	
Mature Wave dominated	Hunter R.	High	High	Low	High	1
	Port Kembla	High	No data	Low	High	
Youthful Intermittent	Narrabeen L.	High	High	Low	High	1
	Wamberal L.	Medium	Medium	Medium	Medium	2
	Avoca L.	Medium	Medium	Low	Medium	
	Cochrone L.	Medium	Medium	Low	Medium	
	Terrigal L.	Low	Low	Low	High	
Mature Intermittent	Dee Why L.	High	High	Low	Medium	1
	Wattamolla L.	Medium	Medium	High	Low	
	Harbord L.	Medium	Medium	Low	High	
	Towradgie Ck.	Medium	Medium	Low	High	
	Manly L.	Low	Low	Low	High	

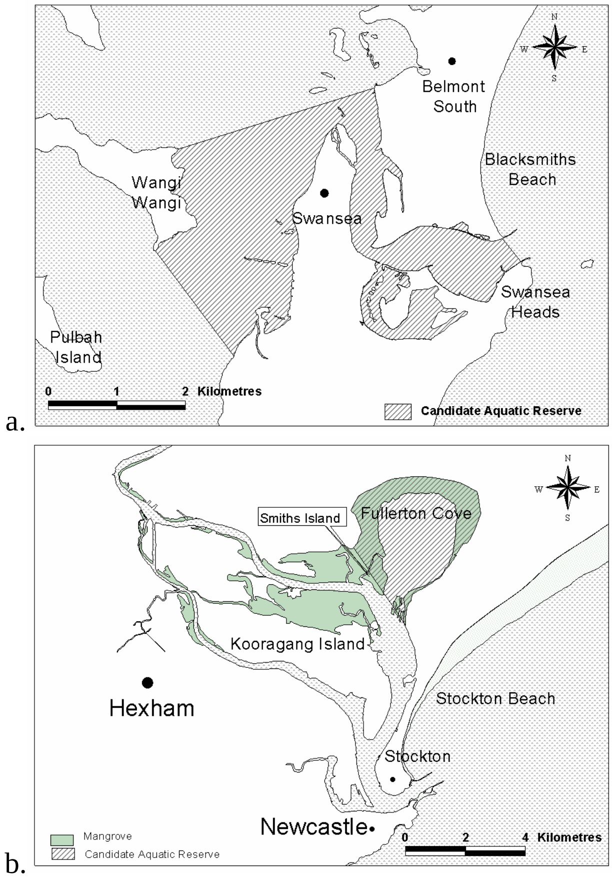


Figure 7.7. Priority candidate aquatic reserves at a. Lake Macquarie b. Fullerton Cove on the Hunter River (NSW Fisheries Office of Conservation 2001).

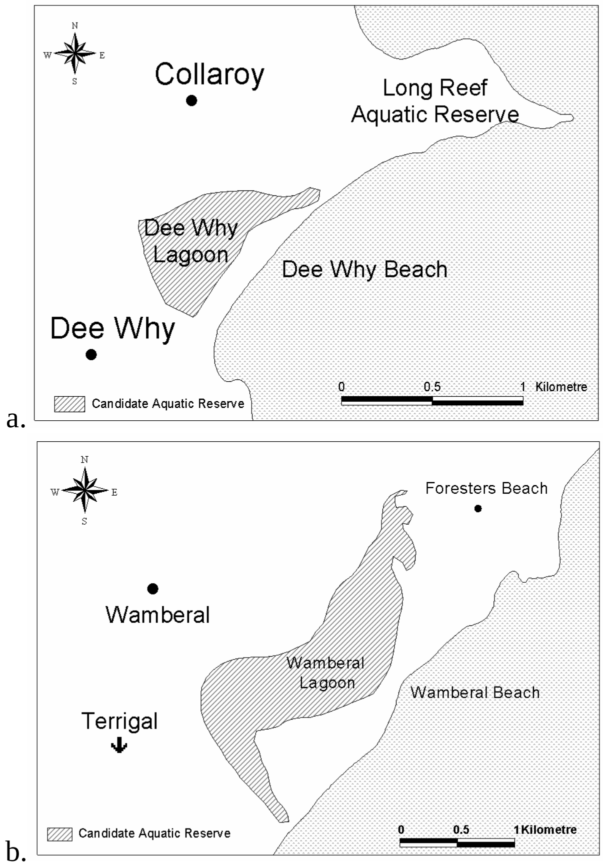


Figure 7.8. Priority candidate aquatic reserves at a. Dee Why Lagoon and b. Wamberal Lagoon (NSW Fisheries Office of Conservation 2001).

Ocean ecosystems

Data source

Derived from NSW Waterways and Australian Hydrographic Office (AHO) data.

Data description

Four depth zones (0-20 m, 20-60 m, 60-200 m and > 200 m) derived from AHO hydrographic chart depth contours digitised by NSW Waterways.

Criterion

Comprehensiveness.

Assessment measures

Area of depth zones within broad scale planning units (sections of exposed coast and ocean).

Assessment

Options for representation of the defined ocean ecosystems are spread evenly throughout the latitudinal extent of the bioregion if both Commonwealth and State waters are considered (Figure 7.10). However, if only NSW waters within the 3 nm limit are considered, representation of the 60-200 m depth zone can only be achieved at the southern end of the bioregion (i.e. in the Narrabeen-Stanwell Park and Towradgi Creek – Shellharbour sections) as this depth zone does not come within 3 nm of the coast between the Hunter River and Narrabeen Lake (Figure 7.9c).

Inshore areas of the 0-20 m depth zone are protected in Barrenjoey Head, Narrabeen Head, Long Reef, Cabbage Tree Bay, Bronte-Coogee, Cape Banks and Boat Harbour Aquatic Reserves and in Bouddi National Park (Figure 7.9a).

The are currently no areas of the 60-200 m depth zone included in any form of marine protected area in the Hawkesbury Shelf bioregion (Figure 7.9c). Small areas of the 20-60 m depth zone are represented in the marine extension of Bouddi National Park (Figure 7.9b). The marine component of Bouddi National Park has temporary protection for fish and marine invertebrates through a closure under the *NSW Fisheries Management Act 1994* which requires renewing every five years (Figure 7.9a).

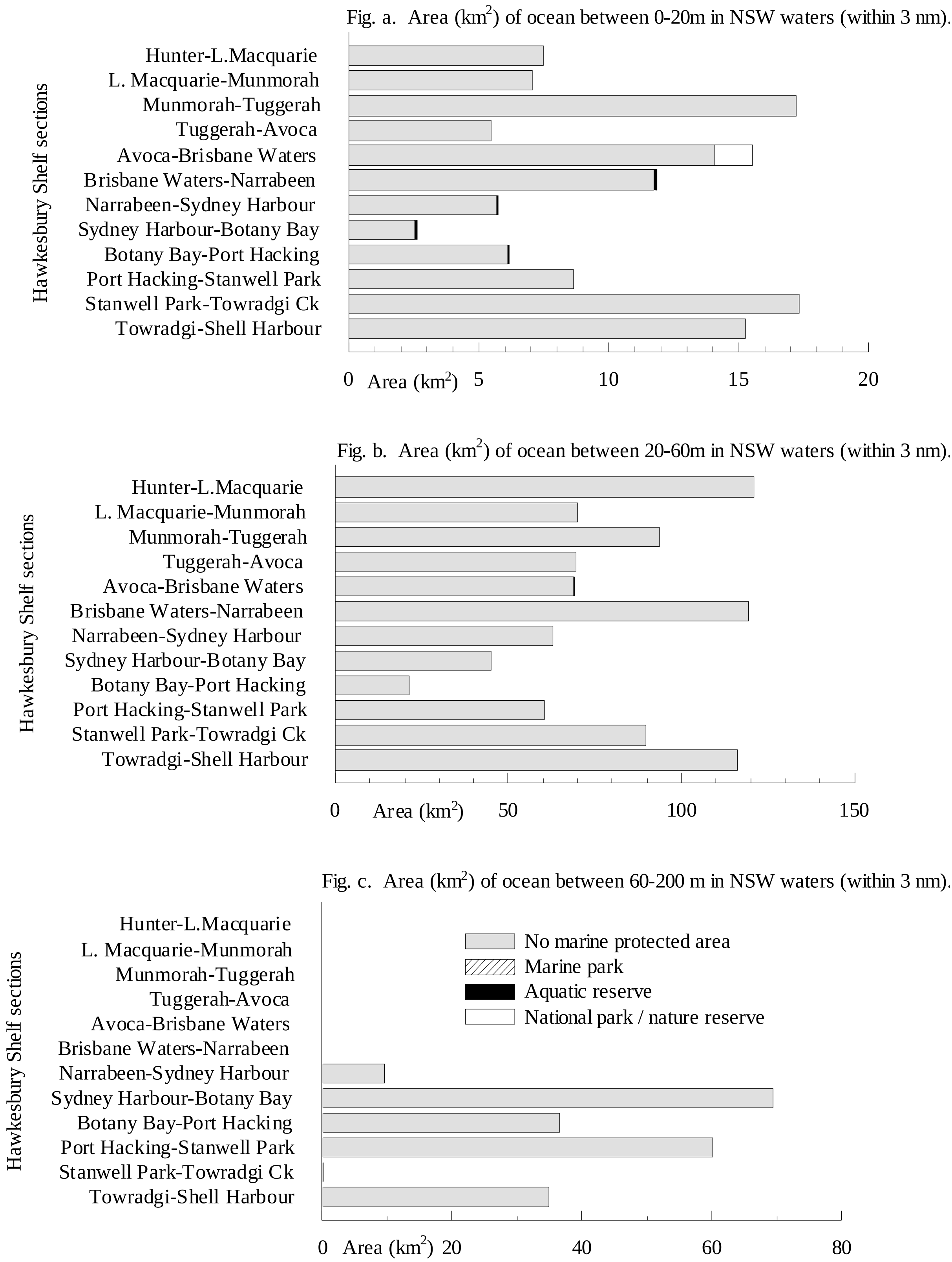


Figure 7.9a-c. Area (km^2) of ocean depth zones in marine protected areas within sections of ocean coast in NSW waters (within 3 nm) of the Hawkesbury Shelf bioregion.

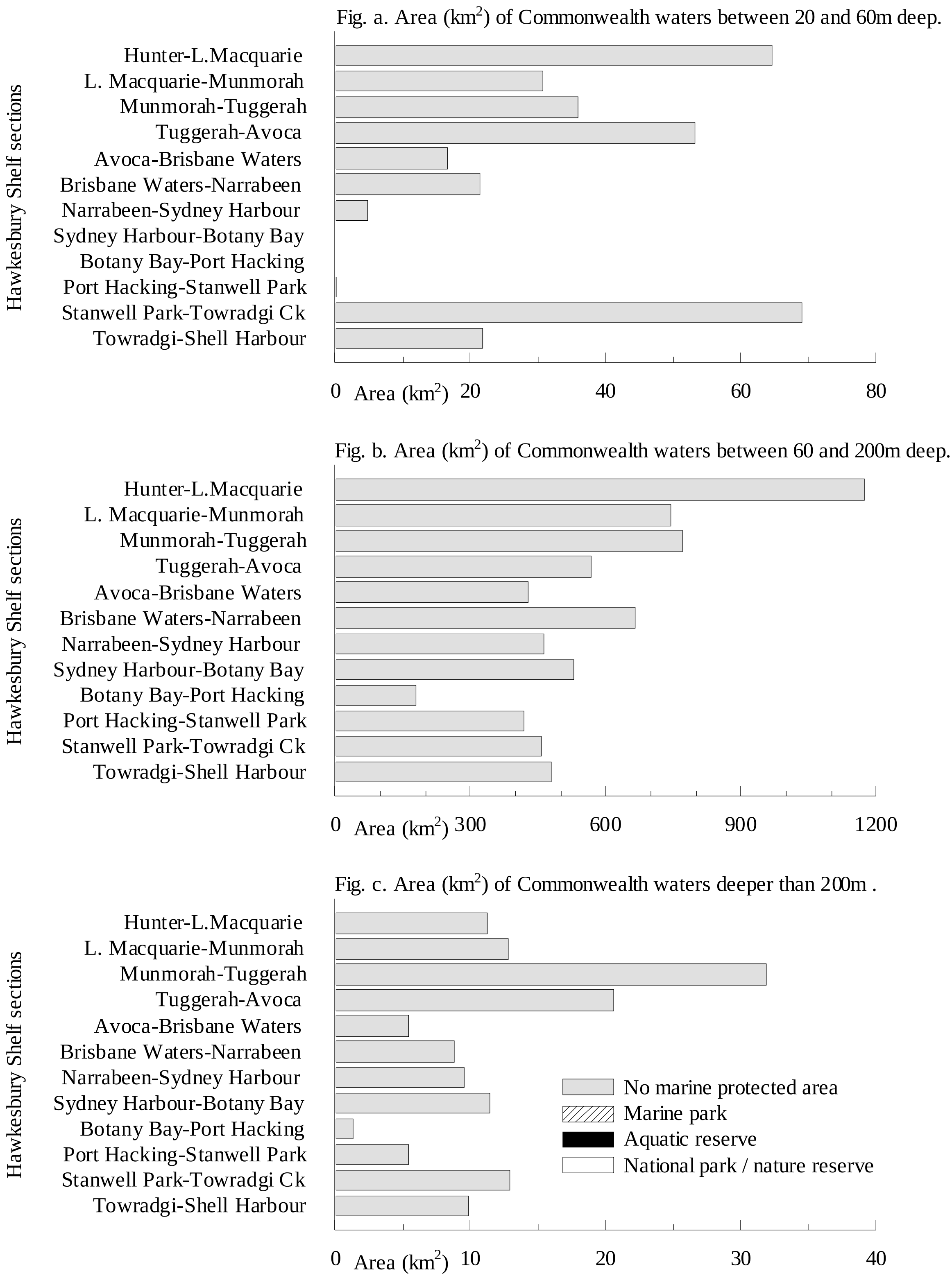


Figure 7.10a-c. Area (km^2) of ocean depth zones in marine protected areas for Commonwealth waters (outside of 3 nm) of the Hawkesbury Shelf bioregion.

7.4.3 Oceanography - East Australian Current

Data description

A summary of the key oceanographic processes operating in the Hawkesbury Shelf bioregion (Cresswell *et al*. 1983, Pollard *et al*. 1997, Cresswell 1998, CSIRO Australia 2001)

Criteria

Comprehensiveness, representativeness, ecological importance and productivity.

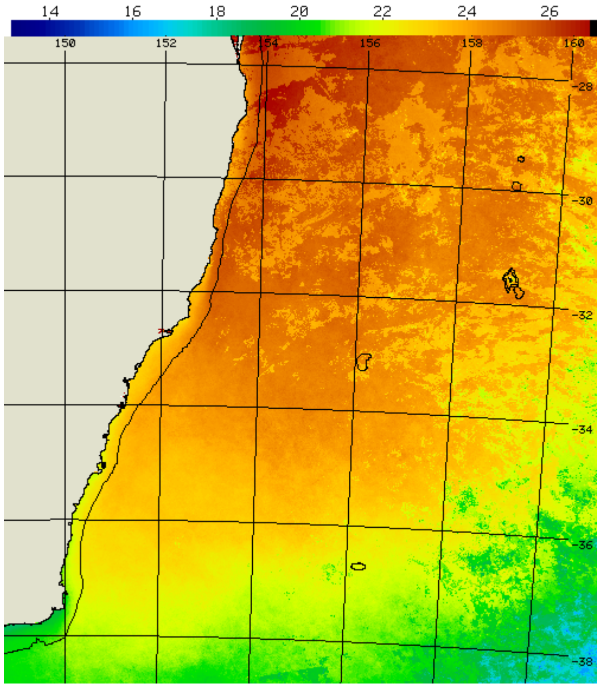
Data description and assessment

The East Australian Current (EAC) runs south along the East Coast of Australia from the Coral Sea into the Tasman Sea bringing warm tropical and sub tropical water into the cooler temperate waters of NSW (Figure 7.11 and Figure 7.12). It has a significant influence on the marine biodiversity of coastal and offshore waters through its influence on water temperature, density and chemistry, production of eddies, counter currents and upwellings, primary productivity, transport of larvae and food supply. The influence of the current, eddies and upwellings on phytoplankton and productivity has been well studied and the movements of other organisms such as gemfish, tuna and a range of pelagic species are also thought to be influenced by the current (CSIRO Australia 2001).

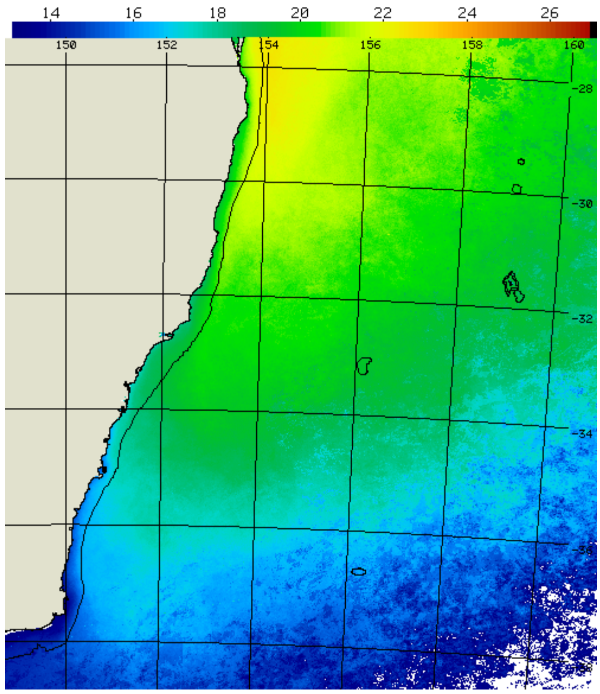
The current moves at speeds up to 5 knots, transports up to 30 million cubic metres of water per second, and can affect waters down to 500 metres in depth and 100 kilometres in width. The EAC is strongest in summer, with the flow up to twice that occurring in winter months (CSIRO Australia 2001).

The EAC often moves inshore across the continental shelf, generating northward flowing currents and small clockwise 'cold core' eddies. It periodically advances south and retreats north at the Tasman Front leaving behind large anti-clockwise warm-core eddies up to 200 km in width, and 1000 m deep with currents of up to four knots at their periphery. These eddies often migrate south transporting warm water, larvae and plankton into cold temperate waters (CSIRO Australia 2001).

The EAC moves away from the coast most frequently near South West Rocks and Seal Rocks in the Manning Shelf bioregion yet sometimes leaves the coast as far south as Ulladulla. A preliminary assessment by Pollard *et al*. (1997) estimated that the EAC influences NSW coastal waters between Tweed Heads and Seal Rocks about 90% of the time, but that this decreases to 50% of the time between Seal Rocks and Jervis Bay, and to 10% of the time between Jervis Bay and Cape Howe. This indicates that while the Tweed-Moreton and Manning Shelf bioregions are often influenced by subtropical waters, and the Batemans and Twofold Shelf bioregions are more often influenced by temperate conditions, the current on the Hawkesbury Shelf tends to alternate between the two extremes.

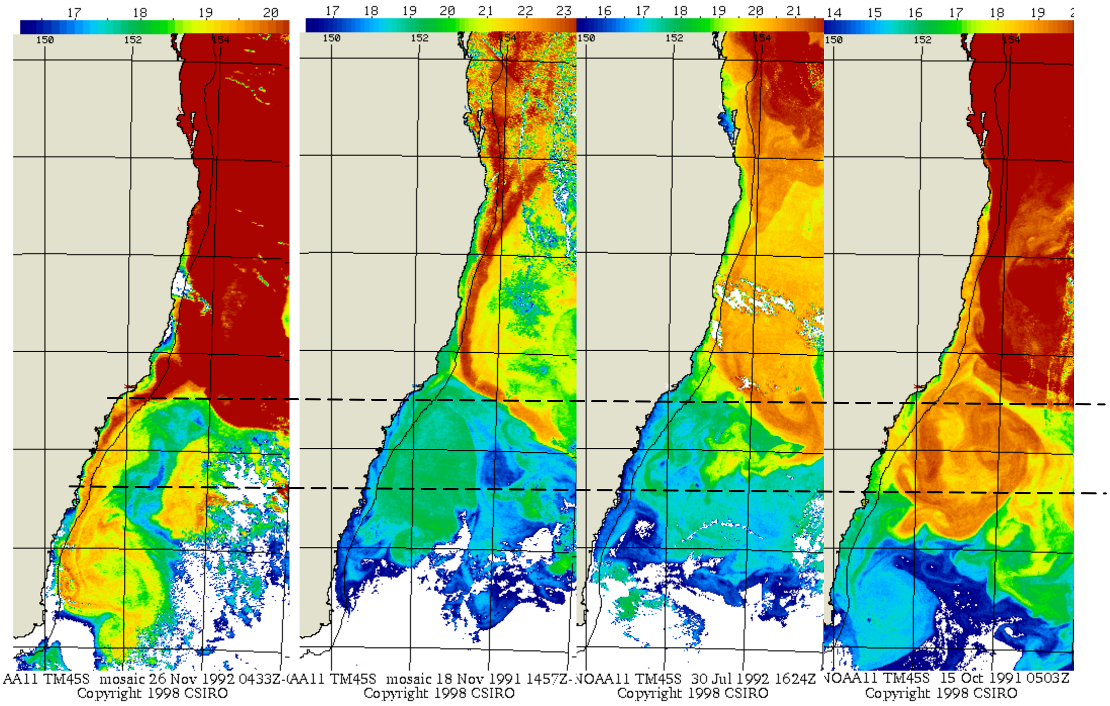


a.



b.

Figure 7.11. Mean sea surface temperature off NSW coast averaged for summer (January-March) and b. winter (July-September) (Cresswell 1998). Colour scale for temperature in degrees Celsius across the top of each map.



a. b. c. d.

Figure 7.12. Broad scale oceanographic processes off the NSW continental shelf represented by sea surface temperature (SST) NOAA11 TM45S satellite images (after Cresswell 1998):

a. East Australian current warming inshore waters of the Hawkesbury Shelf in November;

b. cool inshore waters during November as EAC heads offshore from South West Rocks;

c. cool inshore waters during July; and

d. warm inshore waters in October associated with an eddy of the EAC.

(dashed lines = Hawkesbury Shelf bioregion, colour scales for temperature in degrees Celsius across the top of each map).

7.4.4 Seagrass, mangrove and saltmarsh habitats

Data sources

Estuarine vegetation maps from West *et al*. (1985) digitised by the NPWS[1].

Data description

Estuarine plant communities were mapped between 1981 and 1984 using 1:25,000 scale aerial photographs and a 1:25,000 scale topographic map base. More recent surveys by Fisheries are underway (pers. comm. Robert Williams and Greg West, Fisheries, NSW DPI).

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area of habitat.

Assessment

Lake Macquarie and Tuggerah Lakes include the largest areas of seagrass in the Hawkesbury Shelf bioregion and the third and fourth largest areas of seagrass in NSW (after Wallis Lake and the Clarence River (Figure 7.13a).

Large areas of seagrass are also found in Brisbane Waters, Lake Illawarra, Botany Bay, Pittwater, Port Jackson, Port Hacking, the Hawkesbury River and Narrabeen Lagoon. Smaller areas of seagrass habitat have also been recorded from the Georges River, Wamberal Lagoon, Terrigal Lagoon, Avoca Lake and other areas.

A total of 6% of the bioregions seagrass habitat is currently included in Towra Point Aquatic Reserve, Towra Point Nature Reserve, North Sydney Harbour Aquatic Reserve, Wamberal Lagoon Nature Reserve, and other national parks on the Hawkesbury River, Pittwater, Brisbane Waters and Port Hacking.

The largest areas of mangrove habitat in the bioregion are recorded from the Hunter and the Hawkesbury Rivers. After Port Stephens, these are the largest areas of mangrove in NSW. Large areas of mangrove habitat are also found in Botany Bay, the Georges River, Brisbane Waters, Lake Macquarie and Port Jackson with smaller areas in several other estuaries (Figure 7.13b).

A total of 7% of all mangrove habitat in the bioregion is included in the Towra Point Aquatic Reserve with a further 42% represented in nature reserves and national parks on the Hunter River, Hawkesbury River, Brisbane Waters, Botany Bay, Port Hacking, Pittwater and Port Jackson. However over half of the mangrove habitat within national parks and nature reserves occurs inland of the mapped coastline, within the ‘terrestrial’ components of these reserves.

The Hunter River area includes the largest area of saltmarsh habitat in the bioregion and the third largest area of saltmarsh in the state after Port Stephens and Lake Cathie (Figure 7.13c). Large areas of saltmarsh are also found near Botany Bay, the Hawkesbury River, Brisbane Waters, and Lake Macquarie with smaller areas on the Georges River, Lake Illawarra, Port Hacking and several other locations.

A total of 44% of the area of saltmarsh in the bioregion is included in nature reserves and national parks on the Hunter River, Georges River, Brisbane Waters, Hawkesbury River, Botany Bay and Port Hacking. As with mangrove habitat, most of the saltmarsh habitat in national parks and nature reserves occurs inland of the mapped coastline with only a small proportion of saltmarshes below the high water mark in marine protected areas.

[1] now within the NSW Department of Environment and Conservation

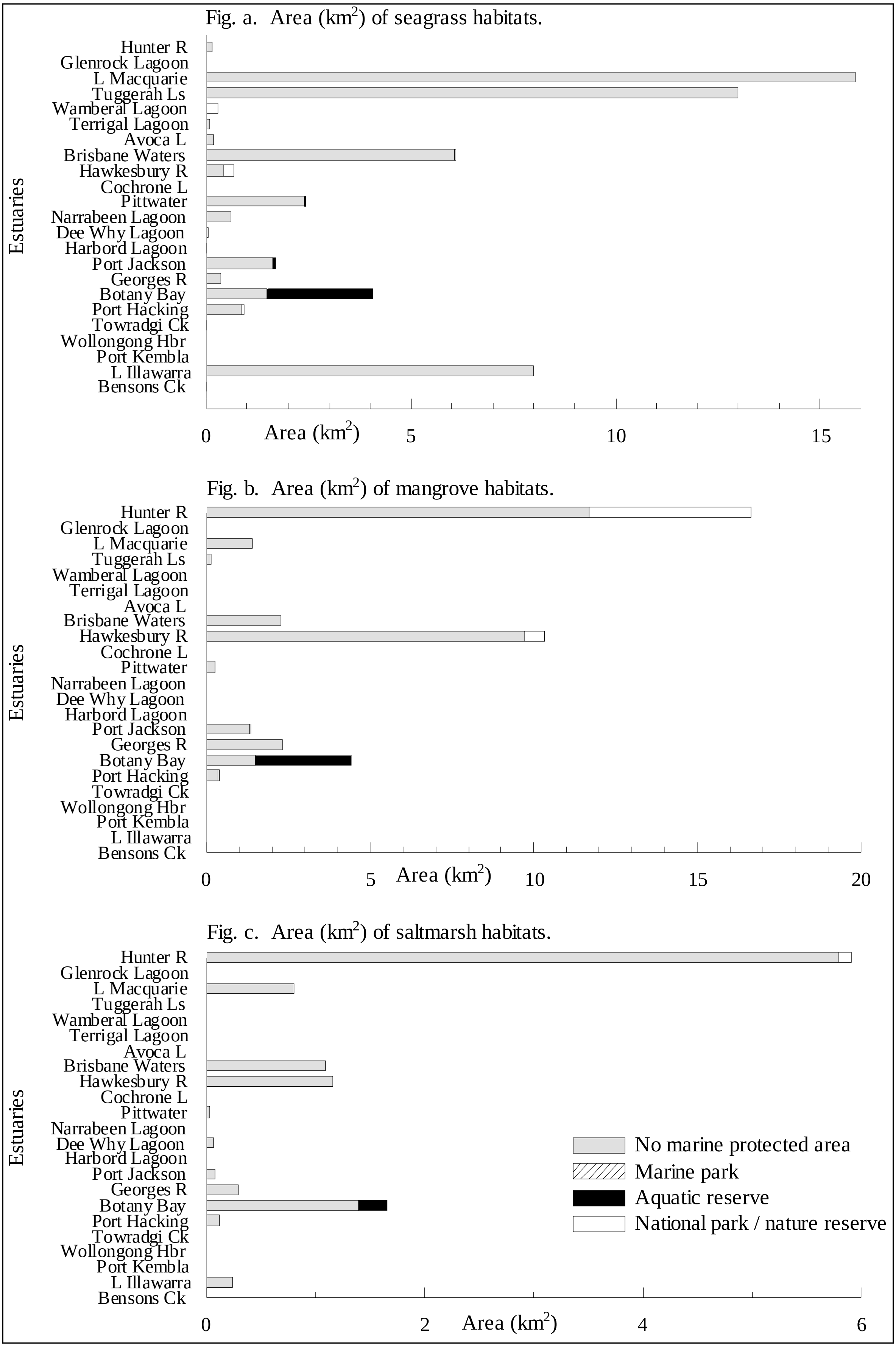


Figure 7.13a-c. Area (km^2) of seagrass, mangrove and saltmarsh habitat in marine protected areas of the Hawkesbury Shelf bioregion.

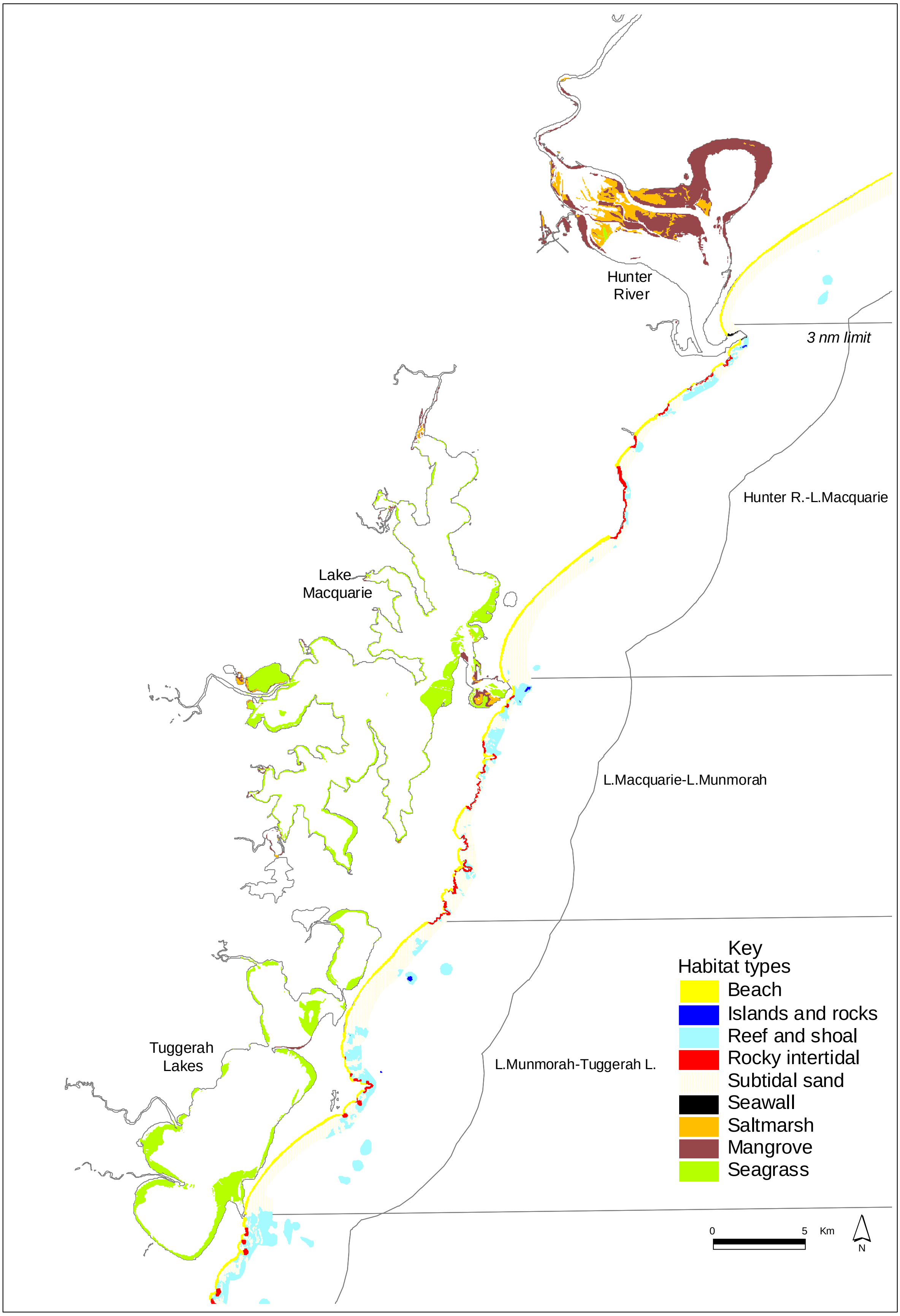


Figure 7.14. Mapped habitat types between the Hunter River and Tuggerah Lakes.

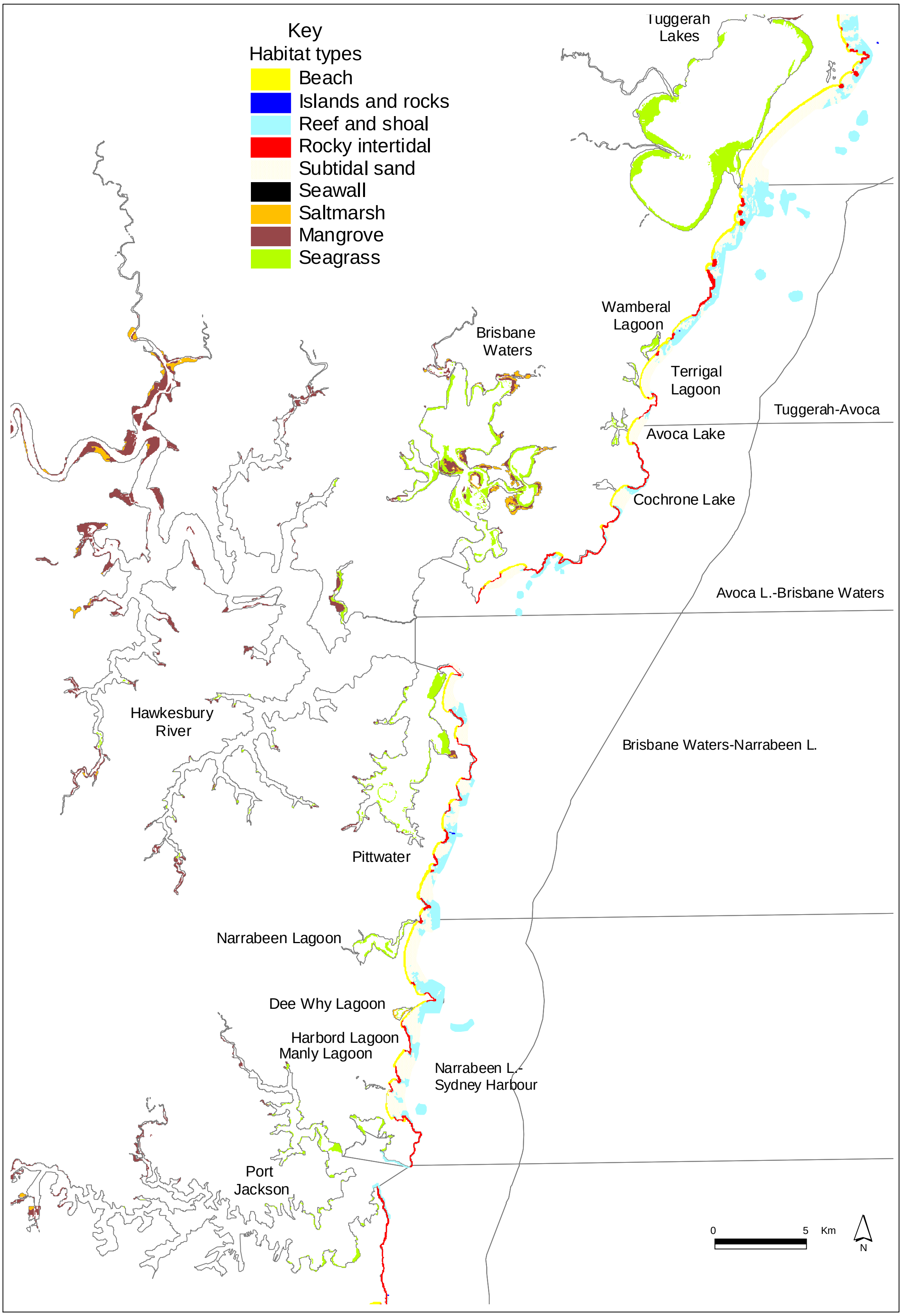


Figure 7.15. Mapped habitat types between Tuggerah Lakes and Sydney Harbour.

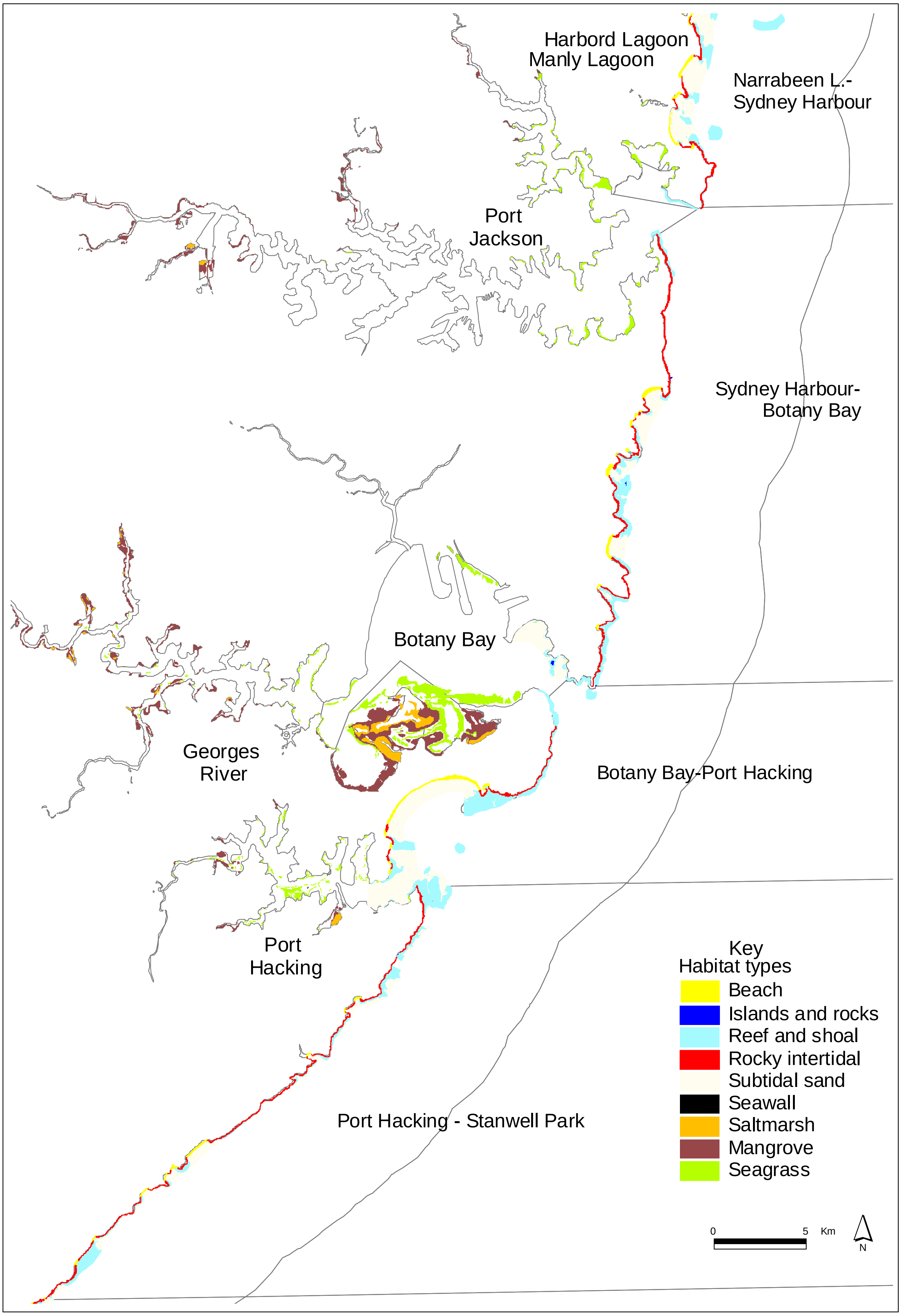


Figure 7.16. Mapped habitat types between Sydney Harbour and Port Hacking.

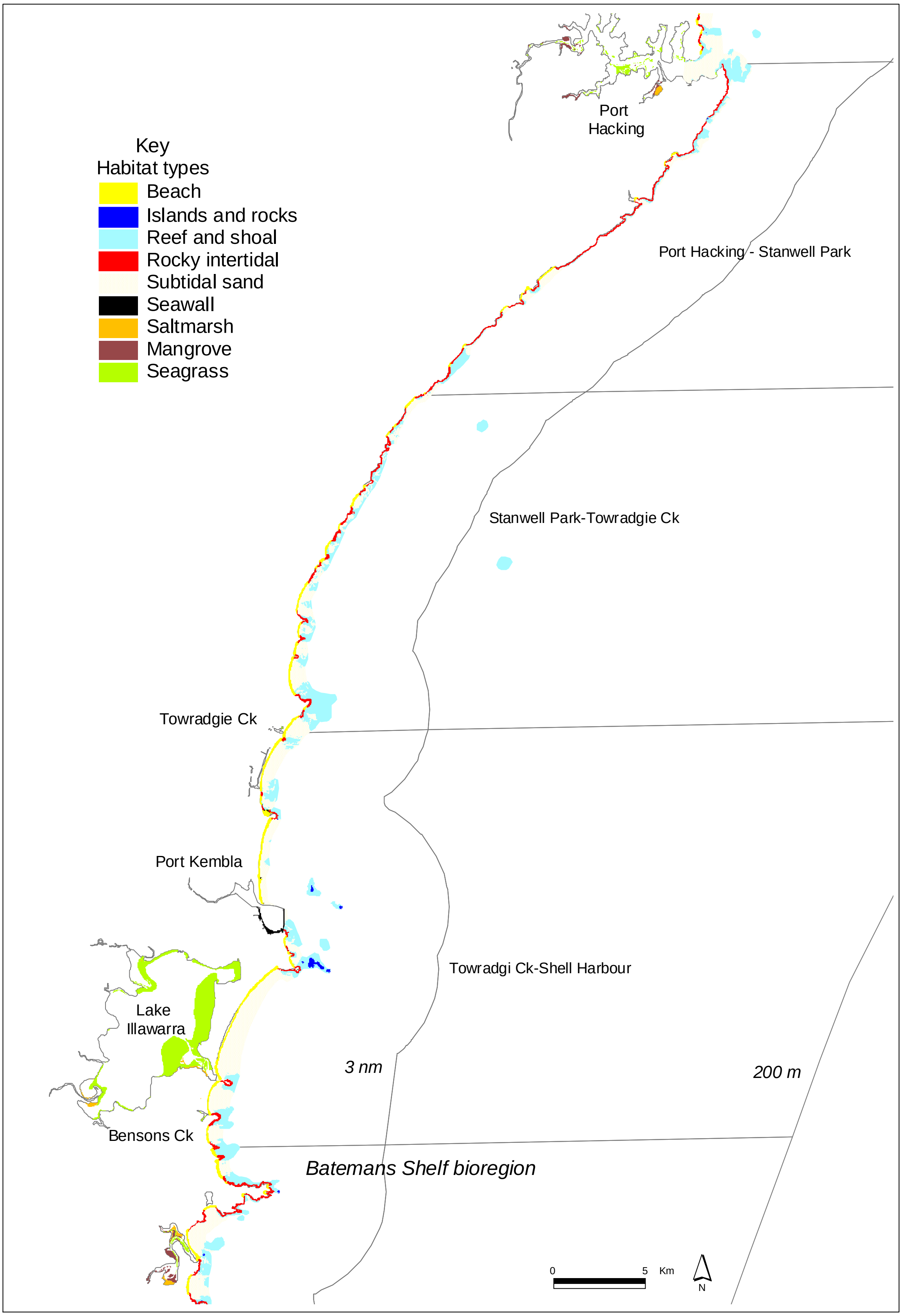


Figure 7.17. Mapped habitat types between Port Hacking and Shellharbour.

7.4.5 Shallow subtidal reef

Data source

Aerial photography provided by the NSW DIPNR

Offshore reefs and shoals digitised from AHO survey charts.

Data description

Near shore reefs digitised from high resolution (1:8000 –1:25:000 aerial photographs).

Offshore reefs digitised from shoal areas on AHO charts.

Reefs were also classified by distance offshore (more or less than 1 km).

These mapped areas represent only a small proportion of reefs in deeper water and should therefore be interpreted cautiously.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area of reefs in broad scale planning units.

Assessment

The largest areas of mapped reef occurred in the Tuggerah L.–Avoca L. section (7 km^2 or 15% of all mapped reef in the bioregion), followed by Stanwell Park–Towradgi Ck (5.8 km^2), Towradgi-Shellharbour, Munmorah-Tuggerah (5 km^2) decreasing to a minimum of 2.2 km^2 for the Hunter R.-L. Macquarie section (Figure 7.18a).

When classified into reefs less than or greater than 1 km from shore, the inshore reefs show a similar pattern to overall pattern described above. However, the area of shallow reef greater than 1 km offshore is markedly higher for the Munmorah-Tuggerah (1.5 km^2) and Tuggerah-Avoca (1.5 km^2) sections and relatively high for the Towradgi-Shellharbour (0.8 km^2) and Narrabeen-Sydney Harbour sections (0.5 km^2, Figure 7.18c).

A total of 1.4 km^2 of mapped shallow reef is included in aquatic reserves between Barrenjoey and Boat Harbour, representing 3% of the total area of this habitat in the bioregion. Bouddi National Park includes an additional 0.8 km^2 of mapped reef which represents 1.6% of the total area of this habitat in the bioregion. All of this reef is near shore and no reefs beyond 1 km are represented within marine protected areas.

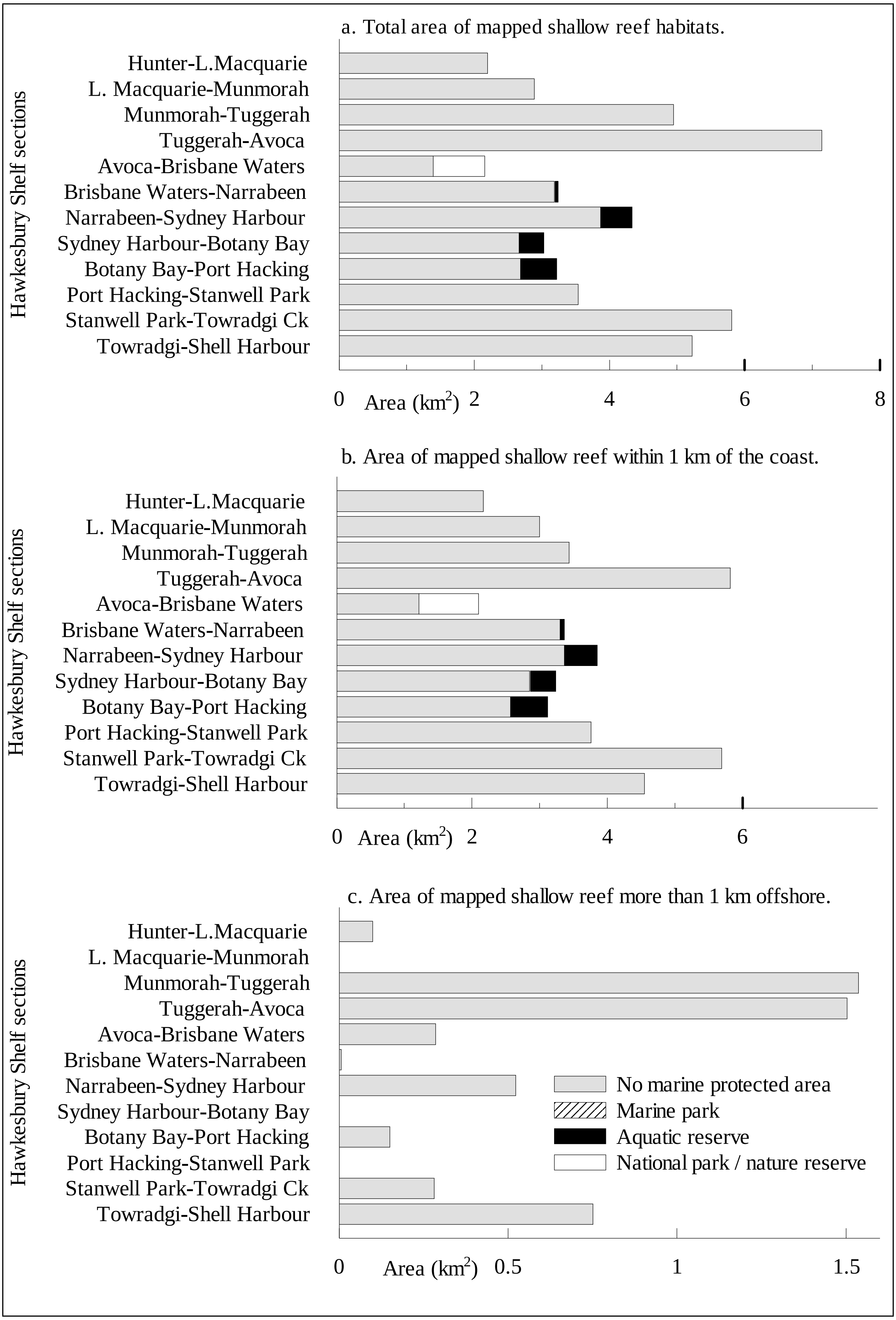


Figure 7.18. Area of mapped shallow reef for sections of ocean coast.

7.4.6 Islands

Data source

GIS data of islands and emergent rocks from the AMBIS database provided by Geoscience Australia (Commonwealth of Australia 2001).

Data description

Absolute areas of islands were graphed and 100 m buffers extending out from islands and exposed rocks were used to represent the influence of islands on adjacent waters in reserve selection simulations. Islands were classified by distance offshore (more or less than 1 km from shore).

Criteria

Comprehensiveness and representativeness.

Assessment measure

Area of islands within broad scale plan units. Area of island buffers in fine scale units are used to represent these habitats in reserve selection tools.

Assessment

By far the largest area of islands (0.3 km^2) occurred in the Towradgi-Shellharbour section of exposed coast and ocean representing 76% of the area of islands in the bioregion (Figure 7.19). This area is composed primarily of islands within 1 km of shore. Islands greater than 1 km from shore occurred only in the Towradgi-Shellharbour section and in the Munmorah-Tuggerah sections of exposed coast and ocean.

Approximately 0.0001 km^2 of islands and rocks are represented in Long Reef Aquatic Reserve. Therefore 0.21% of the total area of this habitat in the bioregion is represented in MPAs.

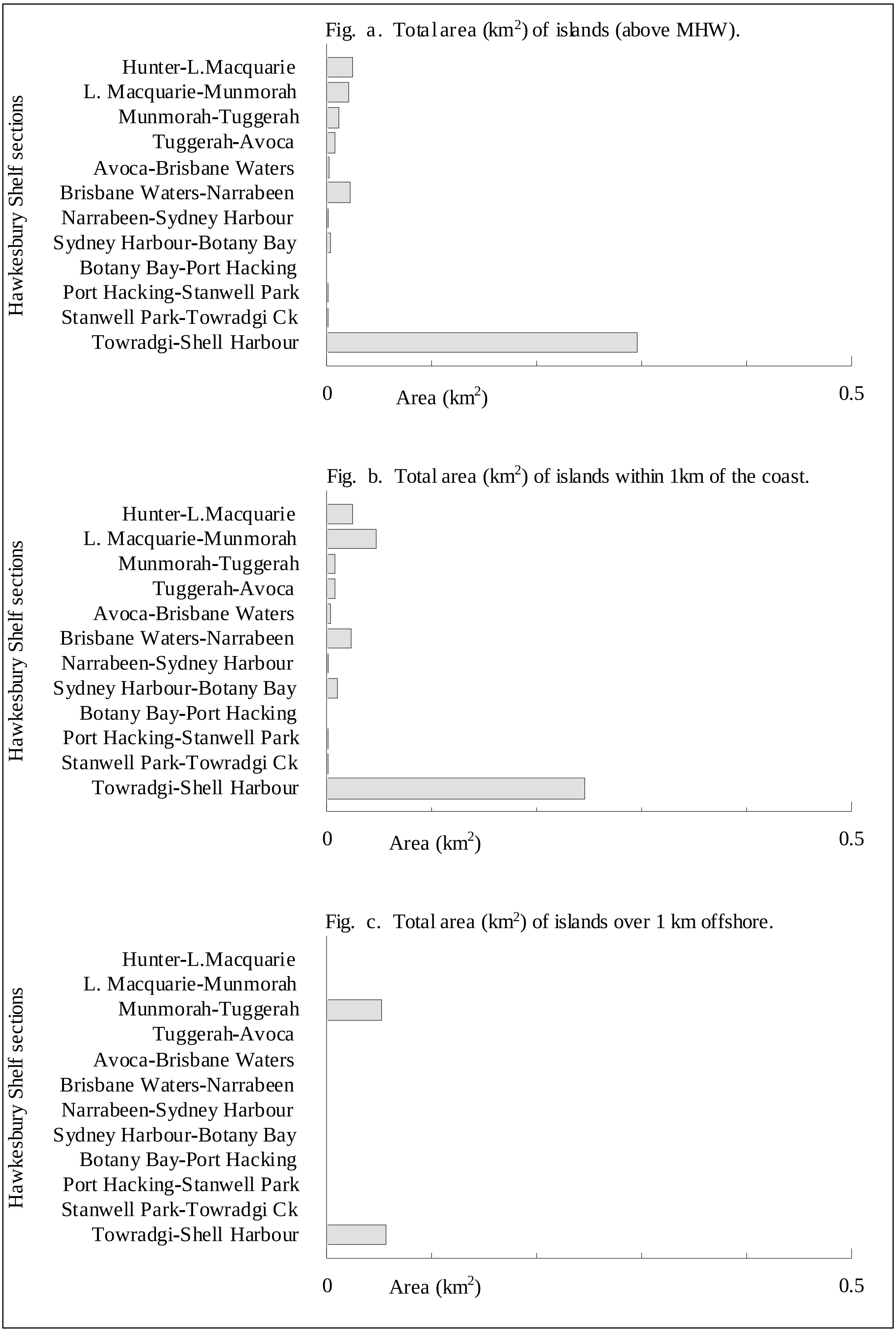


Figure 7.19a-c. Area (km^2) of total, inshore and offshore islands (above mean high water) for coastal sections (NSW waters within 3nm) of the Hawkesbury Shelf bioregions.

7.4.7 Shallow subtidal sand

Data source

Near shore sand digitised by Ron Avery (NSW National Parks) from aerial photography provided by the NSW DIPNR.

Data description

Near shore habitats digitised from high resolution (1:8000 –1:25:000) aerial photographs. These mapped areas represent only a small proportion of environments which extend into deeper water and should therefore be interpreted cautiously.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area of sand in broad scale plan units (section of exposed coast and ocean).

Assessment

The largest areas of mapped inshore sand occurred in the Munmorah-Tuggerah (13 km^2), Towradgie-Shellharbour (12 km^2) and the Hunter-Lake Macquarie (12 km^2) sections of exposed coast and ocean with each of these areas equivalent to approximately 17% of the total area of this habitat for the bioregion (Figure 7.20a).

A total of 0.35 km^2 of subtidal sand was represented in aquatic reserves between Brisbane Waters and Port Hacking representing 0.5% of the total area of this habitat in the bioregion. A further 0.15 km^2 of subtidal sand was represented in Bouddi National Park representing 0.14% of the total area of this habitat in the bioregion.

7.4.8 Intertidal beach

Data sources

Land and Property Information Centre 1: 25 000 topographic maps and digital cadastre database.

Data description

Ocean beaches were identified from 1:25 000 topographic maps and their areas calculated from the difference between the high and low water marks in the digital cadastre database. Sheltered estuarine beaches were not assessed as reliable data for these areas were not available.

Criteria

Comprehensiveness and representativeness.

Assessment measure

Area of beach within broad scale plan units (sections of exposed coast and ocean).

Assessment

The area of intertidal beach within sections of exposed coast and ocean was largest for the Hunter-Lake Macquarie (1 km^2) section representing 19% of this habitat for the bioregion followed by 0.9 km^2 for the Munmorah-Tuggerah section and 0.73 km^2 for the Towradgi-Shellharbour section (Figure 7.20b). The Port Hacking-Stanwell Park section included the least intertidal beach (0.07 km^2).

A total of 0.07 km^2 of intertidal ocean beach was included in aquatic reserves between Brisbane Waters and Port Hacking representing 1.4% of the total area of this habitat in the bioregion. Bouddi National Park included 0.01 km^2 of ocean intertidal beach representing 0.2% of the total area of this habitat in the bioregion.

7.4.9 Intertidal rocky shore

Data sources

Land and Property Information Centre 1: 25 000 topographic maps and digital cadastre database.

Data description

Ocean intertidal rocky shores were identified from 1:25 000 topographic maps and their areas calculated from the difference between the high and low water marks on the digital cadastre database. Sheltered estuarine rocky shores were not assessed as reliable data were not available for these areas.

Criteria

Comprehensiveness and representativeness.

Assessment measure

Area of rocky intertidal shore within broad scale plan units (sections of exposed coast and ocean).

Assessment

The largest area of exposed, intertidal rocky shore occurred in the Sydney Harbour-Botany Bay (0.67 km^2) section of coast representing 14% of the total area of this habitat in the bioregion. Large areas of rocky shore were also present in the Tuggerah-Avoca (0.57 km^2), Stanwell Park-Towradgi (0.52 km^2) and Hunter-Lake Macquarie (0.51 km^2) sections. The least area of rocky shore occurred in the Botany Bay-Port Hacking section (0.14 km^2, Figure 7.20c).

A total of 0.22 km^2 of exposed intertidal rocky shore was represented in aquatic reserves between Brisbane Waters and Port Hacking representing 4.6% of the total area of this habitat in the bioregion. A further 0.14 km^2 of rocky shore was represented in Bouddi National Park representing 2.9% of the total area of this habitat in the bioregion.

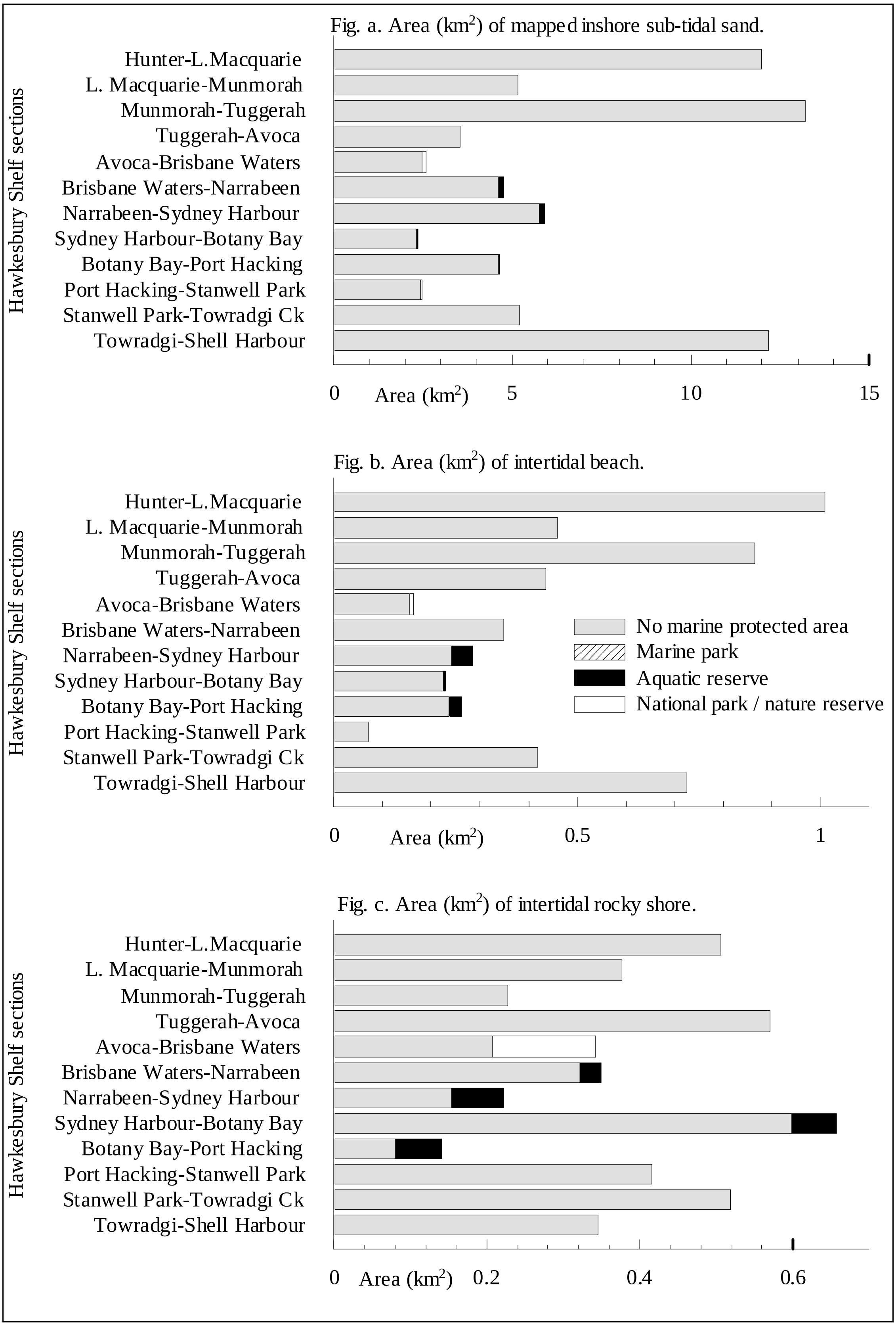


Figure 7.20a-c. Area (km^2) of mapped (inshore) subtidal sand, intertidal beach, and intertidal rocky shore habitat in marine protected areas within coastal sections (NSW waters within 3nm) of the Hawkesbury Shelf bioregion.

7.4.10 NSW Fisheries[2] assessment of rocky intertidal communities

Data source

Otway, N. (1999). “Identification of candidate sites for declaration as aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf bioregions.”

Data Description

Rocky shores short-listed by an advisory committee of stakeholders and community members were surveyed by Otway (1999), scored for species richness and the presence of platform, boulder, rubble, pool and crevice microhabitats with recommendations made for suitability as MPAs.

Criteria

Comprehensiveness, representativeness and adequacy.

Assessment

Six locations (Nobby’s Head, Toowoon Point, Yumbool Point, Tudibaring Head, Green Point and Brickyard Point) were recommended as candidate sites for MPAs by the advisory committee. Otway (1999) surveyed these areas and found 4-5 microhabitats and a higher species richness at Toowoon Point (135 spp.), Tudibaring Head (144 spp.) and Brickyard Point (139 spp.). These shores were recommended as candidate locations for marine protected areas (Figure 7.21, Figure 7.22 and Figure 7.23). Three microhabitats and a lower species richness were found at the remaining locations.

Toowoon and Yumbool Points are located in the Tuggerah-Avoca section of ocean coast, Tudibaring Head is located in the Avoca-Brisbane Waters section and Brickyard Point is located in the Stanwell Park-Towradgi Ck section.

[2] now within the NSW Department of Primary Industry

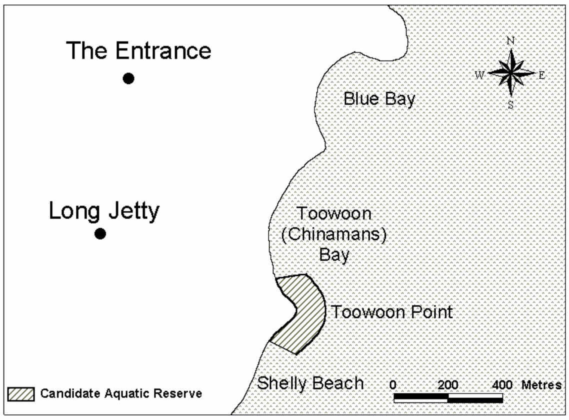


Figure 7.21. Towoon Bay candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

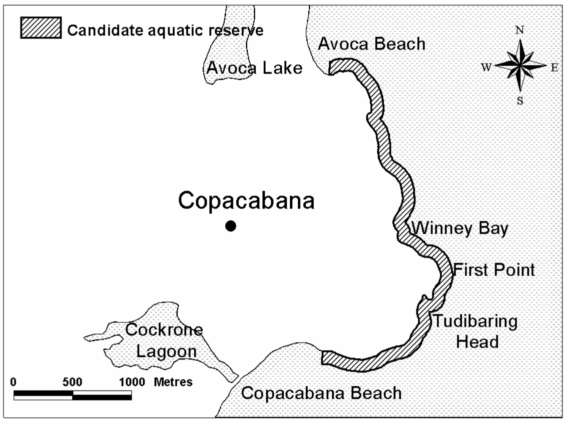


Figure 7.22. Tudibaring Head candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

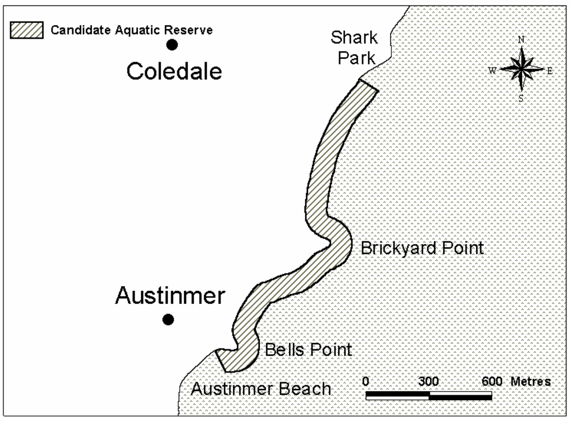


Figure 7.23. Brickyard Point candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

7.4.11 Coastal rock platforms (Total Environment Centre)

Data source

Short J.M. (1995). "Protection of coastal rock platforms in NSW."

Data description

This database of 'significant rock platforms' identifies 198 separate rock platforms in NSW, 33 of which lie in the Hawkesbury Shelf bioregion.

Criteria

Representativeness, uniqueness and naturalness (condition).

Assessment measures

The data base includes attributes relating to: location, access, platform dimensions, physical characteristics, geology, biology, impacts, existing management and recommendations.

Assessment

Based on the assessment of the characteristics described above, Short (1995) recommended 25 rock platforms in the Hawkesbury Shelf bioregion for protection. These were:

- Little Redhead Point and Redhead Point in the Hunter-Lake Macquarie section
- Swansea Heads, Catherine Hill Bay, Flat Rocks Point, Bongo and Wybong Heads in the L. Macquarie-Munmorah section
- Norah Head and Pelican Point in the Munmorah-Tuggerah section
- Cape Three Points, Bouddi, Gerri Point and Box Head in the Avoca-Brisbane Waters section
- Carrel Head, Hole in Wall and Termite Head in the Brisbane Waters-Narrabeen section
- North Harbord and Queenscliff in the Narrabeen-Sydney Harbour section
- South Head in the Sydney Harbour-Botany Bay section
- Port Hacking Point in the Port Hacking-Stanwell Park section
- Bulli/Wonoona Point and Collins Rock in the Stanwell Park-Towradgi section and
- Towradgi Point, Red Point and Windang in the Towradgi-Shellharbour section.

7.4.12 Irreplaceability analysis for ecosystem and habitat units

Irreplaceability is a measure designed to estimate the likelihood of a site being required to meet a conservation target or, the extent to which conservation options are reduced if that site is unavailable. Conservation targets are usually defined as areas, numbers or proportions for a range of different habitats, species or other ‘features’. *Summed* irreplaceability is calculated by adding the feature irreplaceabilities for all the different features in a site. High values indicate that a site is important for achieving conservation goals for many different features.

Figure 7.24 shows summed irreplaceability for the fine scale planning units and a hypothetical goal of 20% of the area of each ecosystem (estuary types and ocean depth zones) and habitat feature (seagrass, mangrove, saltmarsh, rocky intertidal, beach, subtidal sand, reef, and island). Higher values indicate those sites more likely to contribute to targets for more than one habitat or ecosystem, thus minimising the total area required to represent those habitat or ecosystem features. High values for *summed* irreplaceability do not necessarily imply that a site is required to meet a goal, only that it is likely to contribute more to one or more feature targets.

Localised areas of high summed irreplaceability are evident at the mouths of several estuaries and at several locations along the coast where different ocean habitats occur together (Figure 7.24). Relatively high summed irreplaceabilities are also present in estuaries where different estuarine habitats occur together. Low irreplaceabilities offshore reflect the relative scarcity of detailed data for these areas.

Figure 7.25 and Figure 7.26 show *summed* irreplaceabilities for large scale planning units calculated for a hypothetical representation of 20% of mapped ecosystems and habitat units. Figure 7.25a. shows very high summed irreplaceabilities for the Hunter River, Hawkesbury River, Lake Macquarie and Tuggerah Lakes and moderate scores for Botany Bay, Lake Illawarra, Brisbane Waters, Narrabeen Lagoon, Avoca Lake and the Parramatta River.

Figure 7.25b shows adjusted irreplaceabilities which account for the areas of habitat already included in existing aquatic reserves. The result is a reduction in some irreplaceabilities in response to the inclusion of seagrass, mangrove and saltmarsh in Towra Point Aquatic Reserve and North Sydney Harbour Aquatic Reserve. In Figure 7.25c, the existing marine components of national parks and nature reserves are added to the model with further small reductions in irreplaceability in, for example, the Hawkesbury River.

Summed irreplaceabilities for sections of ocean coast are highest for Towradgi-Shellharbour, Munmorah-Tuggerah, Hunter-Tuggerah and Stanwell Park-Towradgi reflecting the larger areas of island habitat and 60-200 m depth zones in the southern part of the bioregion and the Munmorah-Tuggerah section (Figure 7.26a-c). Irreplaceability is used here as a static index to summarise general patterns. However, its full potential is realised in an iterative process where different alternatives are explored using experience from managers, scientists and key stakeholders.

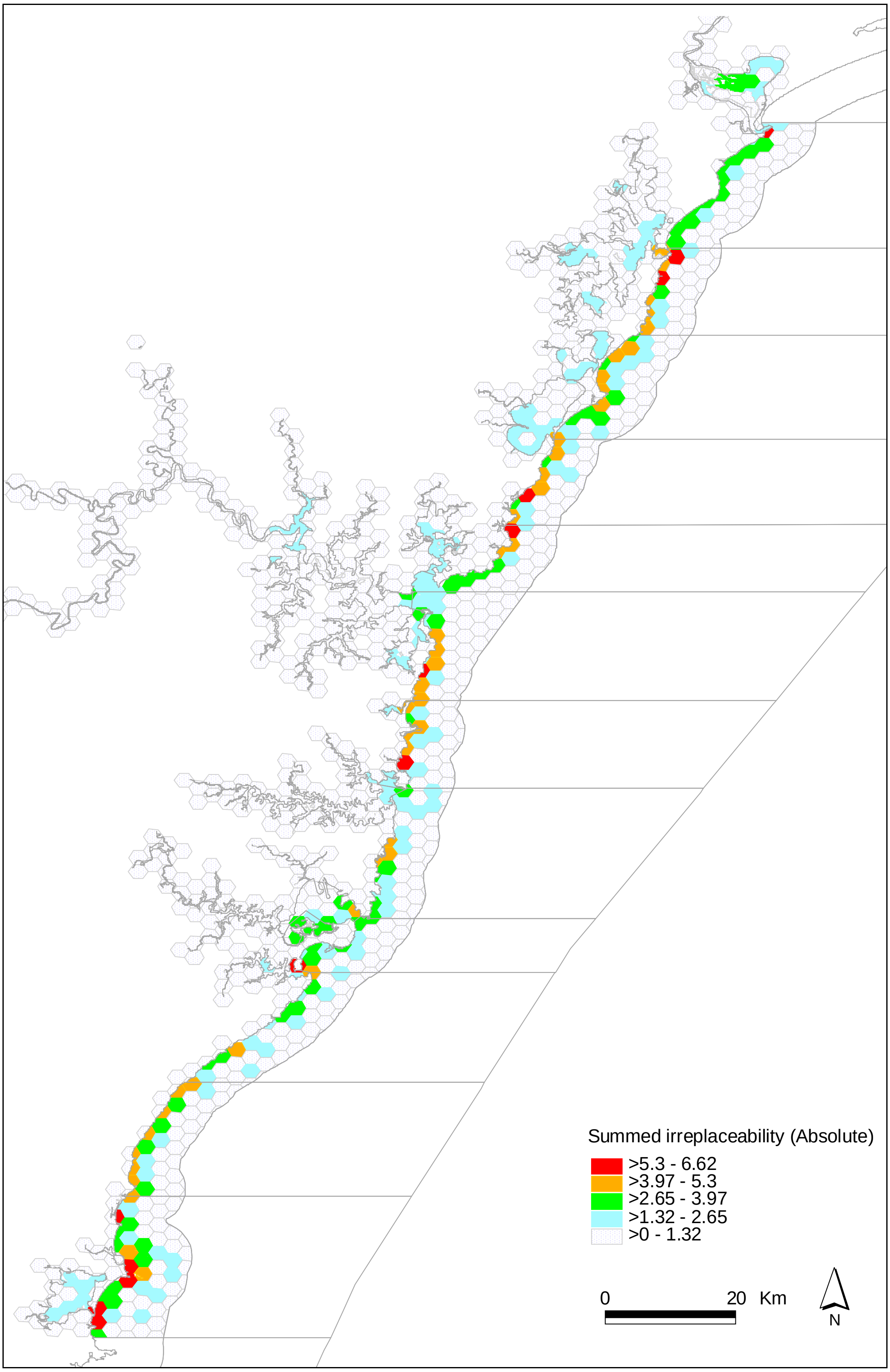


Figure 7.24. Summed irreplaceability of fine scale (4 km^2) planning units for ecosystem and habitat types in the NSW waters (within 3 nm) of the Hawkesbury Shelf bioregion. Values indicate the degree to which a unit can contribute to meeting a hypothetical 20% goal for a number of different estuarine and oceanic ecosystem and habitat types. Values estimated using C-Plan reserve selection software (NPWS[1]2001).

[1] now within the NSW Department of Environment and Conservation

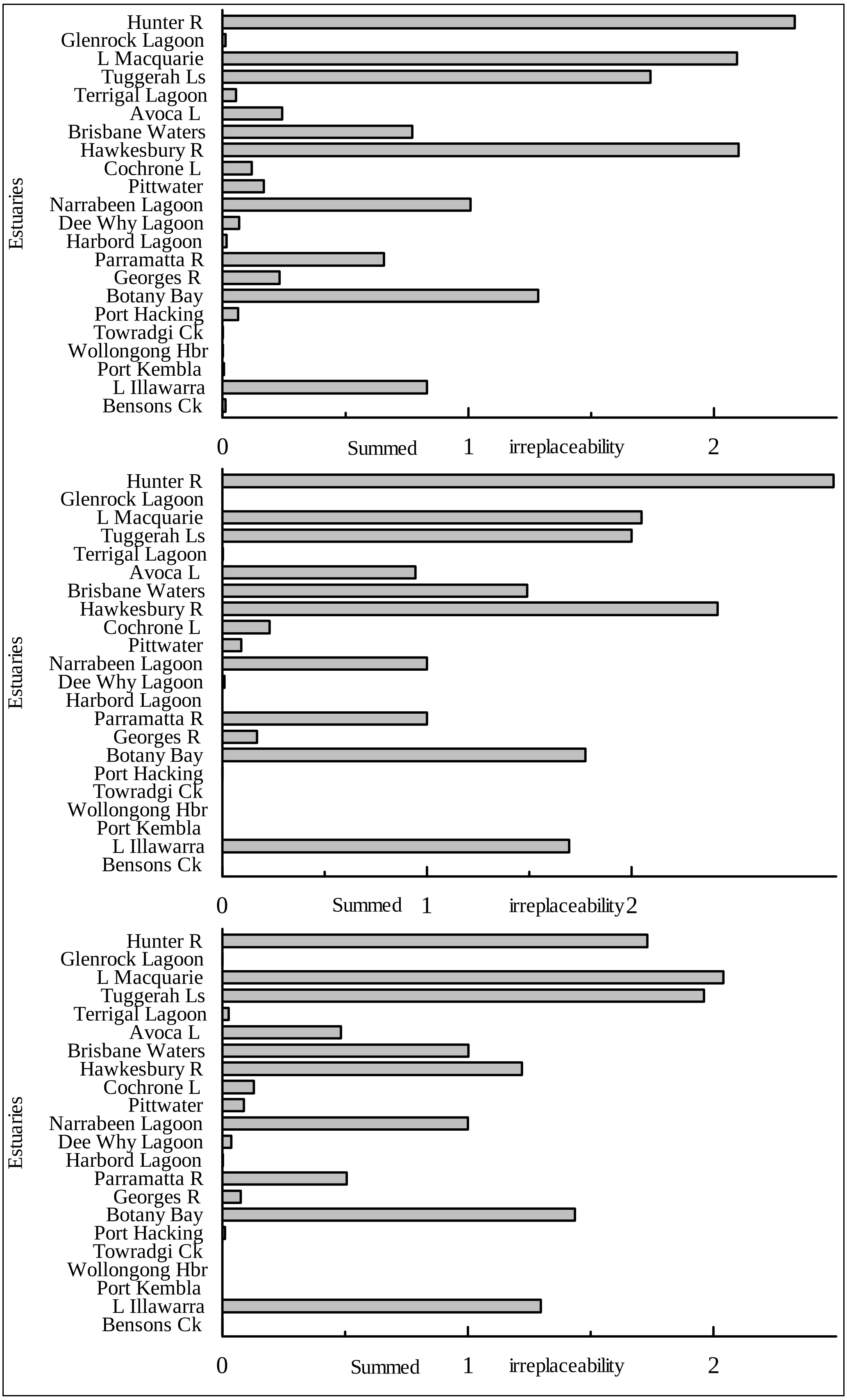


Figure 7.25. Summed irreplaceability scores for estuaries a. assuming there are no existing MPAs; b. allowing for areas in marine parks and aquatic reserves. c. allowing for areas included in marine parks, aquatic reserves, national parks and nature reserves. Values estimated using C-Plan reserve selection software (NPWS 2001).

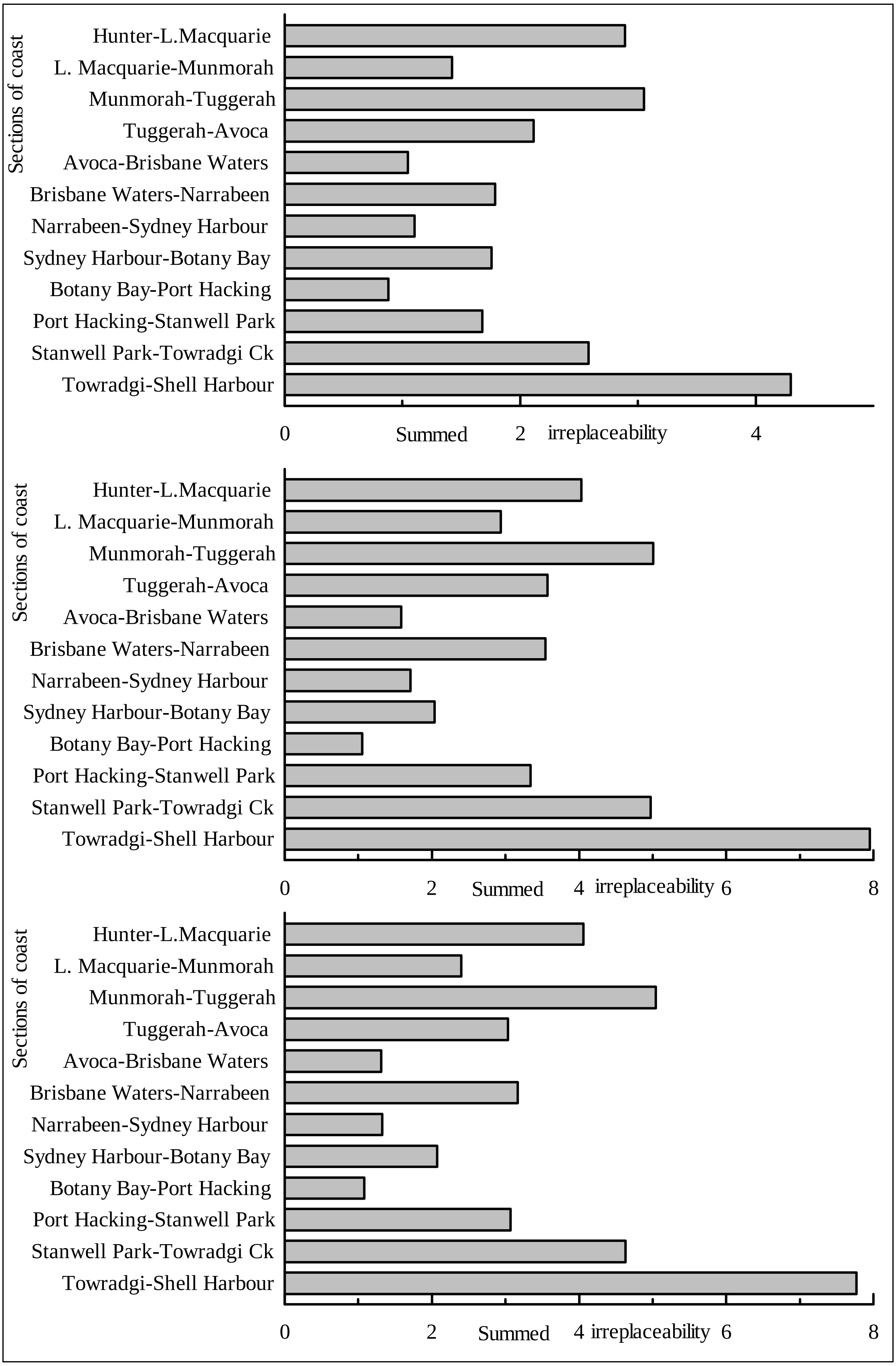


Figure 7.26. Summed irreplaceability scores for sections of coast a. assuming no existing MPAs; b. allowing for areas included in marine parks and aquatic reserves. c. allowing for areas included in marine parks, aquatic reserves, national parks and nature reserves. Values estimated using C-Plan reserve selection software (NPWS[1] 2001).

[1] now within the NSW Department of Environment and Conservation

7.4.13 Estuarine juvenile fish and invertebrate biodiversity

Data source

NSW Fisheries[2], Office of Conservation, Estuarine Fish Biodiversity project funded by the National Heritage Trust (pers. comm. R. Williams, Fisheries, DPI).

Data description

Juvenile fishes and invertebrates were sampled by seine net along estuarine shores in vegetated and bare substrata in 2-3 zones between the estuary mouths and riverine habitats. Currently 500,000 fish from 176 taxa have been collected throughout NSW but the survey has not yet sampled all estuaries or analysed all data.

Identification criterion

Representativeness.

Assessment measures

Summed irreplaceability for representation of at least one of each species.

Assessment

Summed irreplaceability scores for species representation at sites (total catch from five seine hauls) is shown in Figure 7.27a-g. For all sites summed irreplaceability was relatively low (<4) given the high number of species overall (>100). This may be due in part to the low number of hauls per site but may also reflect the widespread occurrence of many species.

The highest values occurred in Tuggerah Lake, Pittwater, Port Jackson, Botany Bay, the Georges River and Port Hacking, but estuaries were not markedly different relative to the amount of variation within estuaries. In addition, there were large variations among estuaries in the number of sites sampled, and these differences were strongly correlated with overall species richness and irreplaceability scores for each estuary. These differences make it difficult to make unbiased comparisons among different estuaries.

[2] now within the NSW Department of Primary Industry

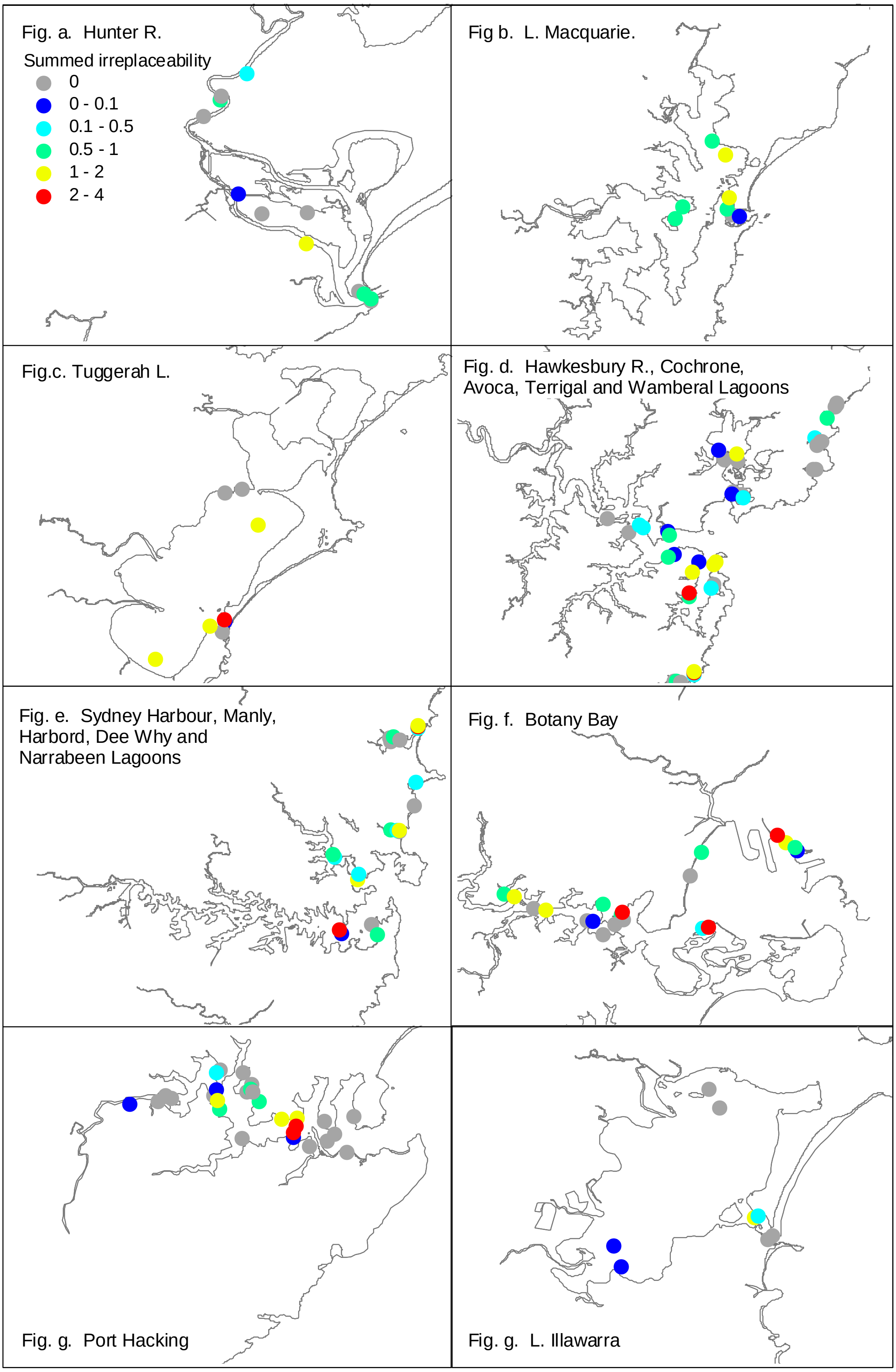


Figure 7.27 a-h. Summed irreplaceability (values from C-Plan, NPWS 2001) for representation of at least one of each species of juvenile fish and invertebrate sampled by seine net (n=5 hauls) along estuary shores in the Hawkesbury Shelf bioregion. Data from Natural Heritage Trust funded, NSW Fisheries[2], Office of Conservation, Estuarine Fish Biodiversity project (pers. comm. R. Williams).

2 now within the NSW Department of Primary Industry

7.4.14 NSW Fisheries[2] commercial catch data

Data Source

NSW Fisheries[2] Commercial catch database.

Tanner and Liggins (1999). "NSW Commercial Fisheries Statistics 1993/94 to 1997/98."

Data description

Commercial fish and invertebrate catch from mandatory catch return forms submitted by commercial fishers.

Criteria

Representativeness, productivity, potential threats and human use.

Assessment measures

Number of species, catch and summed irreplaceability for representation of each species.

Assessment

Summed irreplaceability and the number of species caught commercially in estuaries was highest for the Hawkesbury River and Sydney Harbour. The differences, however, probably reflect the high catches for these areas and the data may also be confounded by catches brought in from other locations.

Summed irreplaceability and the number of species landed at ocean ports was highest for Newcastle and Sydney and again this probably reflects the much greater catch landed at these ports and the potential for catches to be brought in from other fishing areas.

These results should be regarded cautiously given the likely bias in species richness towards areas receiving more catch, and in determining exactly where catch was caught as opposed to landed. More detailed analyses of catch data have been made by Pease (1999).

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[2] now within the NSW Department of Primary Industry

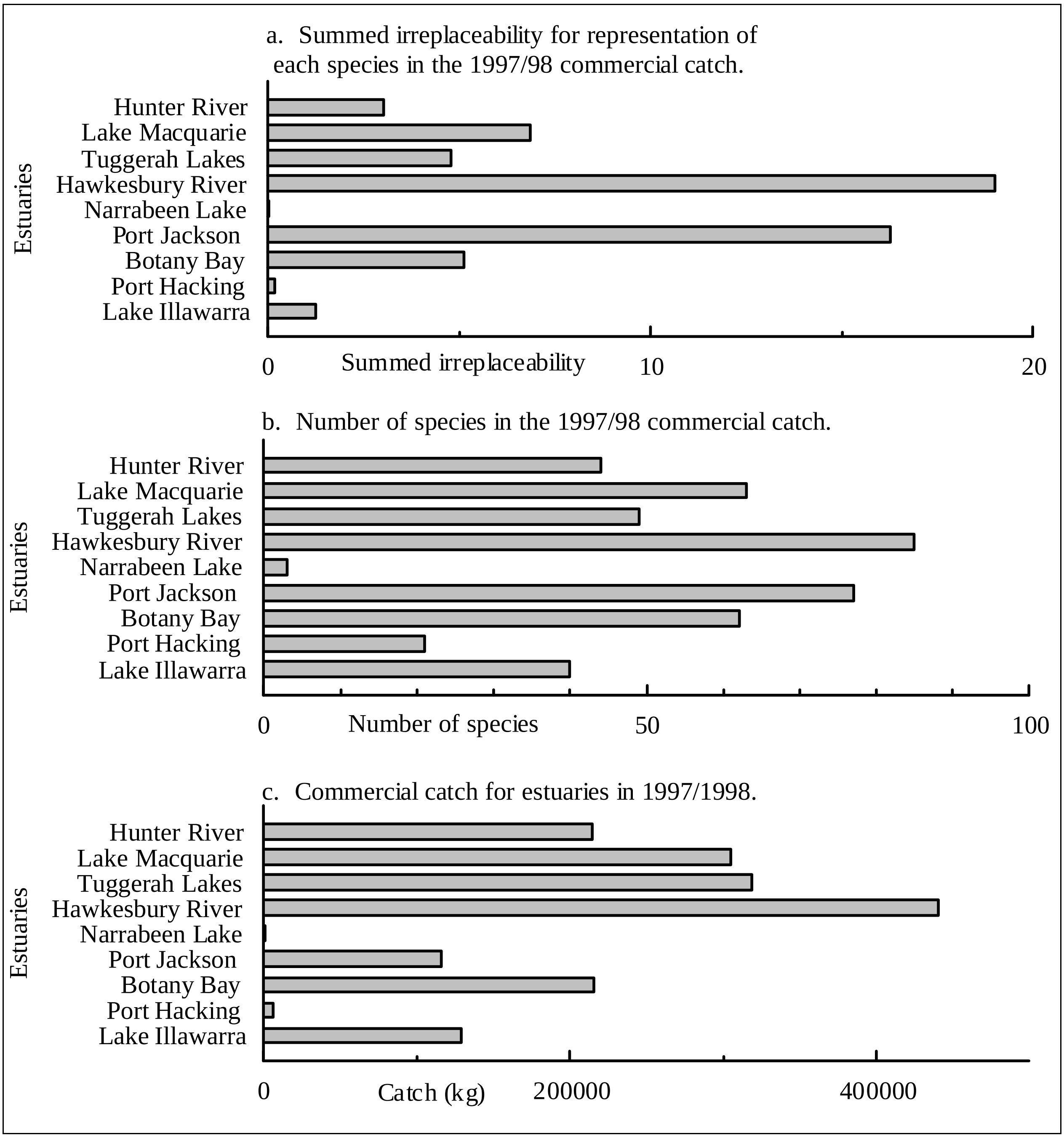

Figure 7.28. Summed irreplaceability (values from C-Plan (NPWS 2001), number of species and weight of commercial catch for estuaries in the Hawkesbury Shelf bioregion in 1997/98. Data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry

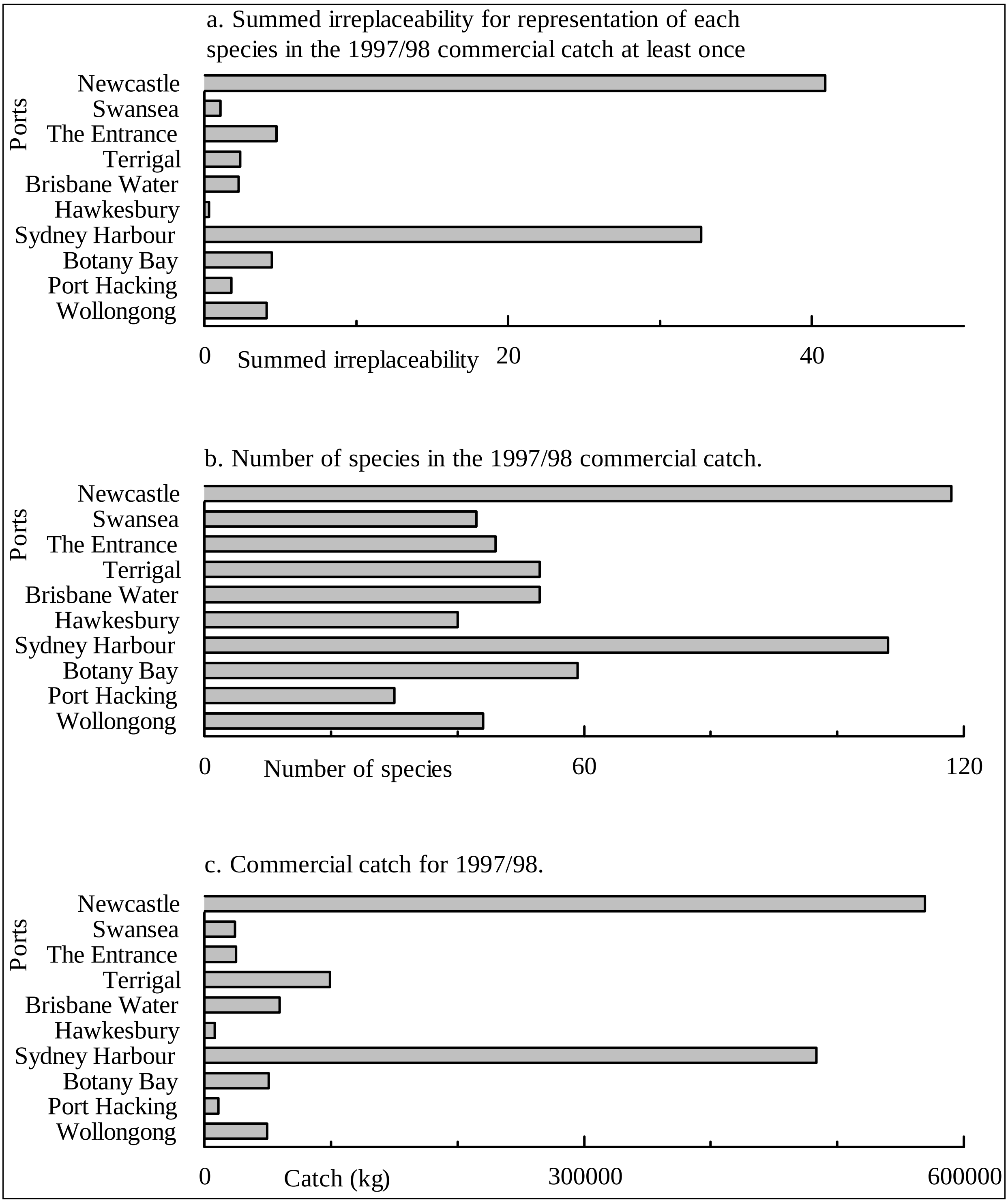

Figure 7.29. Summed irreplaceability (values from C-Plan, NPWS 2001), number of species and weight of commercial catch for ocean ports in the Hawkesbury Shelf bioregion in 1997/98. Data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry

7.4.15 NSW Fisheries[2] threatened species database

Data Source

NSW Fisheries[2] threatened species database.

Data Description

The *NSW Fisheries Management Act 1994* includes provisions to declare threatened species of fish and marine vegetation, endangered populations and ecological communities and key threatening processes. Four marine species have been declared threatened:

- Great White Shark (*Carcharodon carcharias*)
- Grey Nurse Shark (*Carcharias taurus*)
- Black Cod (*Epinephelus daemelii*) and the
- Green Sawfish (*Pristis zijsron*).

Seven other marine species are protected in NSW waters:

- Ballina Angelfish (*Chaetodontoplus ballinae*)
- Bleeker's Devil Fish (*Paraplesiops bleekeri*)
- Common Sea Dragon (*Phyllopteryx taeniolatus*)
- Elegant wrasse (*Anampses elegans*)
- Estuary Cod (*Epinephelus coioides*)
- Herbsts Nurse Shark (*Odontaspis ferox*) and
- Queensland Groper (*Epinephelus lanceolatus*).

Other species protected from commercial fishing include:

- Black Marlin (*Makaira indica*)
- Blue Marlin (*Makaira nigricans*)
- Striped Marlin (*Tetrapturus audax*) and
- Blue Groper (*Achoerodus viridis*).

Criteria

Representativeness

Assessment measure

Descriptive summary

Assessment

Sightings in the NSW threatened species database depend on voluntary reports and are currently limited to 129 records for the Hawkesbury Shelf bioregion. While the data are probably too sparse for quantitative analysis, they provide descriptive, site specific information. Table 7.3 lists sightings of threatened fish species in the Hawkesbury Shelf bioregion.

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[2] now within the NSW Department of Primary Industry

Table 7.3. Sightings of threatened fish species in the Hawkesbury Shelf bioregion.

Species	Nearest town	Plan unit
Black Cod	Norah Head	Munmorah-Tuggerah
	Palm Beach	Brisbane Waters-Sydney
	Sydney	Sydney-Botany Bay
	Coogee	Sydney-Botany Bay
	Cronulla	Botany Bay-P. Hacking
	Lake Illawarra	L. Illawarra
Great White Shark	Coogee	Sydney-Botany Bay
Grey Nurse Shark	Newcastle	Hunter-L. Macquarie
	Terrigal	Tuggerah-Avoca
	Sydney	Sydney-Botany Bay
	Coogee	Sydney-Botany Bay
	Maroubra	Sydney-Botany Bay
Bleeker's Devil Fish	Swansea	Lake Macquarie-Munmorah
	Newcastle	Hunter-Lake Macquarie
	Norah Head	Munmorah-Tuggerah
	Terrigal	Tuggerah-Avoca
	Dee Why	Narrabeen-Sydney Harbour
	Sydney	Sydney-Botany Bay
	Coogee	Sydney-Botany Bay
	La Perouse	Sydney-Botany Bay
	Cronulla	Botany Bay-P. Hacking
	Port Hacking	Port Hacking
Elegant Wrasse	Coogee	Sydney-Botany Bay
	Cronulla	Botany Bay-P. Hacking
Estuary Cod	Coogee	Sydney-Botany Bay
	Cronulla	Botany Bay-P. Hacking
Queensland Groper	Coogee	Sydney-Botany Bay
Weedy Sea Dragon	Terrigal	Tuggerah-Avoca
	Palm Beach	Brisbane Water-Narrabeen
	Sydney	Sydney-Botany Bay
	Coogee	Sydney-Botany Bay
	La Perouse	Sydney-Botany Bay
	Kurnell	Botany Bay-P. Hacking
	Cronulla	Botany Bay-P. Hacking
	Wollongong	Towradgi-Shellharbour

7.4.16 Threatened Grey Nurse Shark (Carcharias taurus)

Data source

A GIS coverage of significant Grey Nurse Shark aggregation sites was prepared from data provided by Otway and Parker (2000), Otway *et al.* (2003) and from unpublished data provided by these authors.

Data description

The Grey Nurse Shark is listed as endangered under the *Fisheries Management Act 1994*. NSW Fisheries[2] staff and volunteer SCUBA divers surveyed approximately 65 sites during 4 week survey periods in each season (Summer, Autumn, Winter, Spring) between November 1998 and October 2000.

Criteria

Representativeness, ecological importance and threatened species.

Assessment measure

Maximum number of sharks observed during surveys and other sites where sharks have been observed in the past.

Assessment

Grey Nurse Sharks have been observed at a number of locations in the Hawkesbury Shelf bioregion (Figure 7.30) but recent surveys have identified Magic Point, off South Maroubra as an important aggregation site. Sharks have been observed here for over 50% of surveys in numbers representing 3.5% of the observed population (NSW Fisheries 2002, NSW Draft Recovery Plan for the Grey Nurse Shark).

In December 2002, NSW Fisheries declared an area of critical habitat 200 m out from the shore at Magic Point, with an 800 m buffer extending beyond this. In the critical habitat and buffer zones commercial fishing by drop, drift or set line is now banned as is any fishing with wire trace from an anchored or moored vessel.

In addition, any fishing with bait in the critical habitat zone from a moored or anchored vessel is prohibited but fishing with lure or fly, trolling (with or without trace), drift fishing with a weight less than 500 grams (with or without trace), or fishing without wire trace from the beach or rocks is allowed. Commercial line fishers are limited to using recreational fishing gear in each critical habitat and buffer zone.

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[2] now within the NSW Department of Primary Industry

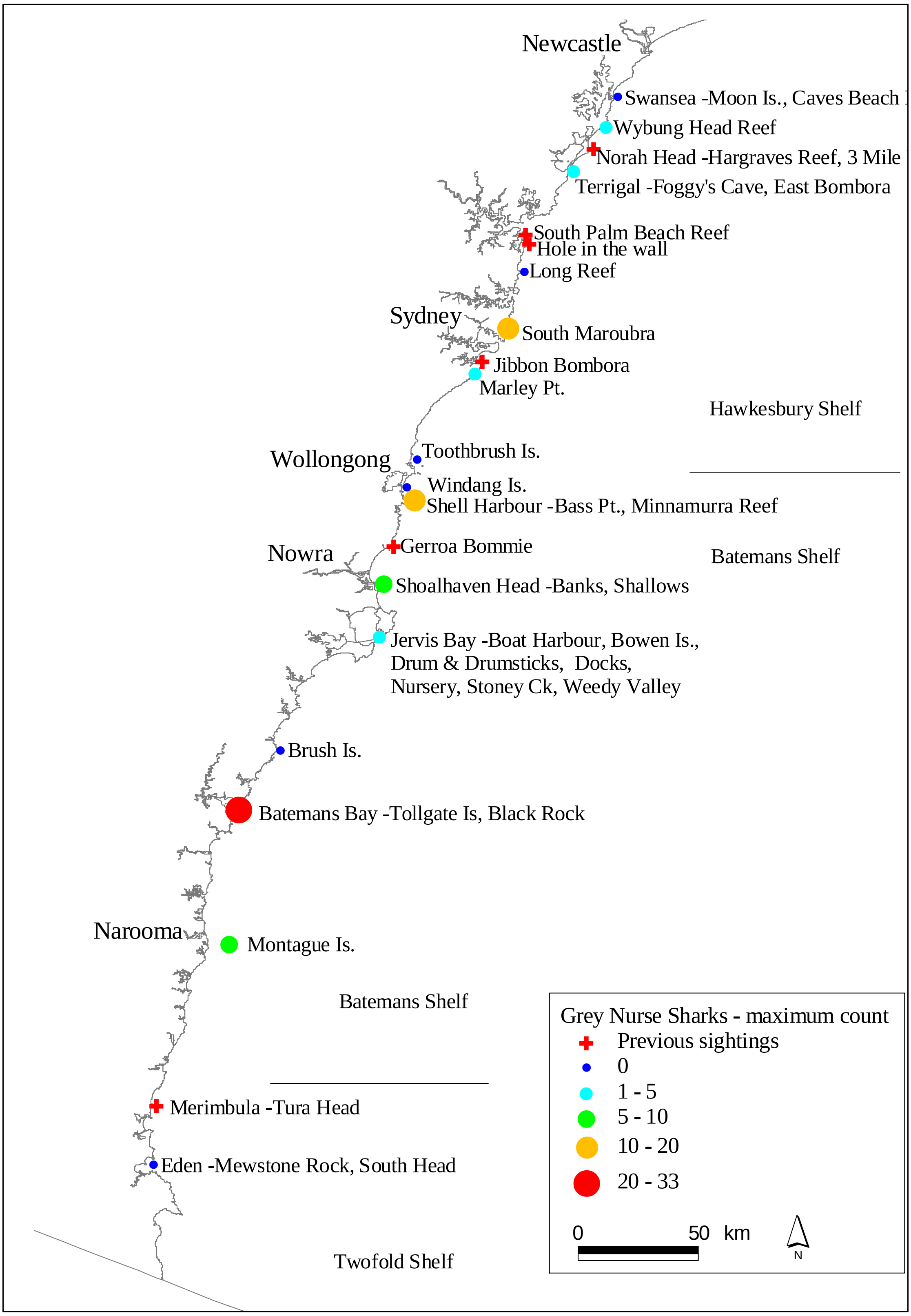

Figure 7.30. Maximum numbers of Grey Nurse Shark (*Carcharias taurus*) observed at dive sites in the Hawkesbury Shelf bioregion during eight survey seasons in 1998 and 2000 and additional previous historical sightings (data from Otway and Parker (2000) and Otway *et al.* (2003)).

7.4.17 Threatened Birds - National Parks and Wildlife Service[1]

Data source

Information on threatened sea bird and wader species was derived from the NSW Wildlife Atlas, threatened species profiles and recovery plans from the NSW National Parks and Wildlife Service[1] (NPWS 1999abc, 2000bcd).

Data description

The NSW Wildlife Atlas records 32 species of waders and sea birds in NSW listed as threatened (i.e. endangered or vulnerable) under the *NSW Threatened Species Conservation Act 1995*. Of these, 30 have been recorded from the Hawkesbury Shelf bioregion (Table 7.4), with five species and one population listed as endangered. One endangered species, the Little Tern, has a significant nesting site at Towra Spit, Botany Bay and a history of nesting at other locations in the bioregion.

Table 7.4. Threatened intertidal waders and sea birds

Endangered	
Beach Stone-curlew *Esacus neglectus*	Little Tern *Sterna albifrons*
Bush Stone-curlew *Burhinus grallarius*	Hooded Plover *Thinornis rubricollis*
Gould's Petrel *Pterodroma leucoptera*	Little Penguin *Eudyptula minor* - North Sydney Harbour population
Vulnerable	
Australasian Bittern *Botaurus poiciloptilus*	Osprey *Pandion haliaetus*
Black Bittern *Ixobrychus flavicollis*	Painted Snipe *Rostratula benghalensis*
Black-browed Albatross *Diomedea melanophrys*	Pied Oystercatcher *Haematopus longirostris*
Black-tailed Godwit *Limosa limosa*	Providence Petrel *Pterodroma solandri*
Black-winged Petrel *Pterodroma nigripennis*	Red-tailed Tropicbird *Phaethon rubricauda*
Broad-billed Sandpiper *Limicola falcinellus*	Sanderling *Calidris alba*
Flesh-footed Shearwater *Puffinus carneipes*	Shy Albatross *Diomedea cauta*
Great Knot *Calidris tenuirostris*	Sooty Albatross *Phoebetria fusca*
Greater Sand Plover *Charadrius leschenaultii*	Sooty Oystercatcher *Haematopus fuliginosus*
Grey Ternlet *Procelsterna cerulea*	Sooty Tern *Sterna fuscata*
Kermadec Petrel *Pterodroma neglecta*	Terek Sandpiper *Xenus cinereus*
Lesser Sand Plover *Charadrius mongolus*	White Tern *Gygis alba*
Little Shearwater *Puffinus assimilus*	

Assessment

Little Tern (Sterna albifrons subspecies *sinensis)*

Habitat requirements and threats for this species are described in section 6.4.13. While no areas of critical habitat for Little Terns have yet been listed under the *Act (1995),* Botany Bay has been identified as a significant nesting site. As the condition and location of nesting habitats can vary greatly over different years, areas of critical habitat will need to be reviewed regularly. The recovery plan for the Little Tern includes provision for exploring and implementing

[1] now within the NSW Department of Environment and Conservation

opportunities for the creation and enhancement of Little Tern nesting habitat. Table 7.5 lists historical nesting sites of Little Tern with the largest and most recent nesting records. Other sightings of Little Terns have been recorded from the Hunter River, Lake Macquarie, Tuggerah Lakes, Long Reef, Brisbane Water, Parramatta River, East Sydney, Botany Bay and Lake Illawarra.

The most significant colony in the Hawkesbury Shelf bioregion was previously located on the northern side of Botany Bay but was relocated to Towra Spit Island in 1993/94 to make way for a third runway at Sydney Airport (NPWS 2000d). This area is currently included in the Towra Point Aquatic Reserve and lies adjacent to the Towra Point Nature Reserve.

Gould’s Petrel

Gould's Petrel (*Pterodroma leucoptera*) breeds on Cabbage Tree and Boondelbah Islands off the coast of Port Stephens in the Manning Shelf bioregion. They do however, forage widely in the Tasman Sea and have been recorded as far north as the Queensland border and west as far as Eyre in Western Australia. The species feeds primarily on surface fish, small squid and krill (NPWS 2000c).

Cabbage Tree and Boondelabah Islands are protected within John Gould Nature Reserve and Boondelbah Nature Reserve. Sightings in the Hawkesbury Shelf bioregion include the Hawkesbury River, Port Jackson, Boat Harbour (south of Botany Bay) and Wollongong.

Table 7.5. Nesting sites of Little Tern in the Hawkesbury Shelf (NPWS 2000d).

Nesting site	Last Record	Largest colony recorded
Hunter River	1972/73	7 pairs 1932/33
Redhead	pre 1969	No data
Swansea	1959/60	4 pairs 1959/60
Budgewoi	1960's	no data
The Entrance	1994/95	2 pairs 1994/95
Dee Why Lagoon	1947/48	2-3 pairs 1947/48
Homebush Bay	1964/65	1 pair 1964/65
Maroubra	1943/44	1 pair 1943/44
Botany Bay	1996/97	60 pairs 1996/97
Boat Harbour	1958/59	4-5 pairs pre-1950
Bellambi Point	1977/78	20 pairs 1964/65
Towradgi Beach	pre 1950	no data
South Wollongong Beach	1984-85	50 pairs 1956/57
Port Kembla Harbour	1965/66	50 pairs 1955/56
Port Kembla Beach	pre 1977	A few pairs pre 1977
Lake Illawarra	1978/79	1 pair 1978/79
Shellharbour	1978/79	1 pair pre 1978/79

Beach Stone-curlew

The Beach Stone-curlew (*Esacus neglectus*) was known from around northern Australia as far south as the Manning River, but has largely disappeared from the south eastern extent of its range. It has been estimated that the current Australian population may be as few as 15 breeding pairs. It occurs on open undisturbed beaches, islands, reefs, rock platforms and intertidal sand and mud flats in estuaries and near river mouths. Its diet includes crabs and other marine invertebrates. Threats to this species include loss of habitat to development, human disturbance from sources including four wheel driving and boating, predation by raptors, cats, dogs and pigs, high tides and nest desertion (NPWS 1999a).

Sightings in the Hawkesbury Shelf include the Sydney area and a recent sighting in Cabbage Tree Basin in Port Hacking. A recovery plan has not yet been prepared for this species.

Bush Stone-curlew

The Bush Stone-curlew (*Burhinus grallarius*) is widespread throughout northern Australia and was once widespread along the east coast of NSW including much of the Cumberland plain and in the Tweed, Brunswick, Richmond, Clarence, Macleay, Manning and Hunter Valleys.

However, recently the east coast NSW population appears to be restricted to areas near Gosford (near Brisbane Water), Port Macquarie, Grafton, Port Stephens and Karuah.

This species is generally found in open woodland and feeds on insects, molluscs, centipedes, crustaceans, frogs, lizards, snakes and some vegetation. Threats include loss of habitat (including fallen woody debris), altered fire regimes, disturbance from humans, cultivation, over grazing and forestry, poison rabbit baits and predation by foxes, pigs, dogs and cats (NPWS 1999b). Most sightings in the Hawkesbury Shelf bioregion have been recorded from around Brisbane Water but there are also reports from near Tuggerah Lakes, Pittwater, the Georges River, Towra Point in Botany Bay and Cabbage Tree Basin in Port Hacking. A recovery plan is being prepared for this species.

Hooded plover

The hooded plover (*Thinornis rubricollis*) occurs throughout south eastern and south western Australia. Within NSW, it occurs south of Jervis Bay but was known previously as far north as Port Stephens and has occasionally been sighted in Wollongong and Sydney. In Australia, this species is found mostly on long stretches of sandy shore adjacent to lagoons and nesting on sparsely vegetated sand dunes. Its diet consists of marine worms, molluscs, crustaceans, insects, water plants and seeds. Threats include predation by silver gulls, foxes and raptors, loss of habitat to development, destruction of nests by stock and disturbance during the breeding season from humans and four drive driving in dune areas (NPWS 1999c). A recovery plan has not yet been prepared for this species.

Little Penguin

The Little Penguin (*Eudyptula minor*) colony at North Sydney Harbour is the only known breeding colony in mainland NSW. This colony has been listed as an endangered population. Known nesting areas, possible foraging habitat (seagrass beds in Spring Cove), potential nesting areas (Dobroyd Head, Cannae Point and parts of Little Manly Cove) and aquatic habitat 50 m seaward of the mean high water have been declared critical habitat (Figure 7.31, NPWS 2000b).

Little Penguins are found only in Australia and New Zealand and breed from south of Port Stephens, through Victoria, Tasmania and South Australia to as far west as Freemantle in Western Australia. In the Hawkesbury Shelf bioregion breeding sites include North Sydney Harbour, Lion Island in the Hawkesbury River (300), and the Five Islands off Wollongong (1,500). Throughout NSW there are thought to be around 49,000 breeding pairs at 22 sites including Montague Island (~5,000) Tollgate Island (~5,000) Brush Island (2,500) South Solitary Island, Cabbage Tree Island (100) and Boondelbah Island off Port Stephens. Larger populations are present at Gabo Island (18,000) and Phillip Island (12,000) in Victoria and St Helens Island in Tasmania (15,000).

Nesting occurs in 60-80 cm burrows on the shore in sand dunes, rock piles, sea caves and under houses and over hanging vegetation. Foraging occurs generally within 10-30 km of the colony for adults but dispersal of immature birds occurs over hundreds of kilometres. Their diet includes mainly small schooling fish like anchovies (*Engraulis australis*), pilchards (*Sardinops neopilchardus*), blue sprat (*Spratelloides delicatulus*), common hardyhead (*Atherinomorus ogilbyi*), small mouthed hardy head (*Atherinomorus sp*.), southern herring (*Herklotsichthys castelnaui*), bulls eye (*Priacanthus spp*.), squid and krill (NPWS 2000b).

Threats include predation by dogs, cats and foxes, disturbance from humans and boat traffic, loss of nesting habitat to development, pollution and the potential effects of commercial fishing (NPWS 2000b).

Within critical habitat areas in North Sydney Harbour, interfering with penguins or nests is illegal and pets are not permitted. No fishing is allowed between sunset and sunrise during the breeding season (July 1 to February 28) and anchoring restrictions apply (Figure 7.31). North Sydney Harbour Aquatic Reserve includes most of the critical habitat and restricts recreational fishing and spear fishing but permits commercial haul netting in some areas.

Surveys between 1997 and 2000 indicate a minimum of 50 breeding pairs around North Sydney Harbour. Mainland colonies in the Hawkesbury Shelf bioregion have previously been recorded from Cape Banks in Botany Bay, Avoca Beach and West Head in the Hawkesbury River. Foraging Little Penguins have been reported from inside and outside Sydney Harbour, the Hawkesbury River, Botany Bay, Port Hacking, Wollongong and between the Hunter River and Tuggerah Lakes.

Other threatened bird species

For estuaries, most threatened bird species were sighted at Tuggerah Lakes, Parramatta River, Botany Bay, Hunter River and Lake Illawarra. Most sightings occurred in the Hunter River and Lake Illawarra and the highest summed irreplaceability occurred in Tuggerah Lakes and the Parramatta River (Figure 7.32).

For sections of coast and ocean most threatened bird species were sighted in the Botany Bay-Port Hacking and Sydney Harbour-Botany Bay sections, with most sightings and the highest summed irreplaceability in the Botany Bay-Port Hacking section (Figure 7.33).

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Figure 7.31. Critical habitat for the Little Penguin in North Sydney Harbour (NPWS 2000b).

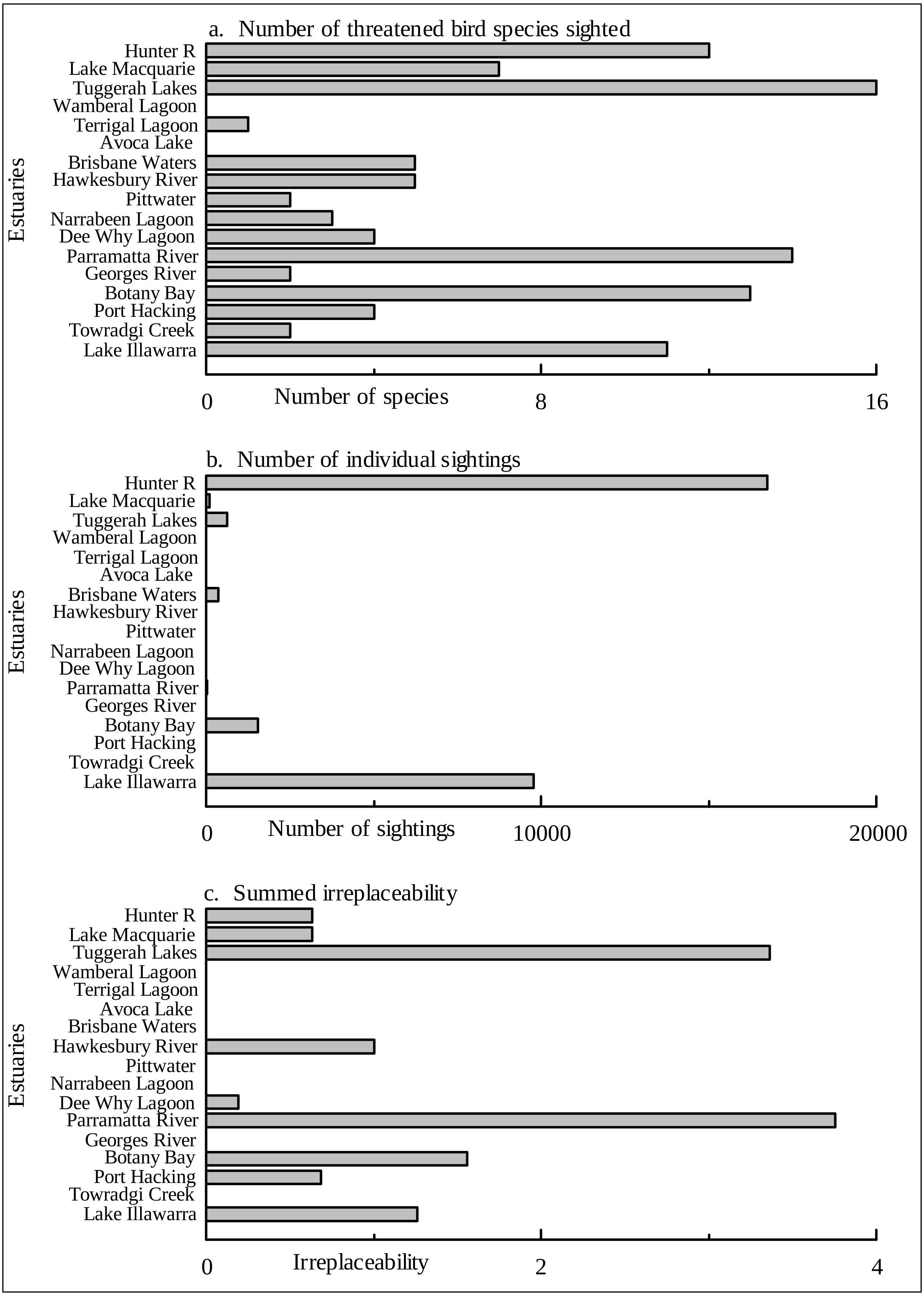

Figure 7.32. Number of threatened bird species sighted, number of sightings and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for estuaries in the Hawkesbury Shelf bioregion (Data from NPWS Wildlife Atlas).

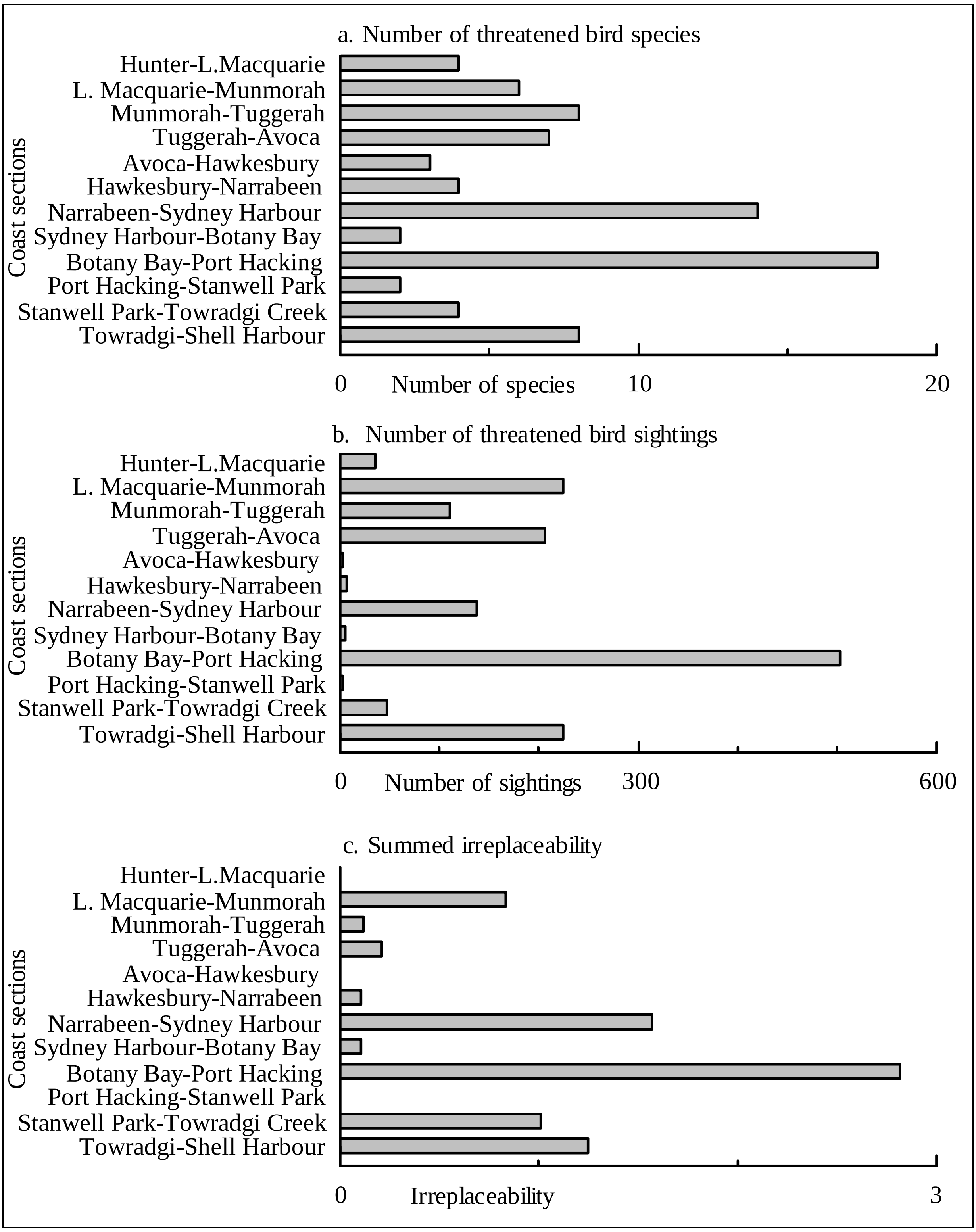

Figure 7.33. Number of threatened bird species sighted, number of sightings and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for sections of ocean and coast in the Hawkesbury Shelf bioregion (Data from NPWS Wildlife Atlas).

7.4.18 Significant areas for shore birds and sea bird islands

Data source

Commonwealth Department of Environment and Heritage (formerly Environment Australia).

Data description

GIS shape files and data tables for areas considered by Wetlands International (Oceania) as significant for shore birds and islands for which Environment Australia has breeding records.

Criteria

Representativeness, threatened species and ecological importance.

Assessment Measures

Area of habitat, number of species, number of birds and summed species irreplaceability.

Data assessment

Lake Macquarie and Tuggerah Lakes had the most nearby area declared as significant for shore birds but the Hunter River had by far the greatest number of shore birds, shore bird species, and summed irreplaceability for representation of each species at least once. Significant shore bird areas also occurred in the Parramatta River and Botany Bay (Figure 7.34).

The Towradgi-Shellharbour section of ocean and coast included the most sea bird islands in the Hawkesbury Shelf bioregion and the most nesting seabirds, seabird species, and summed irreplaceability for representation of each species once. Sea bird breeding islands were also found between Lake Macquarie and Tuggerah Lakes and in the Hawkesbury River (Figure 7.35).

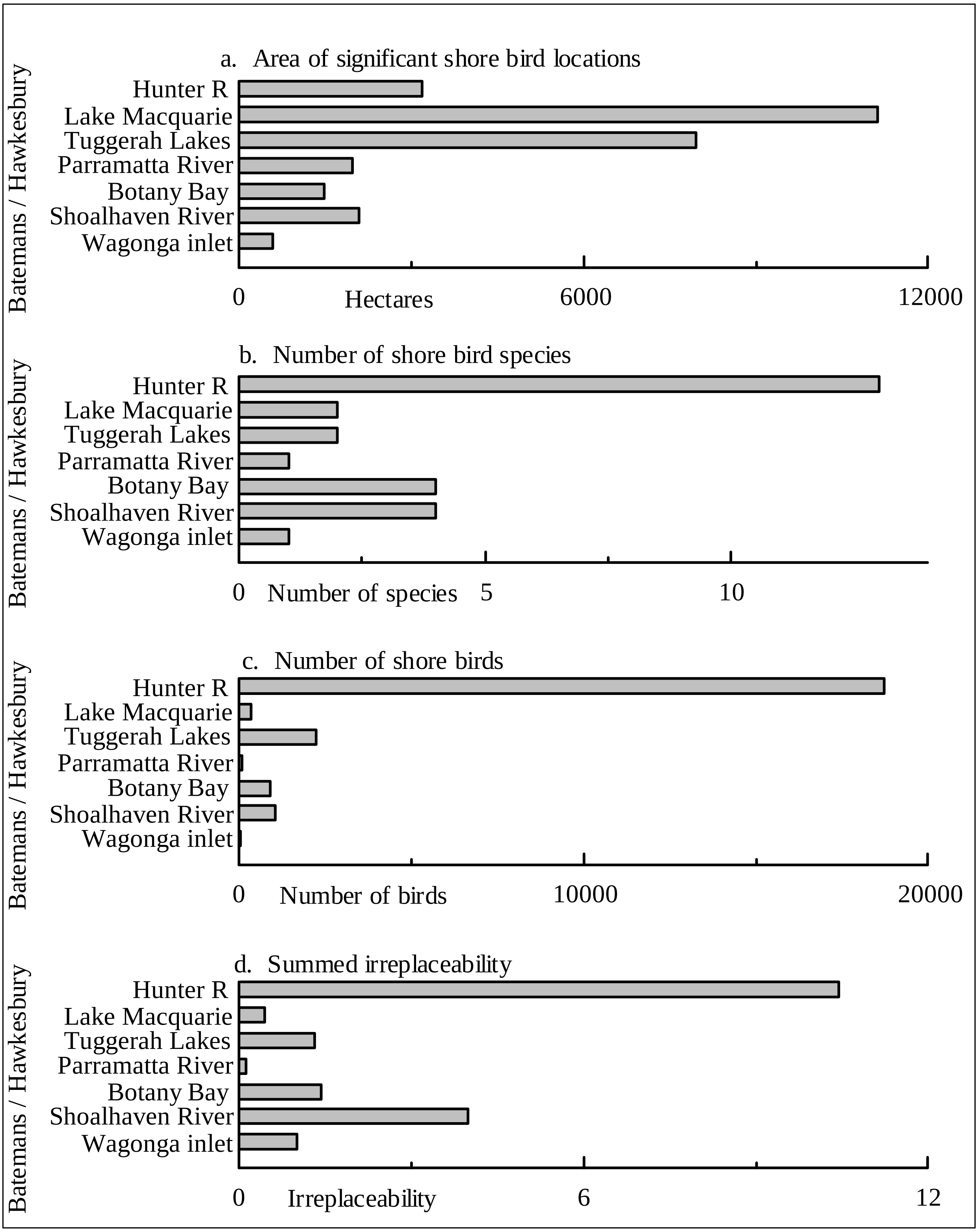

Figure 7.34. Area, number of species, number of birds and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for significant shore bird locations in the Hawkesbury and Batemans Shelf bioregions (data from the Department of Environment and Heritage).

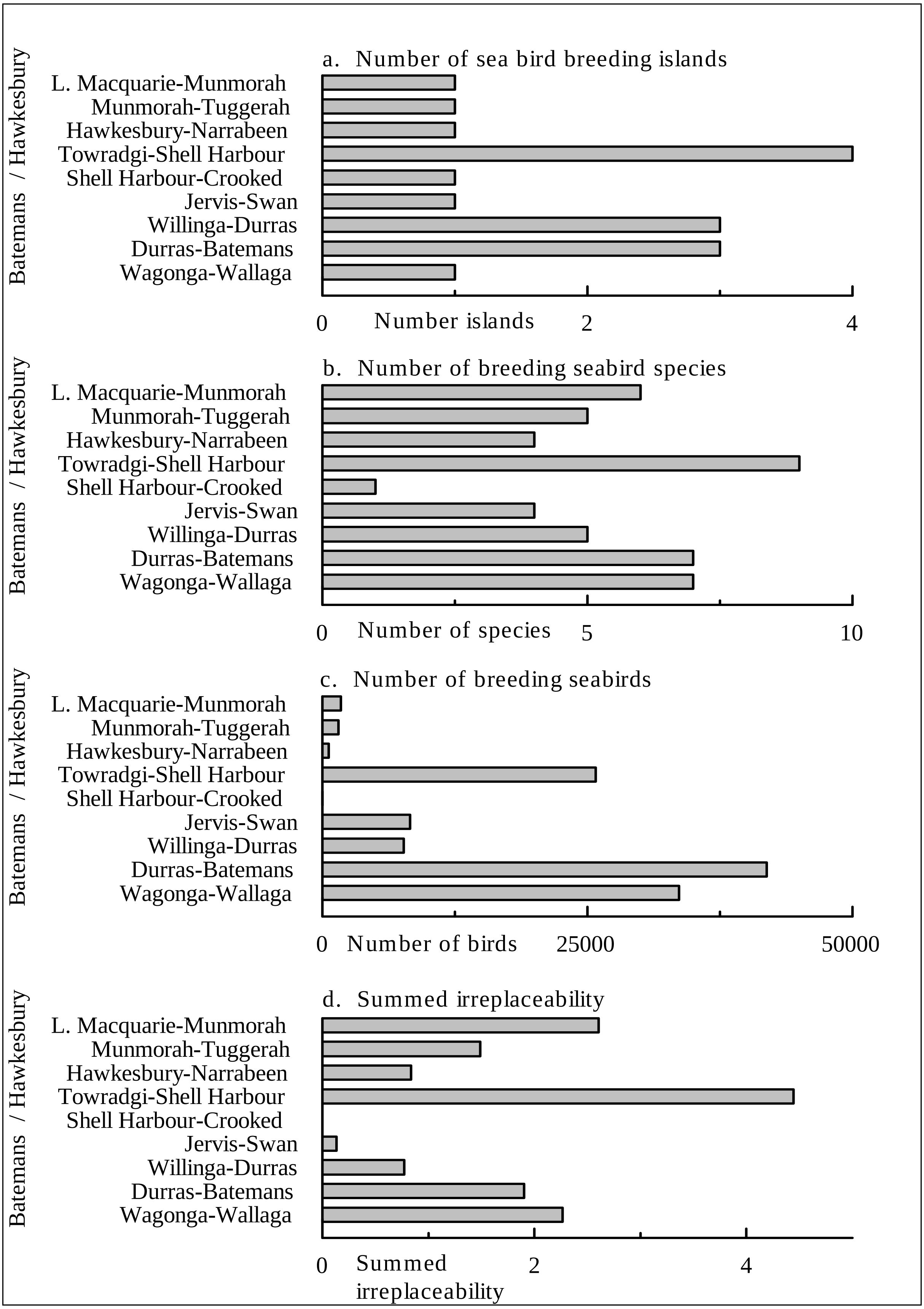

Figure 7.35. Area, number of species, number of birds and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for sea bird breeding islands in the Hawkesbury and Batemans Shelf bioregions (data from the Department of Environment and Heritage).

7.4.19 Marine mammals and reptiles

Data sources

Species of National Significance database from the Department of Environment and Heritage.

Transport Safety Bureau's "NSW Oil Spill Response Atlas" version 2.2 (CD-ROM June 2000).

Data Description

The database held by Environment Australia holds broad scale distribution maps and taxonomic, ecological and management information about Species of National Environmental Significance. The Oil Spill Response Atlas includes sightings data for marine mammals.

Criteria

Representativeness and threatened species.

Assessment measures

Descriptive summary.

Assessment

Marine mammals of national significance with mapped distributions that include the Hawkesbury Shelf bioregion include the Humpback whale (*Megaptera novaeangliae*), Southern Right whale (*Eubalaena australis*), Sei whale (*Balaenoptera borealis*), Fin whale (*Balaenoptera physalus*), Blue whale (*Balaenoptera musculus*), and the Dusky dolphin (*Lagenorhynchus obscurus*). Marine reptiles of national significance with distributions that include the bioregion are the Green turtle (*Chelonia mydas*), Leatherback turtle (*Dermochelys coriacea*), Elegant sea snake (*Hydrophis elegans*), and the Yellow Bellied sea snake (*Pelamis platurus*). The distributions of these species extend well beyond NSW and several are at the limit of their range (Gill *et al*. 2000).

The NSW Oil Spill Response Atlas includes 1002 sightings of marine mammals in the bioregion including Humpback whale, False Killer whale (*Pseudorca crassidens*), Killer whale (*Orcinus orca*), Blaineville's Beaked whale (*Mesoplodon densirostris*), Andrew's Beaked whale (*Mesoplodon bowdoini*), Gray's Beaked whale (*Mesoplodon grayii*), Strap-tooth Beaked whale (*Mesoplodon layardi*), Long Finned pilot whale (*Globicephala melas*), Melon-head whale (*Peponocephala electra*), Minke whale (*Balaenoptera acutorostrata*), Pygmy Sperm whale (*Kogia breviceps*), Dwarf Sperm whale (*Kogia simus*), Sperm whale (*Physeter macrocephalus*), Short-finned pilot whale (*Globicephala macrorhynchus*), Southern Right whale (*Eubalaena australis*), Bottlenose dolphin (*Tursiops truncatus*), Common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), Spotted dolphin (*Stenella attenuata*), Striped dolphin (*Stenella coeruleoalba*), Rough Toothed dolphin (*Steno bredanens*), Dugong (*Dugong dugon*), Leopard seal (*Hydrurga leptonyx*), Australian Fur seal (*Arctocephalus pusillus*), New Zealand Fur seal (*Arctocephalus forsteri*), Subantarctic Fur seal (*Arctocephalus tropicali*) Australian Sea-lion (*Neophoca cinerea*) and Southern Elephant seal (*Mirounga leonina*). Again, these mammals range beyond the bioregion and several are at the limit of their range.

Most sightings occurred in the Tuggerah-Avoca (170), Stanwell Park-Towradgi (121), Hawkesbury River (89), and Munmorah-Tuggerah (78) broad scale plan units. Most species were sighted in the Stanwell Park-Towradgi (17 species) planning unit but all other units included sightings of 11-16 species.

A number of species are relatively common throughout the bioregion. Humpback whales are regularly observed off the NSW coast in June and July migrating to winter breeding grounds off Queensland and returning south between October and November to feeding areas in colder waters. This east Australian population of humpbacks was estimated to have declined from 10,000 to 500 whales during the first half of the 20th century but is now increasing (Baker 1983, Paterson and Paterson 1989, Smith 1997). These whales often pass close to the coast, particularly near prominent headlands, and whale watching tourism is becoming established in several ports.

7.4.20 RAMSAR sites - Nationally and Internationally important wetlands

Data Source

GIS layer of RAMSAR sites mapped from official descriptions

Data Description

The RAMSAR Convention on Wetlands is an intergovernmental treaty signed by 123 parties for the conservation and wise use of wetlands. Contracting parties designate wetlands for inclusion in a List of Wetlands of International Importance. Criteria for identifying RAMSAR sites include representativeness and uniqueness of wetlands, the flora and fauna present (including ‘fish habitat values’) and specific criteria for waterfowl.

Criteria

Representativeness and threatened species.

Assessment measures

Presence and area of RAMSAR sites.

Assessment

One RAMSAR internationally important wetland occurs in the Hawkesbury Shelf bioregion at Kooragang Nature Reserve (including Fullerton Cove, Hexham Swamp and Kooragang Island) and at Towra Point (Figure 7.2). This important site and its significance is discussed in greater detail in Appendix 3.

7.4.21 Directory of important wetlands in Australia

Data Source

GIS layer of wetlands mapped from the description provided in the Directory.

Data Description

The "Directory of Important Wetlands" (ANCA 1996) is a cooperative project between the Commonwealth, State and Territory Governments of Australia, coordinated by the Department of Environment and Heritage to identify nationally important wetlands. The wetlands in the Hawkesbury Shelf and other marine bioregions were mapped in a GIS for these assessments.

The wetlands listed in the Directory are those which meet the criteria of national importance as revised by the ANZECC Wetlands Network in August 1994. All wetlands which meet the criteria have been listed, not just the best representatives of a wetland type. Criteria used to assess Important Wetlands include, is the wetland:

- a good example of a wetland type occurring in the bioregion
- important ecologically or hydrologically in the natural functioning of a major wetland system/complex
- important as habitat for animal taxa at a vulnerable stage of their life cycle, or does it provide refuge in adverse conditions such as drought
- supporting 1% or more of the national population of any plant or animal taxa
- supporting native plant, animal taxa or communities considered endangered or vulnerable at a national level and
- of outstanding historical or cultural significance.

Criteria

Representativeness and International or National Importance.

Assessment measures

Presence of nationally important wetlands.

Assessment

Table 7.6 lists the locations of important wetlands in the Hawkesbury Shelf bioregion and these areas are mapped in Figure 7.2. Detailed descriptions of wetland geomorphology and community ecology were used to support the options for MPAs described in Section 7.5 and Appendix 3.

Table 7.6. Important Wetlands in the Hawkesbury Shelf bioregion (ANCA 1996)

Wetland name	Location description
Kooragang Nature Reserve	Tidal and intertidal wetlands on the north side of the Hunter River.
Hexham Swamp	Largest wetland in the Hunter region at the confluence of Ironbark Creek and the Hunter River, 12 km upstream from Newcastle.
Colongra Swamp	On the western side of lake Munmorah near the Lake Munmorah Power Station inlet channel.
Budgewoi Lake Sand Mass	The Budgewoi sand mass is the site of a former entrance to Tuggerah Lakes which was filled in by heavy seas. The site lies on the eastern side of Budgewoi Lake.
Tuggerah Lake	On the NSW Central Coast between The Entrance and Toukley.
Brisbane Water Estuary	Brisbane Water is a relatively small (27 square kilometre) broad, shallow estuary connected to Broken Bay through a narrow channel.
Newington Wetlands	Mangrove and saltmarsh on the Parramatta River, 1 km west of Homebush Bay.
Botany Wetlands	Northern shore of Botany Bay, Sydney, from Gardeners Road at Mascot to the Bay. Includes the Lachlan Swamps, Mill Pond, Mill Stream and Engine Pond.
Eve Street Marsh	Low lying coastal floodplain off the Cooks River at Arncliffe
Towra Point Nature Reserve and Aquatic Reserve and Taren Point	Towra Point Nature Reserve, Towra Point Aquatic Reserve, Taren Point, and estuarine wetlands associated with Woolooware Bay and Quibray Bay. Located on the southern shore of Botany Bay.
Lake Illawarra	Shallow estuary approximately 8 km south of Wollongong.
Five Islands Nature Reserve	Approximately 500 m off the coast near Port Kembla.
Coomaditchy Lagoon	A small coastal lake between dunes at the original entrance to Lake Illawarra.

7.4.22 Independent inquiry into coastal lakes

Data Source

"Independent public inquiry into coastal lakes: final report" (Healthy Rivers Commission of NSW, April 2002a).

Data Description

The classification assesses lakes for their "natural sensitivity, current condition of the water body and catchment, and recognised ecosystem and resource conservation values." The classification also takes into account existing settlement, resource use, government and court decisions, potential for restoration and development of other lakes in the region.

Assessments were influenced by the availability of information but were informed by data analysed by the Department of Land and Water Conservation in its "Estuaries Inventory", the Commonwealth Government's "National Land and Water Resources Audit" and additional data from universities, independent experts, state agencies, councils and submissions made to the Coastal Lakes Inquiry.

Criteria

Representativeness, uniqueness, threatened species, naturalness, vulnerability, management practicality and human use.

Assessment measures

Qualitative ranks for natural sensitivity, existing catchment and lake condition, recognised conservation value, potential to improve and orientation for management.

Assessment

The assessment examined twelve coastal lake systems in the Hawkesbury Shelf bioregion. Its results are summarised in Table 7.7.

Table 7.7. Classification of coastal lakes in the Hawkesbury Shelf bioregion (Healthy Rivers Commission 2002a).

Coastal Lake	Natural Sensitivity	Existing Condition		Conservation Value	Management Orientation
		Catchment	Lake		
Macquarie	High	Modified	Severely affected	High	Targeted Repair
Tuggerah	Extreme	Modified	Moderately affected	High	Targeted Repair
Wamberal	High	Severely Modified	Severely affected	Low	Healthy Modified Condition
Terrigal	Extreme	Severely Modified	Severely affected	Low	Targeted Repair
Avoca	Extreme	Modified	Moderately affected	Low	Healthy Modified Condition
Cockrone	Extreme	Modified	Moderately affected	Low	Healthy Modified Condition
Narrabeen	Very High	Severely Modified	Moderately affected	Moderate	Healthy Modified Condition
Dee Why	Extreme	Severely Modified	Severely affected	Low	Targeted Repair
Curl Curl	Extreme	Severely Modified	Severely affected	Low	Targeted Repair
Manly	Extreme	Severely Modified	Severely affected	Low	Targeted Repair
Bellambi	Extreme	Modified	Unknown	Low	Targeted Repair
Illawarra	High	Modified	Severely affected	High	Targeted Repair

7.4.23 Environmental inventory of estuaries and coastal lagoons

Data source

Bell and Edwards (1980). "An inventory of estuaries and coastal lagoons in NSW."

Data description

Bell and Edwards (1980) conducted inventories of estuaries in NSW including a description of recreation/tourism significance, degree of disturbance, area, mean annual rainfall, mean annual runoff and conservation features. While these data may not be current in regard to coastal development and catchment use, they provide a relative measure of differences among estuaries and a useful check against more recent inventories.

Criteria

Naturalness and vulnerability.

Assessment measures

Qualitative score between 1-4 for shore/water disturbance and for catchment disturbance.
Verbal description of conservation and human-use values and threats.

Assessment

Scores for disturbance of shore and water range in the Hawkesbury Shelf bioregion are moderate to high for most estuaries with the exception of Port Hacking and Wattamolla Lagoon. Table 7.8 lists scores for twenty two estuaries.

Table 7.8. Disturbance scores for estuaries in the Hawkesbury Shelf bioregion
(0-Very Low to 5-Very High, Bell and Edwards 1980)

Estuary	Shore and water	Catchment
Hunter River	4	3
Lake Macquarie	3	2
Lake Munmorah	4	4
Tuggerah Lake	3	2
Wamberal Lagoon	4	4
Terrigal lagoon	4	4
Avoca Lake	4	4
Cockrone Lake	3	2
Brisbane Water	4	3
Hawkesbury River	2	3
Pittwater	3	2
Narrabeen Lagoon	3	3
Dee Why lagoon	3	4
Harbord Lagoon	4	4
Manly Lagoon	4	4
Port Jackson	4	4
Botany Bay	4	4
Georges River	3	3
Port Hacking	2	2
Wattamolla Lagoon	1	1
Port Kembla	4	4
Lake Illawarra	4	3

7.4.24 Australian Estuaries and the OzEstuaries database

Data source

"Australian estuarine database" (Digby *et al.* 1998).

"Australian estuaries and coastal waterways: a geoscience perspective for improved and integrated resource management" (Heap *et al.* 2001).

Data description

The OzEstuaries database combines data from the Australian estuarine database from Digby *et al*. (1998), with new data acquired for the Natural Land and Water Resources Audit (Heap *et al.* 2001). The new data includes geometrical measurements, facies (habitat) areas, denitrification rates and efficiencies, sedimentation rates and sediment TOC, TN and TP contents for estuaries and other coastal waterways. The Australian estuarine database is derived from Buchner and Saenger (1989) with the revision of some of the spatial data, and the inclusion of additional geographic and climatic data.

Criteria

Ecological importance, naturalness (condition), vulnerability and human use.

Assessment measures

Qualitative scores for condition, conservation value and threat, fisheries value and threat, ecological status and water quality.

Assessment

Table 7.9 summarises the estimated condition of Hawkesbury Shelf estuaries in the OzEstuaries database.

Table 7.9. Condition of estuaries listed in the OzEstuaries database.

Estuary	Condition
Hunter River	extensively modified
Lake Macquarie	extensively modified
Tuggerah Lakes	extensively modified
Brisbane Water	extensively modified
Hawkesbury River	extensively modified
Pittwater	modified
Narrabeen Lagoon	extensively modified
Port Jackson	extensively modified
Botany Bay	extensively modified
Port Hacking	modified
Port Kembla Harbour	extensively modified
Lake Illawarra	extensively modified

In the Australian estuaries database conservation value was high for the Hunter River, Lake Macquarie, Hawkesbury River, Port Jackson and Botany Bay, low for Port Kembla, and moderate for other listed estuaries. Conservation threat was “real” for all estuaries except Brisbane Water and Pittwater where threat was classed as ‘perceived’.

Fisheries value was rated low for Port Hacking and Port Kembla, moderate for Pittwater, Port Jackson and the Hunter River and high for all other listed major estuaries. Fisheries threat was ‘real’ for all estuaries except Brisbane Water and Pittwater where threat was classed as ‘perceived’.

Ecological status was ‘slightly affected’ for Port Hacking, Pittwater and Brisbane Water, moderately affected for Lake Macquarie, Tuggerah Lakes, Hawkesbury River, Botany Bay and Lake Illawarra and considerably affected for the Hunter River, Narrabeen Lagoon, Port Jackson and Port Kembla.

Water quality was rated ‘poor (significant effect on the ecology of the estuary)’ for the Hunter River, Lake Macquarie, Tuggerah Lakes, Narrabeen Lagoon, Port Jackson, Botany Bay and Port Kembla with no data available for the remaining listed major estuaries.

7.4.25 Adjacent national parks and nature reserves

Data source

NSW National Parks and Wildlife Service (NPWS)[1].

Data description

Data includes boundaries of existing national parks, nature reserves, state recreation areas, historic sites, Aboriginal areas, and regional parks declared under the *NSW National Parks and Wildlife Act 1974*. National parks and nature reserves are generally declared on the basis of their high conservation values and high natural condition. Many coastal national parks and natures extend below mean high and low tide and include large areas of open estuary and ocean shore. These areas are regarded as marine protected areas, but additional regulations are required to protect fish and invertebrates from fishing.

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percentage of adjacent lands managed as national park or nature reserve within 1 km of each estuary and within 1 km of the high water mark for sections of exposed coast. These, and the following vulnerability measures, were also calculated for lands within 5 km of the high water mark and as a percentage of all lands within each estuarine subcatchment. The latter measures provided similar information and so results are not reported here.

Areas of national park and nature reserve extending below mean high tide were mapped in ArcView GIS with technical advice provided by Rodney James (NSW National Parks). These areas were used to assess the comprehensiveness of the current system of marine protected areas in the bioregion.

Assessment

For estuaries, the highest percentage of adjacent lands within 1 km managed as national park or nature reserve occurred for Port Hacking (64%), Pittwater (45%), the Hawkesbury River (42%), Brisbane Waters (15%) and Wamberal Lagoon (16%). Other estuaries had less than 10% of adjacent lands within 1 km in national parks or nature reserves. The estimates do not include areas of national park or nature reserve occurring over the estuaries themselves (Figure 7.36a).

For sections of ocean coast, the highest percentage of adjacent lands in national park or nature reserve occurred in the Port Hacking-Stanwell Park section (92%), the Avoca-Brisbane Waters section (42%) and the Botany Bay-Port Hacking section. Tuggerah-Avoca, Munmorah-Tuggerah and Brisbane Waters-Narrabeen had approximately 12% of adjacent land in national park. Other sections of coast had less than 10% of adjacent land in national park or nature reserve (Figure 7.37a).

[1] now within the NSW Department of Environment and Conservation

7.4.26 Wilderness

Data source

NSW National Parks and Wildlife Service[1].

Data description

GIS coverage of areas declared as wilderness by the National Parks and Wildlife Service[1].

Identification criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed as wilderness within 1 km of each estuary and land within 1 km of high water for sections of exposed coast.

Assessment

No wilderness areas occurred within 1 km of any estuary or coast in the Hawkesbury Shelf bioregion although this occurs in most other bioregions in NSW.

7.4.27 SEPP 14 wetlands

Data Source

Department of Planning, Infrastructure and Natural Resources.

Data description

GIS coverage of coastal wetlands protected under State Environmental Planning Policy No. 14 (SEPP14) of the NSW *Environmental Planning and Assessment Act 1979.*

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed under SEPP 14 within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

Brisbane Water, Tuggerah Lakes, Avoca Lake, Lake Macquarie, Hunter River, Wamberal Lagoon, Terrigal Lagoon, Lake Illawarra and Cockrone Lake all had 1-3% of adjacent land within 1 km included within SEPP 14 classification (Figure 7.36c). Areas around estuaries within the Sydney Metropolitan area do not, however, come under SEPP14 classification.

Sections of coast between the Hunter River and Brisbane Water included less than 7% of adjacent land within SEP14 and the classification did not extend to other sections of coast in the Sydney Metropolitan area (Figure 7.37b).

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[1] now the Department of Environment and Conservation

7.4.28 State forest

Data Source

State forests of NSW.

Data description

GIS coverage of the location and extent of lands managed as State Forest.

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed as State Forest within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

The Hawkesbury River (1%) was the only estuary with any land within 1 km in State Forest (Figure 7.36d). No lands within 1 km of the Hawkesbury Shelf coast were included in State Forest.

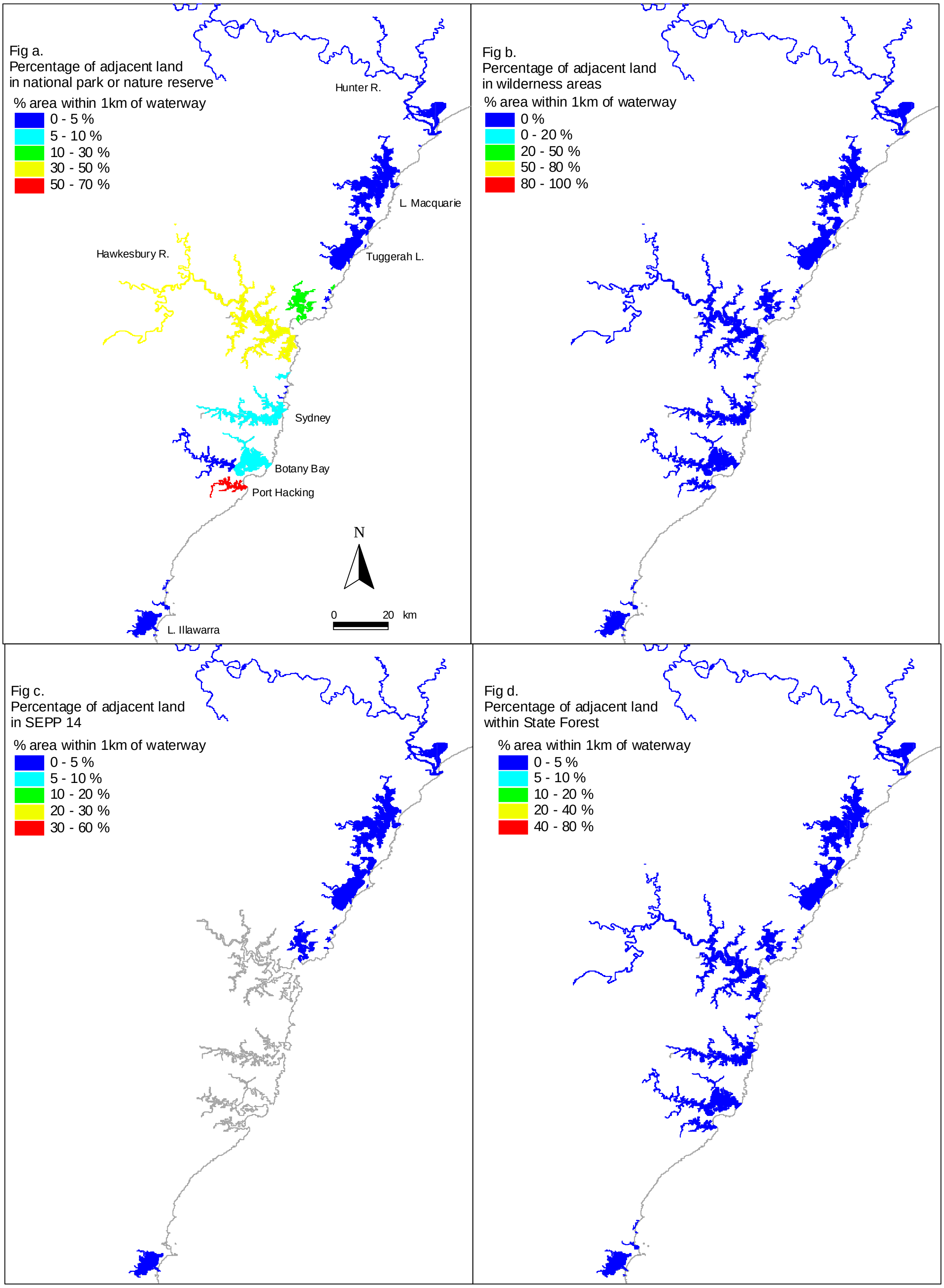

Figure 7.36. Percentage area of lands within 1 km of estuaries within national parks or nature reserves, wilderness areas, State Environmental Planning Policy 14 (wetland) areas and State Forest in the Hawkesbury Shelf bioregion.

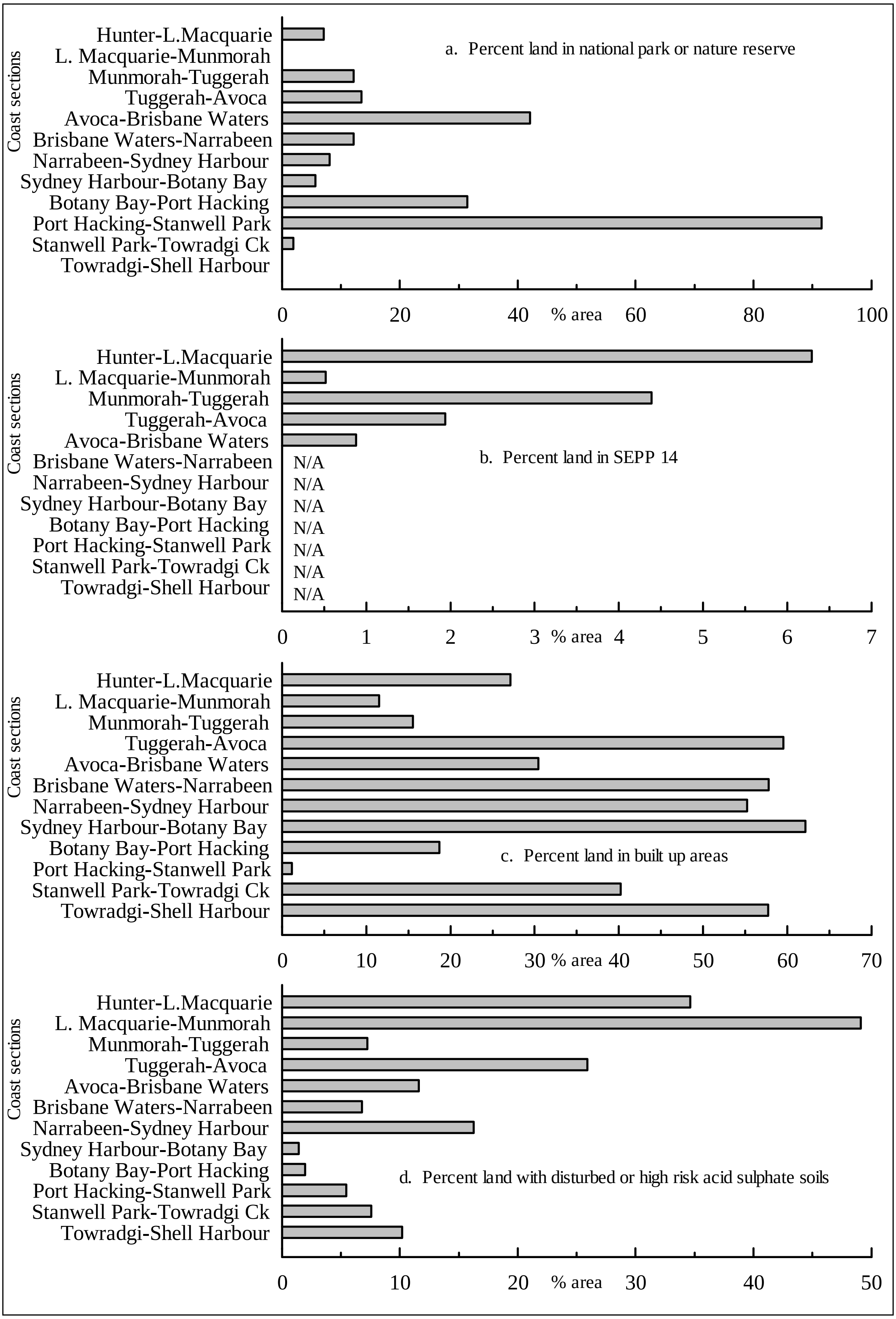

Figure 7.37. Percentage area of land within 1 km of coast in national park or nature reserve, SEPP 14 areas (not available for Sydney Metropolitan Area), built up areas and disturbed or high risk acid sulphate soil areas in the Hawkesbury Shelf bioregion.

7.4.29 Land capability

Data Source

NSW Department of Land and Water Conservation (DLWC)[3].

Data description

GIS coverage of land capability from "Land capability mapping," Soil Conservation Service, DLWC. NSW lands were classed by the capability of different soils and terrains to support 8 main categories of land use. For this assessment, categories are grouped into classes suitable for cultivation (1-3), suitable for grazing (4-6), or suitable for forest or left with natural vegetation (7-8).

Identification criteria

Vulnerability and naturalness (condition).

Assessment measure

Percentage of adjacent lands in each pooled land capability group within 1 km of each estuary and within 1 km of high water for sections of exposed coast. Planning units with a greater percentage of adjacent land suitable for forest are likely to have catchments more suitable for MPAs than those units with a high percentage of adjacent land suitable for grazing or cultivation.

Assessment

Land capability for forest or land to be left under natural vegetation.

The Hawkesbury River (39%), Narrabeen Lagoon (28%), Brisbane Water (20%) and Tuggerah Lakes (18%) had the most adjacent land within 1 km classed as suitable for forest or native vegetation (Figure 7.38a). The Munmorah-Tuggerah (53%), Hunter-Lake Macquarie (47%), Lake Macquarie-Munmorah (23%), Stanwell Park-Towradgi (22%), Tuggerah-Avoca (16%) and Avoca-Brisbane Water (12%) sections had the most adjacent land suitable for forest or native vegetation. All other sections had less than 7% of land suitable for this purpose (Figure 7.39d).

Land capability for cultivation

The Hunter River (36%) and the Hawkesbury River (13%) had the most adjacent land suitable for cultivation. All other estuaries had less than 5% of adjacent land suitable for cultivation (Figure 7.38b). All sections of ocean coast had less than 3% of adjacent land suitable for cultivation (Figure 7.39a).

Land capability for grazing.

For all estuaries from Brisbane Waters north, 10-70% of adjacent lands were classed as suitable for grazing. All estuaries from the Hawkesbury River south had less than 10% of adjacent lands suitable for grazing (Figure 7.38c). Lake Macquarie-Munmorah had the highest proportion of adjacent areas (33%) within 1 km of the coast suitable for grazing. All other sections had less than 10% of land suitable for grazing (Figure 7.39b).

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[3] now the Department of Infrastructure, Planning and Natural Resources

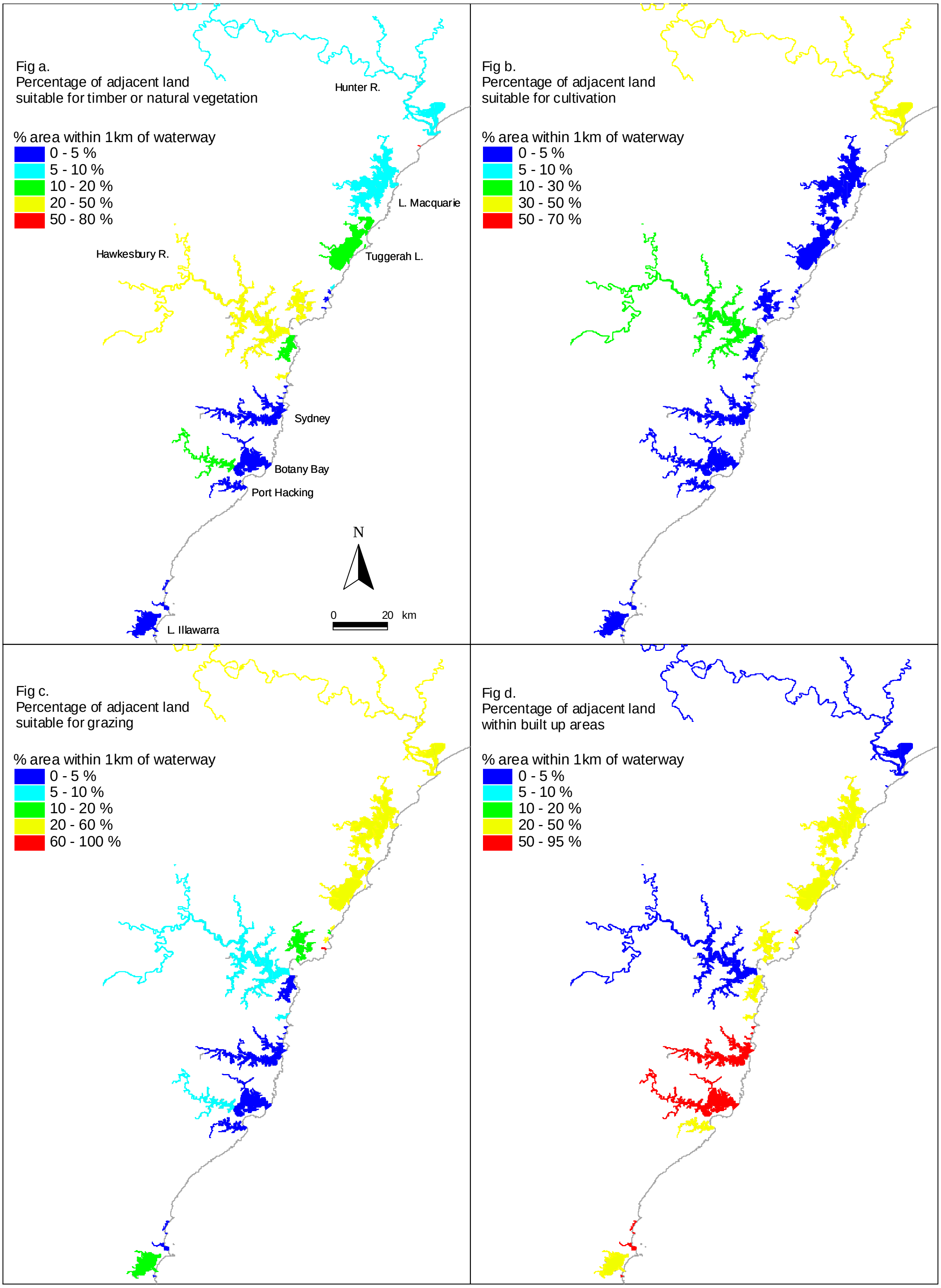


Figure 7.38. Percentage area of lands within 1 km of estuaries suited to different land uses and within built up areas in the Hawkesbury Shelf bioregion.

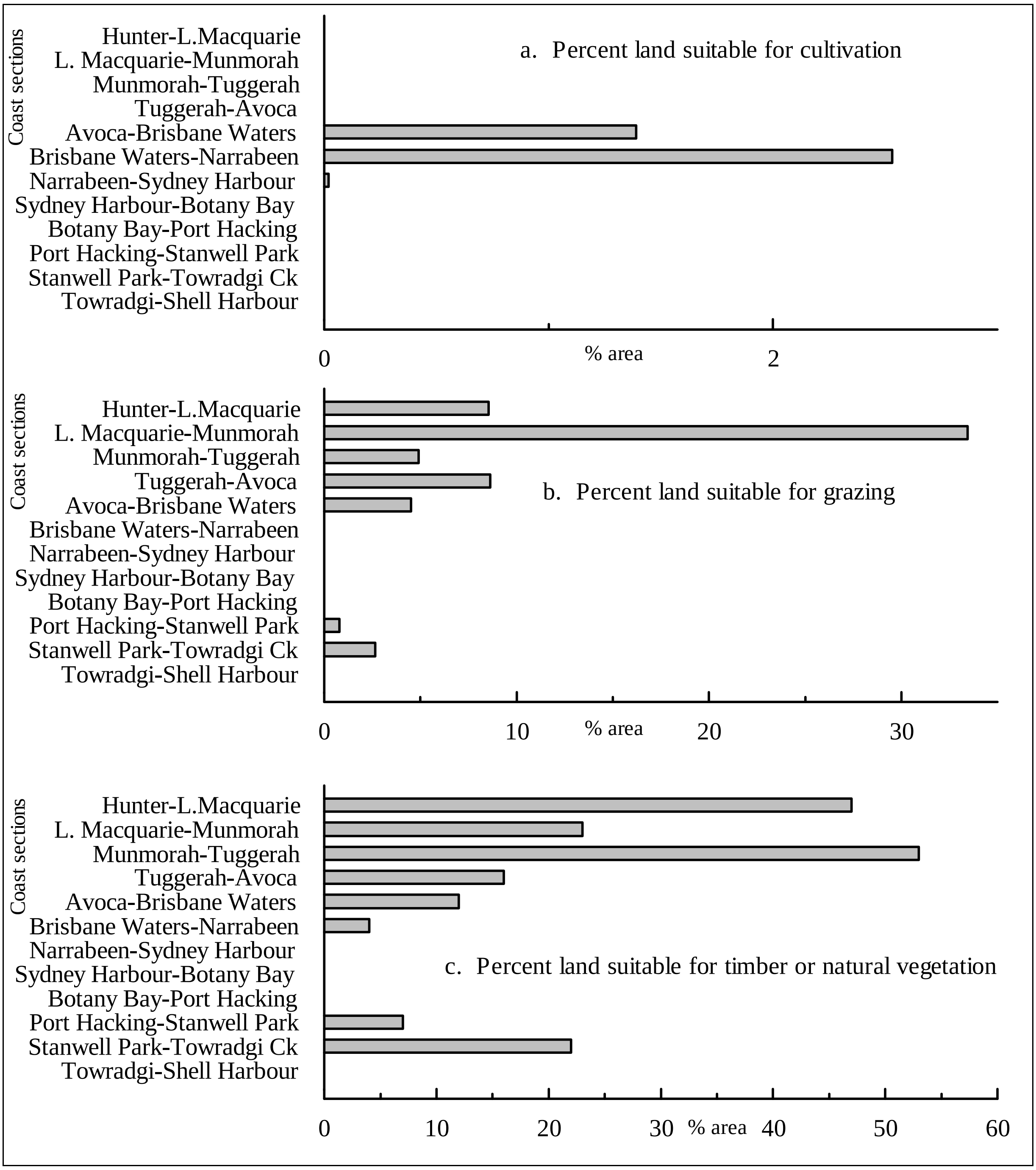


Figure 7.39. Percentage area of land within 1 km of coast in areas suitable for cultivation, grazing and timber or natural vegetation for the Hawkesbury Shelf bioregion.

7.4.30 Built-up areas

Data Source

Geoscience Australia 1:250,000 topographic database.

Data description

GIS layer of built up areas.

Criteria

Vulnerability, naturalness (condition), human use.

Assessment measure

Percent of adjacent lands in built up areas within 1 km of each estuary and within 1 km of high water for sections of exposed coast. Planning units with a high percentage of adjacent urban area may be less suitable for MPAs, but these areas may also face higher risks of degradation.

Assessment

The Hawkesbury (0.6%) and the Hunter Rivers (3%) had the least area within 1 km in urban areas. Lake Macquarie, Cochrone Lake, Tuggerah lake, Pittwater, Narrabeen Lagoon, Port Hacking, Lake Illawarra, Brisbane Waters and Wamberal Lagoon had between 20-44% of land within 1 km in urban areas. All other estuaries had between 53% (Botany Bay) and 88% (Port Kembla) of adjacent land in urban areas (Figure 7.38d).

The Port Hacking-Stanwell Park coast (1.2%) had by far the least area within 1 km in built-up areas, followed by L. Macquarie-Munmorah (12%), Munmorah-Tuggerah (16%) and Botany Bay-Port Hacking (19%).

Sydney Harbour-Botany Bay (62%), Tuggerah-Avoca, Brisbane Water-Narrabeen, Narrabeen-Sydney Harbour, and Towradgi-Shellharbour all had over 50% of adjacent land in built up areas. All other sections of ocean coast had between 20-40% of nearby land in built-up areas (Figure 7.37c).

7.4.31 Acid Sulphate Soils

Data source

NSW Department of Land and Water Conservation[3].

Data description

Acid sulphate soil risk maps predict the distribution of acid soils based on an assessment of the geomorphic environment using 1:25,000 scale aerial photograph interpretation and extensive field and laboratory soil analysis. These soils occur naturally and only become a threat when oxidised through exposure to the air. This occurs when either the water table is lowered artificially or sediments are excavated. Most estuaries in the Hawkesbury Shelf bioregion have these soils present, but these are no risk while left undisturbed. The threat of acid release is related to the probability of inappropriate land use as well as the occurrence of the sediments themselves.

Criteria

Vulnerability.

Assessment measure

Percent of adjacent lands with high risk or disturbed acid sulphate soils within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

Port Hacking (3%), Cochrone Lake, Wollongong Harbour, Pittwater, Dee Why Lagoon, Terrigal Lagoon, Wamberal Lagoon and the Hawkesbury River all had less than 10% of adjacent land with acid sulphate soils (Figure 7.40a).

Port Kembla (62%) and Botany Bay (47%) had the most adjacent land with acid sulphate soils. All other estuaries had between 10-25% of nearby land with acid sulphate soils (Figure 7.37d).

[3] now the Department of Infrastructure, Planning and Natural Resources

7.4.32 ARCCD – Australian river and catchment condition database

Data source

Australian rivers and catchment condition database produced by the Australian Heritage Commission. "The identification of wild rivers: methodology and database development. Australian Heritage Commission" (Stein *et al*. 2000).

Data description

GIS grids with a cell size of 250 m for seven catchment and flow disturbance indices calculated from a wide range of distance weighted, topographic features (e.g. land use, roads, mines, weirs, pollution sources, vegetation etc.)

Criteria

Naturalness (condition) and vulnerability.

Assessment measure

Weighted average (by area) of grid values for lands within 1 km of each estuary and within 5 km of each section of exposed coast.

Assessment

Mean total river disturbance (RDI) :

- Mean RDI was lowest for Port Hacking (.07), Lake Macquarie, Pittwater, Cockrone Lake, Terrigal Lagoon, Wamberal Lagoon and Brisbane Water (0.15-0.18) and highest for Manly Lagoon (0.55), Dee Why Lagoon, Harbord Lagoon, Botany Bay and Port Jackson (Figure 7.40b).
- For sections of ocean coast, mean RDI was lowest for the Port Hacking-Stanwell Park section (0.15), Stanwell Park-Towradgi, Avoca-Brisbane Water and Lake Macquarie-Munmorah and highest for Sydney Harbour-Botany Bay, Narrabeen-Sydney Harbour and Hunter-Lake Macquarie (Figure 7.42a).

Mean Catchment disturbance (CDI) :

- Mean CDI was lowest for Port Hacking (0.14), Hawkesbury River, Hunter River and Lake Illawarra and highest for Port Jackson (0.8), Harbord Lagoon, Manly Lagoon and Dee Why Lagoon, Wollongong Harbour and Towradgi Creek (Figure 7.40b).
- For sections of ocean coast, mean CDI was lowest for Port Hacking-Stanwell Park (0.14) and Botany Bay-Port Hacking and highest for Hunter R.–Lake Macquarie (0.75), Narrabeen–Sydney Harbour, Sydney Harbour-Botany Bay and Towradgi-Shellharbour (Figure 7.42c).

Mean flow disturbance (FDI):

- Mean FDI was highest for Botany Bay (0.4), Dee Why Lagoon, Manly Lagoon, Georges River, Harbord Lagoon, Hunter River, Hawkesbury River and Lake Illawarra and low for all other estuaries (Figure 7.40d).

- Mean FDI is not reported for sections of ocean coast, as this measure is only relevant for rivers and estuaries.

Mean settlement factor (SF):

- Mean SF was lowest for the Hawkesbury River (0.06), Port Hacking, Hunter River and Lake Illawarra and highest for Botany Bay (0.79), Port Jackson, Harbord Lagoon and Manly Lagoon (Figure 7.41a).
- For sections of ocean coast, mean SF was lowest for the Port Hacking-Stanwell Park (0.05), Stanwell Park-Towradgi and Lake Macquarie-Munmorah sections and highest for the Botany Bay-Port Hacking, Hunter-Lake Macquarie, Sydney Harbour-Botany Bay, Narrabeen-Sydney Harbour and Towradgi-Shellharbour (Figure 7.42c).

Mean land use factor (LUF):

- Mean LUF was lowest for Port Hacking (0.09), Pittwater (0.25) and the Hawkesbury River (0.33) and highest for Botany Bay (0.88), Port Jackson, Manly Lagoon, Harbord Lagoon, Lake Illawarra and Dee Why Lagoon (Figure 7.41b).
- For sections of ocean coast, mean LUF was lowest for Port Hacking-Stanwell Park (0.08) and highest for Botany Bay-Port Hacking (0.86), Hunter-Lake Macquarie, Towradgi-Shellharbour, Narrabeen-Sydney Harbour, Sydney Harbour-Botany Bay and Brisbane Water-Narrabeen (Figure 7.43a).

Mean infrastructure factor (IF):

- Mean IF was lowest for the Hawkesbury River (0.16), Port Hacking and the Hunter River and highest for Manly Lagoon (0.77), Harbord Lagoon, Dee Why Lagoon, Wollongong Harbour, Towradgi Creek, Parramatta River, Botany Bay and Port Kembla (Figure 7.41c).
- For sections of ocean coast, mean IF was lowest for Munmorah-Tuggerah (0.13), L. Macquarie-Munmorah, Port Hacking-Stanwell Park and Avoca-Brisbane Water and highest for Towradgi-Shellharbour, Narrabeen-Sydney Harbour, Botany Bay-Port Hacking and Sydney Harbour-Botany Bay (Figure 7.43c).

Mean extractive industry/pollution point source factor (EF):

- Mean EF was lowest for Port Hacking (0.17) and highest for Manly Lagoon (1.0), Harbord Lagoon, Dee Why Lagoon, Lake Illawarra, Botany Bay, Port Jackson, Wollongong Harbour, Narrabeen Lagoon and the Georges River (Figure 7.41d).
- For sections of ocean coast, mean EF was lowest for Port Hacking-Stanwell Park (0.35) and Lake Macquarie-Munmorah and highest for Botany Bay-Port Hacking (1.0), Hunter-Lake Macquarie, Brisbane Waters-Narrabeen and Narrabeen-Sydney Harbour (Figure 7.43b).

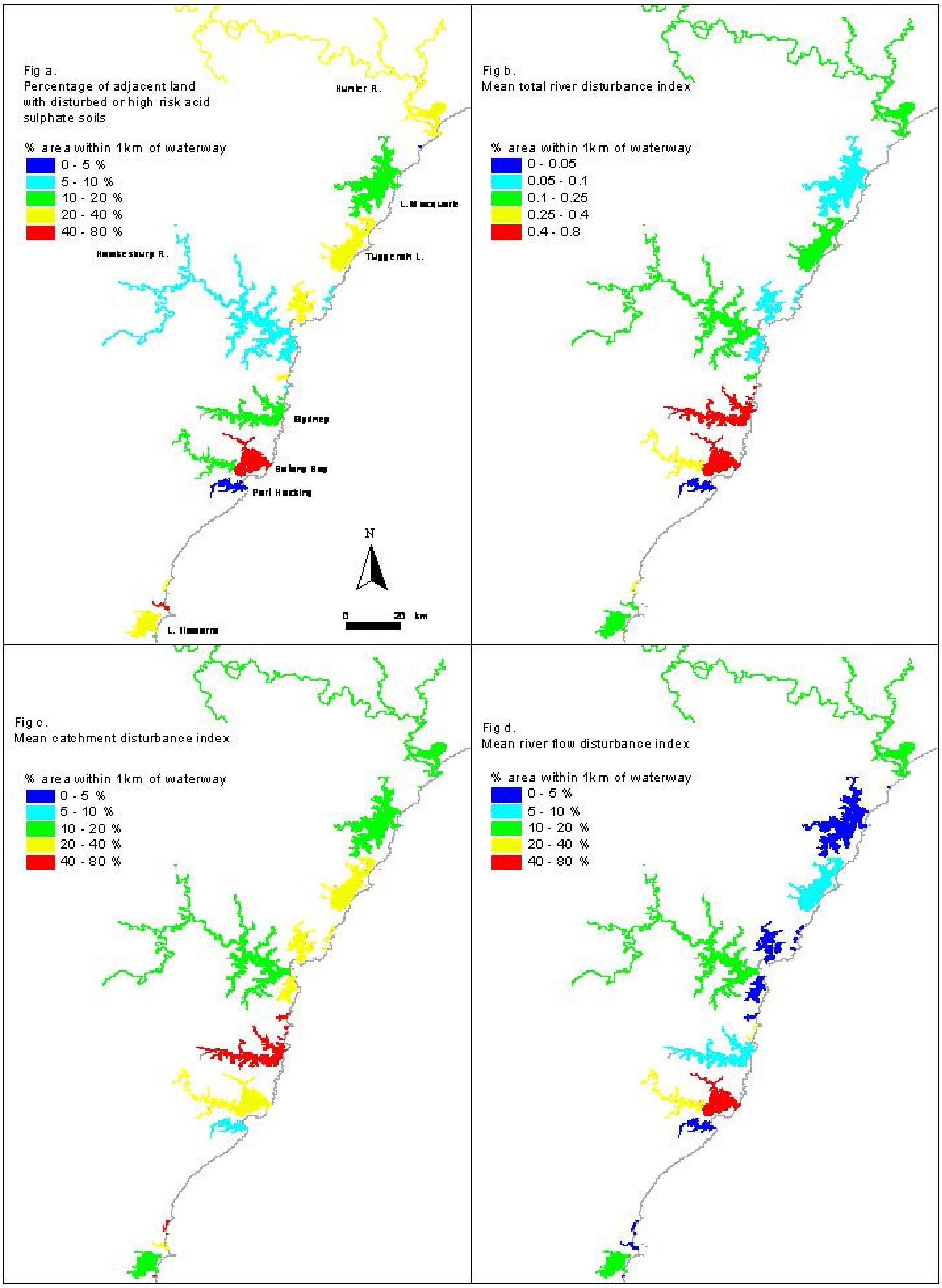


Figure 7.40. Percentage area of lands within 1 km of estuaries with disturbed or high risk acid sulphate soils and mean Australian river and catchment condition indices for estuaries in the Hawkesbury Shelf bioregion.

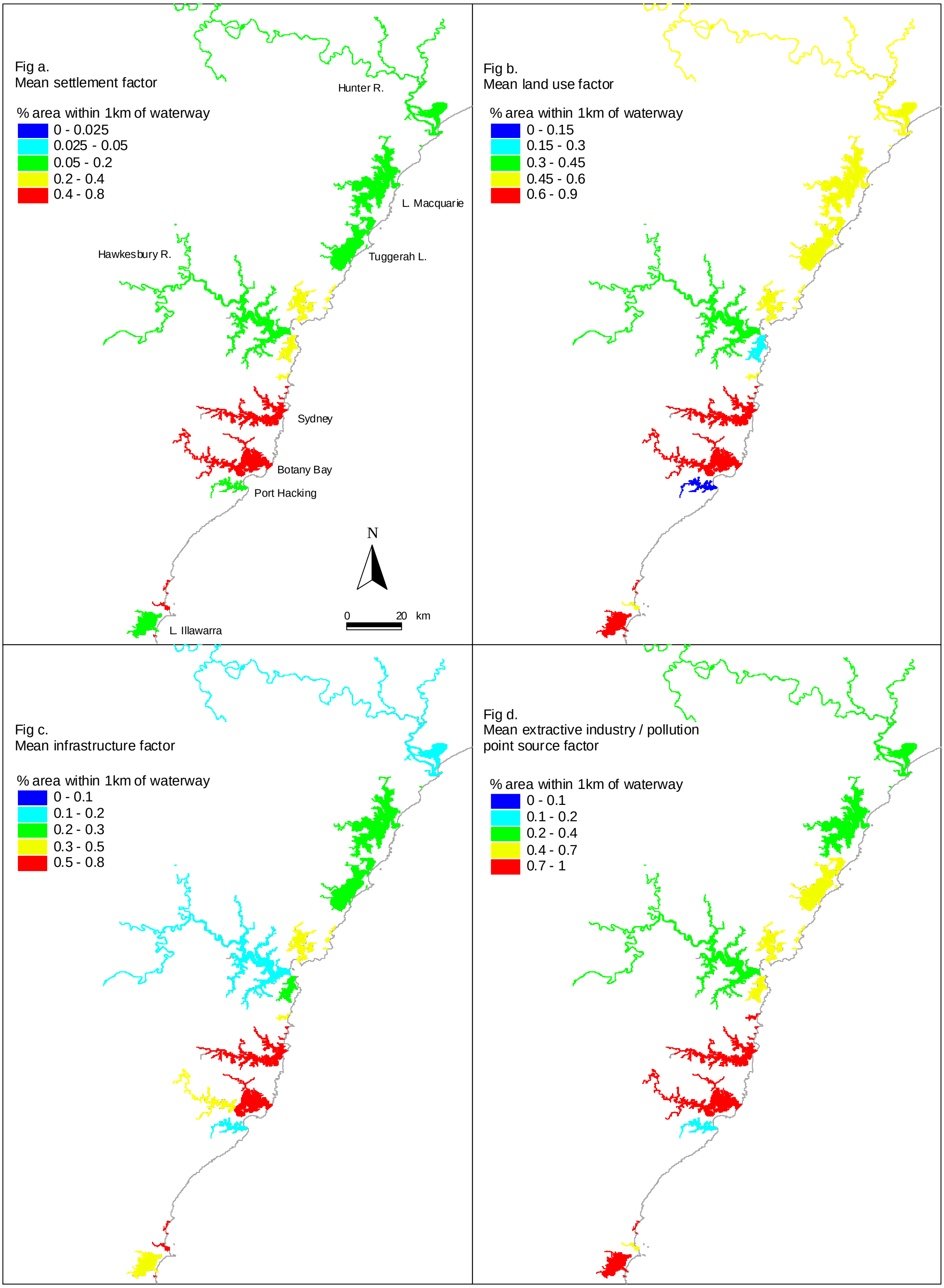


Figure 7.41. Mean Australian river and catchment condition indices (continued) for estuaries in the Hawkesbury Shelf bioregion.

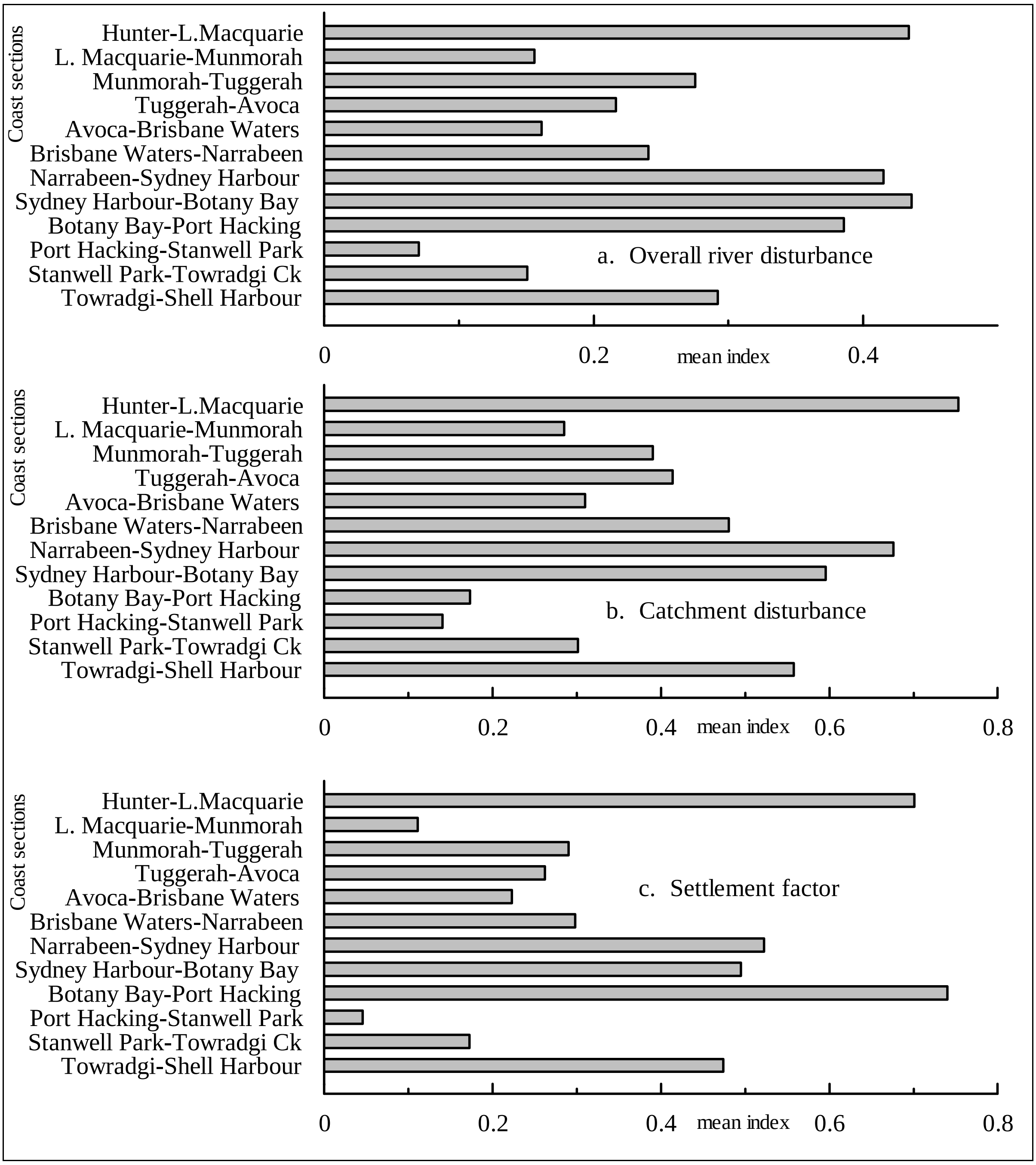


Figure 7.42. Mean Australian river and catchment condition indices within 5 km of coast for overall river disturbance, catchment disturbance and settlement for the Hawkesbury Shelf bioregion.

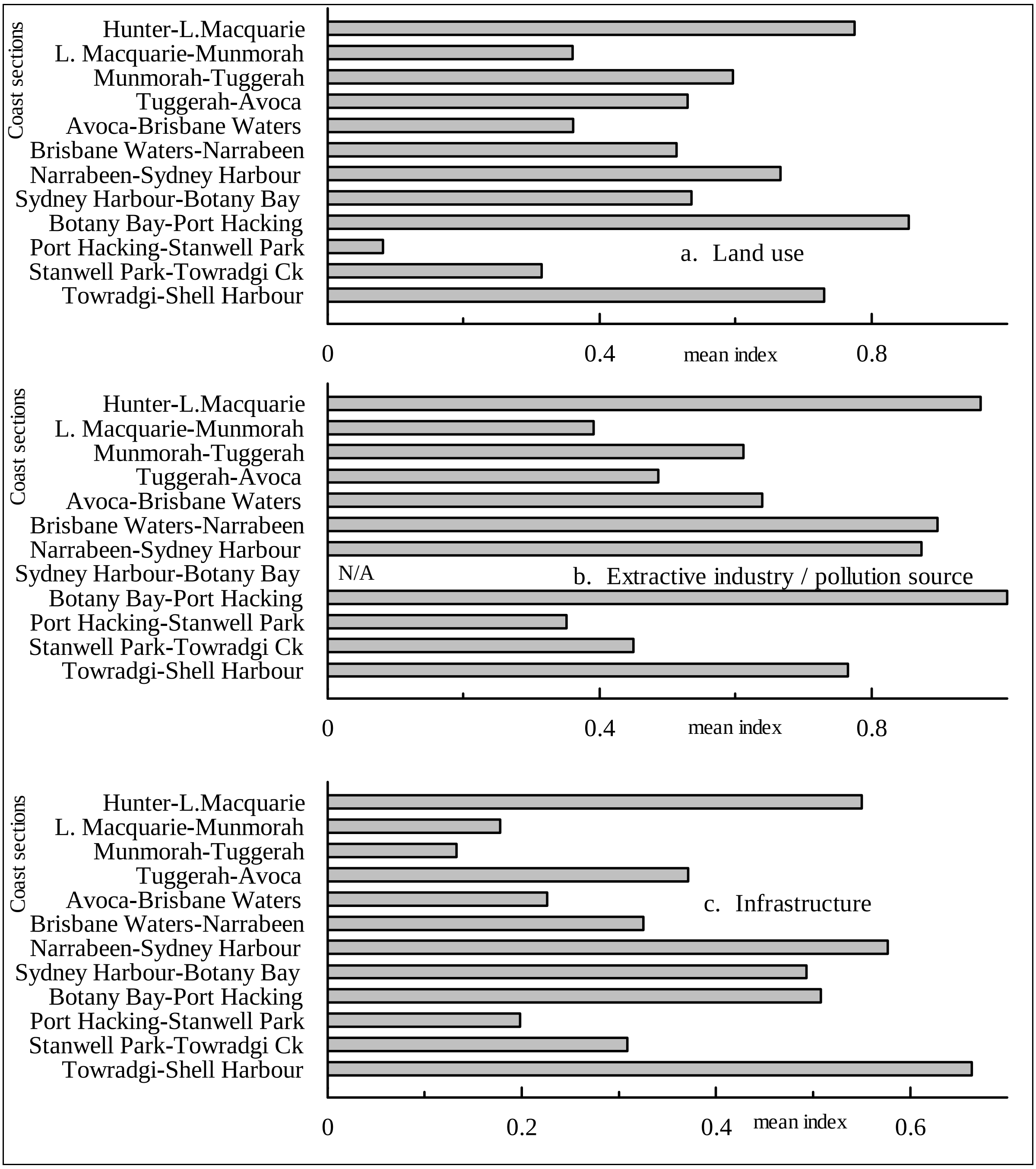


Figure 7.43. Mean Australian river and catchment condition indices within 5 km of coast for land use, extractive industries and pollution, and infrastructure for the Hawkesbury Shelf bioregion.

7.5 Discussion

This assessment provides information and methods to systematically examine options to help plan a system of marine protected areas in the Hawkesbury Shelf bioregion. Because of the scope of this task, and the need for consistent information across areas as large as whole bioregions, approximate surrogates for biodiversity and other criteria are used. However, even at a broad scale, a number of patterns were evident.

There are currently no marine parks in the bioregion, but there are ten aquatic reserves protecting areas of rocky shore and inshore reef along the Sydney coastline, as well as mangrove, saltmarsh, seagrass and ocean embayment in Botany Bay and drowned river valley in North Sydney Harbour.

There are also significant areas of mangrove, saltmarsh, rocky shore, reef and parts of intermittent, barrier and drowned river valley estuaries included in the marine and terrestrial components of national parks and nature reserves. However, only a portion of this area, in the marine extension of Bouddi National Park, has direct protection for fish and invertebrates from fishing.

The total area of aquatic reserves in the Hawkesbury Shelf bioregion is 19.3 km^2, representing just 0.96% of NSW waters in the bioregion. If Commonwealth waters beyond 3 nm of the coast are considered, this area represents 0.2% of the entire marine bioregion.

If the marine components of national parks and nature reserves are added to this, the total area in MPAs increases to 53.6 km^2, representing 2.7% of NSW waters in the bioregion. If Commonwealth waters beyond 3 nm of the coast are considered, this area represents 0.6% of the entire marine bioregion. However, only a small proportion of this area provides full protection for fish and invertebrates from fishing.

The assessment identifies many different areas of high conservation value and the following section identifies four different ways in which some of these values could be included in a large, multiple use marine park. Appendix 3 provides a more comprehensive discussion of these areas.

The options identified are those that best met criteria for representing a range of ecosystems, habitats and species in areas with protected foreshores, catchments and waters relatively unaffected by human impacts. The options for exactly where, and how MPAs can be established, are relatively flexible for all but a few criteria. Therefore, there is the potential to apply reserve design criteria to achieve more effective management, and to accommodate, and even promote, a range of sustainable human activities while still meeting conservation objectives. For marine parks, the exact nature of the protection provided will also depend on subsequent zoning to address different impacts and operational plans to regulate how activities are carried out.

7.5.1 MPA options in the Hawkesbury Shelf bioregion

The primary ecological identification criteria for MPAs adopted in this study were comprehensiveness, representativeness and adequacy of management. According to the environmental classification used, this means representation of each of the four major estuarine ecosystems, the four ocean ecosystems classified by depth, and the nine habitat surrogates, within MPAs that can be effectively managed for the conservation of biodiversity.

Given the uncertainty involved in assessing biodiversity, a strong emphasis is placed on presenting information to allow a range of options to be examined. General boundaries are presented as an approximate indication of extent, but areas could be included or excluded according to different priorities for a variety of criteria.

The following options meet criteria for comprehensiveness and representativeness for most mapped ecosystems, habitats and species. They have, to varying extents: some degree of naturalness and catchment protection; they include areas recommended from previous conservation assessments; they consistently score highly in quantitative analyses for a range of criteria; and they complement existing MPAs and conservation management strategies.

These options are not prescriptive but are meant to present comparisons among alternatives from a range of possible scenarios for a large marine park. The specific locations and values described within each option could also be included in alternative marine park proposals or within other types of reserves in a MPA network to represent geographic variation in biodiversity, and assist in fulfilling the principles of comprehensiveness, adequacy and representativeness. The options (A, B, C and D) listed below in order from north to south are summarised here, but discussed in greater detail in Appendix 3.

Option A. The Hunter River to Avoca Lake.

Option B. Lake Munmorah (Wybung Point) to Narrabeen Lakes.

Option C. Avoca Lake to Port Hacking.

Option D. Cape Banks to Shellharbour.

For each option, approximate areas and percentages of different ecosystems and habitats within estuaries and coastal waters out to 3 nautical miles are shown in Table 7.10.

Option A. Hunter River to Avoca Lake

Some important features that Option A could include are:

- All estuary types except tide dominated drowned river (currently represented in North Sydney Harbour Aquatic Reserve) and ocean embayment (currently represented in Towra Point Aquatic Reserve).
- The largest areas of seagrass in the bioregion in Lake Macquarie and Tuggerah Lakes.
- The largest areas of mangrove and saltmarsh habitat in the bioregion on the Hunter River.
- Some of the largest areas of mapped inshore shallow reef in the bioregion.
- Some of the largest areas of inshore and offshore islands (after Towradgi-Shellharbour).
- Large areas of mapped inshore sand, intertidal beach and intertidal rocky shore.
- Historically important Grey Nurse Shark habitat.
- Two of the most important areas for shore birds (Hunter River and Tuggerah Lakes) and important seabird nesting sites (Moon Island and Bird Island).

This option includes however includes:

- A high level of urban, industrial and rural development and associated pollution and habitat modification in and adjoining areas of the Hunter River and Lake Macquarie.
- Two previously proposed candidate sites for aquatic reserves in the Hunter River and Lake Macquarie that were rejected during community consultation by NSW Fisheries.

Option B. Wybung Point near Lake Munmorah to Narrabeen Lake

Some important features that Option B could include are:

- All estuarine ecosystem types except ocean embayment (currently represented in Towra Point Aquatic Reserve).
- The largest tide dominated, drowned river valley in the bioregion, the Hawkesbury River and Pittwater. This estuary includes the second largest area of mangrove habitat in the bioregion and has a large proportion (45%) of its shores included in National Park.
- Tuggerah Lakes, the second largest wave dominated barrier estuary in the bioregion with the second largest area of seagrass in the bioregion.
- Brisbane Water, the fourth largest wave dominated barrier estuary in the bioregion with the third largest area of seagrass and second largest area of saltmarsh in the bioregion.
- Four intermittent estuaries, Wamberal and Terrigal Lagoons, Avoca and Cockrone Lakes.
- Large areas of inshore shallow reef, exposed rocky intertidal shore, beach and inshore and offshore islands and historically important Grey Nurse Shark habitat.
- One of the most important areas for shore birds (Brisbane Water) and important seabird nesting sites (Bird Island and islands in the Hawkesbury River).

This option includes however includes:

- Potential effects of sewage disposal in the upper Hawkesbury River and moderate levels of urban development adjacent to some key areas of vulnerable habitat.

Option C. Avoca Lake to Port Hacking

Some important features that Option C could include are:

- All estuarine ecosystem types except wave dominated barrier estuaries.
- All of the tide dominated drowned river valleys in the bioregion (Hawkesbury, Parramatta, Georges and Hacking Rivers).
- The only ocean embayment in the bioregion (Botany Bay).
- Most of the intermittent estuaries in the bioregion.
- Moderately large areas of seagrass, mangrove and saltmarsh.
- Large areas of rocky intertidal shore, inshore shallow reef and beach.
- A vulnerable and important Grey Nurse Shark aggregation site at Magic Point, near Maroubra, and other historically important sites for Grey Nurse Shark.
- Three of the most important areas in the bioregion for shore birds (Towra Point, Parramatta River and Brisbane Waters) and important seabird nesting sites (islands in the Hawkesbury River).

This option includes however:

- A very high level of urban and industrial development and associated pollution and habitat modification adjoining Sydney Harbour and Botany Bay and moderate levels of disturbance in other areas.

Option D. Cape Banks to Shellharbour

Some important features that Option D could include are:

- All estuarine ecosystem types except ocean embayment (currently represented in Towra Point Aquatic Reserve).
- Port Hacking, a tide dominated drowned river valley with a large proportion of adjacent land (64%) in national park.
- Lake Illawarra and Port Kembla, wave dominated barrier estuaries.
- Towradgi Creek, an intermittent estuary.
- The largest area of offshore shallow reef in the bioregion.
- The largest area of islands in the bioregion.
- Large areas of exposed rocky intertidal shores and near shore reef with adjacent land and islands in national park or nature reserve.
- Historically important Grey Nurse Shark habitat.
- Important areas for shore birds (Lake Illawarra) and important seabird nesting sites (Five Islands).

This option includes however:

A high level of urban and industrial development threatening some areas of vulnerable habitat.

7.6 Conclusion.

A major consideration in choosing from among these or other options for MPAs in the Hawkesbury Shelf bioregion is the potential for environmental impacts along shores, in catchments, on the seabed and in the waters themselves. Many locations with important habitats and species adjoin areas with heavy agricultural, industrial and urban development.

The potential for impact is evident from the decision, in February 2006, to close Sydney Harbour to all commercial fishing after unsafe levels (for human consumption) of dioxin were detected in commercially caught bream and prawns. The Sydney region however includes some of the most important areas for marine biodiversity in the State, and the same applies for other industrialised areas around Newcastle and Wollongong.

There is a need to rapidly decide whether to select the most extensive examples of ecosystems, those in the best condition or those that are most vulnerable. The nature of these trade-offs will depend on what priority is given to representation of different ecosystems and habitats relative to priorities for condition and vulnerability. These priorities could be addressed using the range of different MPA types available in NSW as well as other conservation tools. For example, large marine parks may be better suited to the protection of the most extensive examples of representative ecosystems and habitats in reasonable condition, while smaller highly protected zones within these parks, aquatic reserves or nature reserves may be used for targeted protection of unique or especially vulnerable areas. For these MPAs to be effective, consideration should also be given to managing activities outside of the MPAs. Indeed, legislation and policy for marine parks in NSW includes the ability to influence the management of activities in adjacent areas.

Given the densely populated coastline and hinterland of the Hawkesbury Shelf bioregion, additional consideration will also need to be given to how consultation for establishing and managing MPAs is conducted. Two new large multiple use marine parks have now been established in the Manning Shelf and Batemans Shelf bioregion but there has been much public controversy over how these have been implemented. If a marine park or other MPAs are to be established in the Hawkesbury Shelf, where many larger communities may be affected, management may need to adopt a more inclusive approach to community engagement. This could involve the more extensive use of information based planning tools in workshops with community representatives and the additional advice and support of marine scientists who, so far, have provided relatively little input into selection processes.

The following chapter describes the MPA assessment for the Batemans and Twofold Shelf marine bioregions and Chapters 9 and 10 describe how decision support tools can be used to integrate ecological and social information with community consultation.

Options	Aquatic Reserves only		All existing MPAs		Hunter-Avoca		Munmorah-Narrabeen		Avoca-Port Hacking		Kurnell-Port Kembla		Total
Feature Name	% in MPA	km² in MPA	% in MPA	km² in MPA	% in MPA	km² in MPA	% in MPA	km² in MPA	% in MPA	km² in MPA	% in MPA	km² in MPA	km² in bioregion
Intermittent estuary	**0.0**	0.0	**6.5**	0.23	**28.3**	1.0	**35.8**	1.3	**76.5**	2.7	**6.5**	0.2	3.5
Wave dominated	**0.0**	0.0	**4.4**	12.12	**80.6**	223.7	**38.1**	105.7	**12.6**	35.0	**15.5**	43.0	277.4
Ocean embayment	**20.4**	8.7	**20.4**	8.7	**20.4**	8.7	**20.4**	8.7	**100.0**	42.6	**20.4**	8.7	42.6
Tide dominated	**1.2**	2.4	**7.2**	14.19	**7.2**	14.2	**64.2**	126.6	**100.0**	197.4	**11.4**	22.4	197.4
0-20M	**0.2**	0.2	**1.4**	1.74	**32.2**	39.0	**42.0**	51.0	**35.2**	42.7	**40.6**	49.2	121.3
20-60M	**0.0**	0.0	**0.0**	0.10	**28.2**	354.4	**28.0**	351.7	**25.3**	317.7	**22.9**	287.7	1256.4
60-200M	**0.0**	0.0	**0.0**	0.00	**0.0**	0.0	**0.0**	0.0	**1.6**	115.7	**1.9**	131.7	7088.5
200M	**0.0**	0.0	**0.0**	0.00	**0.0**	0.0	**0.0**	0.0	**0.0**	0.0	**0.0**	0.0	141.3
Seagrass	**4.9**	2.6	**6.0**	3.26	**59.8**	32.5	**46.7**	25.4	**31.5**	17.1	**22.2**	12.1	54.4
Mangrove	**7.4**	2.9	**21.6**	8.55	**55.0**	21.8	**52.9**	20.9	**66.6**	26.3	**22.5**	8.9	39.5
Saltmarsh	**2.3**	0.3	**3.4**	0.39	**61.0**	7.0	**23.3**	2.7	**40.4**	4.6	**6.4**	0.7	11.4
Beach	**1.3**	0.1	**1.5**	0.08	**53.9**	2.8	**35.7**	1.9	**24.4**	1.3	**29.2**	1.5	5.3
Rocky Shore	**4.4**	0.2	**7.1**	0.35	**41.3**	2.0	**34.1**	1.7	**34.7**	1.7	**39.7**	2.0	4.9
Reef and shoal	**3.2**	1.5	**4.7**	2.31	**39.9**	19.5	**38.9**	19.0	**34.0**	16.6	**40.3**	19.6	48.8
Sand	**0.5**	0.4	**0.6**	0.50	**44.6**	34.4	**31.5**	24.3	**30.4**	23.4	**34.2**	26.4	77.1
Islands	**0.2**	0.0	**0.2**	0.00	**15.6**	0.1	**10.6**	0.0	**12.0**	0.0	**72.8**	0.3	0.4
Total of bioregion (NSW waters)	**0.96%**	*19.3 km²*	**2.70%**	*53.6 km²*	**37%**	*748 km²*	**35%**	*712 km²*	**42%**	*836 km²*	**28%**	*568 km²*	2011 km²

Table 7.10. Area (km^2) and percentage of ecosystems and habitats in the Hawkesbury Shelf bioregion that would be represented in a system of MPAs under scenarios including: existing aquatic reserves only; existing aquatic reserves and the marine components of national parks and nature reserves; and all existing MPAs together with either Options A, B, C or D for a large, multiple use marine park. Total areas and percentages of coastal NSW waters in the bioregion for each scenario are provided below each column.

8 MPA assessment of the Batemans and Twofold Shelf bioregions

8.1 Introduction

The Batemans and Twofold Shelf bioregional assessments are two of several projects to systematically assess broad scale patterns of biodiversity within each of five NSW marine bioregions and identify where additional MPAs may be required (Figure 8.1). However, as only part of the Twofold Shelf bioregion extends into NSW waters, both bioregions are dealt with in this Chapter.

Scientists and conservation managers have identified 65 Australian marine bioregions and provinces (IMCRA 1998) to help plan a national system of marine protected areas. Including the characteristic biodiversity of each bioregion within a system of MPAs aims to ensure that marine ecosystems are effectively managed for the conservation of biodiversity and for sustainable use. National guidelines and criteria have been developed to identify and select MPAs within each bioregion (ANZECC 1998ab, 1999) in accordance with international, national and state strategies (Commonwealth of Australia 1992ab, UNEP 1994, Commonwealth of Australia 1996, NSW Marine Parks Authority 2001).

This chapter summarises the broad scale methods and information used to identify some options for new MPAs on the basis of ecological criteria alone. Broad scale (10's of km^2) and fine scale (4 km^2) planning units are used to assess potential locations for MPAs against over 50 specific criteria derived from state and national guidelines. Assessments were assisted by mapped displays and analyses in a Geographic Information System (GIS) and irreplaceability analysis using C-Plan reserve selection software (NPWS 2001).

Possible areas for large, multiple use marine parks are identified and important locations and conservation values within each are described (Section 8.4 and Appendix 4) Given the uncertainty involved in assessing biodiversity and the complex issues involved, a strong emphasis is placed on presenting information and methods to examine a range of options.

Information used for the assessment was derived from:

- national criteria for the identification of MPAs (Appendix 1)
- a broad scale atlas of marine ecosystems and habitats in NSW
- existing broad scale scientific surveys of habitats, communities and species
- existing data, maps, aerial photographs, literature and conservation assessments
- new data coverages and analyses generated for this study
- ecological guidelines for reserve design (Appendix 1) and
- preliminary discussions with scientists, managers and the community.

A separate selection process is now required for more detailed site assessment and consideration of social, economic and cultural values.

8.2 Geographic extent

The Batemans and Twofold Shelf bioregions were defined by the Interim Marine and Coastal Regionalisation of Australia (IMCRA 1998) from recommendations provided by Pollard *et al.* (1997). The bioregions include estuaries, coast and offshore waters out to the continental shelf break (approximately the 200 m depth contour).

The Batemans Shelf bioregion extends south from Shellharbour (34°'35 S.) to Wallagoot Lake, south of Bega (36° 48' S. Figure 8.1). The Twofold Shelf bioregion continues south from Wallagoot Lake and across the state border to near Corner Inlet in Victoria and also includes areas of Bass Strait in Victorian and Tasmanian state waters (Figure 8.1). This report focuses on NSW state waters within 3 nautical miles of the coast as defined by the Australian Maritime Boundary Information System (AMBIS) data provided by Geoscience Australia (Commonwealth of Australia 2001).

The 1:100,000 map sheets for the NSW sections of the bioregions are:

Kiama	9026	Narooma	8925
Jervis Bay	9027	Bega	8824
Ulladulla	8927	Eden	8823
Batemans Bay	8926	Green Cape	8923

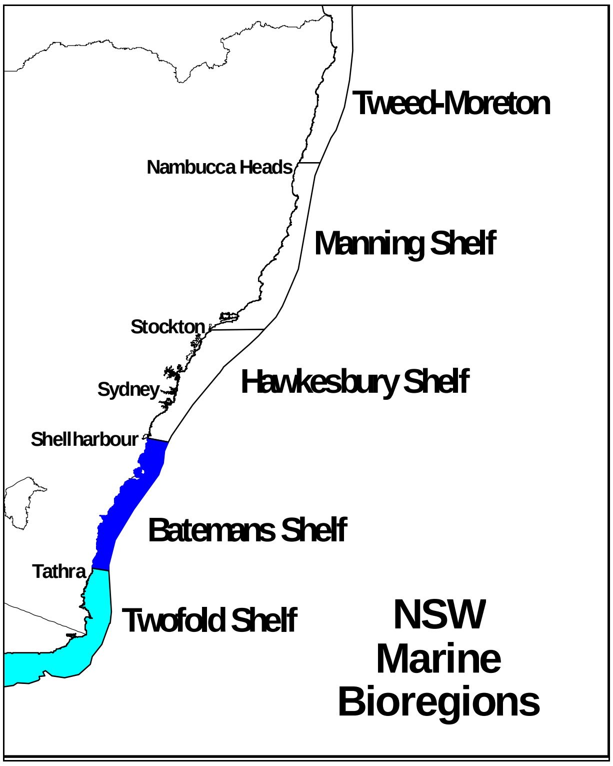


Figure 8.1. Batemans Shelf and Twofold Shelf marine bioregions (IMCRA 1998)

8.3 MPAs in the Batemans and Twofold Shelf bioregions

At the time of this assessment there is one relatively large, multiple use marine park at Jervis Bay that includes a coastal embayment, some smaller estuaries, coastal waters, seagrass, mangrove, saltmarsh, rocky shores, beaches, subtidal reef and sediment. This park is complemented by a smaller Commonwealth Marine Reserve on the southern shores of the bay. There is only one aquatic reserve in the bioregion and this includes a small area of rocky shore and subtidal reef at Bushrangers Bay near Shellharbour. There are also six national parks and nature reserves that extend below mean high water and include parts of estuaries and narrow strips of exposed coast Table 8.1 and Figure 8.2.

There are no marine parks or aquatic reserves in the NSW section of the Twofold Shelf bioregion but three national parks that extend below mean high water. Marine national parks and reserves have however been established in the Victorian and Tasmanian section of the bioregion and these are described in Section 8.4.33. Management for the MPAs in NSW is described in *Developing a representative system of marine protected areas - an overview* (NSW Marine Parks Authority 2001) and at www.mpa.nsw.gov.au.

Table 8.1. Estimated extent of MPAs in coastal waters (estuaries and ocean within 3 nm of the coast) of the Batemans Shelf and Twofold Shelf marine bioregions.

MPA type	**Name**	**Area (km^2)**
Marine parks	Jervis Bay Marine Park	214.5
The total area of marine park represents 9.6% of coastal waters in the Batemans Shelf bioregion.		
Commonwealth Marine Reserve	Booderee National Park	8.3
This total area of marine reserve represents 0.4% of coastal waters in the Batemans Shelf bioregion.		
Aquatic Reserves	Bushrangers Bay	0.04
The total area of aquatic reserve represents 0.002% of coastal waters in the Batemans Shelf bioregion.		
National parks and nature reserves	Comerong Island NR	2.15
	Jervis Bay NP (NSW)	6.52
	Cudmirrah NP	0.41
	Narrawallee Creek NR	0.02
	Meroo NP	1.71
	Eurobodalla NP	7.39
This total area of 18.2 km^2 represents 0.8% of coastal waters in the Batemans Shelf bioregion.		
National parks and nature reserves	Bournda NP	0.31
	Ben Boyd NP	0.10
	Nadgee NR	1.65
This total area of 2.1 km^2 represents 0.3% of coastal waters in the Twofold Shelf bioregion.		

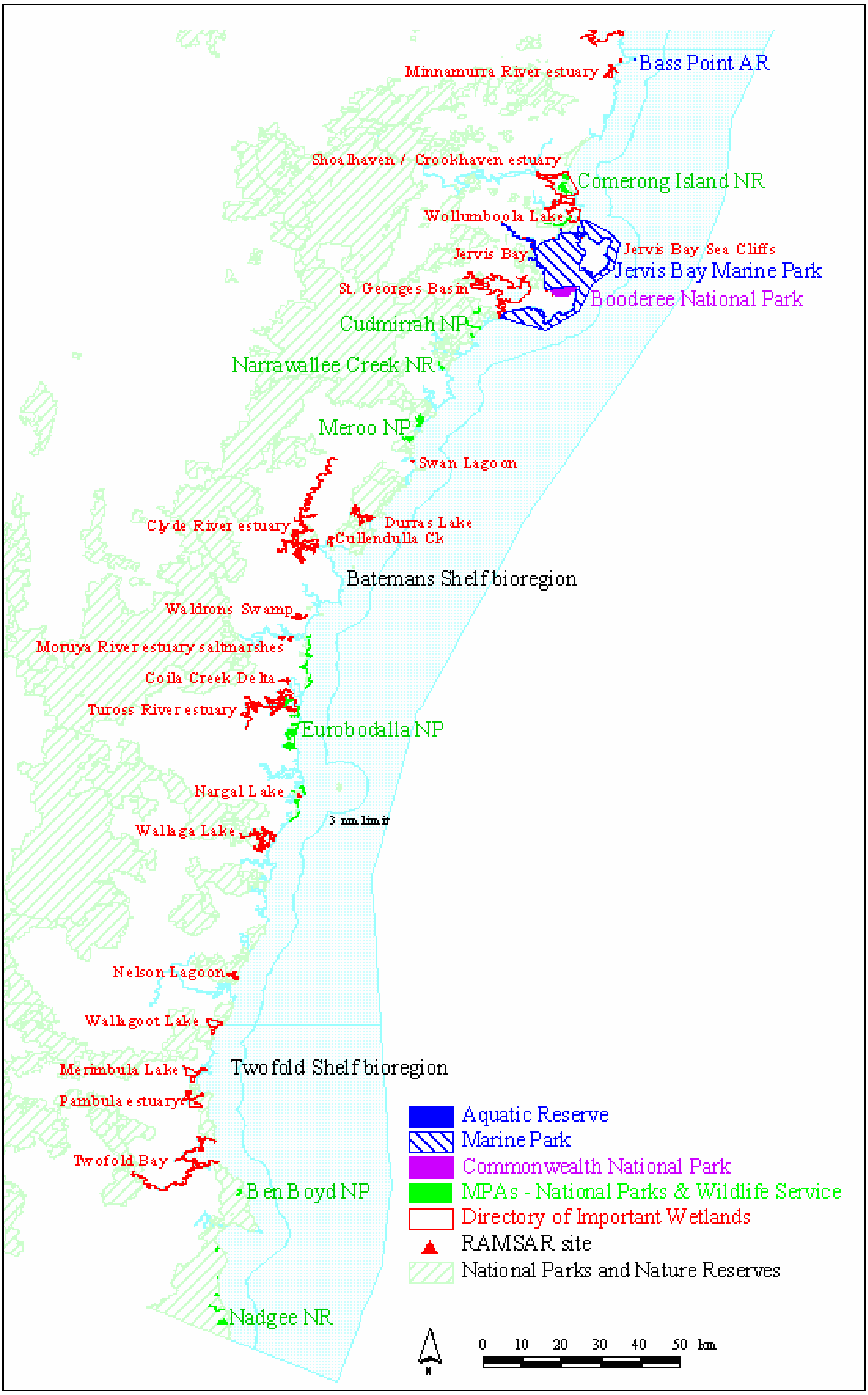


Figure 8.2. Marine protected areas (marine parks, aquatic reserves, Commonwealth National Park and the marine components of NSW national parks and nature reserves), RAMSAR sites (none) and important wetlands in the Batemans and Twofold Shelf bioregions.

8.4 Systematic assessment

8.4.1 Estuarine ecosystems

Data sources

Roy *et al*. (2001). "Structure and function of south-east Australian estuaries."

GIS coverage of estuaries from NSW Waterways.

Oblique aerial photos from the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR).

Data description

A GIS coverage of estuaries from NSW Waterways was classified by estuary type according to Roy *et al*. (2001).

Criterion

Comprehensiveness.

Assessment measures

Area and number of different estuary types represented in marine protected areas.

Assessment

Of the 72 major estuaries in the Batemans and Twofold Shelf bioregions classified according to Roy *et al*., there was only one tide dominated drowned river valley, but four ocean embayments, 24 wave dominated barrier estuaries and 43 intermittent coastal lagoons or creeks (Figure 7.4 - Figure 8.11).

The Clyde River is the only example of a tide dominated, drowned river valley in the Batemans Shelf bioregion and this estuary type is not represented within any MPA (Figure 7.5b).

Jervis Bay, the largest ocean embayment in the Batemans Shelf bioregion is entirely included within Jervis Bay Marine Park and Booderee National Park (Figure 7.5a). Booderee National Park is a Commonwealth protected area owned by the Wreck Bay Aboriginal Community Council and jointly managed by the Aboriginal Community Council and the Department of Environment and Heritage. A Management Plan for Booderee National Park includes management zoning of the marine portion of the national park.

Twofold Bay is the only ocean embayment in the Twofold Shelf bioregion. However, ocean embayments are not represented within MPAs in the NSW section or in any other sections of the bioregion (Figure 8.6 and 8.7a).

St Georges Basin and the Shoalhaven River are the largest wave dominated barrier estuaries in the Batemans Shelf bioregion but there are several other large estuaries of this type in the bioregion including Tuross Lake, Wallaga Lake, Wagonga Inlet, Lake Conjola, Moruya River, Burrill Lake and others (Figure 7.5c). There are approximately 3 km^2 of wave dominated barrier estuary in Currumbene Creek within Jervis Bay Marine Park and in national parks and nature reserves in the Shoalhaven, Tuross and Narrawallee estuaries. In total, this represents 2% of this estuary type within MPAs in the bioregion.

In the Twofold Shelf bioregion there are four wave dominated barrier estuaries, the largest being Pambula Lake. However, there are currently no barrier estuaries represented in MPAs in either the NSW or in any other sections of the bioregion (Figure 8.6 and Figure 8.7c).

Coila Lake, Lake Wollumboola, Swan Lake, Wallagoot Lake and Durras Lake are the largest intermittent estuaries in the Batemans Shelf bioregion and there are over twenty other estuaries of this type in the bioregion (Figure 8.8). Carama Creek is within Jervis Bay Marine Park and all of Lake Wollumboola, Berrara Creek, Termeil Lake, Meringo Creek, Lake Brunderee, Lake Tarouga, Lake Brou, and Mummuga Lake, and parts of Swan Lake, Lake Tabourie, Congo Creek, Nangudga Lake and Corunna Lake are included within national parks and nature reserves representing a total of 11 km^2 or 30% of the area of intermittent estuaries in the Batemans Shelf bioregion included within MPAs.

There are at least twelve intermittent estuaries in the NSW section of the Twofold Shelf bioregion, the largest being Nadgee Lake. Five of these estuaries (Merrica River, Wirra Birra Creek, Table and Little Creek, Nadgee River and Nadgee Lake) are within the declared wilderness of Nadgee Nature Reserve. In total, MPAs include 1.6 km^2 or 50% of the area of this estuarine ecosystem type for the NSW section of the bioregion (Figure 8.6 and Figure 8.8).

In summary, for the Batemans Shelf bioregion, 76% of the bioregion’s ocean embayment, 0% of drowned river valley, 2% of barrier estuary and 30% of the area of intermittent estuarine ecosystems are included within MPAs. Jervis Bay Marine Park includes several areas of estuary with significant proportions of these ecosystems in sanctuary zones. However, those areas in national parks or nature reserves do not have direct protection for fish or aquatic invertebrates from fishing.

In the Twofold Shelf bioregion, there are no ocean embayments or barrier estuaries included within MPAs, but almost 50% of the area of intermittent estuaries in the NSW section of the bioregion is included within national parks or nature reserves.

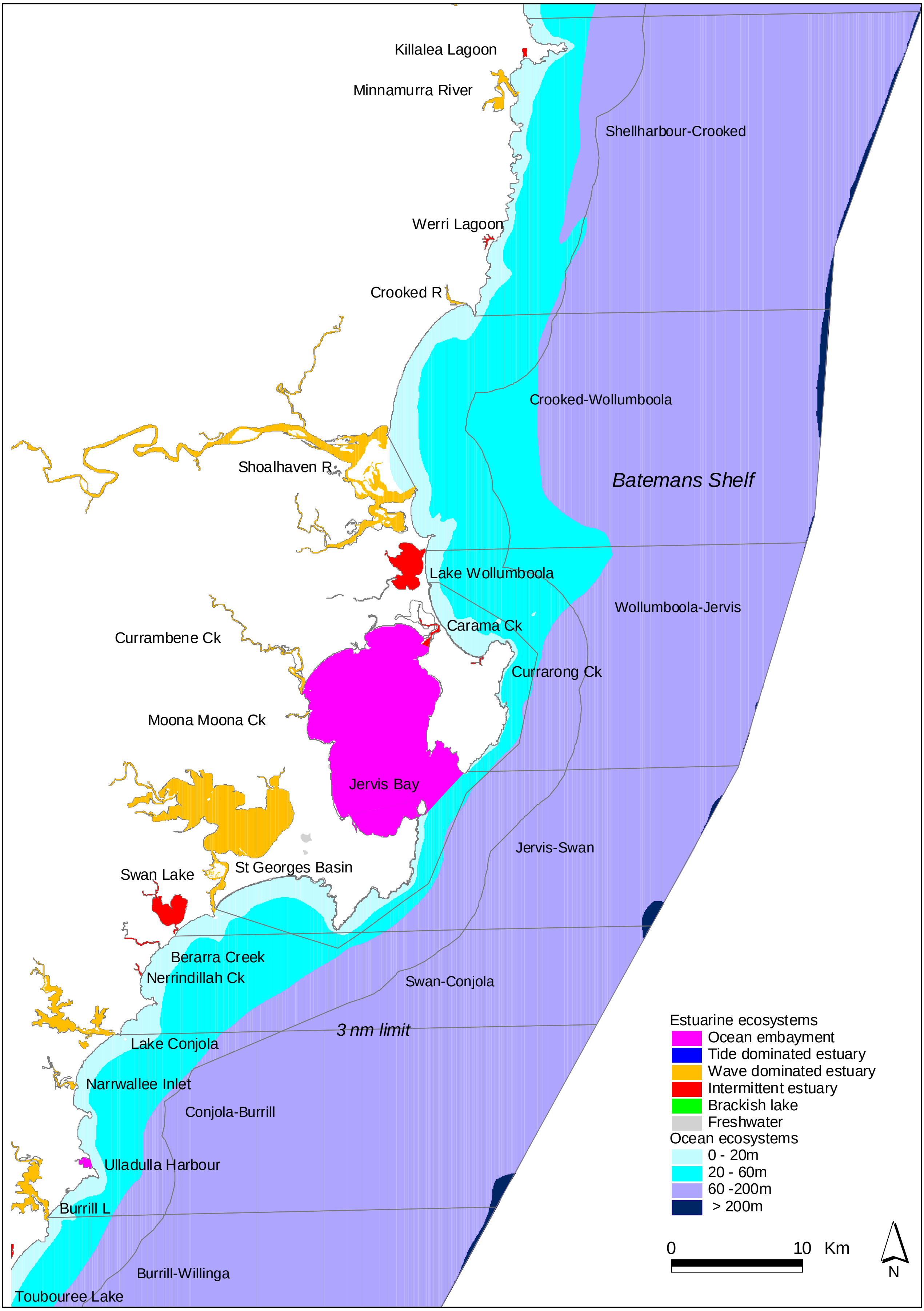


Figure 8.3. Broad scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types – Shellharbour to Burrill Lake.

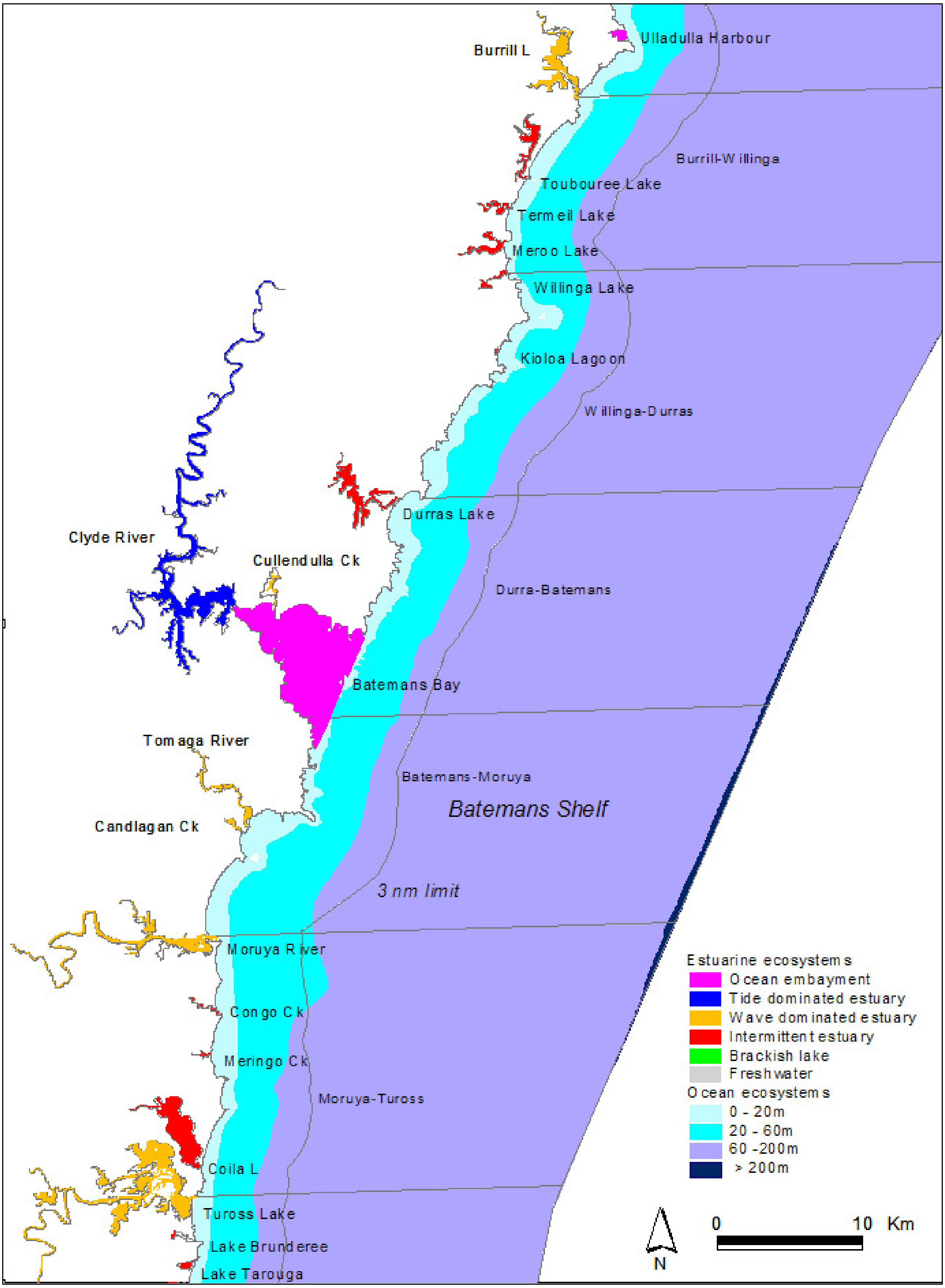


Figure 8.4. Broad scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types – Burrill Lake to Tuross Lake.

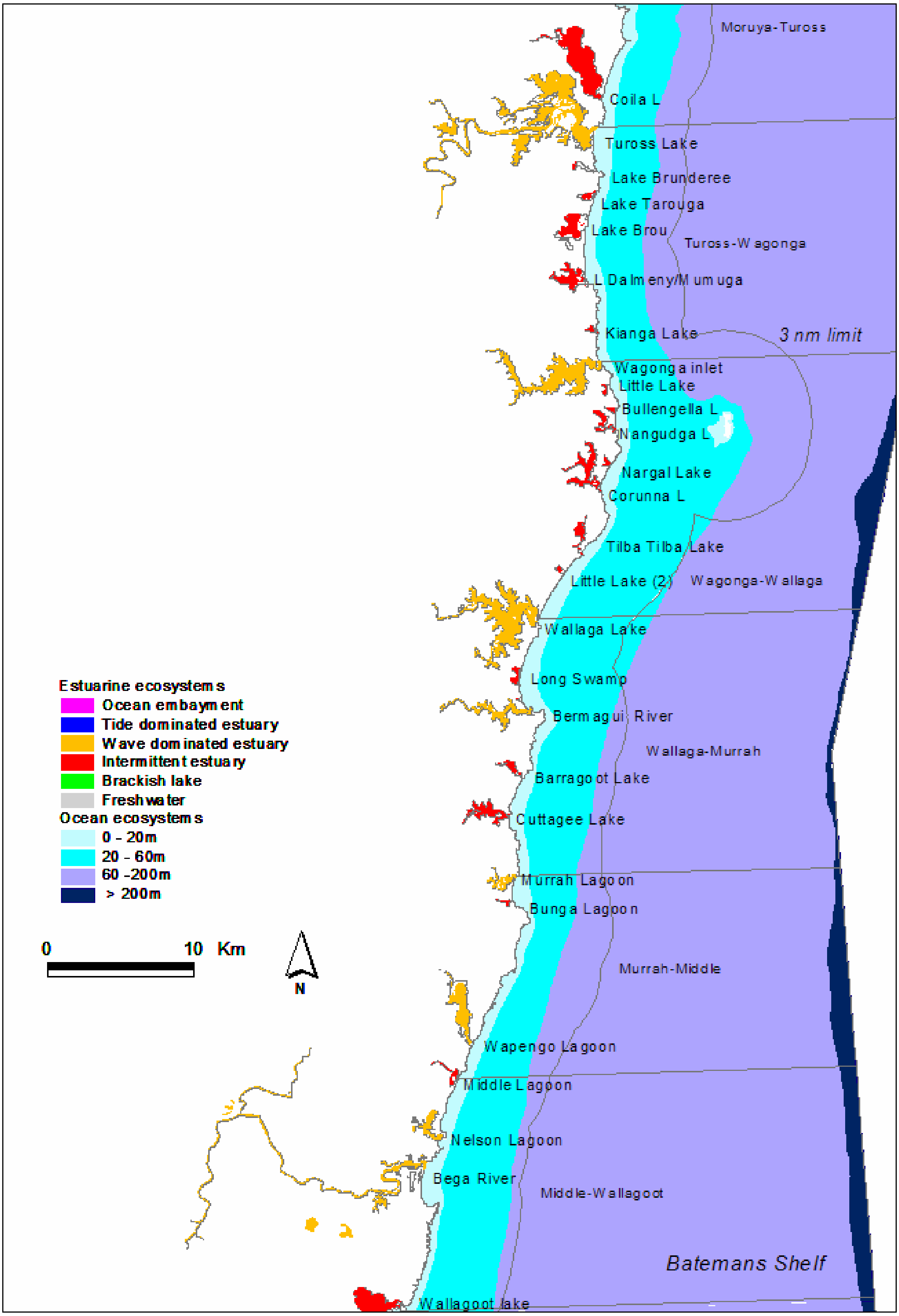


Figure 8.5. Broad scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types – Tuross Lake to Wallagoot Lake.

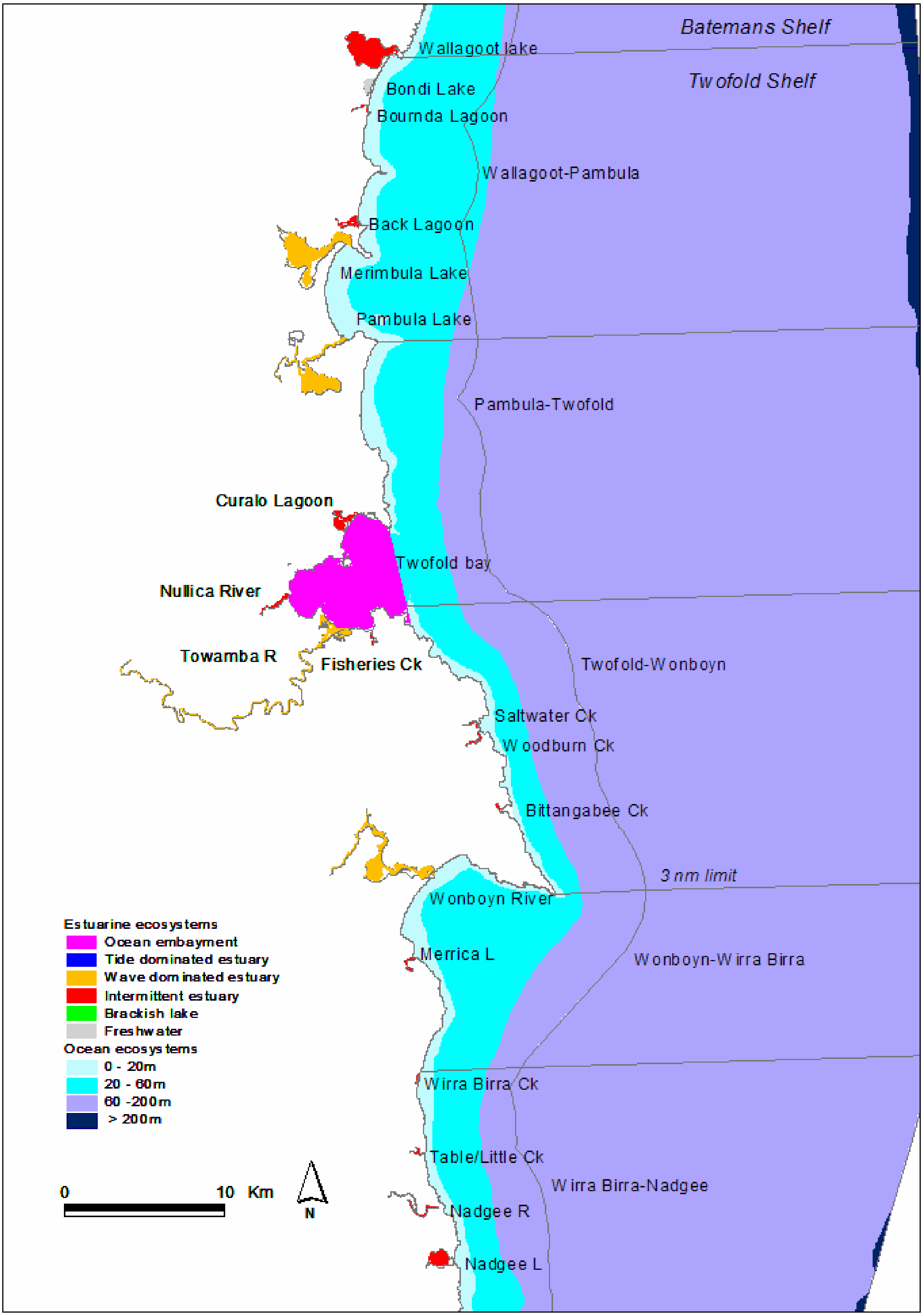


Figure 8.6. Broad scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types – Wallagoot Lake to the Victorian border.

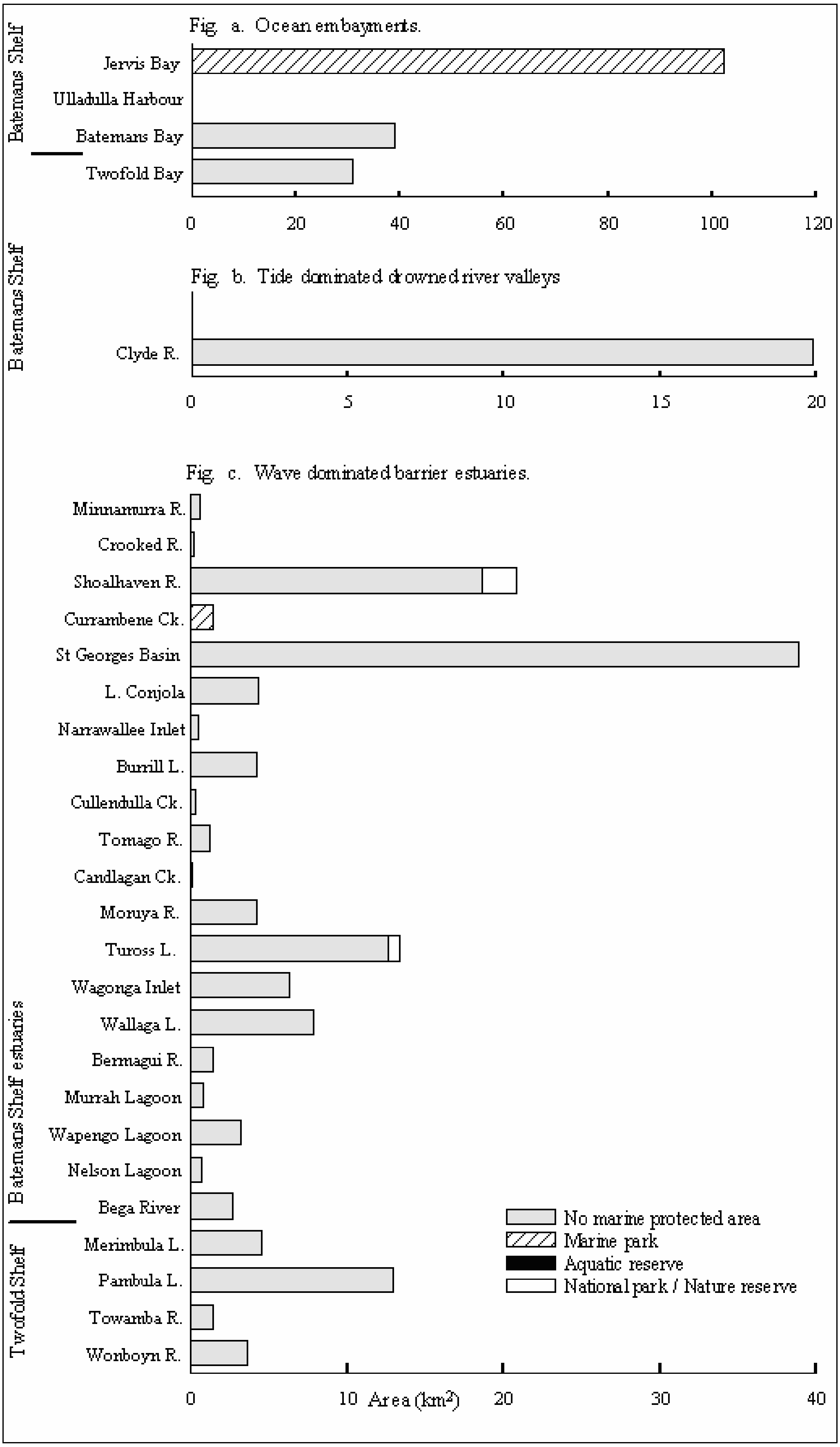


Figure 8.7a-c. Area (km^2) of open water within and outside marine protected areas for different estuary ecosystem types in the Batemans and Twofold Shelf bioregions. Raw data from West *et al.* 1985, estuaries classified according to Roy *et al.* (2001).

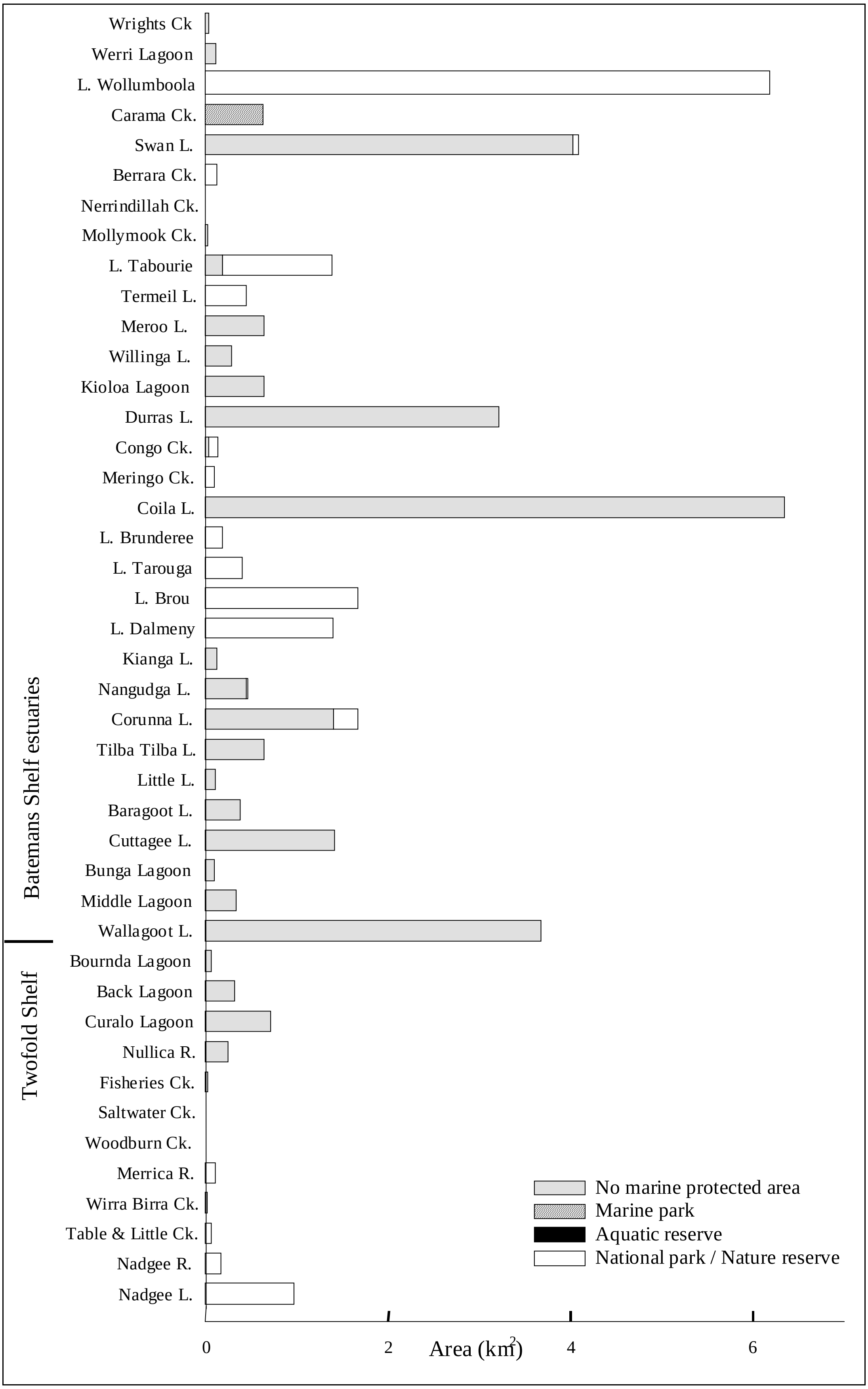


Figure 8.8. Area of open water (km^2) within marine protected areas for intermittent lagoons and creeks in the Batemans Shelf and Twofold Shelf (NSW) bioregions. Raw data from West *et al.* 1985, estuaries classified according to Roy *et al.* (2001).

a. Minnamurra River b. Werri Lagoon c. Crooked River d. Shoalhaven River

e. Lake Wollumboola f. Jervis Bay g. St Georges Basin h. Swan Lake

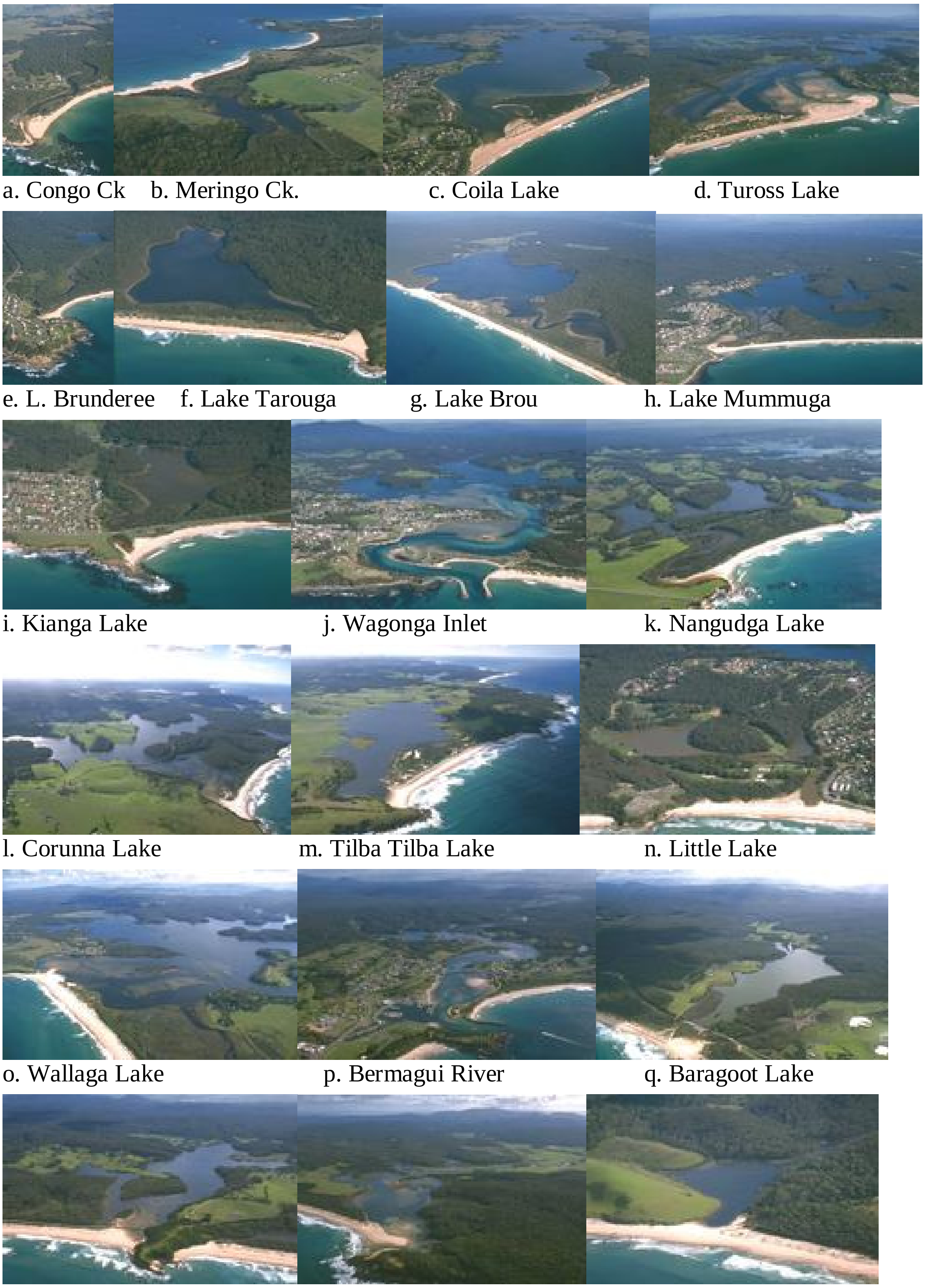
i. Berrara Creek j. Nerrindillah k. Lake Conjola

l. Narrawallee Creek m. Burrill Lake n. Tabourie Lake

o. Termeil Lake p. Meroo Lake q. Willinga Lake r. Durras Lake

s. Batemans Bay t. Tomago River u. Candalagan Ck v. Moruya River

Figure 8.9a-v. Oblique aerial photographs of estuaries in the Batemans Shelf bioregion (provided by the NSW Department of Infrastructure, Planning and Natural Resources).



a. Congo Ck b. Meringo Ck. c. Coila Lake d. Tuross Lake
e. L. Brunderee f. Lake Tarouga g. Lake Brou h. Lake Mummuga
i. Kianga Lake j. Wagonga Inlet k. Nangudga Lake
l. Corunna Lake m. Tilba Tilba Lake n. Little Lake
o. Wallaga Lake p. Bermagui River q. Baragoot Lake
r. Cuttagee Lake s. Murrah Lagoon t. Bunga Lagoon

Figure 8.10a-t. Oblique aerial photographs of estuaries in the Batemans Shelf bioregion (provided by the NSW Department of Infrastructure, Planning and Natural Resources).

a. Wapengo Lagoon b. Middle Lagoon c. Nelson Lagoon
d. Bega River e. Wallagoot Lake f. Back Lagoon
g. Merimbula Lake h. Pambula Lake i. Curalo Lake
j. Twofold Bay k. Towamba River l. Wonboyne River
m. Merrica R. n. Nadgee River o. Nadgee Lake

Figure 8.11a-o. Oblique aerial photographs of estuaries in the Batemans Shelf and Twofold Shelf bioregions (provided by the NSW Department of Infrastructure, Planning and Natural Resources).

8.4.2 NSW Fisheries[2] assessment of wave dominated and intermittent estuaries

Data source

Frances, J. (2000) "Identification of candidate sites for aquatic reserves in the Hawkesbury Shelf and Batemans Shelf bioregions."

Data description

The estuary classification of Roy *et al*. (2001) was used to assess comprehensiveness and representativeness and criteria for ecological importance, uniqueness, national and international importance, productivity, vulnerability and naturalness. An expert panel considered this collated data, provided ratings for estuaries and prioritised sites for declaration as aquatic reserves.

Criteria

Comprehensiveness, representativeness, ecological importance, uniqueness, national and international importance, productivity, vulnerability and naturalness.

Assessment measures

Area and number of different estuary types represented in marine protected areas.

Assessment

Table 8.2 - Table 8.4 display short-listed sites for each estuary type in the assessment, their ratings and their priority for declaration as MPAs. A more detailed description of these sites is given in Appendix 4. Wallaga Lake (Figure 7.7), Nelson Lagoon (Figure 7.8) and Durras Lake (Figure 8.14) were selected as priority candidate aquatic reserves, but after public consultation a final decision on their declaration was deferred until after completion of this assessment. Wallaga and Durras Lakes were subsequently included in a large multiple use marine park. Insufficient data were available for the expert panel to nominate a mature intermittent estuary as a candidate MPA and the assessment did not include estuaries in the Twofold Shelf bioregion.

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[2] now within the NSW Department of Primary Industry

Table 8.2. Ratings (low, medium, high) and priorities for NSW Fisheries[2] estuarine aquatic reserve candidates – youthful wave dominated and intermittent estuaries (Frances 2000). Dash equals "No data."

Type	Estuary	Ecological importance	Uniqueness	Naturalness	Vulnerability	Expert ID	Priority
Youthful Wave dominated	Burrill L.	Med	-	Med	Med	Yes	4
	Wagonga Inlet	High	-	Med	High	Yes	3
	St Georges Basin	High	High	Med	High	Yes	2
	L. Conjola	Low	-	Low	Med		
	Wallaga L	Med	-	High	Low	Yes	1
Youthful Intermittent	Swan L	High	-	High	Low	Yes	
	Werri Lagoon	-	-	Low	High		
	L. Wollumboola	High	High	Med	Low	Yes	1
	Berrara Ck	-	-	High	Low		
	Durras L	High	-	High	Low	Yes	2
	Meringo Ck	-	-	Low	Low		
	Coila L	Med	-	Low	Low	Yes	3
	Mummuga L	-	-	Med	Med		
	Corunna L	-	-	Med	Low	Yes	
	Cuttagee L	-	-	Med	Low		

[2] now within the NSW Department of Primary Industry

Table 8.3. Ratings (low, medium, high) and priorities for NSW Fisheries[2] estuarine aquatic reserve candidates – mature wave dominated estuaries (Frances 2000). Dash equals "No data."

Type	Estuary	Ecological importance	Uniqueness	Naturalness	Vulnerability	Expert ID	Priority
Mature Wave dominated	Minnamurra R	Med	-	Low	High		
	Crooked R	Med	-	Low	High		
	Shoalhaven R	High	High	Low	High	Yes	3
	Crookhaven R	Med	-	Low	High		
	Narrawallee Ck	High	-	Med	Med	Yes	
	Cullendulla Ck	High	High	Med	Med	Yes	
	Tomago R	-	-	Med	Med		
	Candalagan Ck	-	-	Med	Med		
	Moruya R	Med	-	Low	High		
	Tuross L	Med	High	Low	Med	Yes	
	Bermagui R	High	-	Low	Med	Yes	2
	Murrah Lagoon	-	-	Med	Low	Yes	
	Wapengo Lagoon	High	Med	Med	Low	Yes	
	Nelson Lagoon	High	Med	High	Low	Yes	1
	Bega R	Low	-	Low	Low		

[2] now within the NSW Department of Primary Industry

Table 8.4. Ratings (low, medium, high) and priorities for NSW Fisheries[2] estuarine aquatic reserve candidates – mature intermittent estuaries (Frances 2000). Dash equals "No data."

Type	Estuary	Ecological importance	Uniqueness	Naturalness	Vulnerablility	Expert ID	Priority
Mature Intermittent	Bensons Ck	-	-	Low	High		-
	Nerrindillah Ck	-	-	Med	Low		-
	Tabourie L	High	-	Med	Low	Yes	-
	Termeil L	-	-	Med	Low		-
	Meroo Ck	-	-	Med	Low		-
	L. Brou	-	-	Med	Med		-
	Kianga L	-	-	Med	Low		-
	Nangudga Inlet	-	-	Low	Low	Yes	-
	Tilba Tilba L	-	-	Low	Med		-
	Baragoot L	-	-	Low	Low		-
	Bunga Lagoon	-	-	Med	Low		-
	Wrights Ck	-	-	Low	High		-
	Mollymook Ck	-	-	Low	High		-
	Willinga L	-	-	Med	Med		-
	Kiola Lagoon	-	-	High	Low		-
	Congo Ck	-	-	Med	Low		-
	Little L	-	-	Low	Low		-
	Middle Lagoon	High	-	Med	Low	Yes	-

[2] now within the NSW Department of Primary Industry

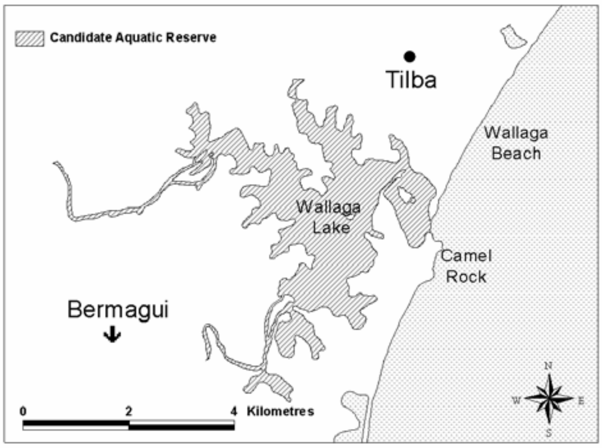


Figure 8.12. Previous candidate aquatic reserve at Wallaga Lake, a young wave dominated estuary (NSW Fisheries[2] Office of Conservation 2001).

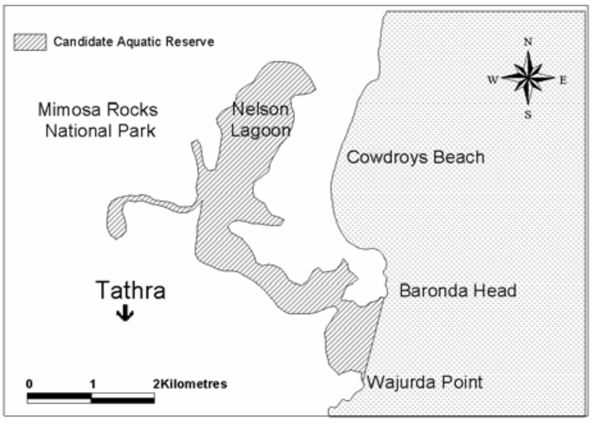


Figure 8.13. Previous candidate aquatic reserve at Nelson Lagoon, a mature wave dominated estuary (NSW Fisheries[2] Office of Conservation 2001).

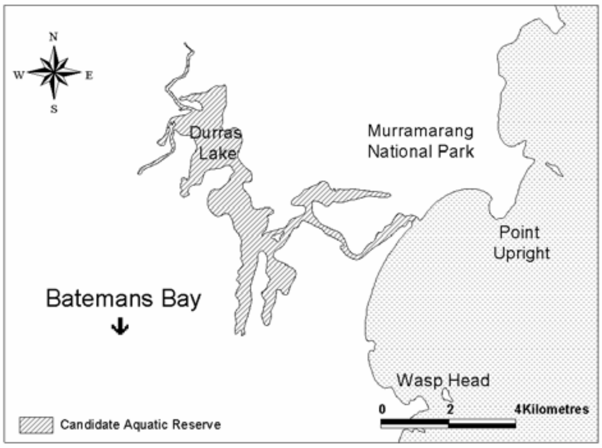


Figure 8.14. Previous candidate aquatic reserve at Durras Lake, a youthful intermittent estuary (NSW Fisheries[2] Office of Conservation 2001).

[2] now within the NSW Department of Primary Industry

8.4.3 Ocean ecosystems

Data source

Derived from NSW Waterways and Australian Hydrographic Office data.

Data description

Four depth zones (0-20 m, 20-60 m, 60-200 m and > 200 m) were derived from depth contours digitised by NSW Waterways from AHO hydrographic charts.

Criterion

Comprehensiveness

Assessment measures

Area of depth zones within broad scale planning units (sections of exposed coast and ocean).

Assessment

Options for representation of the ocean ecosystems, as defined by major depth zones, are spread throughout the latitudinal extent of the bioregion although there tends to be more area in the 0-20 m zone at the northern end of the Batemans Shelf bioregion (Figure 7.9).

Jervis Bay Marine Park includes 39 km^2 of the 0-20 m depth zone (or 13% of this depth zone for the bioregion within 3 nm of the coast) and 52 km^2 of the 20-60 m depth zone (or 5% of this zone within 3 nm). The Marine Park includes only 1.2 km^2 (0.2% of the waters within 3nm) of the 60-200 m depth zone. Larger areas of the deeper zones exist in Commonwealth waters beyond 3 nm of the coast and these are not represented in MPAs (Figure 8.16b and c).

In the NSW section of the Twofold Shelf bioregion there is no representation of these zones in MPAs but this does occur within Victorian and Tasmanian MPAs.

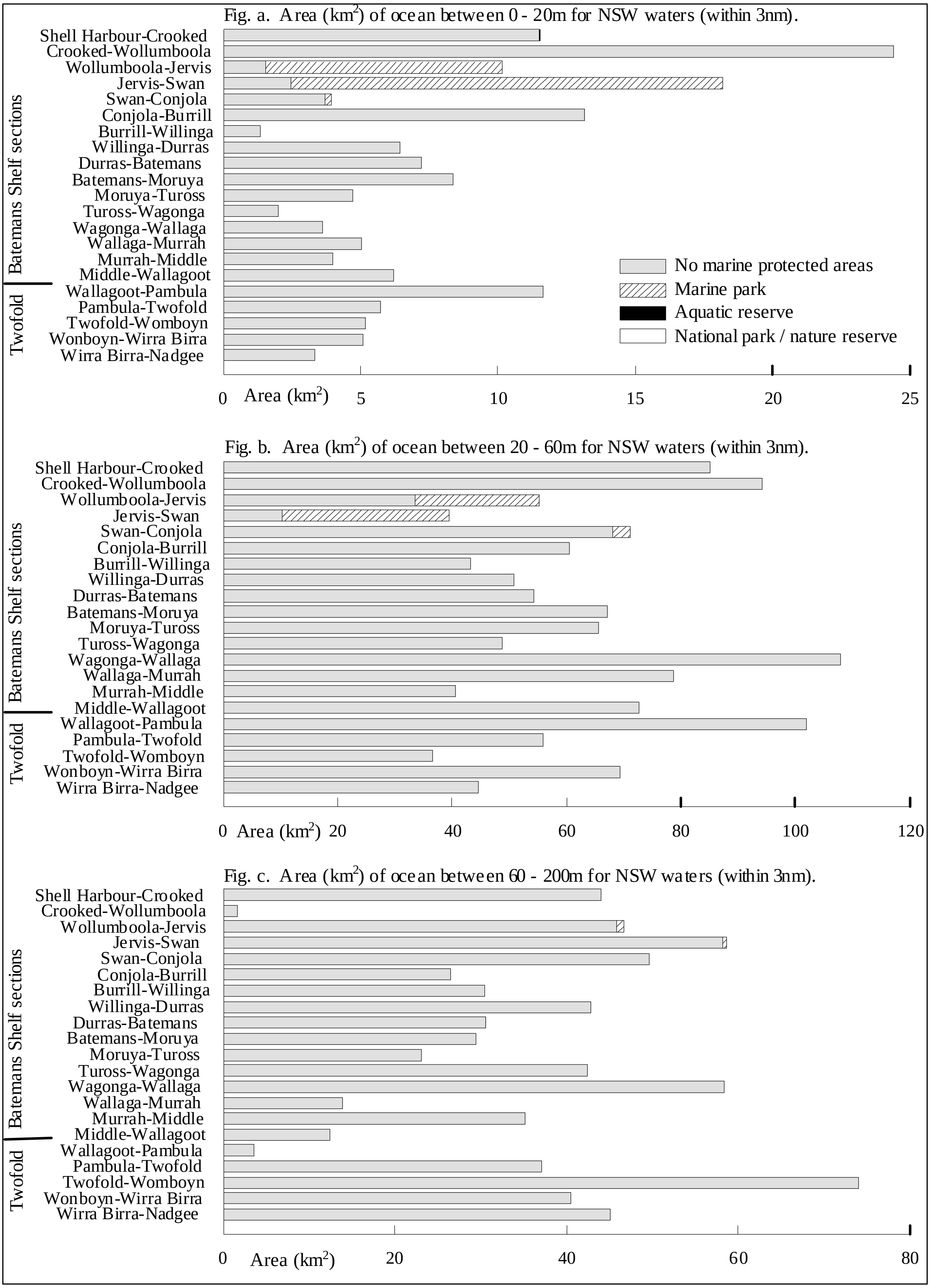


Figure 8.15a-c. Area (km^2) of ocean depth zones in marine protected areas for sections of ocean coast in NSW waters (within 3nm) of the Batemans and Twofold Shelf bioregions.

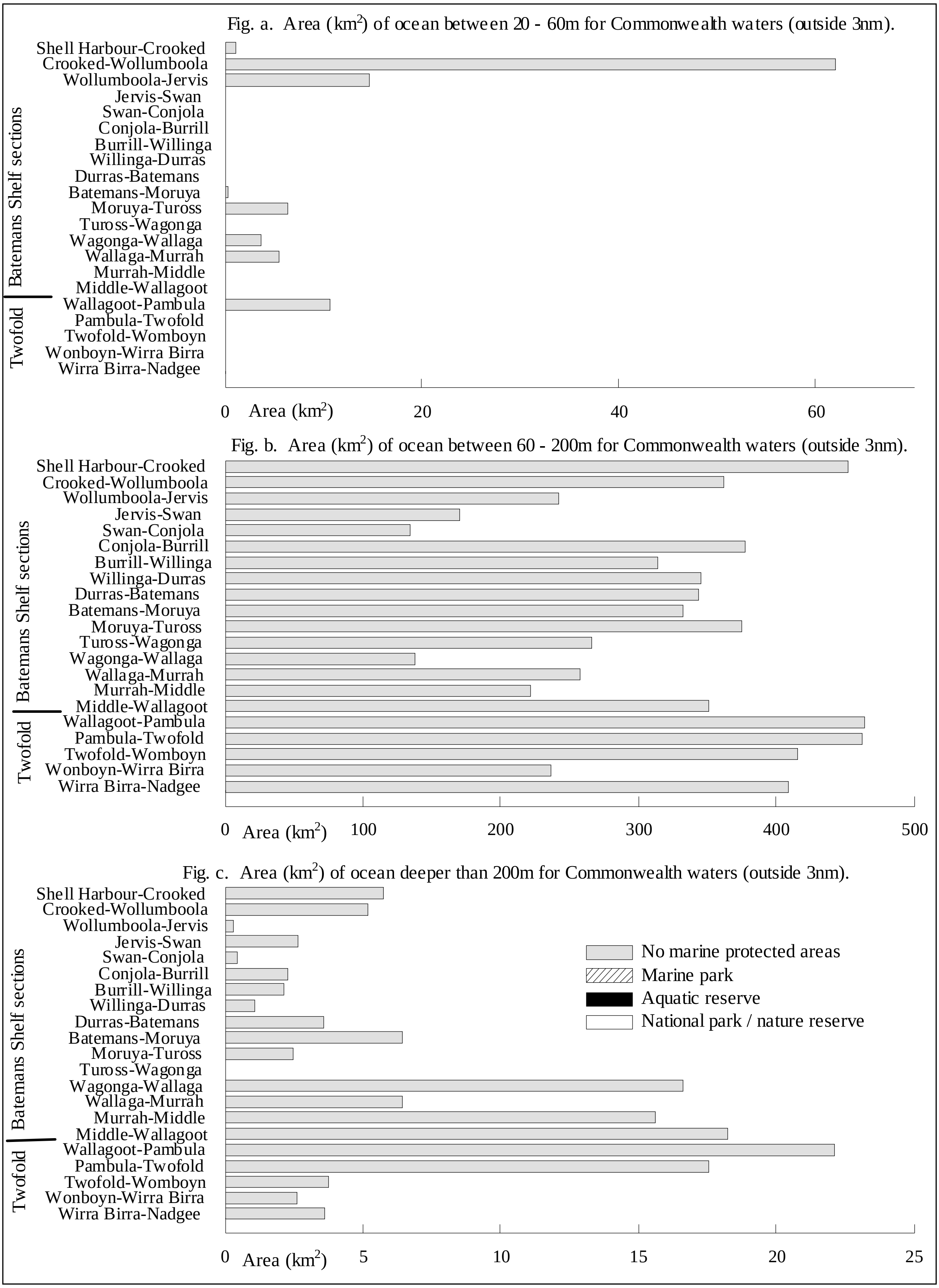


Figure 8.16a-c. Area (km^2) of ocean depth zones in marine protected areas for Commonwealth waters (outside of 3nm) of the Batemans and Twofold Shelf bioregions.

8.4.4 Oceanography - East Australian Current

Data source

A summary of some key oceanographic processes in the Batemans and Twofold Shelf bioregions (Cresswell *et al*. 1983, Pollard *et al*. 1997, Cresswell 1998, CSIRO Australia 2001).

Criteria

Comprehensiveness, representativeness, ecological importance and productivity.

Data description and assessment

The East Australian Current (EAC) runs south along the east coast of Australia from the Coral Sea into the Tasman Sea and brings warm tropical and subtropical water into the cooler temperate waters of NSW (Figure 8.17). It has an important influence on marine biodiversity in coastal and offshore waters throughout NSW through its influence on ocean temperature, density and chemistry, eddies, counter currents, upwellings, primary productivity, transport of larvae and food supply. The influence of the current on phytoplankton and productivity has been well studied and the movements of larger organisms such as gemfish, tuna and a range of pelagic species are also thought to be influenced by the current (CSIRO Australia 2001).

The current moves at speeds up to 5 knots, transports up to 30 million cubic metres of water per second, and can affect waters down to 500 metres in depth and 100 kilometres across. The EAC is strongest in summer, flowing up to twice the strength of the current in winter months (CSIRO Australia 2001).

The EAC often moves inshore across the continental shelf, generating northward flowing currents and small clockwise 'cold core' eddies. It periodically meanders south and retreats north across the Tasman Front, creating large anti-clockwise warm-core eddies up to 200 km in width and 1000 m deep, with currents up to four knots at their periphery. These eddies often continue to migrate south taking warm waters and incumbent larvae and other plankton into cold temperate waters (CSIRO Australia 2001).

The EAC moves away from the coast most frequently near South West Rocks and Seal Rocks in the Manning Shelf bioregion, yet sometimes continues inshore as far south as Ulladulla. An assessment by Pollard *et al*. (1997) estimated that the EAC influences NSW coastal waters between Tweed Heads and Seal Rocks about 90% of the time, but that this decreases to 50% of the time between Seal Rocks and Jervis Bay, and to 10% of the time between Jervis Bay and Cape Howe. This indicates that while the Tweed-Moreton and Manning Shelf bioregions are often influenced by subtropical waters, and the Hawkesbury Shelf alternates between two extremes, the inshore areas of the Batemans and Twofold bioregions are more often influenced by temperate conditions. The complex nature of the current and its eddies means that its influence on coastal and offshore conditions is highly variable, regardless of the seasonal averages (Figure 8.17 and Figure 8.18).

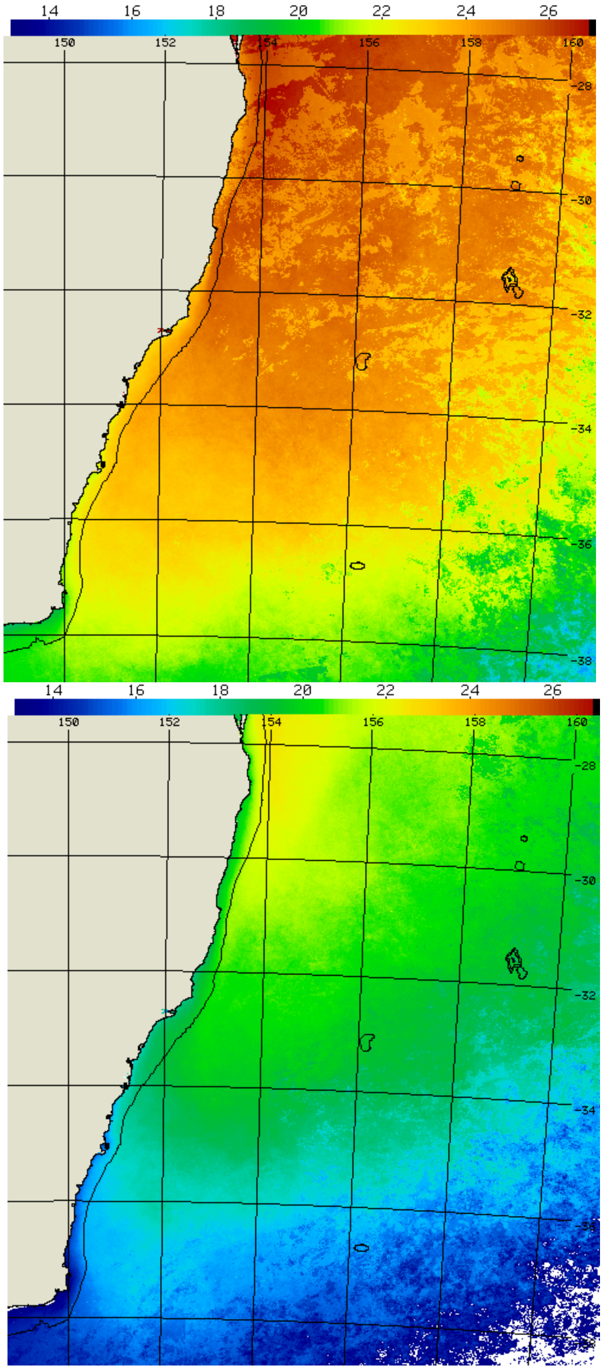
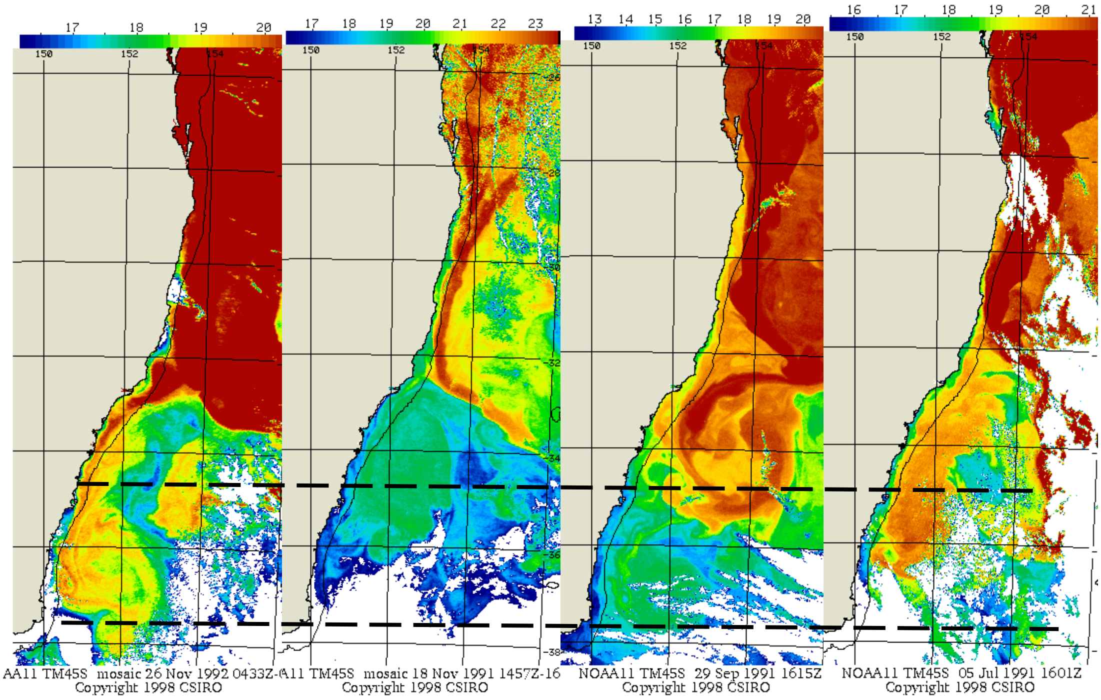


Figure 8.17. Mean sea surface temperature off NSW coast averaged for summer (January-March) and winter (July-September) (Cresswell 1998). Colour scales for temperature in degrees Celsius are across the top of each map.



a. b. c. d.

Figure 8.18. Broad scale oceanographic processes off the NSW continental shelf represented by sea surface temperature (SST) NOAA11 TM45S satellite images (after Cresswell 1998);

a. East Australian current warming inshore waters of the Batemans and Twofold Shelf bioregions during November;

b. cool inshore waters in the Batemans and Twofold Shelf during November as the EAC heads offshore from South West Rocks;

c. Cool inshore waters during September;

d. warm inshore waters in July

(dashed lines = Batemans Shelf; colour scales for temperature in degrees Celsius are across the top of each map, images from Cresswell 1998).

8.4.5 Seagrass, mangrove and saltmarsh habitats

Data sources

Estuarine vegetation maps (West *et al*. 1985) digitised by National Parks and Wildlife Service[1].

Data description

Estuarine plant communities were mapped between 1981 and 1984 using 1:25,000 scale aerial photographs and a 1:25,000 scale topographic map base. Vegetation identified in the digitised GIS data coverage included saltmarshes, mangroves and seagrasses (Figure 8.19 - Figure 8.25). These surveys should be regarded cautiously as a general indication of broad spatial patterns. More recent surveys by Fisheries (DPI) are underway (R. Williams pers. comm.).

Criteria

Comprehensiveness and representativeness.

Assessment

In the Batemans Shelf bioregion, large areas of seagrass habitat (9 km^2) are protected within Jervis Bay Marine Park and Booderee National Park representing 25% of the area of this habitat for the bioregion. Large areas of seagrass are also found in St Georges Basin (8.5 km^2) with smaller areas in many other estuaries. An additional 2 km^2 of seagrass habitat is found in the marine components of national parks and nature reserves.

In the NSW section of the Twofold Shelf bioregion, there are areas of seagrass habitat in Merimbula and Pambula Lakes and smaller areas in other estuaries. However, only 0.1 km^2 of seagrass representing 2% of this habitat in the NSW section of the bioregion occurs within MPAs. As the Victorian and Tasmanian MPAs in the Twofold Shelf bioregion do not include estuaries, seagrass habitats may not be well represented for this bioregion.

The largest areas of mangrove habitat in the bioregion are in the Shoalhaven River and the Clyde River and there are smaller areas in a number of other estuaries. Currently, about 0.7 km^2 of mangrove habitat, accounting for 5% of the area of this habitat in the bioregion is represented in Jervis Bay Marine Park, Comerong Island Nature Reserve in the Shoalhaven River and Eurobodalla National Park in Tuross Lake. Another 2.8 km^2 (21% of the habitat in the bioregion) of mangrove occurs above the mapped high tide mark in terrestrial national parks and nature reserves.

In the Twofold Shelf bioregion, mangrove habitats are only recorded by West *et al*. from Pambula Lake, Merimbula Lake and the Towamba River. None of this habitat is included in MPAs but 0.3 km^2 or 34% of the mangrove in the NSW section of the bioregion occurs above the mapped high water mark in terrestrial national parks and nature reserves. The extent of mangrove habitats within MPAs in the Victorian section of the bioregion is not known but is not likely to be large given the exposed locations of the Victorian Marine National Parks.

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[1] now within the Department of Environment and Conservation

The largest areas of saltmarsh in the Batemans Shelf bioregion occur around Carama Creek, above mapped mean high water, and therefore outside Jervis Bay Marine Park, but within Jervis Bay National Park. Large areas of saltmarsh are also found near the Shoalhaven River but only some of these are included in Comerong Nature Reserve. Smaller areas of saltmarsh (<1 km^2) are also found near almost 40 other estuaries in the bioregion including Currumbene Creek (above high tide and therefore outside Jervis Bay Marine Park), the Clyde River, Moruya River, Coila Lake, Tuross Lake, Wallaga Lake, Lake Brou, Wapengo Lagoon and the Bega River. In total, less than a square kilometre of saltmarsh habitat is included in MPAs in the Batemans Shelf bioregion, but a larger area (2.6 km^2 or 26% of the habitat in the bioregion) occurs above the mapped mean high water mark in terrestrial national parks and nature reserves.

The largest areas of saltmarsh habitat in the Twofold Shelf bioregion occur near Merimbula Lake and the Wonboyne River. None of this habitat is included in MPAs but 0.6 km^2 or 35% of saltmarsh habitat in the NSW section of this bioregion is included in the terrestrial components of Ben Boyd National Park and Nadgee Nature Reserve.

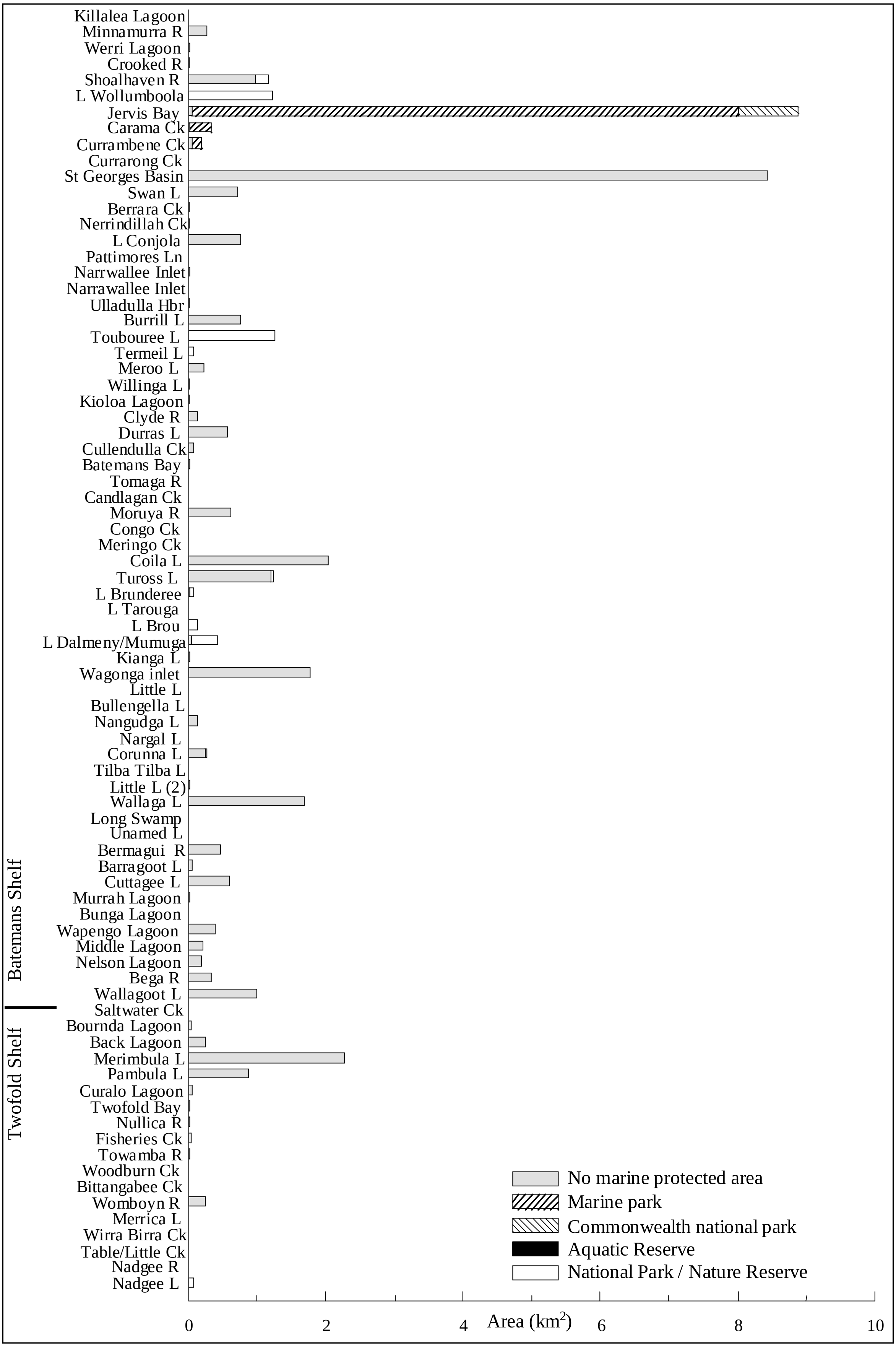

Figure 8.19. Area (km^2) of seagrass habitat in marine protected areas for estuaries of the Batemans Shelf and Twofold Shelf bioregions (raw data from West *et al*. 1985).

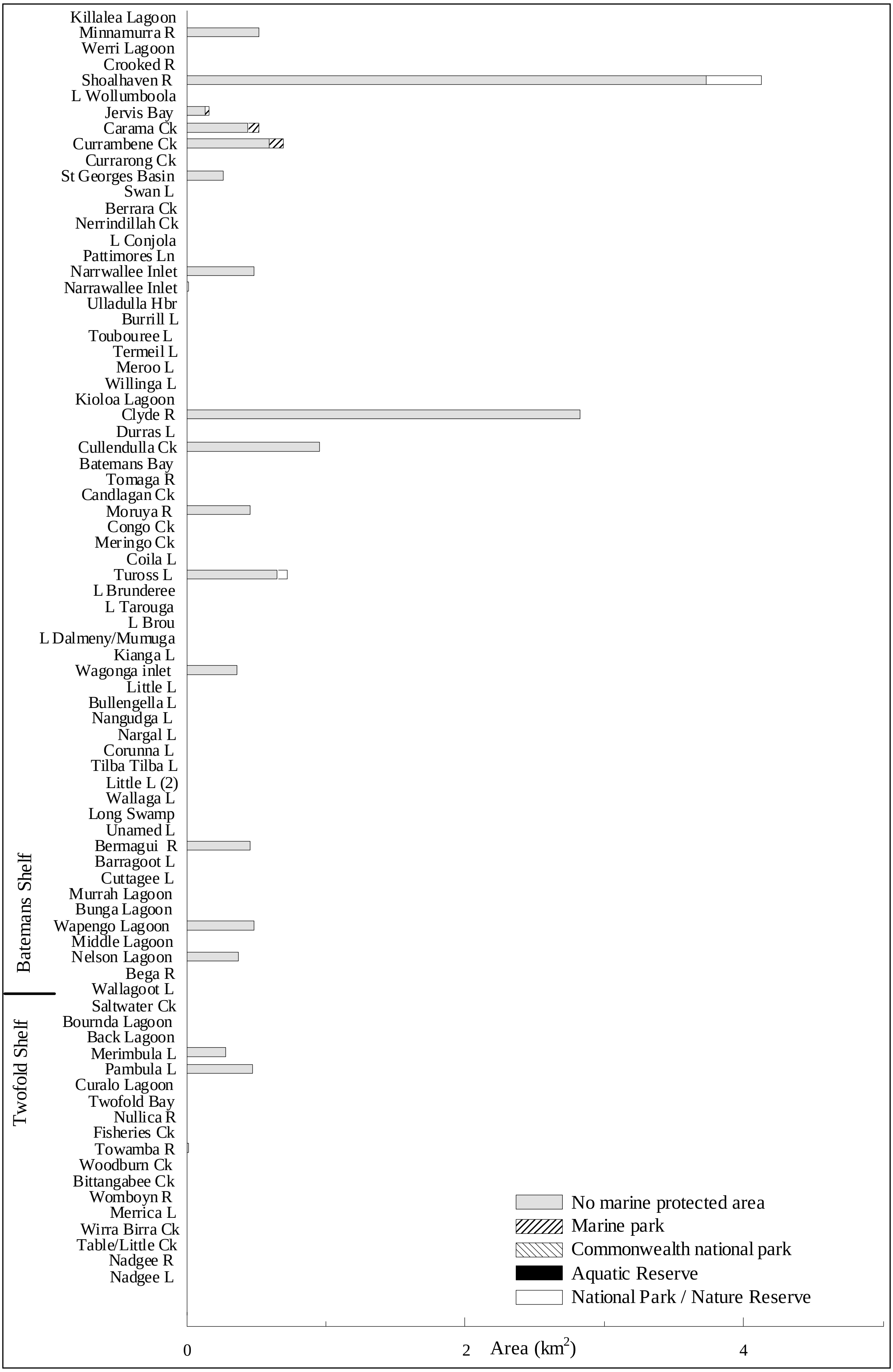

Figure 8.20. Area (km^2) of mangrove habitat in marine protected areas for estuaries of the Batemans Shelf and Twofold Shelf bioregions (raw data from West *et al*. 1985).

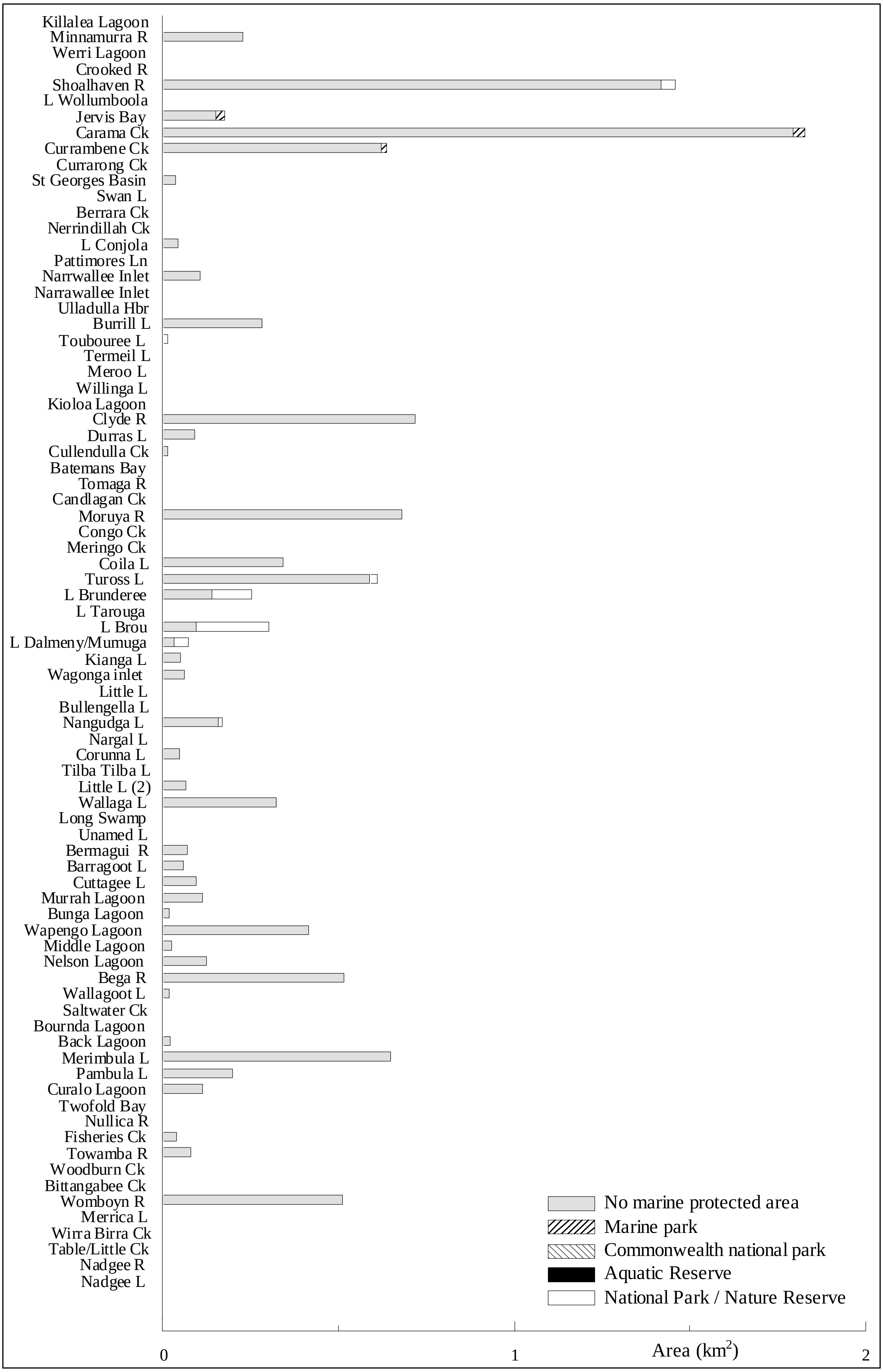

Figure 8.21. Area (km^2) of saltmarsh habitat in marine protected areas for estuaries of the Batemans Shelf and Twofold Shelf bioregions (raw data from West *et al*. 1985).

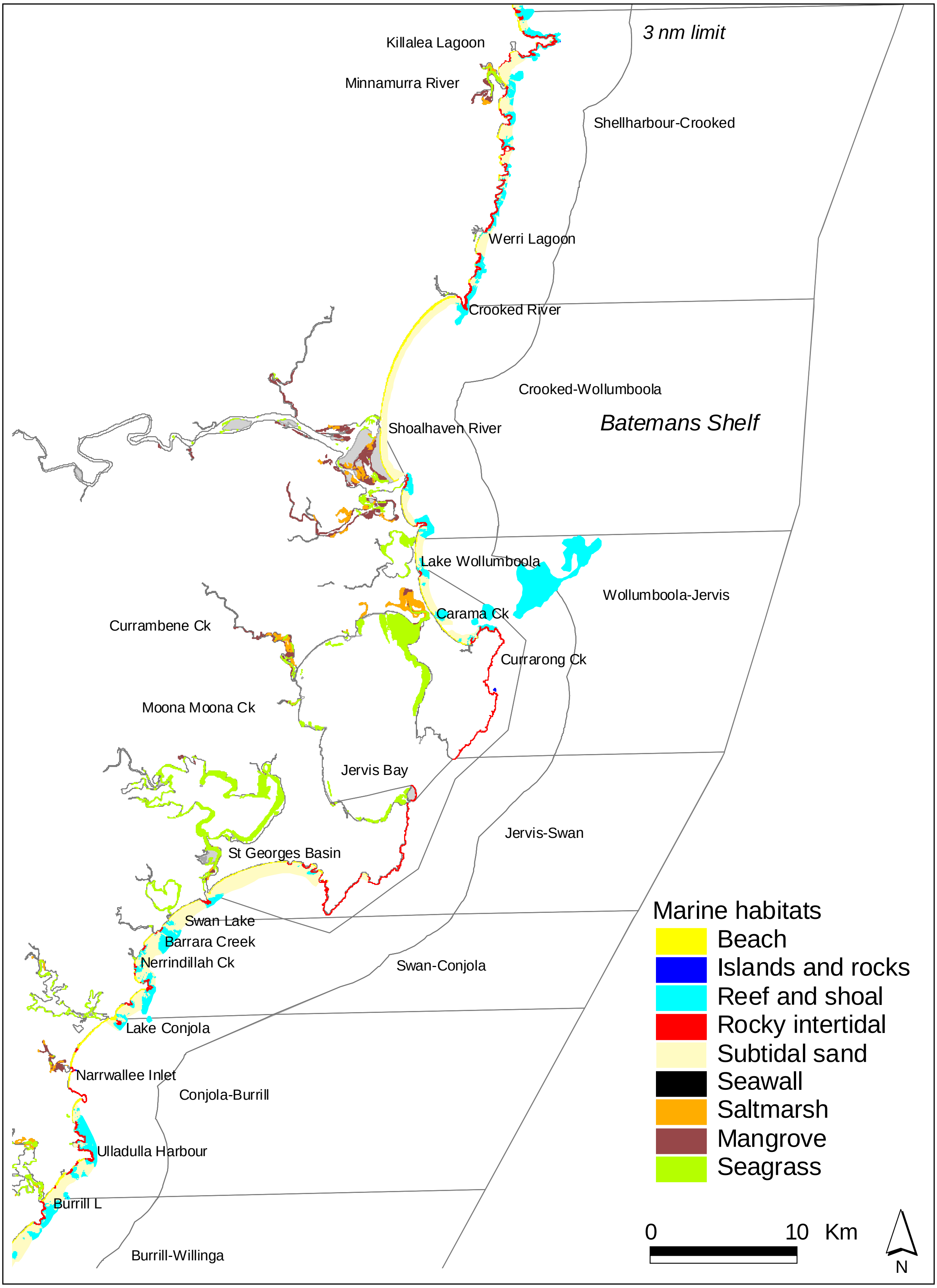

Figure 8.22. Mapped marine habitat types between Shellharbour and Burrill Lake.

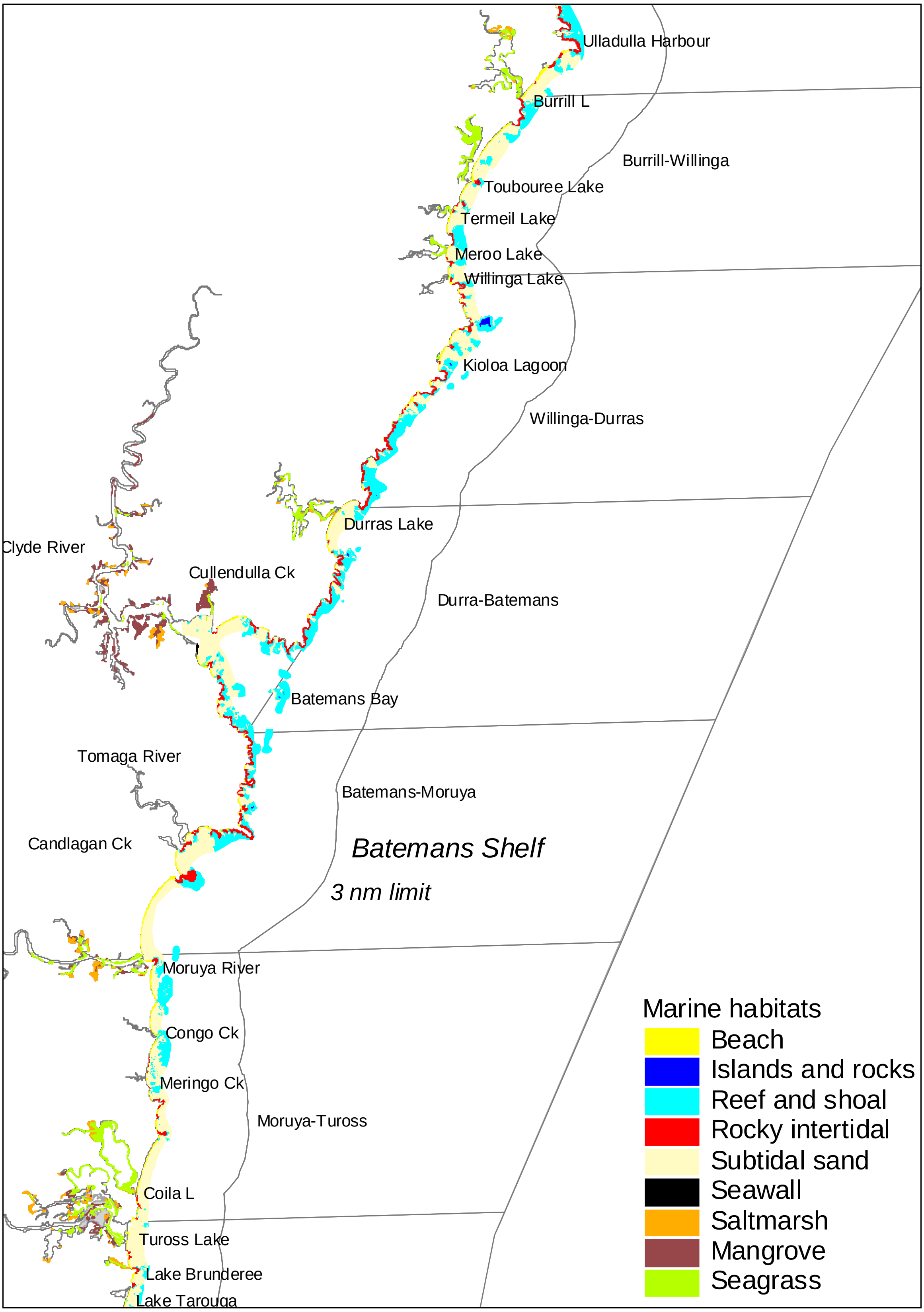

Figure 8.23. Mapped marine habitat types between Burrill Lake and Tuross Lake.

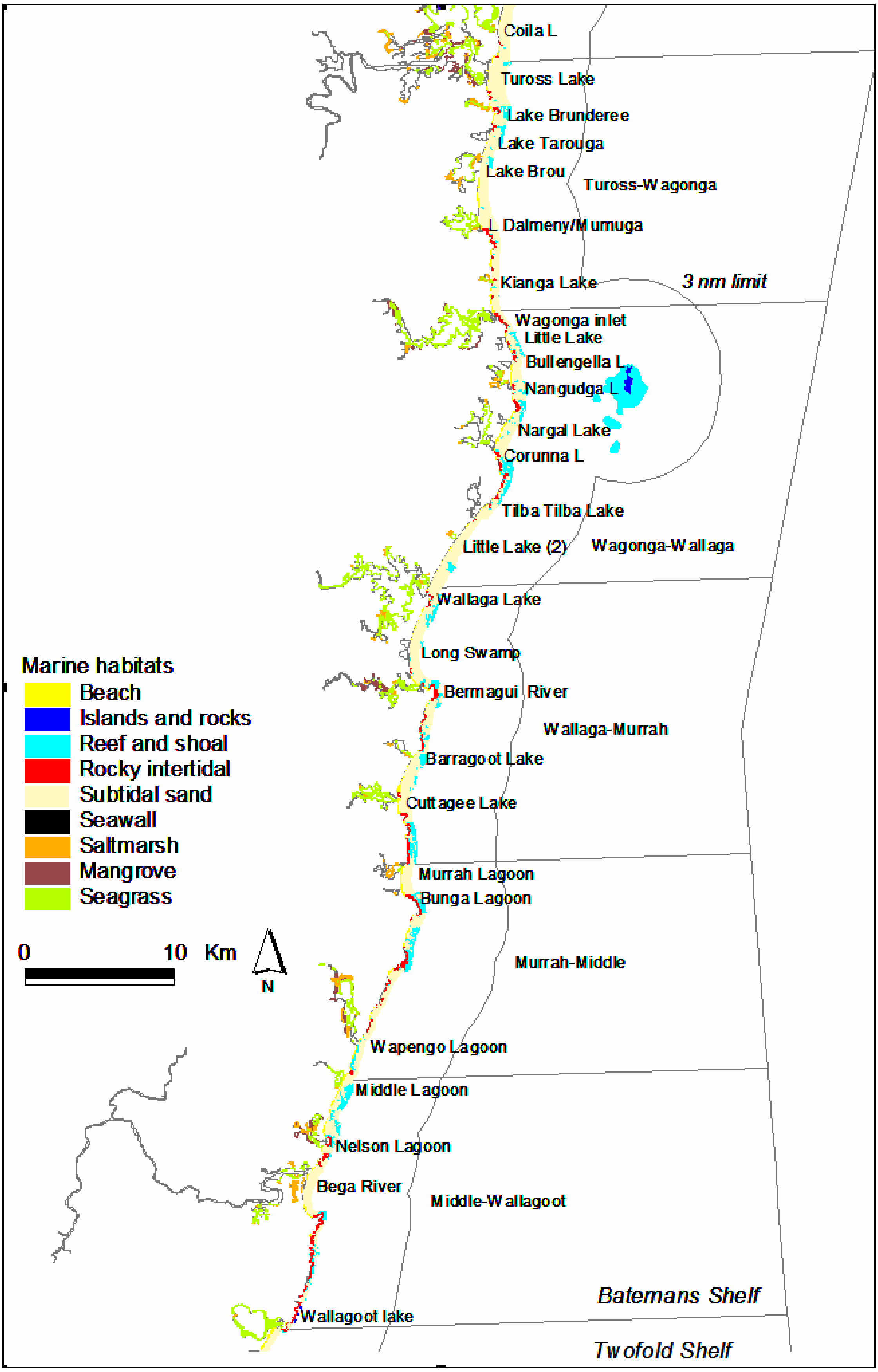

Figure 8.24. Mapped marine habitat units between Tuross Lake and Wallagoot Lake.

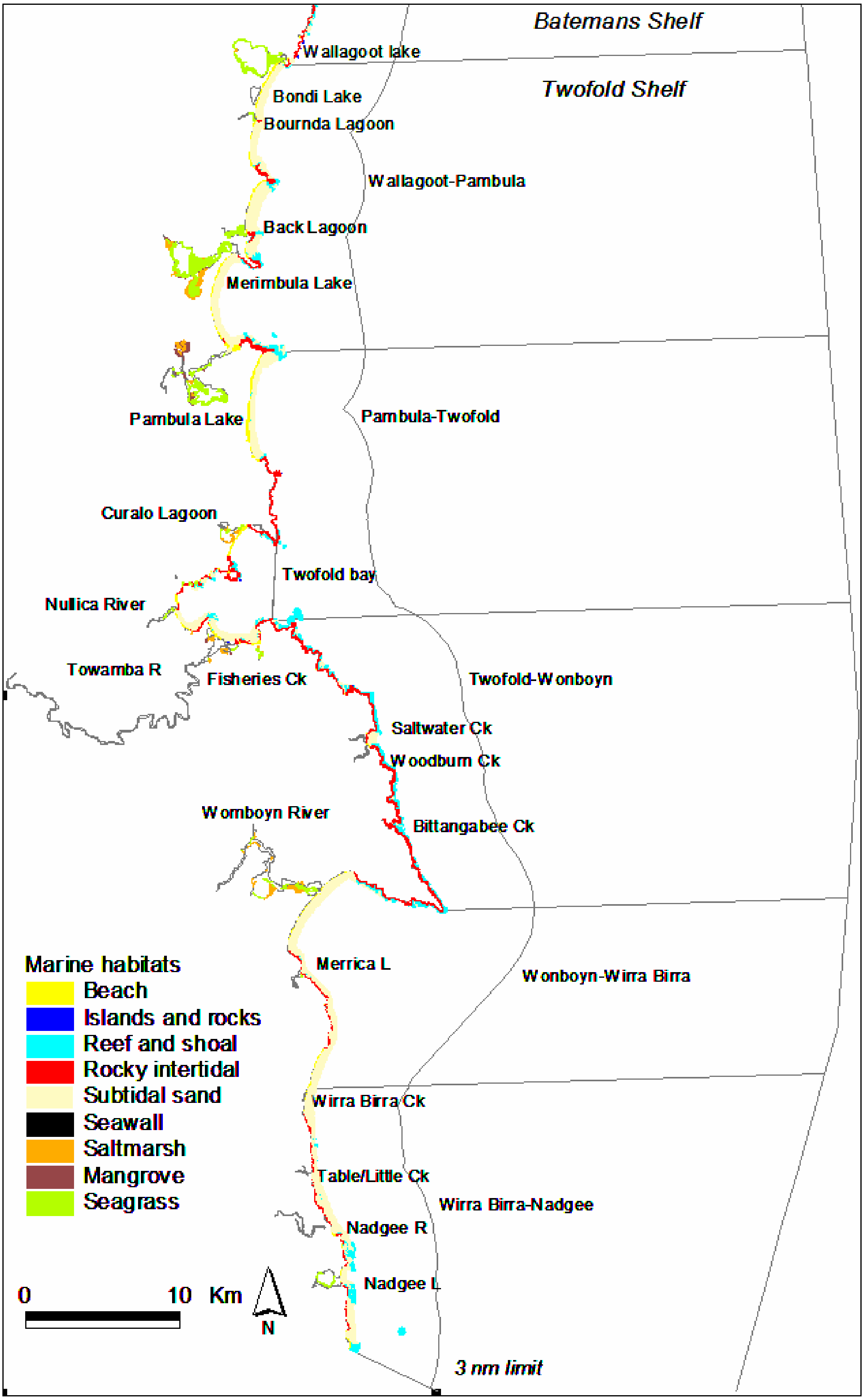

Figure 8.25. Mapped marine habitat units between Wallagoot Lake and the Victorian border.

8.4.6 Shallow subtidal reef and shoal

Data source

GIS coverage of near shore reefs digitised by Ron Avery (Department of Environment and Conservation) from aerial photographs provided by the NSW Department of Infrastructure, Planning and Natural Resources.

Shallow offshore reefs and shoals digitised from Australian Hydrographic Survey Charts.

Data description

Near shore reefs digitised from high resolution (1:8000 –1:25:000) aerial photographs.

Reefs were also classified by distance offshore (greater or less than 1 km from the coast).

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area in broad scale (sections of exposed coast and ocean) and small-scale planning units.

Assessment

Most mapped shallow reef and shoal occurred in the Wollumboolah-Jervis (9.8 km^2), Willinga-Durras (8.4 km^2), Wagonga-Wallaga (7.3 km^2) and Shell Harbour-Crooked (7 km^2) sections of coast. Most of the Wollumboolah-Jervis (7 km^2) and Wagonga-Wallaga (5.1 km^2) reef and shoal occurred more than 1 km offshore, while in the Willinga-Durras section (8.4 km^2) most reef occurred within 1 km of the coast (Figure 7.18).

A total of 2.8 km^2 of mapped reef and shoal lies within Jervis Bay Marine Park and Bushrangers Bay Aquatic Reserve representing 4% of this habitat for the Batemans Shelf bioregion. All of this reef and shoal is within 1 km of shore and there are no mapped offshore reef or shoal habitats within MPAs.

The Twofold-Wonboyn section of coast had the greatest area of mapped reef (3.8 km^2) in the NSW section of the Twofold Shelf bioregion. There are no areas of reef in MPAs in the NSW section of the Twofold Shelf bioregion, but reef habitats do occur in Point Hicks Marine National Park, Cape Howe Marine National Park and Beware Reef Marine Sanctuary in Victorian State waters and in the Kent Group Marine Reserve in Tasmanian waters.

Results for this habitat should be regarded cautiously as the use of aerial photographs to map subtidal habitats is limited to near shore areas and hydrographic charts focus on those reefs and shoals near the surface that pose a hazard for shipping. There is little, readily available information on the distribution of deeper reefs in most offshore areas. It is recommended that a more comprehensive assessment of existing seabed data is made and that, where required, additional seabed surveys are carried out to more accurately assess these environments.

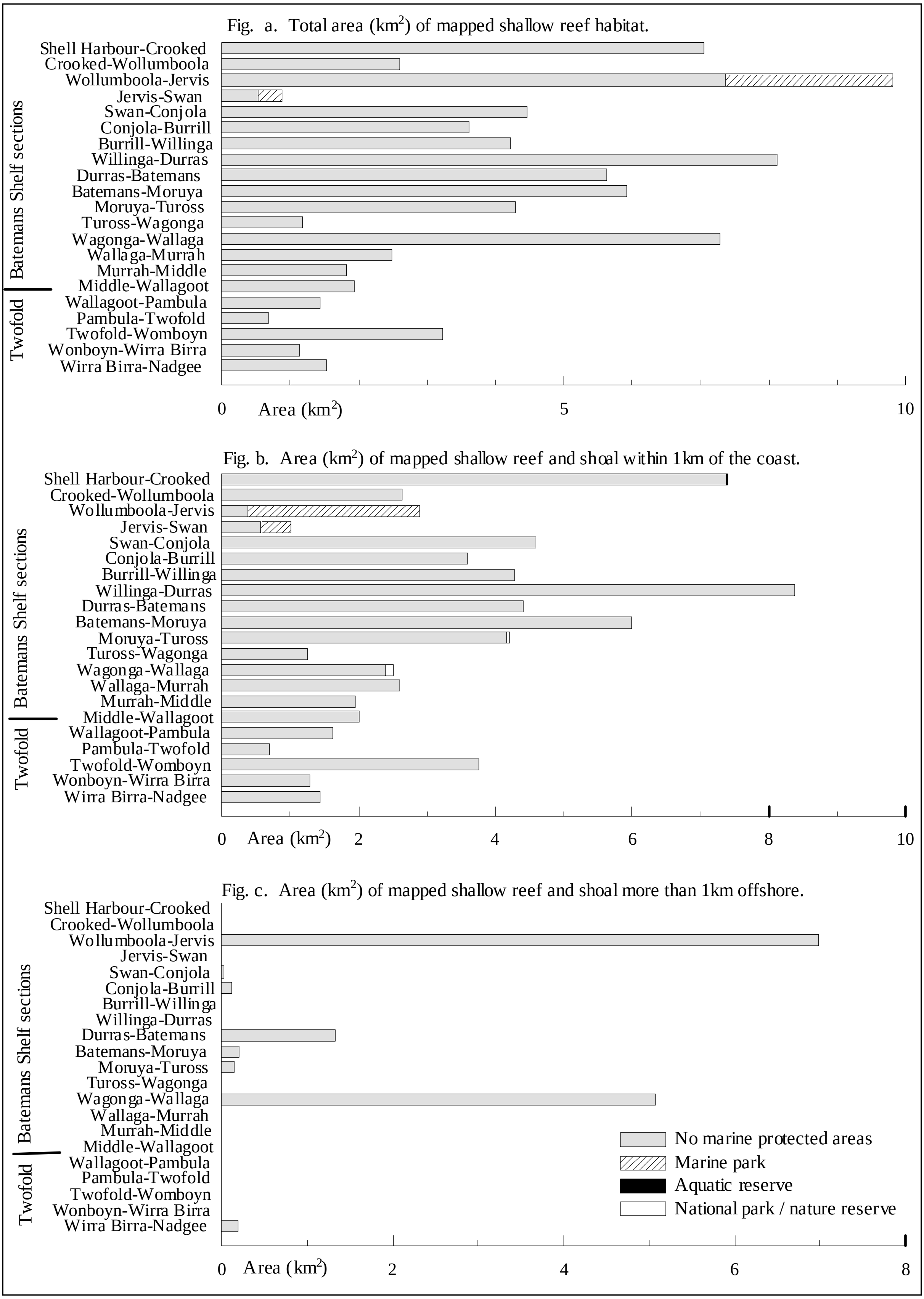

Figure 8.26. Area of mapped shallow reef for sections of ocean coast.

8.4.7 Islands

Data source

GIS cover of islands and emergent rocks from the AMBIS dataset provided by Geoscience Australia (Commonwealth of Australia 2001).

Data description

Areas of islands and exposed rocks categorised by their distance offshore (greater or less than 1 km from the coast).

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area of islands within broad scale plan units.

Assessment

The largest area of islands and rocks occurred in the Wagonga-Wallaga, Jervis-Swan and Willinga-Durras sections of coast. Most islands less than 1 km offshore occurred in the Jervis-Swan and Willlinga-Durras sections of coast and ocean. Most islands over 1 km from shore occurred in the Wagonga-Wallaga section of coast (Montague Island) and the Durras-Batemans section of coast (Tollgate Islands) (Figure 7.19).

Islands and rocks occurred within MPAs in the Jervis Bay Marine Park in the Wollumboola-Jervis (Drum and Drumsticks) and the Jervis-Swan sections (Bowen Island) representing 24% of the total area of islands in the bioregion.

Most islands in the NSW section of the Twofold Shelf bioregion occurred in the Twofold-Wonboyne section within 1 km of the coast. There were no islands in the NSW section of the Twofold Shelf bioregion included within an MPA, but islands do occur within MPAs in the Victorian and Tasmanian sections of the bioregion.

8.4.8 Shallow subtidal sediments

Data source

GIS coverage of near shore sediments digitised by Ron Avery (Department of Environment and Conservation) from aerial photographs provided by the NSW Department of Infrastructure, Planning and Natural Resources.

Data description

Near shore sediment digitised from high resolution (1:8000 –1:25:000) aerial photographs.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area in broad scale (sections of exposed coast and ocean) and small-scale planning units.

Assessment

The area of inshore sand mapped was similar for most sections of the Batemans Shelf bioregion ranging from approximately 5 km^2 up to 11 km^2 in the Jervis-Swan section. About 11.6 km^2 of this habitat was represented in Jervis Bay Marine Park accounting for 9% of the total area of this habitat in the bioregion (Figure 7.20a.)

Relatively large areas of inshore sand were mapped in the Wallagoot-Pambula and Wonboyne-Nadgee sections (5-10 km^2) of the Twofold Shelf bioregion with smaller areas in the sections of coast between Twofold Bay and Wirra Birra Creek (1-3 km^2). There were no areas of inshore sand in MPAs in the NSW section of the Twofold Shelf bioregion but this habitat is likely to be represented in the Ninety Mile Beach Marine National Park and other Victorian and Tasmanian MPAs.

Results for this habitat should be regarded cautiously as the use of aerial photos is limited to shallow areas. Further research into existing seabed data is needed and where required, additional seabed surveys should be carried out to accurately characterise offshore sediments.

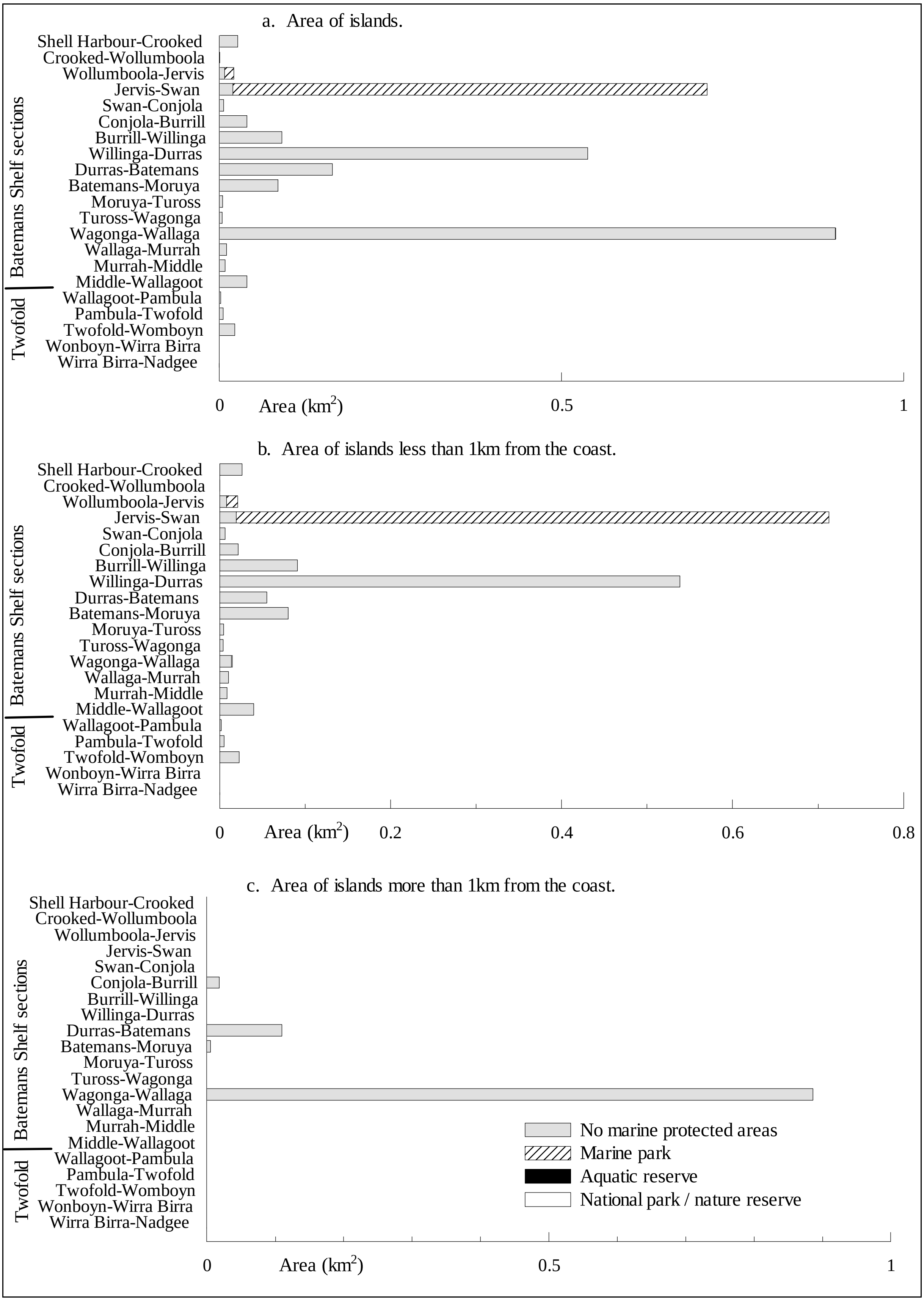

Figure 8.27a-c. Area (km^2) of total, inshore and offshore islands for coastal sections (NSW waters within 3nm) of the Batemans and Twofold Shelf bioregions.

8.4.9 Exposed intertidal beach

Data sources

Digital cadastre database and 1: 25 000 topographic maps provided by the Land and Property Information Division (NSW Department of Lands).

Data description

Ocean beaches were identified from 1:25 000 topographic maps and their areas calculated from the difference between the high and low water marks in the digital cadastre.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area in broad scale (sections of exposed coast and ocean) and small-scale planning units.

Assessment

The largest area of intertidal beach occurred in the Crooked-Wollumboola section (1.3 km^2) (Figure 7.20b) but most sections had similar areas of this habitat. Approximately 0.6 km^2 of exposed sandy beach occurred in Jervis Bay Marine Park and an additional 0.9 km^2 in Eurobodalla National Park together representing 16% of the total area of this habitat in the bioregion.

Most exposed intertidal beach in the Twofold Shelf section occurred in the Wallagoot-Pambula section (1.3 km^2). No areas of this habitat were included in MPAs within the NSW section of the bioregion. However, this habitat is represented in Ninety Mile Beach Marine National Park and in other Victorian and Tasmanian MPAs.

8.4.10 Intertidal rocky shore

Data sources

Digital cadastre database and 1: 25 000 topographic maps provided by the Land and Property Information Division (NSW Department of Lands).

Data description

Ocean intertidal rocky shores were identified from 1:25 000 topographic maps and their areas calculated from the difference between the high and low water marks on the digital cadastre.

Criteria

Comprehensiveness and representativeness.

Assessment measures

Area in broad scale (sections of exposed coast and ocean) and small-scale planning units.

Assessment

Most intertidal rocky shore occurred in the Shellharbour-Crooked, Willinga-Durras, Batemans-Moruya and Wagonga-Wallaga sections of coast. Approximately 1 km^2 of rocky shore occurred in Jervis Bay Marine Park and Bushrangers Bay Aquatic Reserve and another 0.4 km^2 in Eurobodalla National Park together representing 15% of the total area of this habitat in the Batemans Shelf bioregion (Figure 7.20c).

Most rocky shore in the NSW section of the Twofold Shelf bioregion occurred in the Twofold-Wonboyn section (1.9 km^2, Figure 7.20c). This habitat is not represented in MPAs in the NSW section of the bioregion but does occur in the Point Hicks and Cape Howe Marine National Parks in Victoria and the Kent Group Marine Reserve in the Tasmanian section of the Twofold Shelf bioregion.

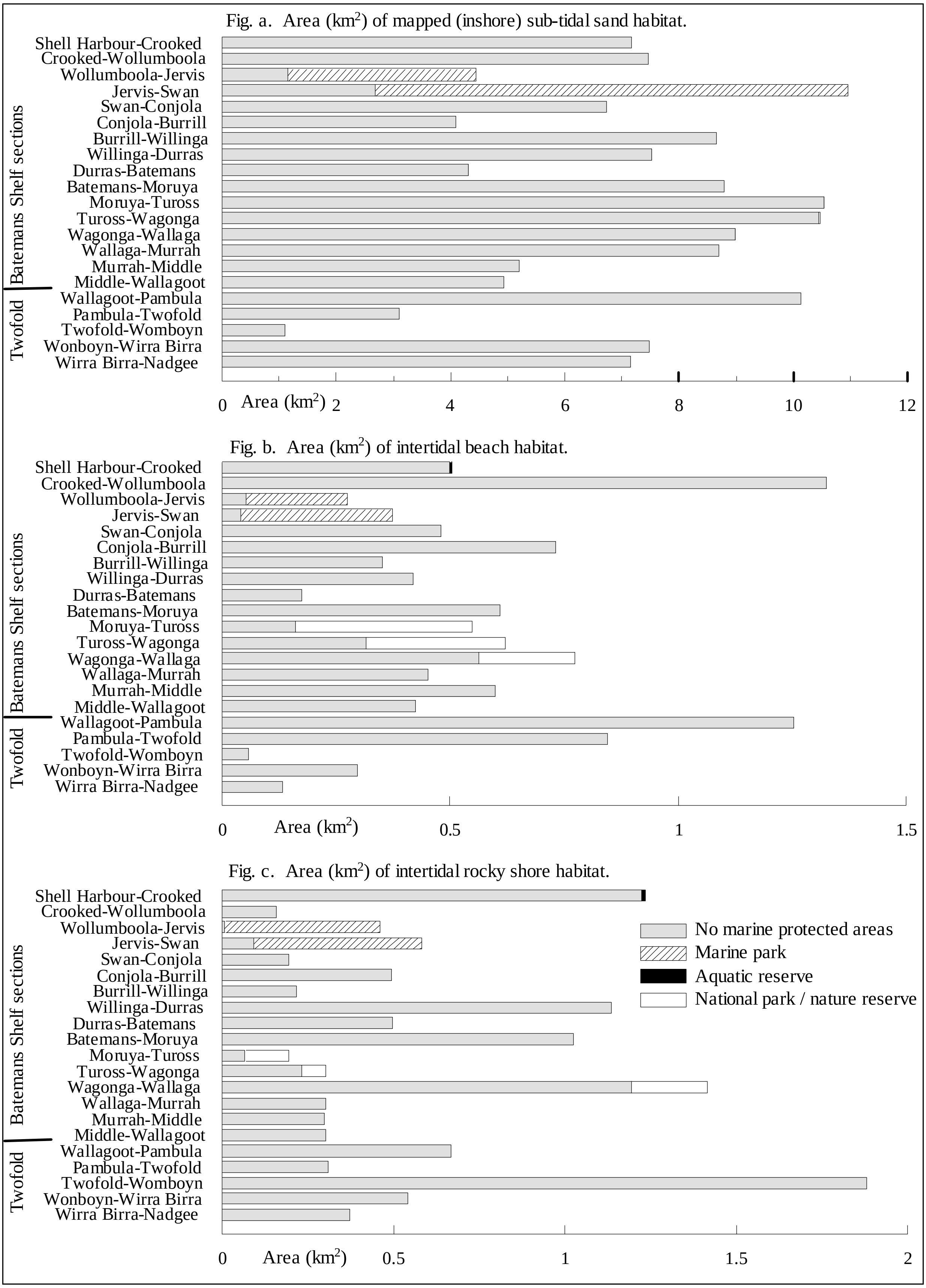

Figure 8.28a-c. Area (km^2) of mapped (inshore) sub-tidal sand, intertidal beach, and intertidal rocky shore habitat in marine protected areas.

8.4.11 NSW Fisheries[2] assessment of rocky intertidal communities

Data source

Otway, N. (1999). "Identification of candidate sites for declaration as aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf bioregions."

Data Description

Rocky shores short-listed by an advisory committee of stakeholders and community members were surveyed by Otway (1999), scored for species richness and the presence of platform, boulder, rubble, pool and crevice microhabitats with locations recommended for MPAs.

Criteria

Comprehensiveness, representativeness and adequacy.

Assessment

Seventeen locations, (Bass Point, Cathedral Rocks, Bombo Head, Cudmirrah National Park, Inyadda Point, Preservation Point, Ulladulla Head, Warden Head, Bawley Point, Wasp Head, Observation Head, Mossy Point, Toragy Point, Tuross Head, Dalmeny Head, Wagonga Head and Cuttagee Point) were recommended as candidate sites for MPAs by the advisory committee.

Otway (1999) surveyed these areas and found 4-5 microhabitats and a higher species richness at Bombo Head (119 spp.), Inyadda Point (138 spp.), Preservation Point (123 spp.), Warden Head, (154 spp.) and Wagonga Head (134 spp.) and recommended these sites as candidate locations for marine protected areas along with Bass Point which lies adjacent to important Grey Nurse Shark habitat (Figure 7.21 - Figure 7.23). Three microhabitats and a lower species richness were found at the remaining locations.

The advisory committee also short-listed Tathra Head and Short Point as candidate aquatic reserves. Short Point included four habitat types but did not include boulder habitats, while extensive platform, boulder and cobble areas were absent from Tathra Head.

[2] now within the NSW Department of Primary Industry

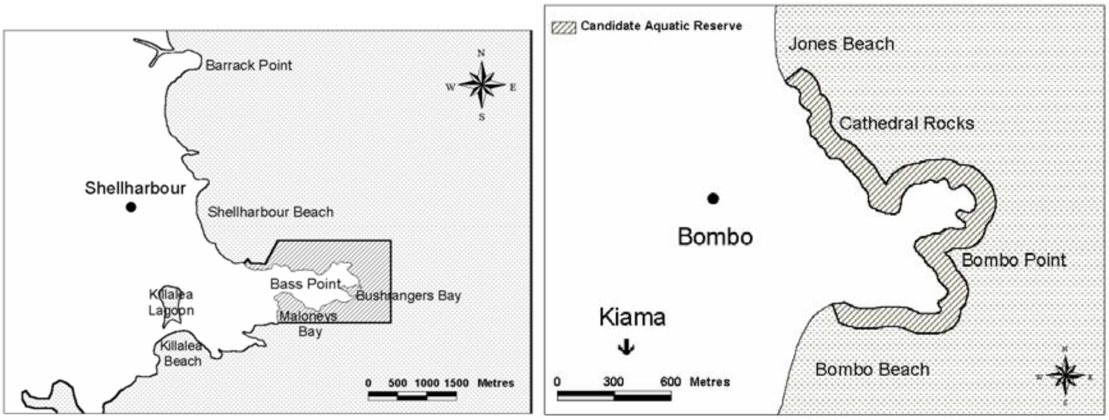

Figure 8.29. Bass Point and Bombo Head, previous candidate rocky intertidal aquatic reserves (NSW Fisheries[2] Office of Conservation 2001).

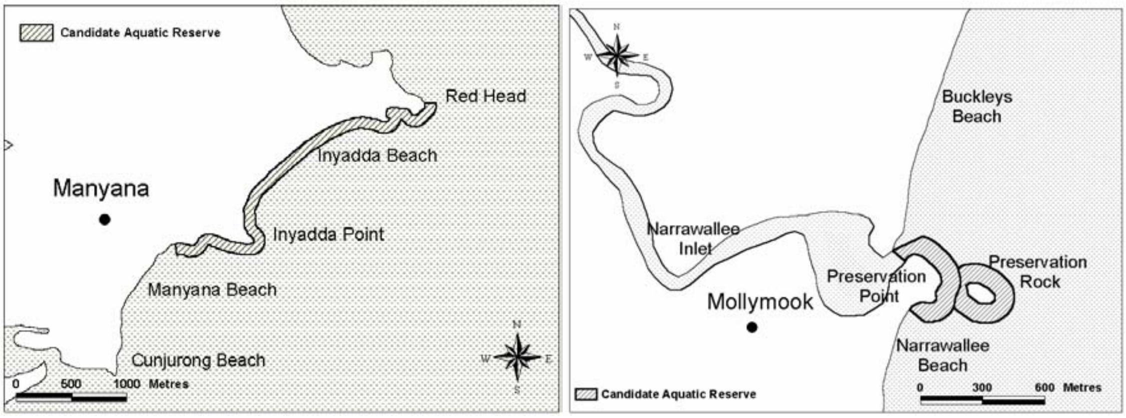

Figure 8.30. Inyadda Point and Preservation Point, previous candidate rocky intertidal aquatic reserves (NSW Fisheries[2] Office of Conservation 2001).

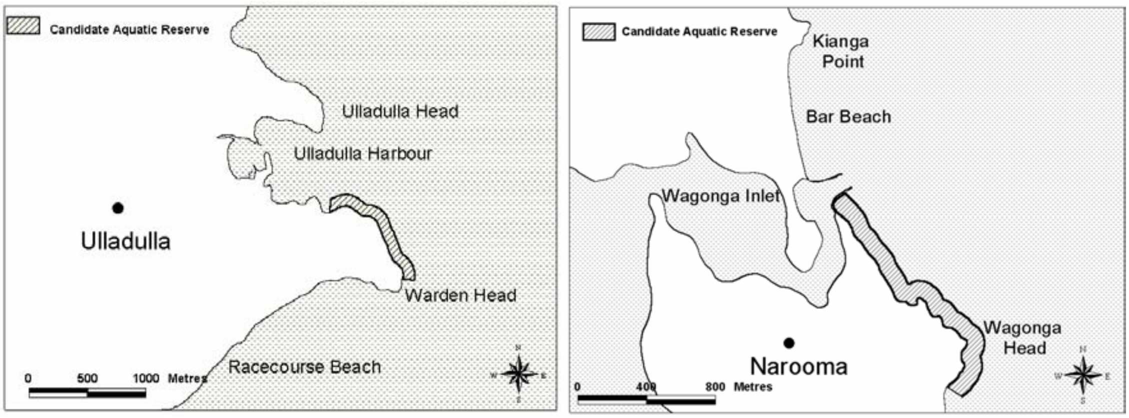

Figure 8.31. Warden Head and Wagonga Head, previous candidate rocky intertidal aquatic reserves (NSW Fisheries[2] Office of Conservation 2001).

[2] now within the NSW Department of Primary Industry

8.4.12 Coastal rock platforms (Total Environment Centre)

Data source

Short J.M. (1995). "Protection of coastal rock platforms in NSW."

Data description

This database of 'significant rock platforms' identifies 198 separate rock platforms in NSW, 33 of which lie in the Batemans and Twofold Shelf bioregions.

Criteria

Representativeness, uniqueness and naturalness (condition).

Assessment measures

The database includes attributes relating to location, access, platform dimensions, physical characteristics, geology, biology, impacts, existing management and recommendations.

Assessment

Based on the assessment of the characteristics described above, Short (1995) recommended 25 rock platforms in the Batemans and Twofold Shelf bioregions for protection. These were:

- Pheasant, Blowhole and Marsden Points in the Shellharbour-Crooked section
- Crookhaven Heads in the Crooked to Wollumboola section
- Beecroft Peninsula in the Wollumboola-Jervis section
- St Georges Head in the Jervis-Swan section
- Red Head (Bendalong) in the Swan-Conjola section
- North Ulladulla Harbour Head in the Conjola-Burrill section
- Murramurrang Point, O'Hara Head, Snapper Point and Point Upright in the Willinga-Durras section
- Wasp Head, Flat Rock Island and the northern head of Batemans Bay in the Durras-Batemans section
- Broulee Point and Island in the Batemans-Moruya section
- Bunga Head in the Murrah-Middle section
- Baronda Head, Wajurda, Tathra Head and Turingal Head in the Middle-Wallagoot section
- Bournda Island and Haycock Island in the Wallagoot-Pambula section
- Long Beach, Worang Point, Jews Head and Red Point in the Pambula-Twofold section
- Green Cape in the Twofold-Wonboyn section and
- Black Head and Nadgee Point in the Wirra Birra-Nadgee section.

8.4.13 Irreplaceability analysis for ecosystem and habitat units

Irreplaceability is a measure designed to estimate the likelihood of a site being required to meet conservation targets or, the extent to which conservation options are reduced if that site is unavailable. Conservation targets are usually defined as areas, numbers or proportions for a range of different habitats, species or other 'features'. *Summed* irreplaceability is calculated by adding the feature irreplaceabilities for all the different features in a site. High values indicate that a site is important for achieving conservation goals for many different features.

Figure 8.32 shows summed irreplaceability for the fine scale planning units in the Batemans Shelf using a hypothetical goal of 20% of the area of each ecosystem (estuary types and ocean depth zones) and habitat feature (seagrass, mangrove, saltmarsh, rocky intertidal, beach, subtidal sand, reef, and island). Higher values indicate those sites more likely to contribute to targets for more than one habitat or ecosystem thus minimising the total area required to represent those features. High values for *summed* irreplaceability do not necessarily imply that a site is required to meet a goal, only that it is likely to contribute more to one or more feature targets.

In Figure 8.32, localised areas of high summed irreplaceability are evident at the mouths of several estuaries and at several locations along the coast where different ocean habitats occur together. Relatively high summed irreplaceabilities are also present in estuaries where different estuarine habitats occur together. Low irreplaceabilities offshore reflect the lack of data to distinguish among these areas.

Figure 8.33 shows summed irreplaceability for the fine scale planning units in the Twofold Shelf using a hypothetical goal of 20% of the area of each ecosystem and habitat feature. Again localised areas of high summed irreplaceability are evident at the mouths of estuaries and where different ocean habitats occur together. In this case however, the display does not account for the whole of the Twofold Shelf bioregion as specific data were not available for the Victorian or Tasmanian sections.

Figure 8.34 - Figure 8.36 show summed irreplaceabilities for estuarine broad scale planning units calculated for a hypothetical representation of 20% of mapped ecosystems and habitat units. Figure 8.34 shows high summed irreplaceabilities for the Shoalhaven River, Clyde River, St Georges Basin and moderate summed irreplaceabilities for Coila Lake, Tuross Lake, Durras Lake, Swan Lake and the Moruya River. Note that while initial values for existing MPAs at Jervis Bay and Lake Wollumboola were not graphed, they were among the highest in the bioregion.

Figure 8.35 shows summed irreplaceabilities adjusted for features already included in Bushrangers Bay Aquatic Reserve and Jervis Bay Marine Park. Figure 8.36 shows irreplaceabilities adjusted for features represented in all MPAs, including the marine components of national parks and nature reserves. The high scores for the Shoalhaven River and the Clyde River are maintained in all three simulations as they include features such as barrier estuary, drowned river valley, mangrove and saltmarsh that are not well represented in the existing system of MPAs.

Figure 8.37 a-c. shows summed irreplaceabilities for sections of ocean coast while accounting for features represented in existing aquatic reserves, marine parks and the marine components of national parks and nature reserves. The highest consistent values, after accounting for all existing MPAs occur for the Wagonga-Wallaga, Willinga-Durras and Shellharbour-Crooked sections.

Although irreplaceability provides a convenient static index to summarise general patterns it's full potential is only realised in a more iterative process where alternatives can be explored using experience from managers, scientists and key stakeholders. The models developed here can be easily used in such a process and be refined as more data becomes available.

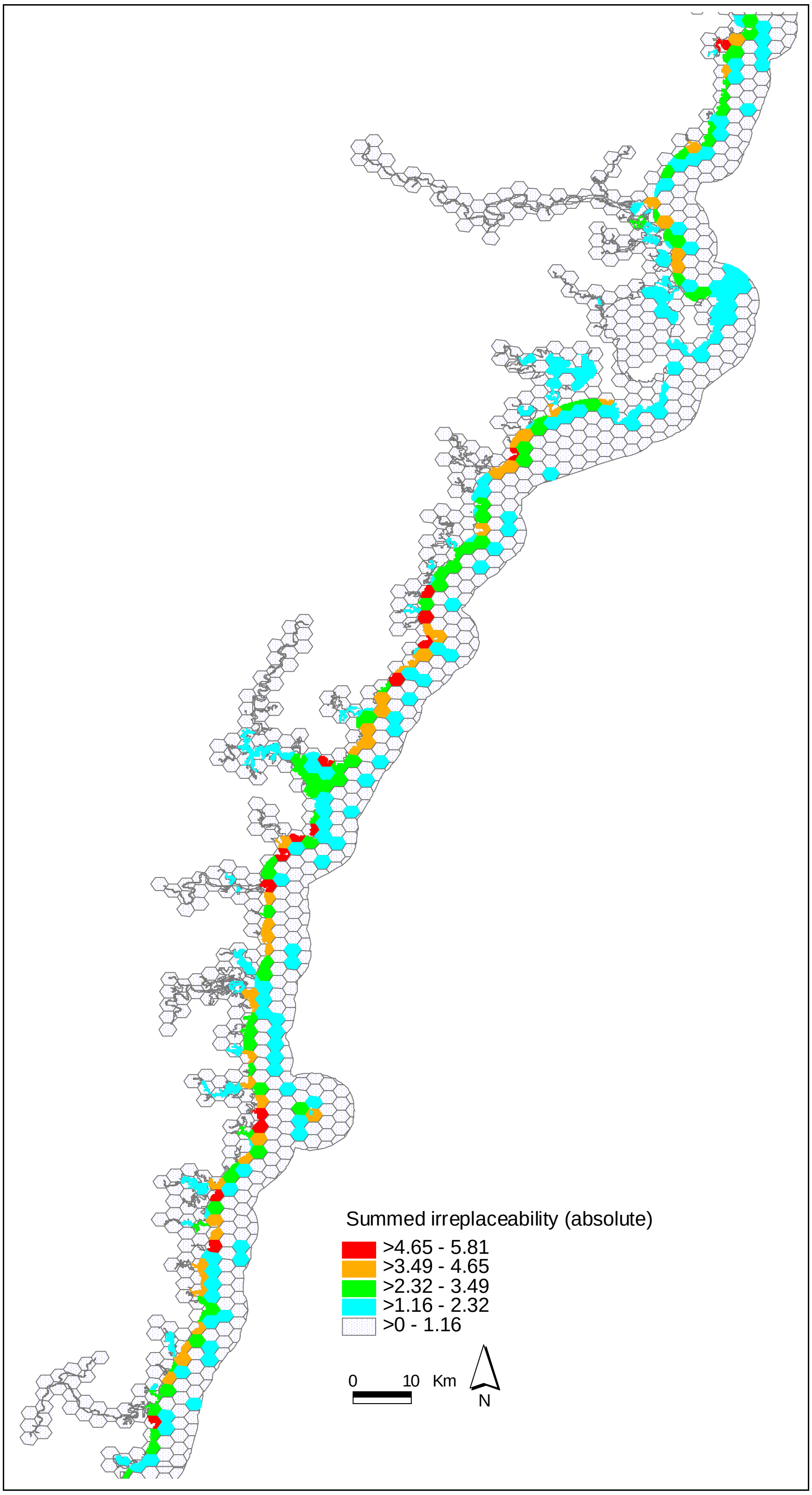

Figure 8.32. Summed irreplaceability of fine scale (4 km^2) planning units for ecosystem and habitat types within NSW waters (within 3 nm) of the Batemans Shelf bioregion. Values indicate the degree to which a unit can contribute to meeting a hypothetical 20% goal for a number of different estuarine and oceanic ecosystem and habitat types (from C-Plan reserve selection software provided by the NSW Department of Environment and Conservation).

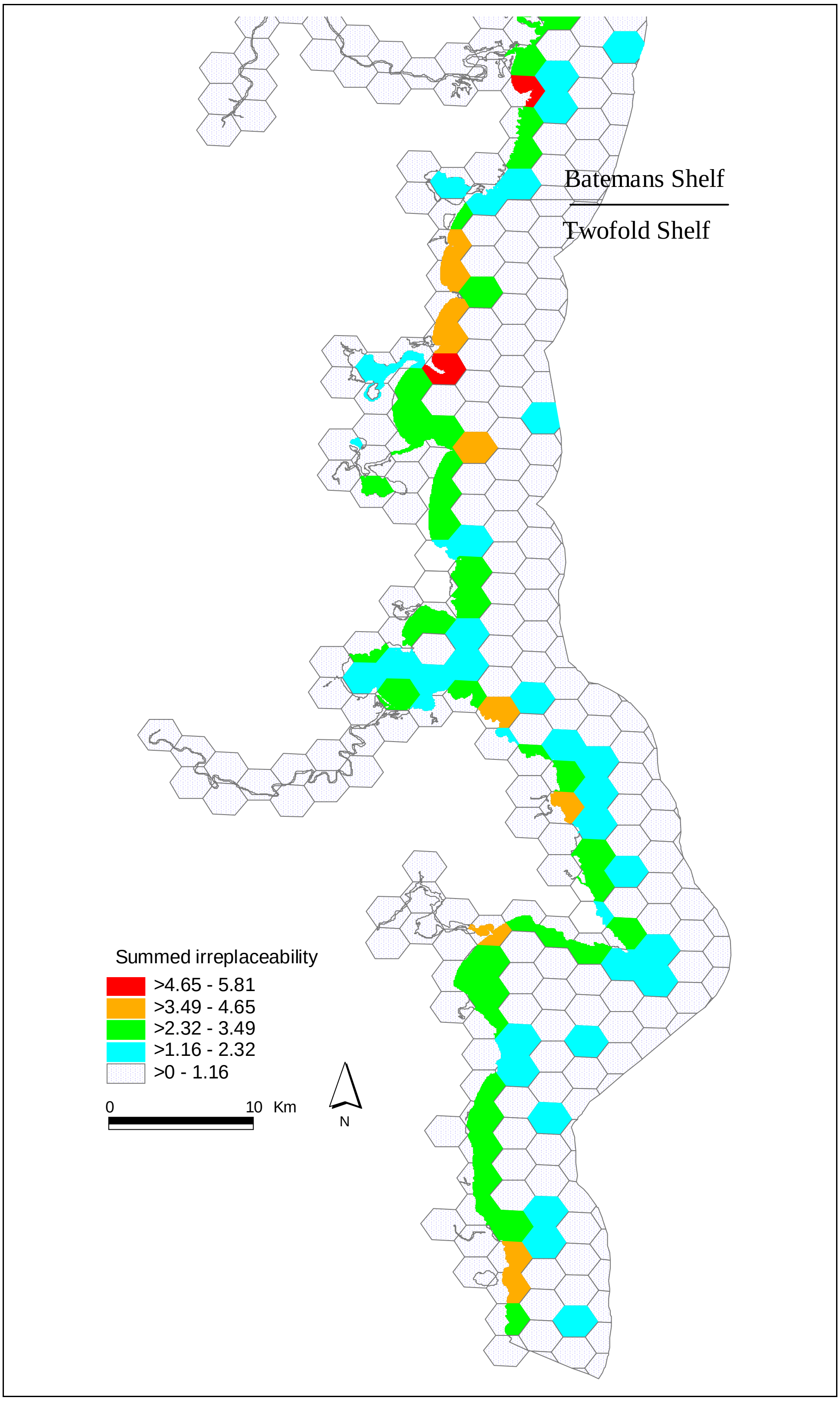

Figure 8.33. Summed irreplaceability of fine scale (4 km^2) planning units for ecosystem and habitat types in NSW waters (within 3 nm) of the Twofold Shelf bioregion. Values indicate the degree to which a unit can contribute to meeting a hypothetical 20% goal for a number of different estuarine and oceanic ecosystem and habitat types (values from C-Plan reserve selection software provided by the NSW Department of Environment and Conservation).

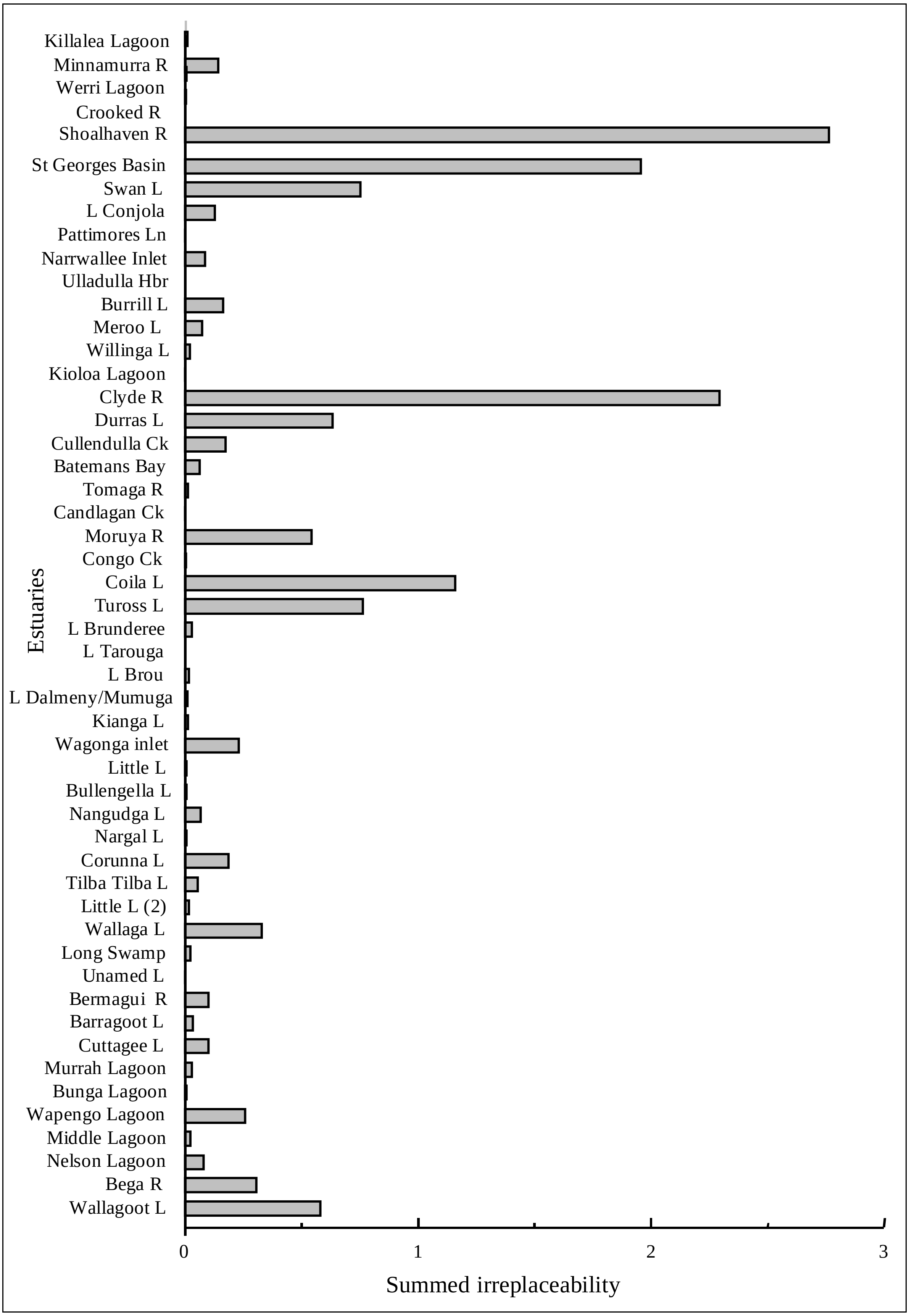

Figure 8.34. Summed irreplaceability scores of areas not already in MPAs for representation of a hypothetical goal of 20% of the area of estuarine ecosystem and habitat classes in the Batemans Shelf marine bioregion - assuming there are no existing MPAs.

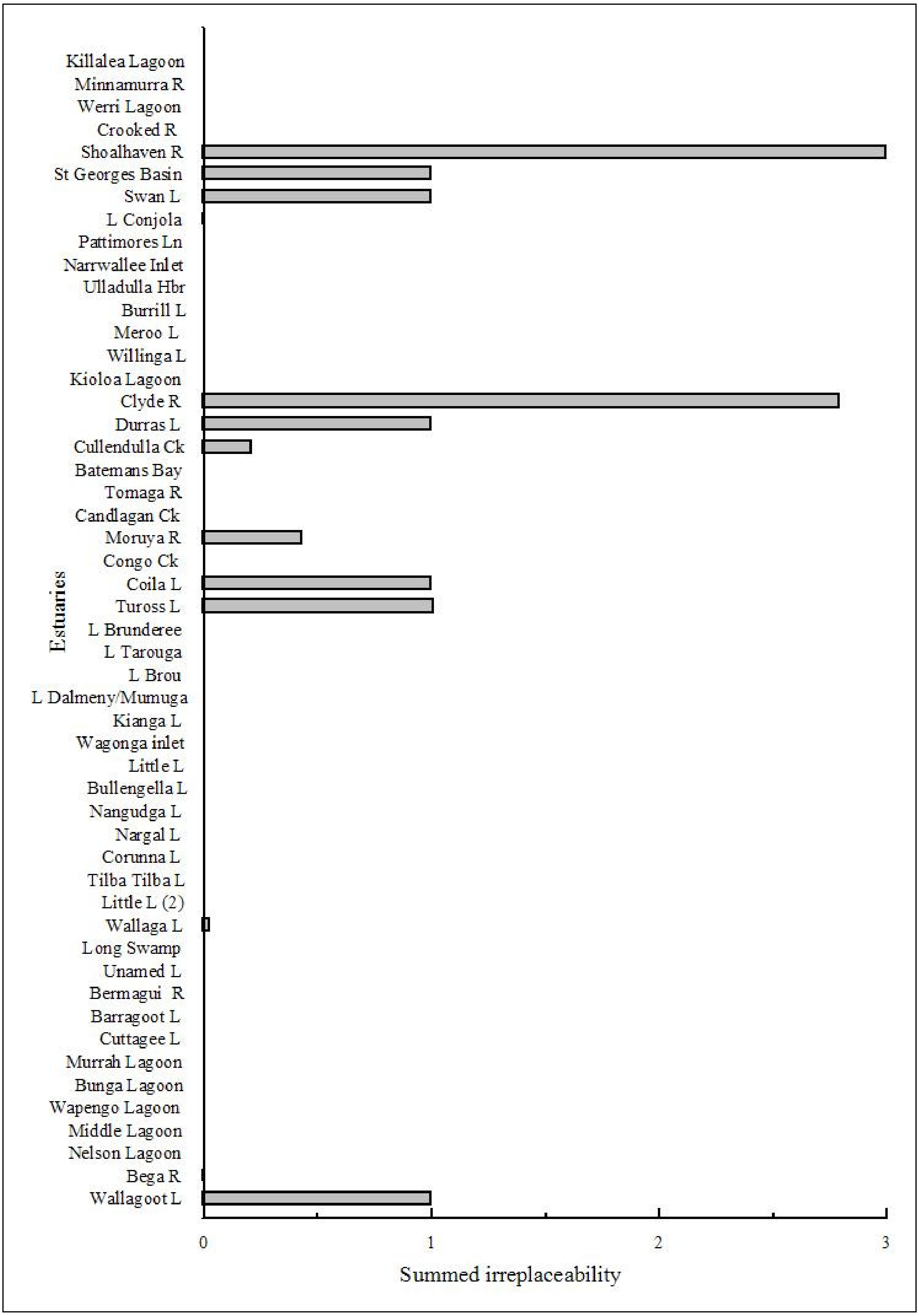

Figure 8.35. Summed irreplaceability scores of areas not already in MPAs for representation of a hypothetical goal of 20% of the area of estuarine ecosystem and habitat classes in the Batemans Shelf marine bioregion - allowing for areas already included in existing marine parks and aquatic reserves.

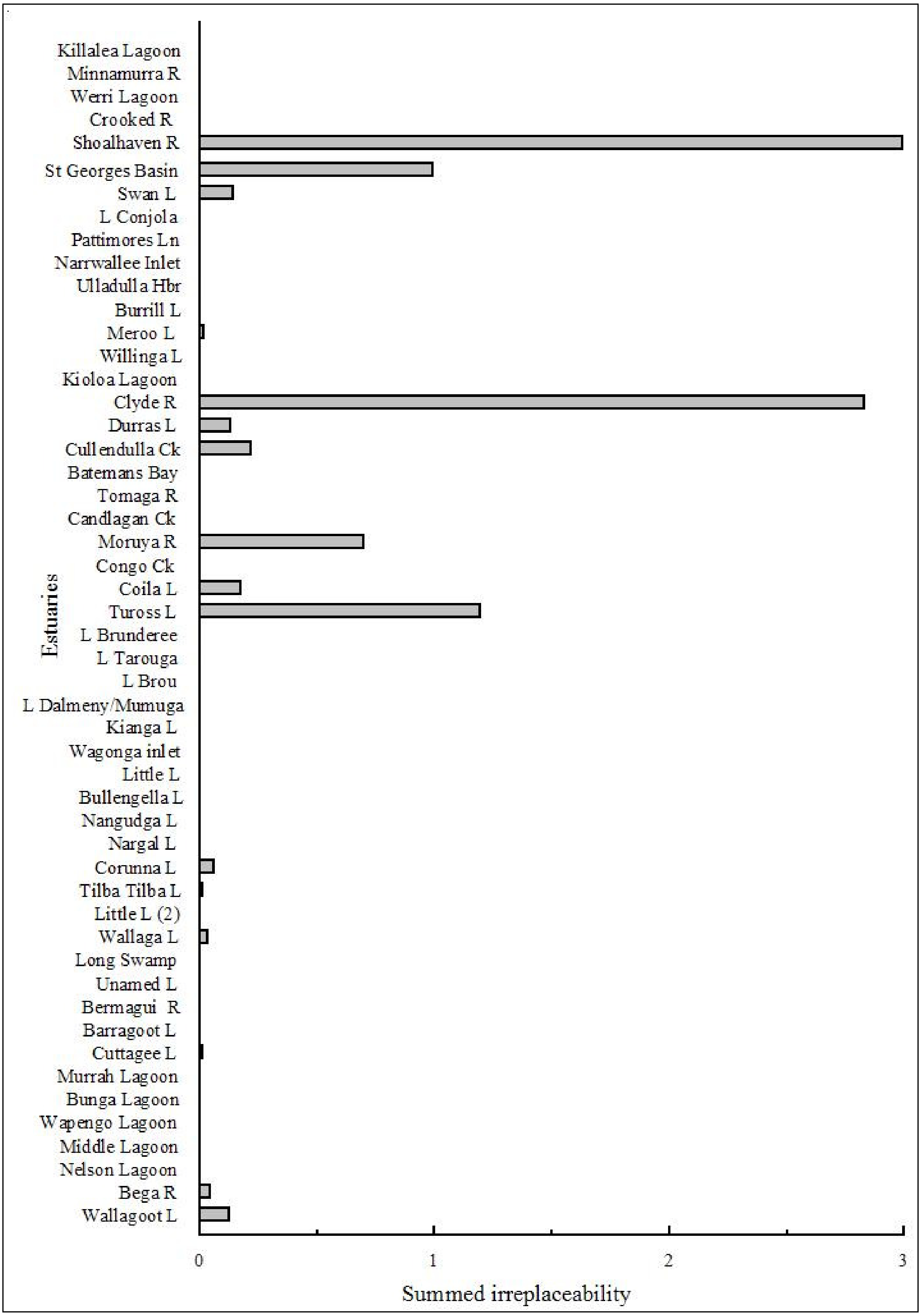

Figure 8.36. Summed irreplaceability scores of areas not already in MPAs for representation of a hypothetical goal of 20% of the area of estuarine ecosystem and habitat classes in the Batemans Shelf marine bioregion - allowing for areas included in existing marine parks, aquatic reserves, national parks and nature reserves.

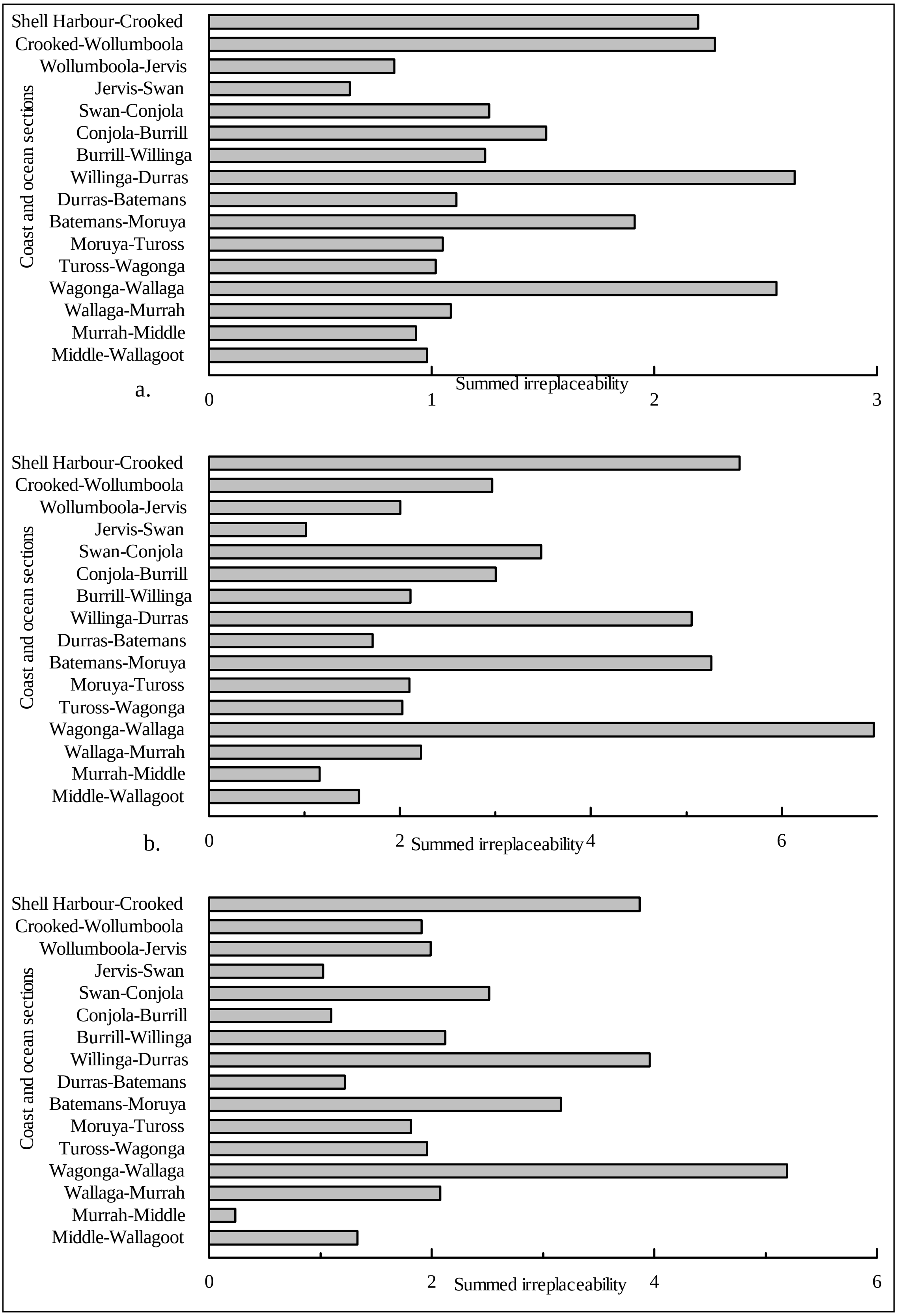

Figure 8.37. Summed irreplaceability scores for 20% representation of ocean ecosystem and habitat classes in the Batemans Shelf marine bioregion a. assuming there are no existing MPAs; b. allowing for areas included in marine parks and aquatic reserves. c. allowing for areas included in marine parks, aquatic reserves, national parks and nature reserves.

8.4.14 Estuarine juvenile fish and invertebrate biodiversity

Data source

Estuarine fish biodiversity project undertaken by the NSW Fisheries[2] Office of Conservation and funded by the Natural Heritage Trust (R. Williams, pers. comm.)

Data description

Juvenile fishes and invertebrates were sampled by seine net along estuarine shores on vegetated and bare substrata, within 2-3 zones between the estuary mouth and riverine habitats. Currently 500,000 fish from 176 taxa have been collected throughout NSW. The survey has not yet sampled all estuaries or analysed all data (R.J. Williams, pers. comm.).

Identification criterion

Representativeness.

Assessment measures

Summed irreplaceability for representation of at least one of each species.

Assessment

Summed irreplaceability scores for sites (for representation of each species in the total catch from five seine hauls) are shown in Figure 8.38a-h. For most sites, summed irreplaceability was relatively low (<4) given the high number of species overall (>100). This may be due in part to the low number of hauls per site but may also reflect the widespread occurrence of many common species.

High values occurred in St Georges Basin, Clyde River, Wagonga Inlet, Merimbula Lake and the Wonboyne River, but estuaries did not differ markedly given the amount of variation within estuaries. In addition, there were large variations among estuaries in the number of sites sampled, and these differences were strongly correlated with overall species richness and irreplaceability scores for each estuary.

These differences made it difficult to make unbiased comparisons among different estuaries. However, a more detailed analysis of this data is warranted as systematic surveys of species diversity and abundance have the potential to provide a more direct assessment of marine biodiversity than coarser scale surrogates.

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[2] now within the NSW Department of Primary Industry.

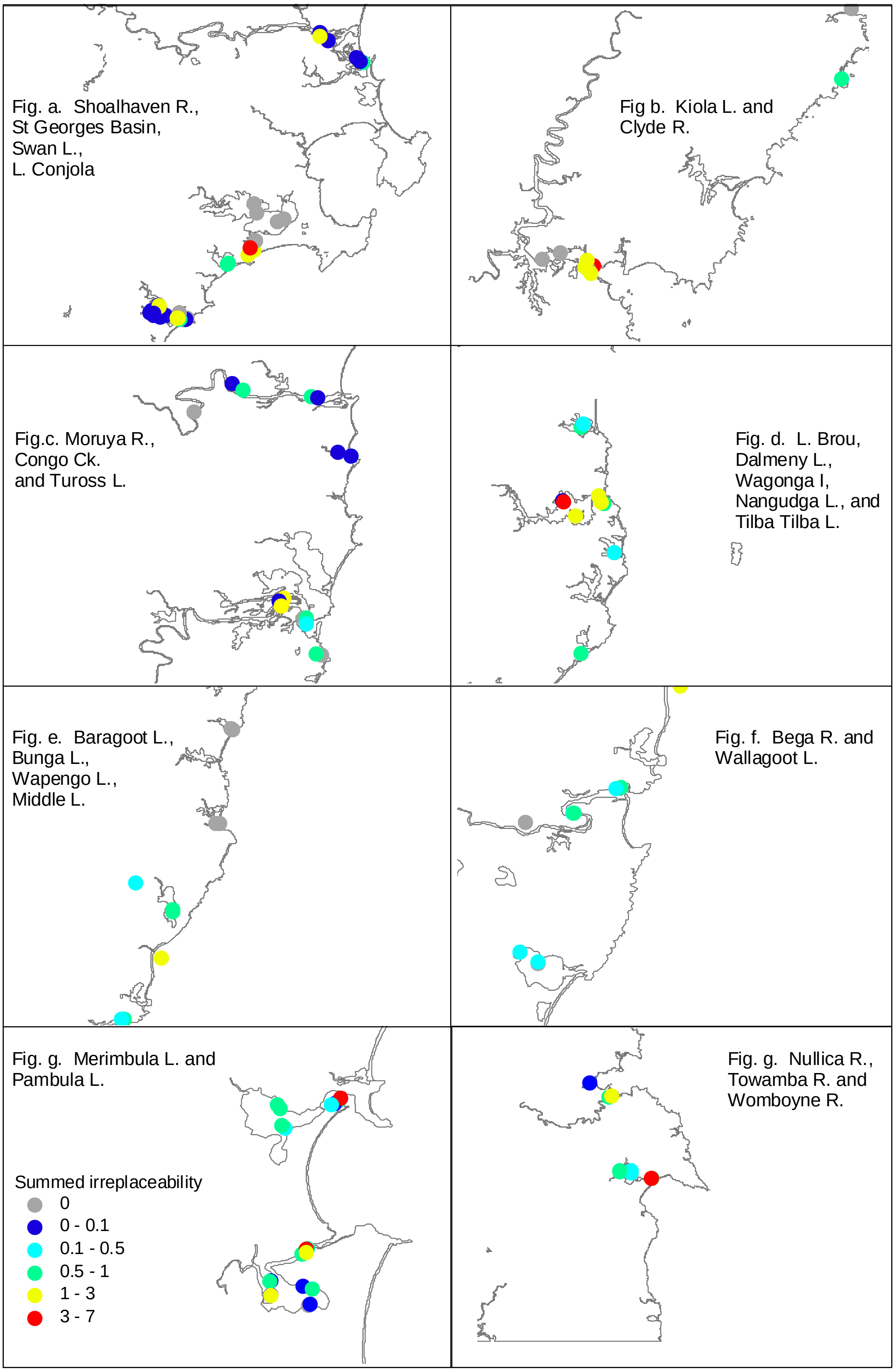

Figure 8.38a-h. Summed irreplaceability for representation of at least one of each species of juvenile fish and invertebrates sampled by seine net (n=5 hauls) along estuarine shores in the Batemans and Twofold Shelf bioregions. Raw data from the Natural Heritage Trust funded NSW Fisheries[2], Office of Conservation, Estuarine Fish Biodiversity project (pers. comm. R.J. Williams). [2] now within the NSW Department of Primary Industry

8.4.15 NSW Fisheries[2] commercial catch data

Data Source

NSW Fisheries[2] Commercial Catch Returns database.

Tanner and Liggins (1999). NSW Commercial Fisheries Statistics 1993/94 to 1997/98.

Data description

Commercial fish and invertebrate catch and effort statistics from mandatory catch return forms submitted by commercial fishers.

Criteria

Representativeness, productivity, potential threats and human use.

Assessment measures

Number of species, catch and summed irreplaceability for representation of each species.

Assessment

Summed irreplaceability and the number of species caught commercially in estuaries were highest for Jervis Bay, the Shoalhaven River, St Georges Basin and Tuross Lake. The differences however, probably reflect the high catches for these areas. Summed irreplaceability, species richness and catch in the Twofold Shelf bioregion were highest for Pambula Lake but low when compared to scores for the Batemans Shelf bioregion (Figure 8.39 - Figure 8.41).

Summed irreplaceability and the number of species landed at ocean ports were highest for Ulladulla, Eden, Kiama, Greenwell Point, Batemans Bay and Bermagui and again this probably reflects the size of the catch landed at these ports and potentially, catches brought in from other fishing locations (Figure 8.42).

These results should be regarded cautiously given the likely bias in species richness towards areas receiving more catch, and potential biases in determining exactly where catch was caught, as opposed to landed. More detailed analyses of catch data have been made by Pease (1999).

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[2] now within the NSW Department of Primary Industry.

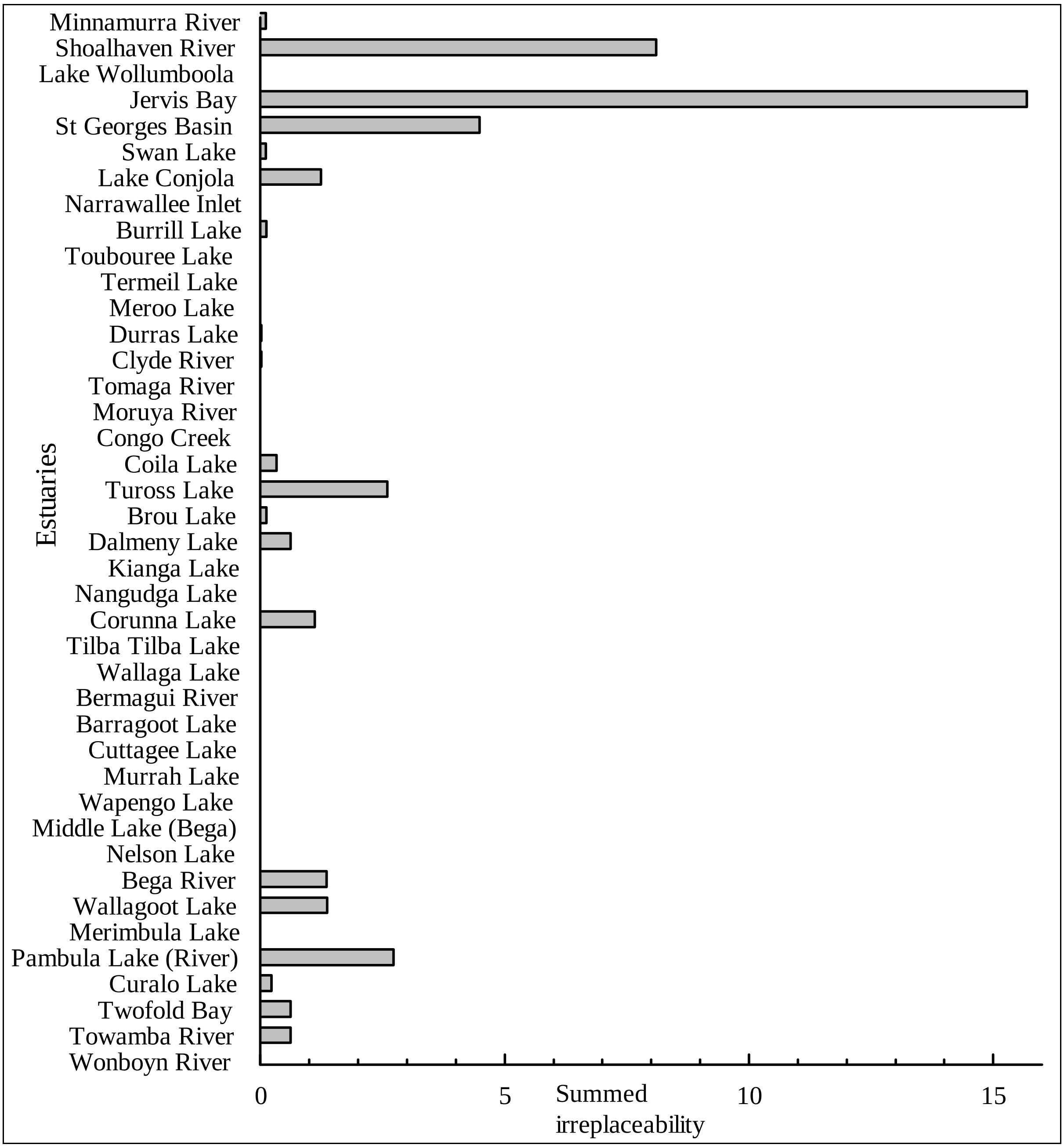

Figure 8.39. Summed irreplaceability for representation of at least one of each species in the commercial catch for **estuaries** in the Batemans and Twofold Shelf bioregions in 1997/98. Raw data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry.

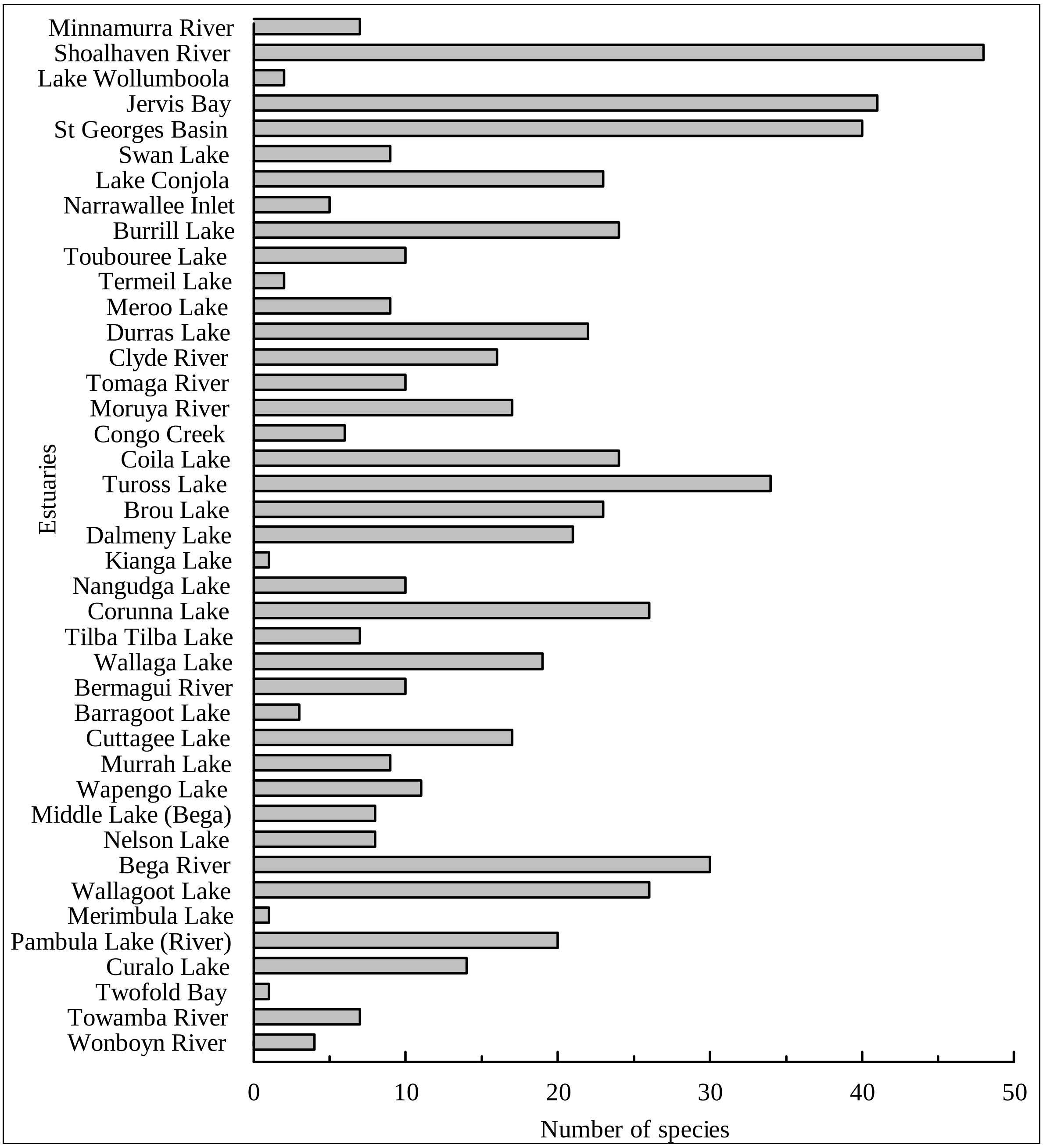

Figure 8.40. Number of species in commercial catch for **estuaries** in the Batemans and Twofold Shelf bioregions in 1997/98. Raw data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry.

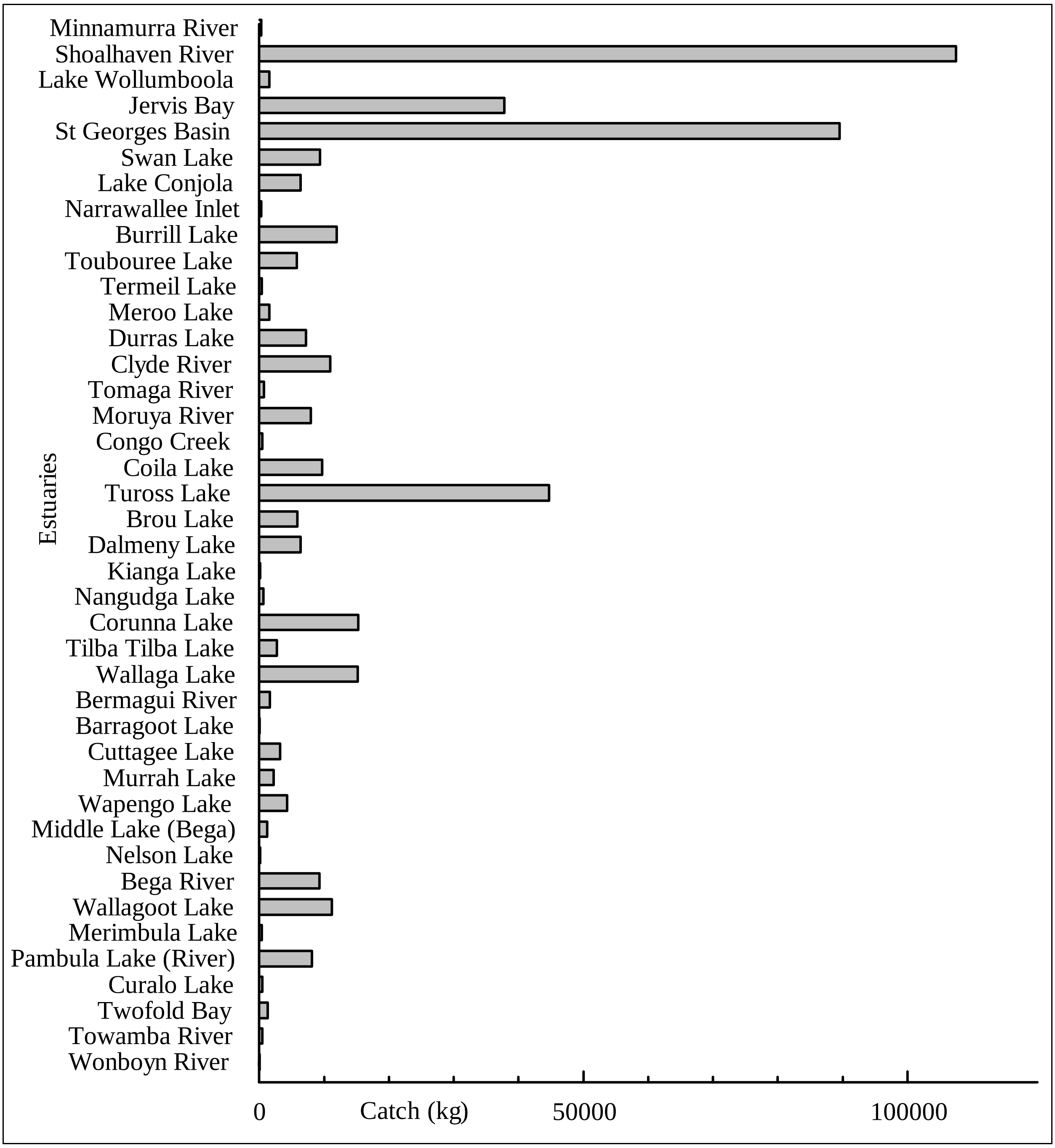

Figure 8.41. Weight of commercial catch (kg) for **estuaries** in the Batemans and Twofold Shelf bioregions in 1997/98. Raw data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry

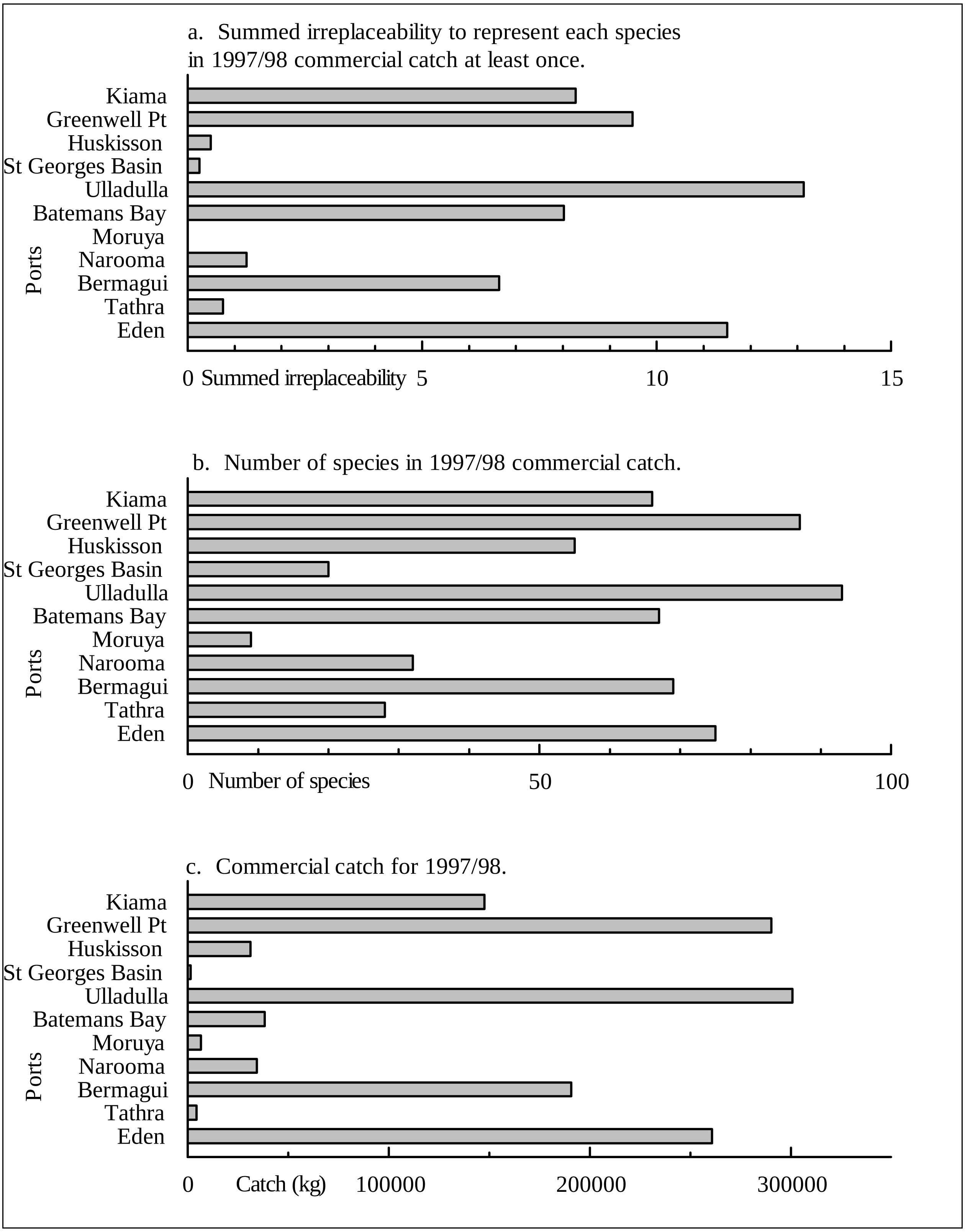

Figure 8.42. Summed irreplaceability, number of species and weight of commercial catch for **ocean ports** in the Batemans and Twofold Shelf bioregions in 1997/98. Raw data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry

8.4.16 Threatened fish species sightings database

Data Source

Database held by Fisheries (DPI) of sightings of threatened fish species reported by volunteers.

Data Description

The *NSW Fisheries Management Act 1994* includes provisions to declare threatened species of fish and marine vegetation, endangered populations and ecological communities, and key threatening processes.

Four marine species have been declared threatened:

- Great White Shark (*Carcharodon carcharias*)
- Grey Nurse Shark (*Carcharias taurus*)
- Black Cod (*Epinephelus daemelii*) and the
- Green Sawfish (*Pristis zijsron*).

Seven other marine species are protected in NSW waters:

- Ballina Angelfish (*Chaetodontoplus ballinae*)
- Bleeker's Devil Fish (*Paraplesiops bleekeri*)
- Common Sea Dragon (*Phyllopteryx taeniolatus*)
- Elegant wrasse (*Anampses elegans*)
- Estuary Cod (*Epinephelus coioides*)
- Herbsts Nurse Shark (*Odontaspis ferox*) and
- Queensland Groper (*Epinephelus lanceolatus*).

Other species protected from commercial fishing include:

- Black Marlin (*Makaira indica*)
- Blue Marlin (*Makaira nigricans*)
- Striped Marlin (*Tetrapturus audax*) and
- Blue Groper (*Achoerodus viridis*).

Sightings in the threatened fish species database depend on voluntary reports and are currently limited to 129 records for the Batemans and Twofold Shelf bioregions. While the data are probably too sparse for quantitative analysis, they provide descriptive, site specific information.

Criteria

Representativeness.

Assessment measure

Descriptive summary.

Assessment

Table 8.5 lists sightings of threatened fish species in the Batemans and Twofold Shelf bioregions.

Table 8.5. Sightings of threatened fish species in the Batemans and Twofold Shelf bioregions.

Species	Nearest town	Plan unit	bioregion
Black Cod	Shellharbour	Shellharbour-Crooked	Batemans Shelf
	Gerringong	Shellharbour-Crooked	Batemans Shelf
	Crookhaven	Shellharbour-Crooked	Batemans Shelf
	Bendalong	Swan-Conjola	Batemans Shelf
	Durras	Durras-Batemans	Batemans Shelf
	Tathra	Middle-Wallagoot	Batemans Shelf
	Merimbula	Wallagoot-Pambula	Twofold Shelf
	Eden	Twofold-Wonboyn	Twofold Shelf
Great White Shark	Kiola	Willinga-Durras	Batemans Shelf
Grey Nurse Shark	Shellharbour	Shellharbour-Crooked	Batemans Shelf
	Huskisson	Jervis-Swan	Batemans Shelf
	Cunjurong	Swan-Conjola	Batemans Shelf
	Batemans Bay	Durras-Batemans	Batemans Shelf
	Narooma	Wagonga-Wallaga	Batemans Shelf
	Merimbula	Wallagoot-Pambula	Twofold Shelf
Bleeker's Devil Fish	Shellharbour	Shellharbour-Crooked	Batemans Shelf
	Huskisson	Jervis-Swan	Batemans Shelf
	Broulee	Bateman-Moruya	Batemans Shelf
	Merimbula	Wallagoot-Pambula	Twofold Shelf
Estuary Cod	Nowra	Shoalhaven R	Batemans Shelf
	Huskisson	Jervis-Swan	Batemans Shelf
	Batemans Bay	Batemans Bay	Batemans Shelf
	Narooma	Wagonga Inlet	Batemans Shelf
Queensland Groper	Batemans Bay	Batemans Bay	Batemans Shelf
Weedy Sea Dragon	Shellharbour	Shellharbour-Crooked	Batemans Shelf
	Huskisson	Jervis-Swan	Batemans Shelf
	Ulladulla	Conjola-Burrill	Batemans Shelf
	Merimbula	Wallagoot-Pambula	Twofold Shelf

8.4.17 Threatened Grey Nurse Shark

Data source

A GIS coverage of significant Grey Nurse Shark (*Carcharias taurus*) aggregation sites was prepared from data provided by Otway and Parker (2000) and Otway *et al.* (2003).

Data description

The Grey Nurse Shark is listed as endangered under the *Fisheries Management Act 1994*. NSW Fisheries[2] staff and volunteer SCUBA divers surveyed approximately 65 sites during 4 week long survey periods in each season (Summer, Autumn, Winter, Spring) between November 1998 and October 2000.

Criteria

Representativeness, ecological importance and threatened species.

Assessment measure

Maximum number of sharks observed during surveys and other sites where sharks have been observed in the past.

Assessment

Grey Nurse Sharks have been observed at a number of locations in the Batemans and Twofold Shelf bioregions (Figure 8.43) but recent surveys have identified Bass Point, near Shellharbour, the Tollgate Islands in Batemans Bay and Montague Island as the most important aggregation sites.

At Bass Point, sharks have been observed at two sites during 10% of surveys in numbers representing approximately 1% of the observed population (NSW Fisheries 2002, NSW Draft Recovery Plan for the Grey Nurse Shark). In December 2002, NSW Fisheries[2] declared an area of critical habitat extending 200 m out from the southern point of Bushrangers Bay, with an 800 m buffer extending beyond this.

At the Tollgate Islands, sharks have been observed during 90% of surveys in numbers representing 8.9% of the observed population and 15.4% of the observed female population. This site is the most important known aggregation site for females, and it is thought that the females may be gestating at this site during summer and autumn. A 200 m critical habitat zone and 800 m buffer zone now extends seaward of the most easterly island.

At Montague Island, sharks aggregate mainly at the northern tip of the island but also at three sites on the western side of the island. Sharks were observed during 20% of surveys at this site in numbers representing 1.3% of the total observed population. Most sharks surveyed here were females and a number of these may have been pregnant. A 200 m critical habitat zone extends out from the main aggregation site north of the island and a 800 m buffer zone extends out from the entire island.

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[2] now within the NSW Department of Primary Industry

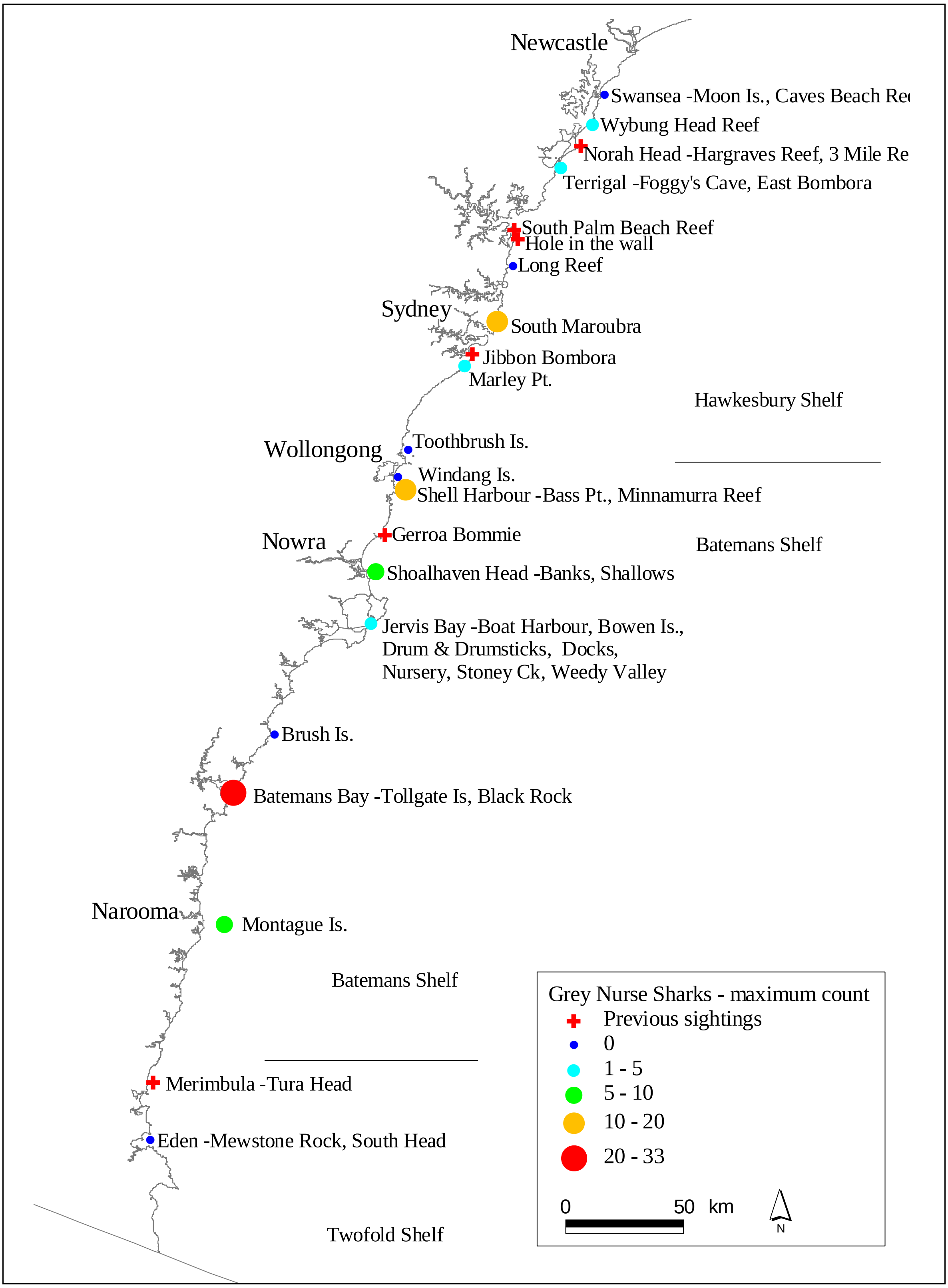

Figure 8.43. Maximum numbers of Grey Nurse Shark (*Carcharias taurus*) observed at dive sites in the Hawkesbury, Batemans and Twofold Shelf bioregions during eight survey seasons in 1998 and 2000 and additional historical sightings (data from Otway and Parker 2000 and Otway *et al.* 2003).

8.4.18 Threatened Birds

Data source

Information on threatened sea bird and wader species was derived from the NSW Wildlife Atlas, threatened species profiles and threatened species recovery plans from the NSW National Parks and Wildlife Service[1] (NPWS 1999abc, 2000d).

Data description

The NSW Wildlife Atlas records 32 species of sea birds and intertidal wader in NSW listed as threatened under the *NSW Threatened Species Conservation Act 1995*. Of these, 23 have been recorded from the Batemans and Twofold Shelf bioregions with four species listed as endangered (Table 8.6).

Table 8.6. Threatened intertidal waders and sea birds.

Endangered	
Beach Stone-curlew *Esacus neglectus*	Little Tern *Sterna albifrons*
Bush Stone-curlew *Burhinus grallarius*	Hooded Plover *Thinornis rubricollis*
Vulnerable	
Australasian Bittern *Botaurus poiciloptilus*	Osprey *Pandion haliaetus*
Black Bittern *Ixobrychus flavicollis*	Pied Oystercatcher *Haematopus longirostris*
Black-browed Albatross *Diomedea melanophrys*	Providence Petrel *Pterodroma solandri*
Black-tailed Godwit *Limosa limosa*	Sanderling *Calidris alba*
Broad-billed Sandpiper *Limicola falcinellus*	Shy Albatross *Diomedea cauta*
Flesh-footed Shearwater *Puffinus carneipes*	Sooty Albatross *Phoebetria fusca*
Great Knot *Calidris tenuirostris*	Sooty Oystercatcher *Haematopus fuliginosus*
Greater Sand Plover *Charadrius leschenaultii*	Sooty Tern *Sterna fuscata*
Lesser Sand Plover *Charadrius mongolus*	Terek Sandpiper *Xenus cinereus*
Little Shearwater *Puffinus assimilus*	

Assessment

Little Tern (*Sterna albifrons* subspecies *sinensis*)

Habitat requirements and threats for this species are described in section 6.4.13. While no areas of critical habitat for Little Terns have been listed under the *Act (1995)*, significant nesting sites have been identified near Comerong Island, Lake Wollumboola, Lake Conjola, Tuross Lake, Brou Lake, Tilba Lake, Wallaga Lake and the Bega River. As the condition and location of nesting habitats can vary greatly over different years, areas of critical habitat will be reviewed regularly. The recovery plan for the Little Tern includes provision for exploring and implementing opportunities for the creation and enhancement of Little Tern nesting habitat (NPWS 2000). Table 8.7 lists historical nesting sites of Little Tern with the most recent and most successful nesting records.

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[1] now within the NSW Department of Environment and Conservation.

Table 8.7. Nesting sites of Little Tern in the Batemans and Twofold Shelf bioregions with largest and most recent nesting records (NPWS 2000d).

Nesting site	Last Record	Largest colony recorded
Shellharbour	1930s	No data
Minnamurra	1967/68	4 pairs 1967/68
Comerong Island	1996/97	13 pairs 1976/77
Lake Wollumboola	1996/97	30 pairs 1995/96
Lake Conjola	1996/97	10 pairs 1940's/50's
Narrawallee Creek	1984/85	2 pairs 1984/85
Burrill Lake	early 1950's	10 pairs 1940's/50's
Tabourie Lake	early 1950's	10 pairs 1940's/50's
Meroo Lake	pre 1963	no data
Mossy Point	1960/61	2-3 pairs 1960/61
Congo Creek	1994/95	1-2 pairs 1994/95
Mullimburra Point	early 1980's	3 pairs early 1980's
Coila Lake	1994/95	3 pairs 1982/83
Tuross Lake	1994/95	12 pairs 1985/86
Brou Lake	1993/94	35 pairs 1990/91
Tilba Lake	1994/95	35 pairs 1988/89
Wallaga Lake	1996/97	34 pairs 1993/94
Murrah Lagoon	1995/96	4 pairs 1989/90
Middle Lagoon	1996/97	1 pair 1996/97
Nelson lagoon	1996/97	1 pair 1996/97
Bega River	1996/97	13 pairs 1996/97
Wallagoot Lake	1994/95	12 pairs 1989/1990
Nadgee Lake	1984/85	9 pairs 1980/81

Beach Stone-curlew

Sightings of Beach Stone-curlew in the Batemans and Twofold Shelf bioregions are limited to the Comerong Island area of the Shoalhaven River estuary. A recovery plan has not yet been prepared for this species.

Bush Stone-curlew

The Bush Stone-curlew (*Burhinus grallarius*) is widespread throughout northern Australia and was once widespread along the east coast of NSW including much of the Cumberland Plain and in the Tweed, Brunswick, Richmond, Clarence, Macleay, Manning and Hunter Valleys. The NSW population now appears to be centred near Gosford (near Brisbane Water), Port Macquarie, Grafton, Port Stephens and Karuah. Sightings in the Batemans and Twofold Shelf bioregions are restricted to near the Shoalhaven River estuary.

Hooded plover

The hooded plover (*Thinornis rubricollis*) occurs throughout south eastern and south western Australia. Within NSW, it occurs south of Jervis Bay but was known previously as far north as Port Stephens and has occasionally been sighted in Wollongong and Sydney. In Australia, this species is found mostly on long stretches of sandy shore adjacent to lagoons and nesting on sparsely vegetated sand dunes. Its diet consists of marine worms, molluscs, crustaceans, insects, water plants and seeds. Threats include predation by silver gulls, foxes and raptors, loss of habitat to development, destruction of nests by stock and disturbance during the breeding season from humans and the use of four wheel drive vehicles in dune areas. There have been sightings of Hooded Plover at range of locations along the Batemans Shelf coast. A recovery plan has not yet been prepared for this species (1999c).

Other threatened bird species

For estuaries, most threatened bird species were sighted around the Shoalhaven River (14 species) and at Durras Lake, Batemans Bay, Moruya River, Tuross Lake, Wagonga Inlet, Tilba Tilba Lake, Wallaga Lake, Lake Conjola and the Bega River. By far the most sightings occurred at the Shoalhaven River and the highest summed irreplaceability occurred at the Shoalhaven River, Batemans Bay, Durras Lake and the Moruya River (Figure 8.44 - Figure 8.46).

For sections of coast and ocean, most threatened bird species were sighted in the Moruya-Tuross, Shellharbour-Crooked and Crooked-Wollumboola sections, with most sightings in the Crooked-Wollumboola section and the highest summed irreplaceability in the Shellharbour-Crooked and Crooked-Lake Wollumboola sections (Figure 8.47).

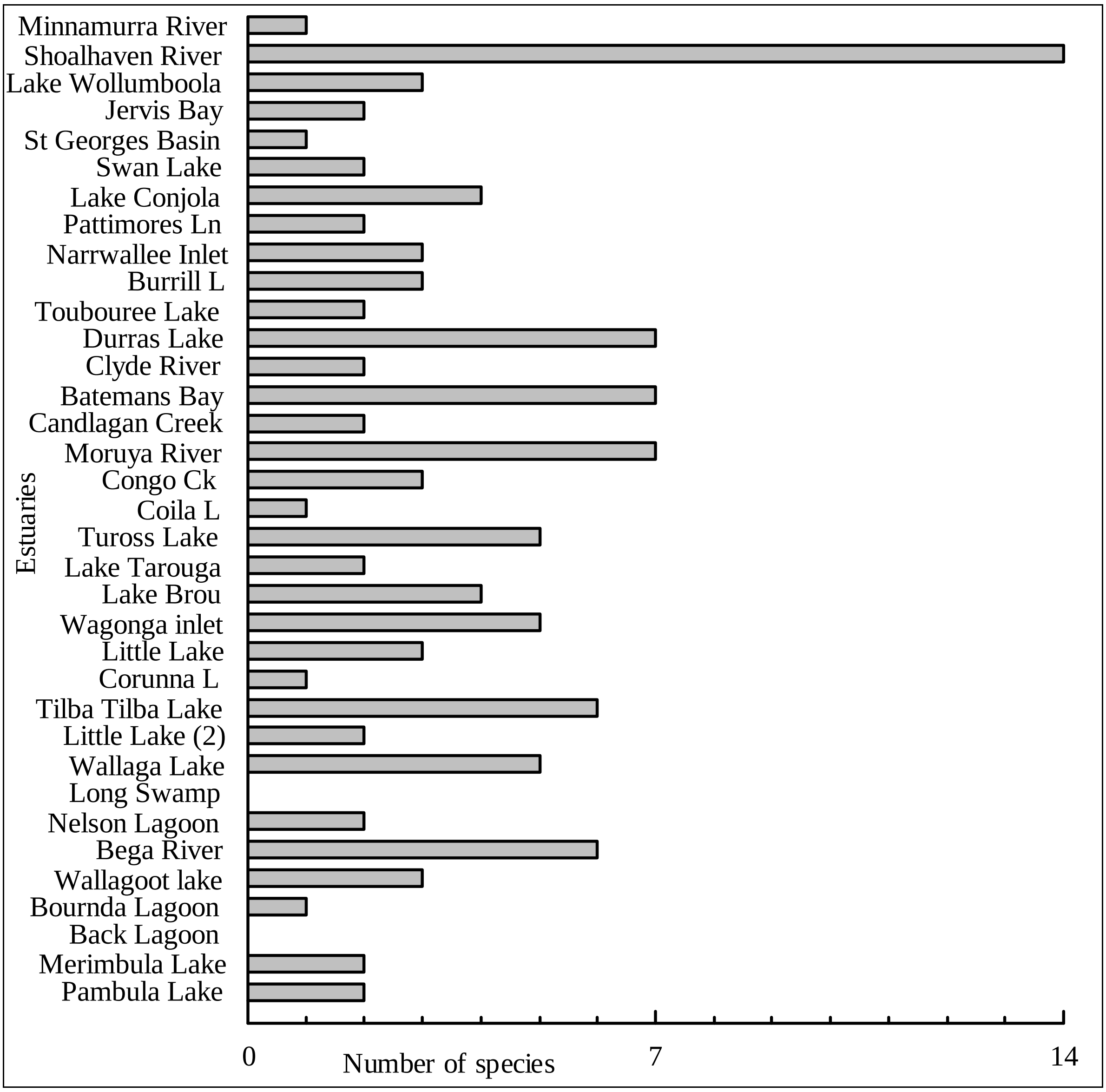

Figure 8.44. Number of threatened bird species sighted near estuaries in the Batemans and Twofold Shelf bioregions (raw data from NPWS Wildlife Atlas).

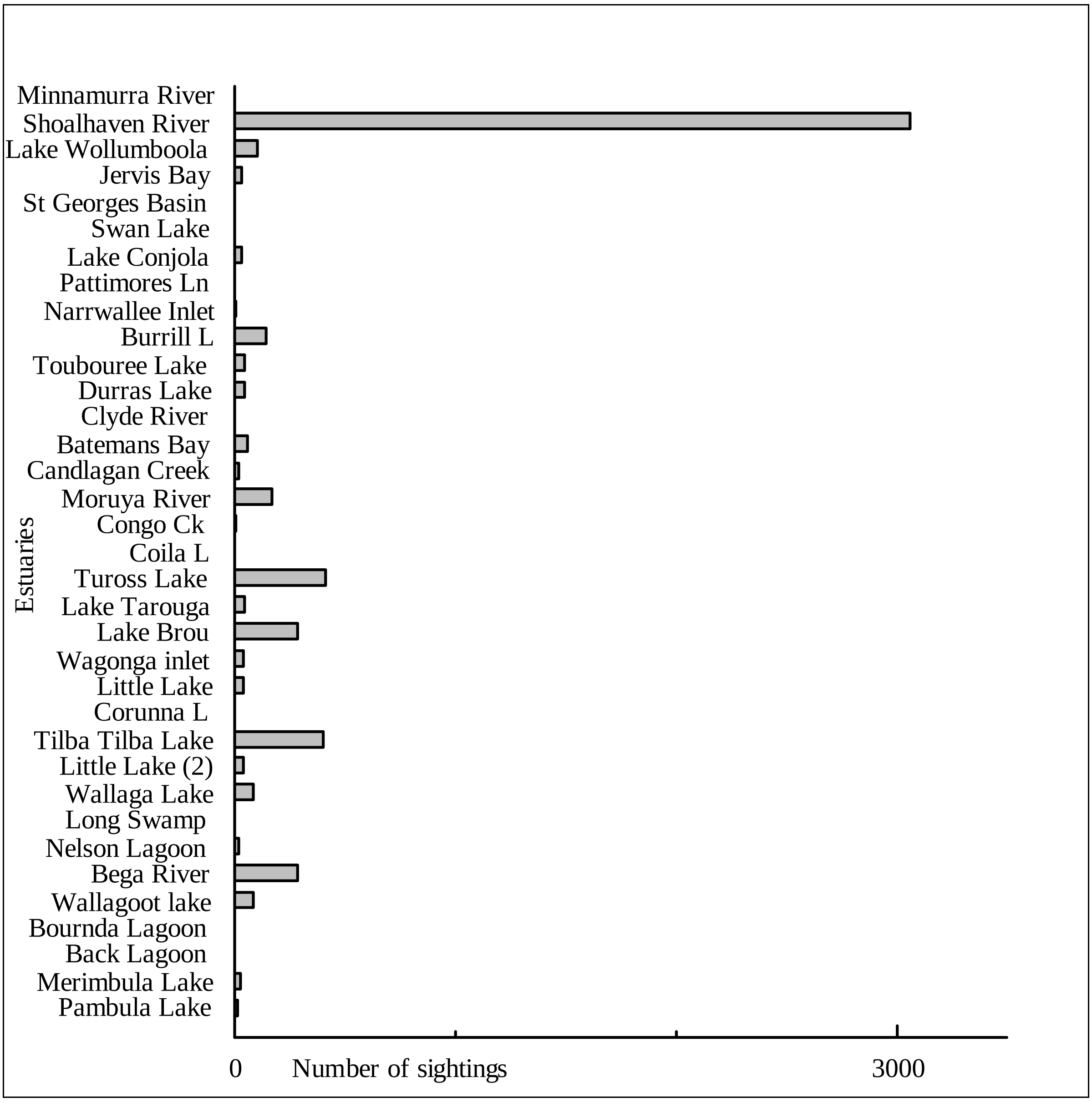

Figure 8.45. Number of sightings of threatened bird species near estuaries in the Batemans and Twofold Shelf bioregions (raw data from NPWS Wildlife Atlas).

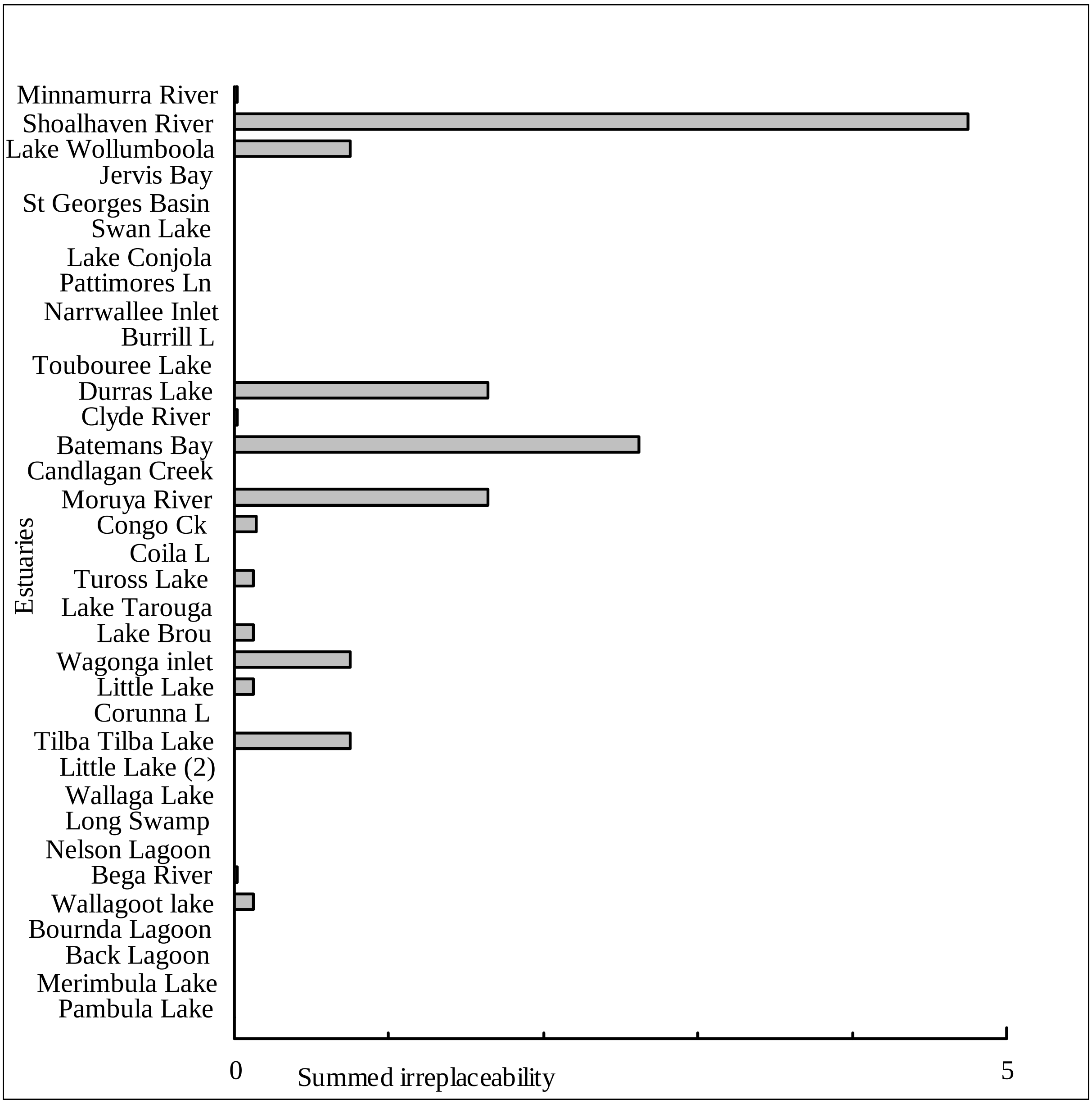

Figure 8.46. Summed irreplaceability for representation of at least one sighting of each threatened bird species for estuaries in the Batemans and Twofold Shelf bioregions (raw data from NPWS Wildlife Atlas).

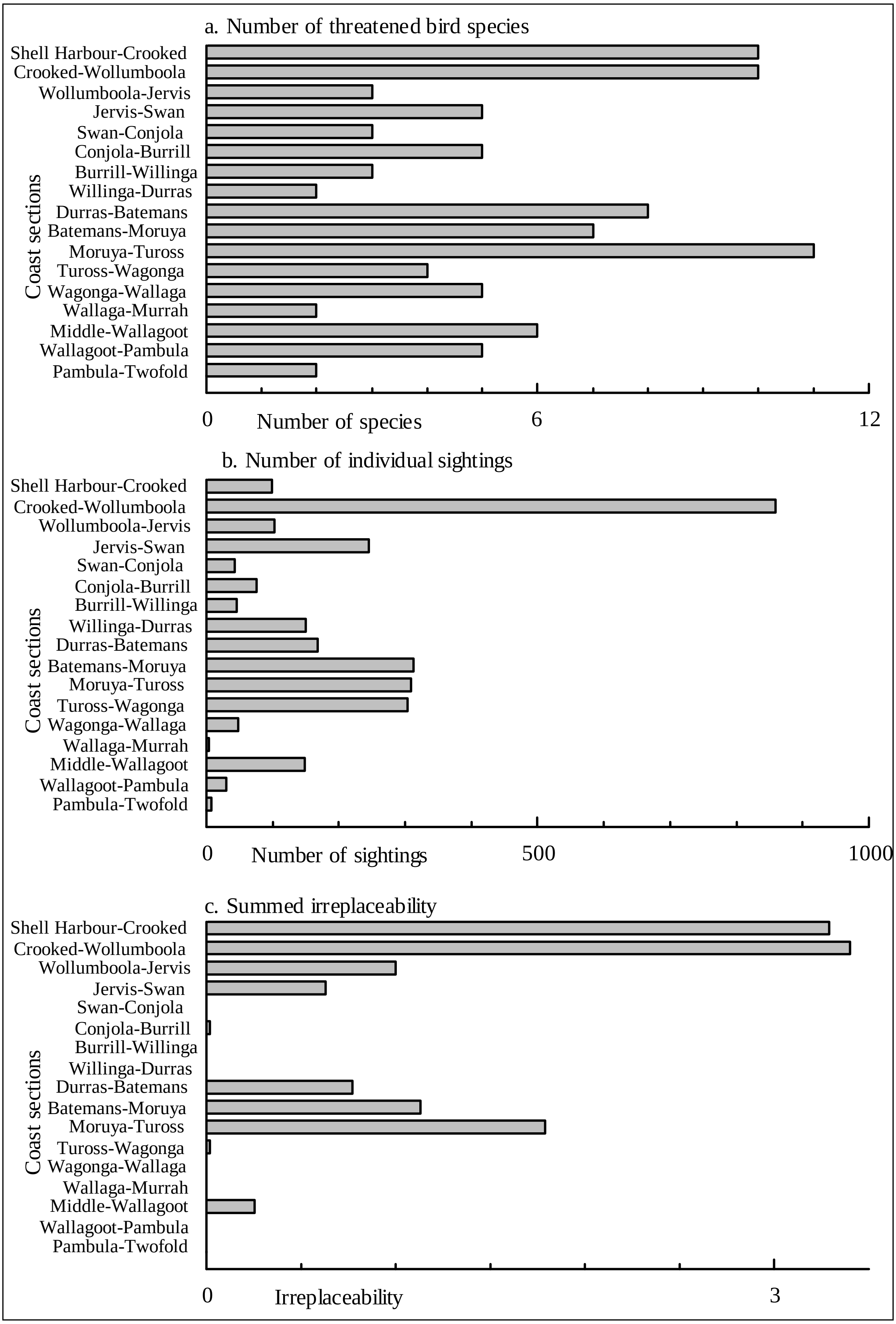

Figure 8.47. Number of threatened bird species sighted, number of sightings and summed irreplaceability for representation of each species at least once for sections of ocean and coast in the Batemans and Twofold Shelf bioregions (raw data from NPWS Wildlife Atlas).

8.4.19 Significant areas for shore birds and sea bird islands – Department of Environment and Heritage.

Data source

Australian Department of Environment and Heritage database of significant shorebird areas and seabird islands.

Data description

GIS shape files and data tables for areas considered by Wetlands International (Oceania) as significant for shore birds (from Watkins D. 1993. A National Plan for Shorebird Conservation in Australia. RAOU Report No. 90.) and islands for which the Department of Environment and Heritage has breeding records.

Criteria

Representativeness, threatened species and ecological importance.

Assessment Measures

Area of habitat, number of species, number of birds, summed species irreplaceability.

Data assessment

The Shoalhaven River and Wagonga Inlet had large areas of significant shorebird habitat with the Shoalhaven River having a greater number of shorebird species, abundance and summed irreplaceability (Figure 7.34).

The Willinga-Durras and Durras-Batemans sections included the most sea bird islands in the Batemans and Twofold Shelf bioregions, but the Durras-Batemans and Wagonga-Wallaga sections included the most nesting seabirds, seabird species, and summed irreplaceability for representation of each species at least once (Figure 7.35).

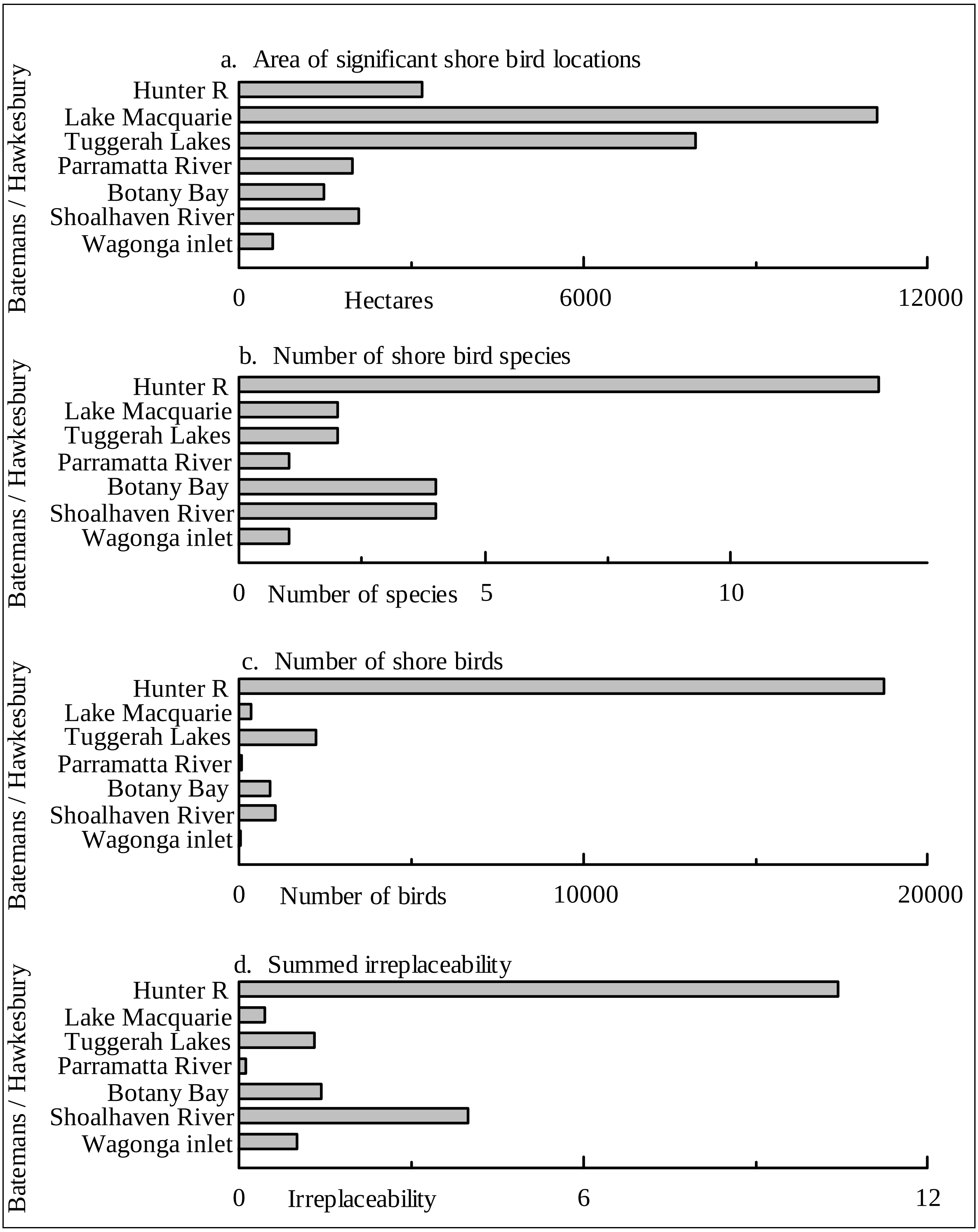

Figure 8.48. Area, number of species, number of birds and summed irreplaceability for representation of each species at least once for significant shore bird locations in the Hawkesbury and Batemans Shelf bioregions (raw data from the Department of Environment and Heritage).

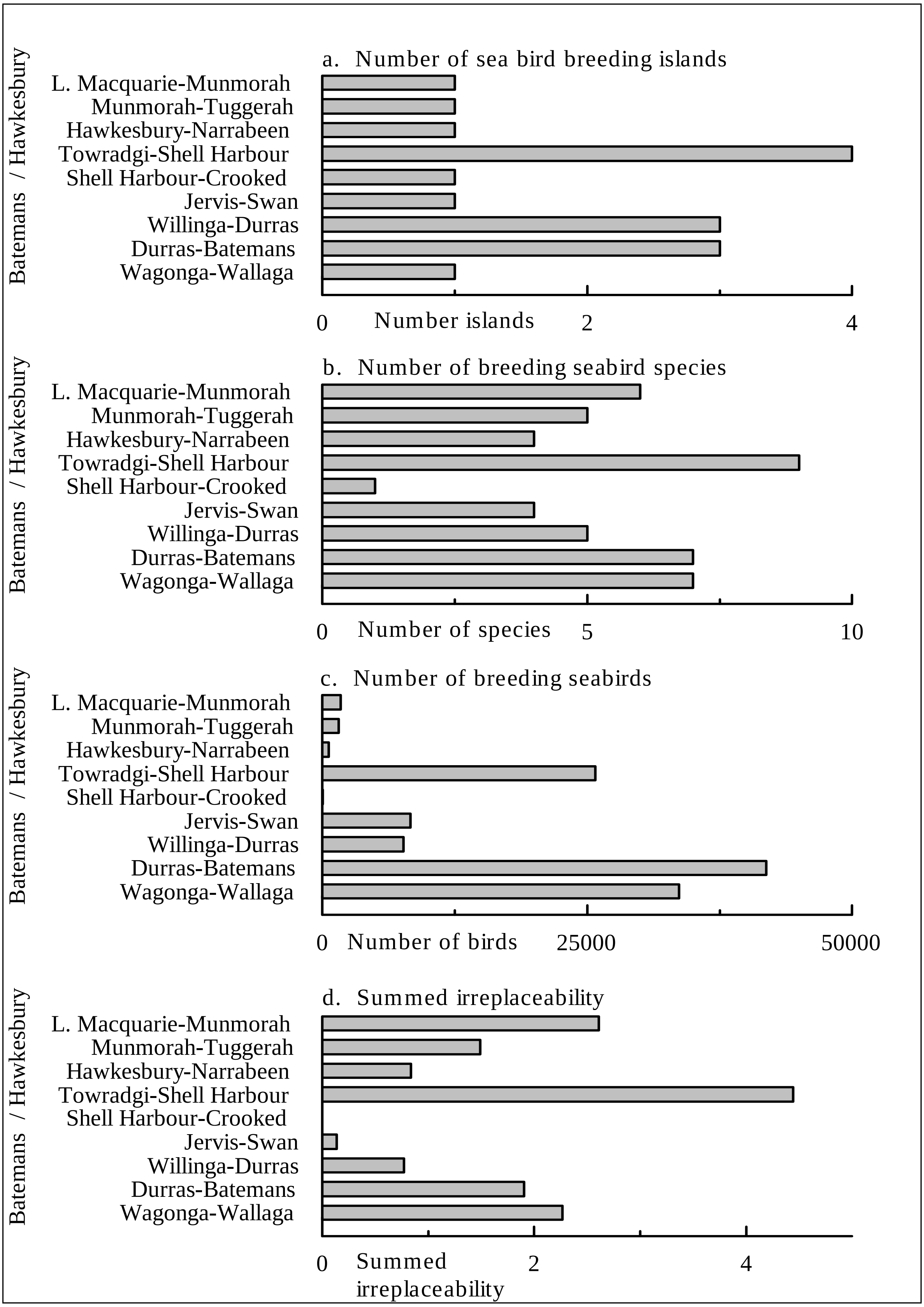

Figure 8.49. Area, number of species, number of birds and summed irreplaceability for representation of each species at least once for sea bird breeding islands in the Hawkesbury and Batemans Shelf bioregions (raw data from the Department of Environment and Heritage).

8.4.20 Marine mammals and reptiles

Data sources

Australian Government Department of Environment and Heritage.

Transport Safety Bureau's "NSW Oil Spill Response Atlas" version 2.2 (CD-ROM June 2000).

Data Description

The database held by the Department of Environment and Heritage holds broad scale distribution maps and taxonomic, ecological and management information about Species of National Environmental Significance as listed under the *Environment Protection and Biodiversity Conservation Act 1999*. The "NSW Oil Spill Response Atlas" includes sightings data for marine mammals in NSW.

Criteria

Representativeness and threatened species.

Assessment measures

Descriptive summary.

Assessment

Marine mammal distributions in the bioregions include the Humpback whale (*Megaptera novaeangliae*), Southern Right whale (*Eubalaena australis*), Sei whale (*Balaenoptera borealis*), Fin whale (*Balaenoptera physalus*), Blue whale (*Balaenoptera musculus*), and the Dusky dolphin (*Lagenorhynchus obscurus*. Marine reptile distributions in the Batemans Shelf bioregion include the Green Turtle (*Chelonia mydas*) which extends south to Jervis Bay and the Leatherback Turtle (*Dermochelys coriacea*), which extends south to Eden. These distributions extend well beyond NSW and several species are at the limit of their range.

The NSW Oil Spill Response Atlas includes 1002 sighting records of marine mammals in the bioregions including sightings of Humpback whale, Killer whale (*Orcinus orca*), Gray's Beaked whale (*Mesoplodon grayii*), Dense Beaked whale (*Mesoplodon densirostis*), Strap Toothed Beaked whale (*Mesoplodon layardi*), Gingko Beaked whale (*Mesoplodon gingkodens*), Long Finned Pilot whale (*Globicephala melas*), Melon-head whale (*Peponocephala electra*), Minke whale (*Balaenoptera acutorostrata*), Pygmy Sperm whale (*Kogia breviceps*), Dwarf Sperm whale (*Kogia simus*), Sperm whale (*Physeter macrocephalus*), Short-finned pilot whale (*Globicephala macrorhynchus*), Southern Right whale (*Eubalaena australis*), Pygmy Right whale (*Caperea marginata*), Southern Bottlenose whale (*Hyperoodon planiforms*), Bottlenose dolphin (*Tursiops truncatus*), Common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), Striped dolphin (*Stenella coeruleoalba*), Leopard seal (*Hydrurga leptonyx*), Australian Fur seal (*Arctocephalus pusillus*), New Zealand Fur seal (*Arctocephalus forsteri*), Australian Sea-lion (*Neophoca cinerea*) and Southern Elephant seal (*Mirounga leonina*). The distributions of these mammals extend well beyond the bioregion and several are at the extreme limit of their range. Most sightings (predominantly seals) occurred in the Wagonga-Wallaga section (93).

Montague Island is the most northerly and only remaining haul out site in NSW for Australian fur seals (*Arctocephalus pusillus*). The number of seals at the island ranges from around 25 for most of the year, to 700 in the breeding season and numbers appear to be increasing. It is thought that the island is not a breeding colony although there are anecdotal reports of seal pups being born there. There is only a limited knowledge of use of the island by seals and research is needed into the potential impacts of disturbance by humans (NPWS 1995b).

Humpback whales are regularly observed off the NSW coast in June and July migrating to winter breeding grounds off Queensland and returning south between October and November to feed in colder waters. This east Australian population of humpbacks was estimated to have declined from 10,000 to 500 whales during the first half of the 20th century but is now increasing slowly each year (Baker 1983, Paterson and Paterson 1989, Smith 1997). These whales often pass relatively close to the coast, particularly near prominent headlands, and whale watching tourism is becoming established in several coastal ports including Jervis Bay, Batemans Bay, Narooma, Bermagui and Eden.

8.4.21 Directory of important wetlands in Australia

Data Source

GIS layer of wetlands mapped from the descriptions provided in the Directory.

Data Description

The “Directory of Important Wetlands” (ANCA 1996) is a cooperative project between the Commonwealth, State and Territory Governments of Australia and is coordinated by The Department of Environment and Heritage to identify nationally important wetlands. The wetlands listed in the Directory are those which meet the criteria of national importance as revised by the ANZECC Wetlands Network in August 1994. Criteria used to assess important wetlands include, whether the wetland is:

- a good example of a wetland type occurring in the bioregion
- important ecologically or hydrologically in the natural functioning of a major wetland
- important as habitat for animal taxa at a vulnerable stage of their life cycle, or provides refuge in adverse conditions such as drought
- supporting 1% or more of the national population of any plant or animal taxa
- supporting native plant, animal taxa or communities considered endangered or vulnerable at a national level or
- of outstanding historical or cultural significance.

Criteria

Representativeness and International or national importance.

Assessment measures

Presence of nationally important wetlands and descriptive summaries in Section 8.5 and Appendix 4.

Assessment

Table 8.8 lists locations of important wetlands in the Batemans and Twofold Shelf bioregions. These areas are mapped in Figure 8.2 and discussed in more detail in Appendix 4.

Table 8.8. Important Wetlands in the Batemans and Twofold Shelf bioregions (ANCA 1996).

Wetland name	Area (ha)
Killalea Lagoon	20
Minnamurra River Estuary	200.
Shoalhaven / Crookhaven Estuary	2,500
Coomonderry Swamp	670
Wollumboola Lake	850
Jervis Bay	30, 000
Jervis Bay Sea Cliffs	175 ha, 25 km long
St Georges Basin	4400
Swan Lagoon	6
Durras Lake	400
Clyde River Estuary	2,900
Cullendulla Creek and Embayment	220
Waldrons Swamp	225
Moruya River Estuary Saltmarshes	50
Coila Creek Delta	40
Tuross River Estuary	1,200
Wallaga Lake	950
Nargal Lake	25
Nelson Lagoon	200
Bondi Lake	50
Wallagoot Lagoon	360
Merimbula Lake	450
Pambula Wetlands	200
Twofold Bay	850

8.4.22 Independent inquiry into coastal lakes

Data Source

"Independent public inquiry into coastal lakes: final report", Healthy Rivers Commission of NSW (2002a).

Data Description

The classification assesses lakes on their "natural sensitivity, current condition of the water body and catchment, and recognised ecosystem and resource conservation values." The classification also takes into account existing settlement, resource use, government and court decisions, potential for restoration and development of other lakes in the region.

Assessments were influenced by the availability of information, but were informed by data analysed by the Department of Land and Water Conservation[6] in its "Estuaries Inventory," the Commonwealth Government's "National Land and Water Resources Audit" and additional data from universities, independent experts, state agencies, councils and submissions made to the Coastal Lakes Inquiry.

Criteria

Representativeness, uniqueness, threatened species, naturalness, vulnerability, management practicality and human use.

Assessment measures

Qualitative ranks for natural sensitivity, existing catchment and lake condition, recognised conservation value, potential for improvement and orientation for management.

Assessment

The assessment examined over fifty coastal lakes in the Batemans and Twofold Shelf bioregions. Its results are summarised in Table 8.9 below. The category "management orientation" identifies the suggested approach to managing each lake and its catchment according to guidelines provided in the Coastal Lakes Inquiry. These guidelines range from CP, which indicates the need for 'Comprehensive Protection' for relatively natural lakes to SP, 'Significant Protection', HMC, 'Healthy Modified Condition' and TR, 'Targeted Repair' for the most degraded lakes.

Wollumboola, Termeil, Meroo, Durras, Brunderee, Tarouga, Brou, Nargal, Nelson and Bondi Lakes and Lagoons in the Batemans Shelf bioregion were recommended for comprehensive protection by the Coastal Lakes Inquiry. In the Twofold Shelf bioregion, Bournda Lagoon and Nadgee Lake were recommended for comprehensive protection.

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[6] now within the NSW Department of Infrastructure, Planning and Natural Resources.

Table 8.9. Classification of coastal lakes in the Batemans and Twofold Shelf bioregions (Healthy Rivers Commission 2002).

Coastal Lake	Natural Sensitivity	Existing Condition		Conservation Value	Management Orientation
		Catchment	Lake		
Killalea	Extreme	Modified	Unknown	Moderate	HMC
Werri	Extreme	Modified	Moderately affected	Low	HMC
Wollumboola	Extreme	Largely Unmodified	affected	High	CP
St Georges Basin	High	Modified	Slightly affected	High	HMC
Swan	Extreme	Largely Unmodified	Slightly affected	High	SP
Conjola Berringer	High	Modified	Slightly affected	Moderate	SP
Narrawallee	High	Modified	Slightly affected	Moderate	HMC
Burrill	High	Modified	Moderately affected	Moderate	HMC
Tabourie	Extreme	Modified	Slightly affected	Moderate	SP
Termeil	Extreme	Near Pristine	Unknown	Moderate	CP
Meroo	Extreme	Near Pristine	Slightly affected	Moderate	CP
Willinga	High	Largely Unmodified	Slightly affected	Moderate	SP
Swan	Extreme	Modified	Unknown	Moderate	HMC
Kioloa	Extreme	Largely Unmodified	Unknown	Moderate	HMC
Durras	Very High	Near Pristine	Slightly affected	Moderate	CP
Candalagan	High	Largely Unmodified	Unknown	Low	SP
Congo	Very High	Modified	Unknown	Low	HMC
Meringo	Extreme	Largely Unmodified	Unknown	Low	SP
Mullimburra	Extreme	Modified	Unknown	Moderate	HMC
Bingie	Extreme	Modified	Unknown	Unknown	SP
Coila	Extreme	Largely Unmodified	Slightly affected	Moderate	HMC
Tuross	High	Largely Unmodified	Slightly affected	High	HMC
Brunderee	Extreme	Near Pristine	Unknown	Low	CP
Tarourga	Extreme	Near Pristine	Unknown	Low	CP
Brou	Extreme	Near Pristine	Slightly affected	Moderate	CP
Mummuga	Very High	Largely Unmodified	Slightly affected	Moderate	SP
Kianga	Extreme	Largely Unmodified	Severely affected	Moderate	HMC
Wagonga	High	Largely Unmodified	Slightly affected	High	HMC

Table 8.9 (continued).
Classification of coastal lakes in the Batemans and Twofold Shelf bioregions (Healthy Rivers Commission 2002a).

Coastal Lake	Natural Sensitivity	Existing Condition		Conservation Value	Management Orientation
		Catchment	Lake		
Little	Extreme	Severely Modified	Moderately affected	Unknown	TR
Bullengella	Extreme	Modified	Unknown	Low	HMC
Nangudga	High	Modified	Unknown	Low	HMC
Nargal	Extreme	Near Pristine	Pristine	High	CP
Corunna	Very High	Largely Unmodified	Slightly affected	Moderate	SP
Tilba Tilba	Extreme	Modified	Moderately affected	Moderate	HMC
Little	Extreme	Modified	Unknown	Moderate	HMC
Wallaga	High	Largely Unmodified	Slightly affected	High	HMC
Long Swamp	Extreme	Modified	Moderately affected	Moderate	HMC
Baragoot	High	Largely Unmodified	Unknown	Low	SP
Cuttagee	Very High	Near Pristine	Slightly affected	Low	SP
Murrah	High	Largely Unmodified	Slightly affected	Low	HMC
Bunga	Extreme	Largely Unmodified	Unknown	Low	SP
Wapengo	High	Largely Unmodified	Slightly affected	High	SP
Middle	Extreme	Largely Unmodified	Slightly affected	Moderate	SP
Nelson	High	Near Pristine	Slightly affected	High	CP
Wallagoot	Very High	Largely Unmodified	Slightly affected	Moderate	SP
Bondi	Extreme	Near Pristine	Pristine	High	CP

Twofold Shelf bioregion

Bournda	Extreme	Near Pristine	Pristine	Moderate	CP
Back	Very High	Largely Unmodified	Moderately affected	Low	SP
Merimbula	High	Modified	Moderately affected	High	HMC
Pambula	High	Largely Unmodified	Slightly affected	High	HMC
Curalo	Very High	Largely Unmodified	Slightly affected	Moderate	HMC
Wonboyn	High	Near Pristine	Slightly affected	High	SP
Nadgee	Extreme	Near Pristine	Pristine	High	CP

8.4.23 Environmental inventory of estuaries and coastal lagoons

Data source

Bell and Edwards (1980). "An inventory of estuaries and coastal lagoons in NSW."

Data description

Bell and Edwards (1980) conducted inventories of NSW estuaries including descriptions of recreation and tourism significance, degree of disturbance, area, mean annual rainfall, mean annual runoff and conservation features. While these data may not be the most current in regards to coastal development and catchment use, they provide a relative measure of differences among estuaries and a useful check against more recent inventories.

Criteria

Naturalness and vulnerability.

Assessment measures

Qualitative score between 1-4 for shore and water disturbance and for catchment disturbance.
Verbal description of conservation and human-use values and threats.

Assessment

Table 8.10 lists disturbance scores for over fifty estuaries. With some exceptions most of the scores are low particularly when compared to estuaries in the Hawkesbury Shelf, Manning Shelf and Tweed-Moreton bioregions.

Table 8.10. Disturbance scores for estuaries in the Batemans and Twofold Shelf bioregions (0-Very Low to 5-Very High, Bell and Edwards 1980).

Estuary	Shore and water	Catchment
Batemans Shelf bioregion		
Minnamurra River	3	3
Werri Lagoon	3	3
Crooked Creek	3	4
Shoalhaven River	3	2
Lake Wollumboola	3	1
Jervis Bay	3	2
St. Georges Basin	2	1
Swan Lake	1	1
Berrara Creek	1	1
Nerrindillah Creek	0	1
Lake Conjola	2	2
Narrawallee Creek	1	3
Burrill Lake	2	3
Tabourie Lake	1	1
Termeil Lake	1	1
Meroo Lake	1	1
Willinga Lake	3	2
Durras Lake	1	1
Batemans Bay and Clyde R.	2	1
Tomaga River	3	2
Candalagan Creek	3	2
Moruya River	3	1
Congo Creek	2	3
Coila Lake	3	2
Tuross Lake	3	2
Lake Brunderee	1	1
Lake Tarouga	1	1
Lake Brou	1	1
Lake Mummuga	3	1
Kianga Lake	3	2
Wagonga Inlet and Narooma R.	3	2
Nangudga Lake	3	3

Table 8.10 (continued).
Disturbance scores for estuaries in the Batemans and Twofold Shelf bioregions (0-Very Low to 5-Very High, Bell and Edwards 1980).

Estuary	Shore and water	Catchment
Batemans Shelf bioregion (continued)		
Corunna Lake	3	3
Tilba Tilba Lake	4	4
Wallaga Lake	1	3
Bermagui River	3	3
Baragoot Lake	1	1
Cuttagee and Little Lakes	3	1
Murrah Lagoon	3	3
Bunga Lagoon	2	1
Wapengo Lagoon	2	2
Middle Lagoon	1	2
Nelson Lagoon	1	0
Bega River	4	3
Wallagoot Lake	3	2

Twofold Shelf bioregion	Shore and water	Catchment
Bondi Lake	0	1
Sandy Beach Creek	1	1
Back Lagoon	3	1
Merimbula Lake	4	3
Pambula R. and Lake	3	2
Curalo Lake	4	2
Nullica River	1	1
Towamba River	1	3
Bittangabee Bay	0	0
Wonboyn R. and Lake	1	2
Merrica River	0	1
Little Creek	0	1
Nadgee River	0	0
Nadgee Lake	0	0

8.4.24 Australian Estuaries and the OzEstuaries database

Data source

Digby *et al.* (1998). “Australian estuarine database.”

Heap *et al.* (2001). “Australian estuaries and coastal waterways: a geoscience perspective for improved and integrated resource management.”

Data description

The OzEstuaries database combines data from the Australian estuarine database from Digby *et al.* (1998), with new data acquired for the National Land and Water Resources Audit. The new data includes geometrical measurements, facies (habitat) areas, denitrification rates and efficiencies, sedimentation rates and sediment chemistry for estuaries and other coastal waterways. The Australian estuarine database is derived from Buchner and Saenger (1989) with a revision of some of the spatial data, and the inclusion of additional geographic and climatic data.

Criteria

Ecological importance, naturalness (condition), vulnerability and human use.

Assessment measures

Qualitative scores for condition, conservation value and threat, fisheries value and threat, ecological status and water quality.

Assessment

Table 8.11 summarises the estimated condition of Batemans Shelf and Twofold Shelf estuaries in the OzEstuaries database. Condition ranges from extensively modified for the Shoalhaven River and Curalo Lagoon to near pristine for Meroo, Willinga and Durras Lakes and the Merrica River.

Table 8.11. Condition of estuaries listed in the OzEstuaries database.

Estuary	Condition
Minnamurra River	modified
Shoalhaven/Crookhaven River	extensively modified
Wollumboola Lake	largely unmodified
Jervis Bay	largely unmodified
Currambene Creek	largely unmodified
Saint Georges Basin	modified
Swan Lake	largely unmodified
Lake Conjola	modified
Narrawallee Inlet	largely unmodified
Burrill Lake	largely unmodified
Tabourie Lake	modified
Meroo Lake	near pristine
Willinga Lake	near pristine
Durras Lake	near pristine
Clyde River/Batemans Bay	largely unmodified
Tomaga River	largely unmodified
Moruya River	modified
Coila Lake	modified
Tuross Lake	modified
Lake Brou	largely unmodified
Lake Mummuga	largely unmodified
Wagonga Inlet	modified
Corunna Lake	largely unmodified
Tilba Tilba Lake	largely unmodified
Wallaga Lake	largely unmodified
Bermagui River	modified
Cuttagee Lake	largely unmodified
Murrah Lagoon	largely unmodified
Wapengo Lagoon	largely unmodified
Middle Lagoon	largely unmodified
Nelson Lagoon	largely unmodified
Bega River	modified
Wallagoot Lake	largely unmodified
Merimbula Lake	modified
Pambula Lake	largely unmodified
Curalo Lagoon	extensively modified
Nullica River	largely unmodified
Towamba River	largely unmodified
Wonboyn River	largely unmodified
Merrica River	near pristine

8.4.25 Adjacent national parks and nature reserves

Data source

NSW National Parks and Wildlife Service[1].

Data description

GIS boundaries of existing national parks, nature reserves, state recreation areas, historic sites, Aboriginal areas, and regional parks declared under the NSW National Parks and Wildlife Act 1974. National parks and nature reserves are generally declared on the basis of their high conservation values and high natural condition. Their declaration helps ensure long term protection of these values, and provides an important permanent buffer for estuaries and coastal environments against the effects of inappropriate land use. Many coastal national parks and natures extend below mean high and low tide marks and include large areas of open estuary and ocean shore. These areas are regarded as marine protected areas, but additional regulations are required to protect fish and invertebrates from fishing.

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measures

Percent of adjacent lands managed as national park or nature reserve within 1 km of each estuary and within 1 km of the high water mark for sections of exposed coast. Areas of national park and nature reserve extending below mean high tide were mapped in ArcView GIS with advice provided by Rodney James (NSW National Parks). These areas were used to assess the comprehensiveness of the current system of marine protected areas in the bioregion.

Assessment

For estuaries in the Batemans Shelf bioregion, the highest percentage of adjacent lands within 1 km managed as national park or nature reserve was highest for Nelson Lagoon (83%), Termeil Lake (72%), Berrara Creek (71%), Tabourie Lake (67%), Carama Creek (64%), Swan Lake (63%), Durras Lake, Meroo Lake, Middle Lagoon, Nerrindillah Creek, Lake Tarouga and Lake Brou (40-60%; Figure 8.50a).

The cover of national park or nature reserve within 1 km was less than 10% for Nangudga Lake, Lake Brunderee, St Georges Basin, Tuross Lake, Bega River, Bermagui River, Candalagan Creek, Coila Lake, Moruya River, Bullengella Lake and the Crooked River. There were no adjacent national parks or nature reserves for Kianga Lake, Killalea Lagoon, Little Lake, Minnamurra River, Murrah Lagoon, Tomaga River, Ulladulla Harbour, Wagonga Inlet, Bunga Lagoon and Werri Lagoon (Figure 8.50a).

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[1] now within the NSW Department of Environment and Conservation.

For sections of ocean coast in the Batemans Shelf bioregion, the highest percentage of adjacent lands within 1 km in national park or nature reserve occurred between Durras-Batemans (76%), Middle-Wallagoot (64%), Willinga-Durras (55%), Murrah-Middle (55%) and Burrill-Willinga (43%). The least area in national park or nature reserve occurred for the Shellharbour-Crooked (0%), Batemans-Moruya (1.5%), Wallaga-Middle (4%) and the Jervis-Swan sections (4%) (Figure 8.51a).

For estuaries in the Twofold Shelf bioregion all of the adjacent lands within 1 km of Nadgee River, Wirra Birra Creek, Merrica Lake, Table and Little Creek were included in Nadgee Nature Reserve and Wilderness area. All lands around Woodburn, Saltwater and Bittangabee Creeks were included in Ben Boyd National park and all land around Bondi Lake and Bournda Lagoon were included in Bournda National Park (Figure 8.50a).

Pambula Lake (42%), Wonboyn River (27%), Curalo Lagoon (20%), Twofold Bay (20%) and Towamba River (10%) also had significant areas of national park and nature reserve within 1 km of their shores (Figure 8.50a).

For sections of ocean coast in the Twofold Shelf bioregion, all sections except the Wallagoot-Pambula (34%) section had over 90% of adjacent land in national park or nature reserve (Figure 8.51a).

8.4.26 Wilderness

Data source

Comprehensive Regional Assessment (CRA) by the former NSW National Parks and Wildlife Service[1].

Data description

GIS coverage of areas declared as wilderness by the National Parks and Wildlife Service[1].

Identification criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed as wilderness within 1 km of each estuary, and land within 1 km of high water for sections of exposed coast.

Assessment

No wilderness areas occurred within 1 km of any estuaries or coasts in the Batemans Shelf bioregion (Figure 8.50b). However, in the Twofold Shelf bioregion, all adjacent lands within 1 km of Nadgee River, Wirra Birra Creek, Merrica Lake, Table and Little Creek were included in wilderness area (Figure 8.50b) and all of the coast between Wirra Birra and Nadgee and 40% of the coast between Wonboyn and Wirra Birra was included in a wilderness area (Figure 8.51b).

8.4.27 State forest[4]

Data Source

State Forests of NSW[4]

Data description

GIS coverage of the location and extent of state forests.

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed as state forest within 1 km of each estuary, and within 1 km of high water for sections of exposed coast.

Assessment

In the Batemans Shelf bioregion, the Clyde River (49%), Bermagui River (40%), Nerrindillah Creek (32%) and Mummuga Lake (30%) had the most adjacent land within 1 km in State Forest. Lake Brou, Cuttagee Lake, Berrara Creek, Kianga Lake, Wagonga Inlet, Lake Brunderee and the Tomaga River had 10-20% of nearby land in State Forest and all other estuaries had less than 10% of adjacent lands in State Forest (Figure 8.50c). All sections of coast in the Batemans Shelf bioregion had less than 3% of adjacent land in state forest (Figure 8.51c).

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[1] now within the NSW Department of Environment and Conservation.

[4] now Primary Industry Trading in the NSW Department of Primary Industry.

In the Twofold Shelf bioregion, Fisheries Creek (62%), Nullica River (35%), the Wonboyne River (30%) and Towamba River (27%) had the highest proportion of adjacent land in State Forest. All other estuaries had less than 6% in State Forest (Figure 8.50c). Coastal sections in the Twofold Shelf bioregion all had 1% or less of adjacent land in State Forest (Figure 8.51c). However a large proportion of the upper catchments for rivers south of Merimbula is included in state forest.

8.4.28 State Environmental Planning Policy – Wetlands (SEPP 14)

Data Source

NSW Department of Infrastructure, Planning and Natural Resources.

Data description

GIS coverage of coastal wetlands protected under State Environmental Planning Policy No. 14 (SEPP14) of the NSW *Environmental Planning and Assessment Act 1979.*

Criteria

Ecological importance, naturalness (condition) and vulnerability.

Assessment measure

Percent of adjacent lands managed under SEPP 14 within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

In the Batemans Shelf bioregion, Carama Creek (36%) and Moona Moona Creek (33%) had the most area of adjacent land within 1 km included within SEPP 14 classification. Narrawallee Creek, Candalagan Creek, Cullendulla Creek, Little Lake, Currambene Creek, Congo Creek and the Minnamurra River had between 10-20% of adjacent land in SEPP 14. All other estuaries had less than 10% of nearby areas in SEPP14 (Figure 8.50d).

The Wollumboola-Jervis and Durras-Batemans section of coast had approximately 4% of adjacent land in SEPP 14 and all other sections had 1% or less of nearby land in SEPP 14 (Figure 8.52a).

In the Twofold Shelf bioregion, Nadgee Lake and River had 100% of nearby land in SEPP 14 and other estuaries had less than 10% of adjacent land within 1 km in SEPP14 (Figure 8.50d). All sections of coast in the Twofold Shelf bioregion had less than 1% of adjacent land in SEPP 14 (Figure 8.52a).

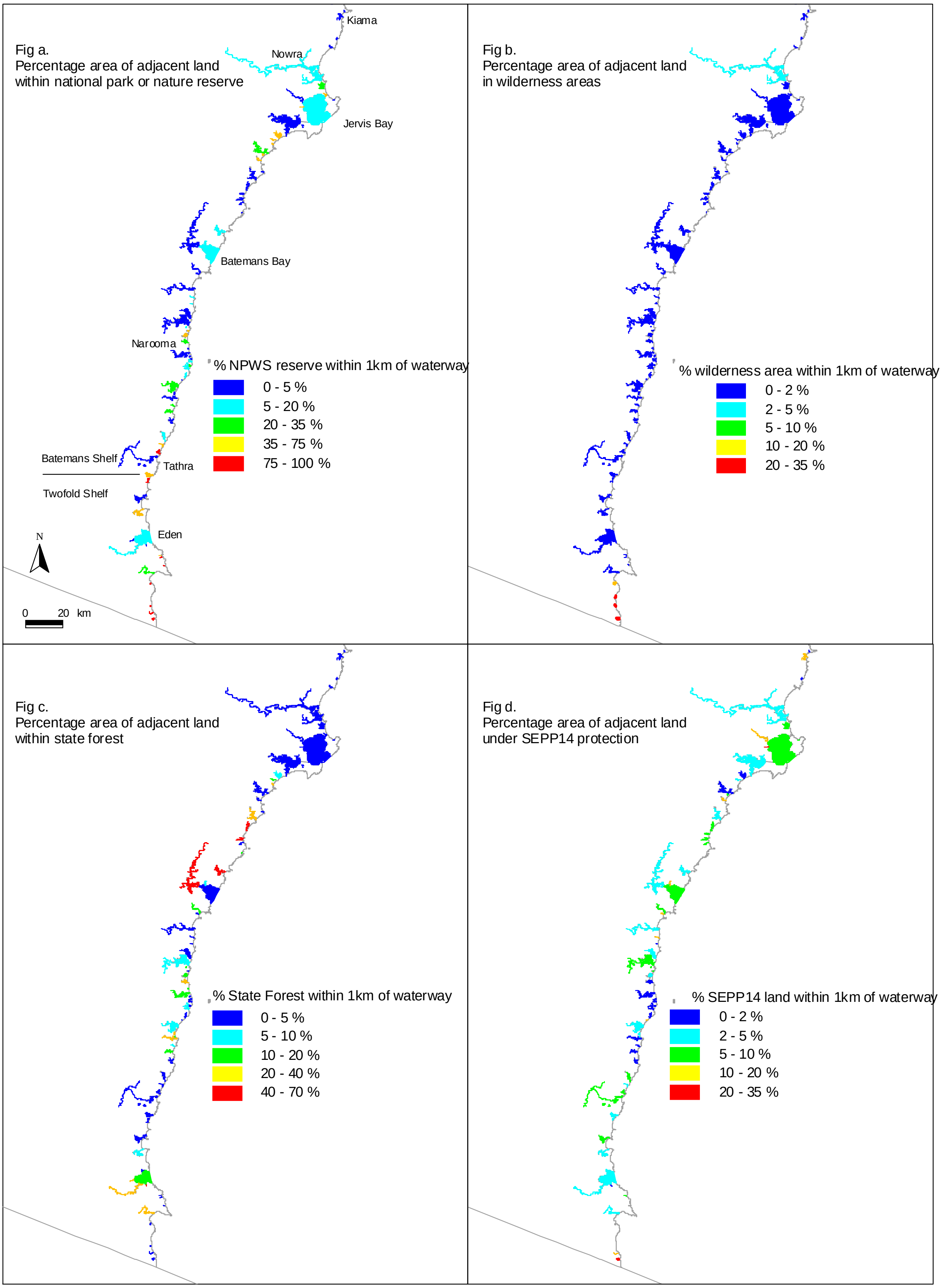

Figure 8.50. Percentage area of lands within 1 km of estuaries within national parks or nature reserves, wilderness areas, state forest and State Environmental Planning Policy 14 (wetland) areas in the Batemans and Twofold Shelf bioregions.

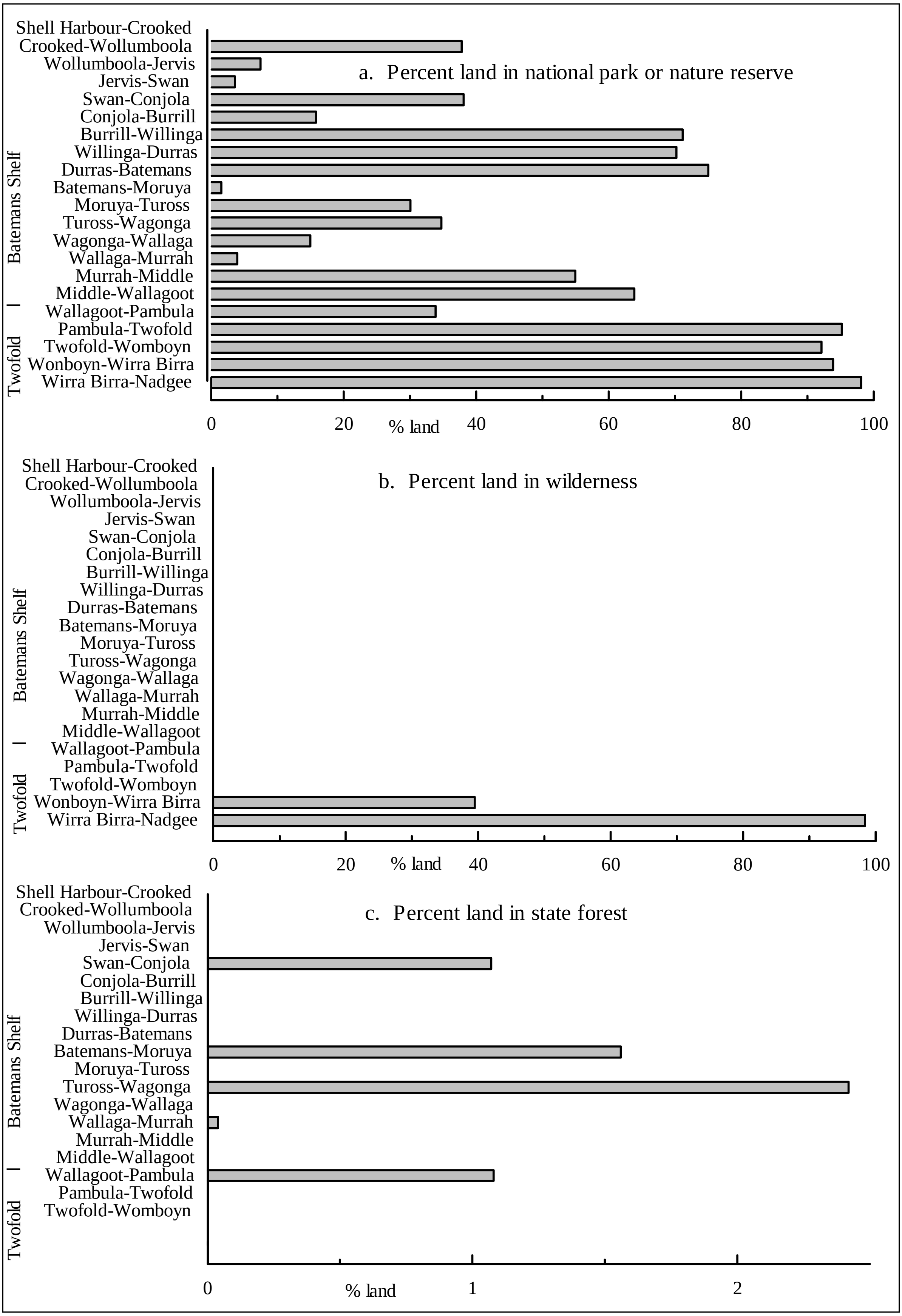

Figure 8.51. Percentage area of land within 1 km of coast in national park or nature reserve, wilderness areas, or State Forest in the Batemans and Twofold Shelf bioregions.

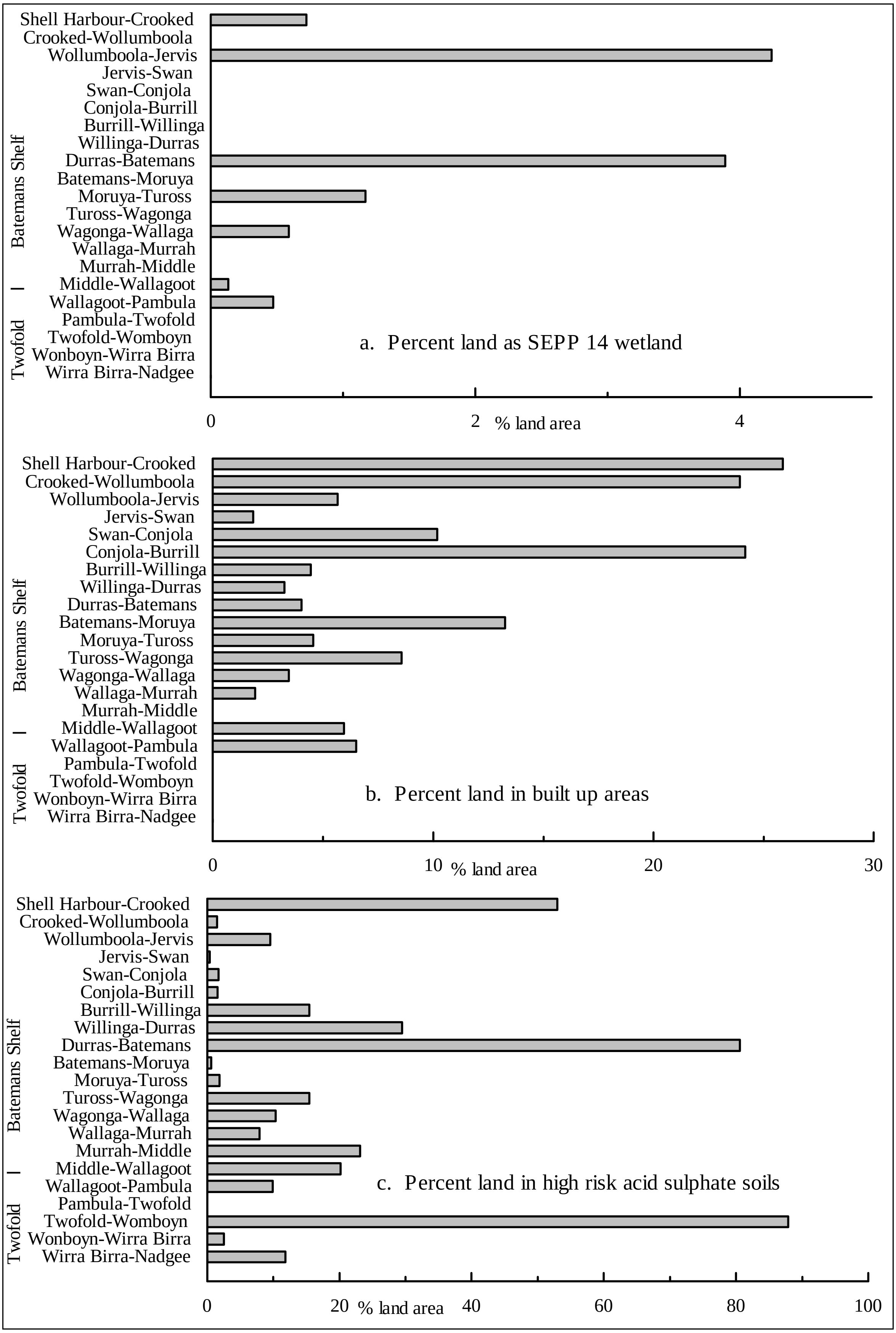

Figure 8.52. Percentage area of land within 1 km of coast in SEPP 14 areas, built up areas and with high risk or disturbed acid sulphate soils.

8.4.29 Land capability

Data Source

NSW Department of Land and Water Conservation (DLWC)[3]

Data description

GIS coverage of land capability from "Land capability mapping," Soil Conservation Service, DLWC. NSW lands were classed by the capability of different soils and terrains to support 8 main categories of land use. These categories were grouped into those classes suitable for cultivation (1-3), suitable for grazing (4-6), or suitable for forest or left with natural vegetation (7-8).

Identification criteria

Vulnerability and naturalness (condition).

Assessment measures

Percentage of adjacent lands in each pooled land capability group within 1 km of each estuary and within 1 km of high water for sections of exposed coast.

Assessment

Land capability for forest or land to be left under natural vegetation

Carama Creek (72%), Moona Moona Creek (47%) and Narrawallee Inlet (43%) had the most adjacent land within 1 km classed as suitable for forest or native vegetation (Figure 8.53a).

The Burrill-Willinga (38%), Crooked-Wollumboola (33%) and Wollumboola-Jervis Bay (28%) sections of coast had the most adjacent land suitable for forest or native vegetation (Figure 8.54c).

Land capability for cultivation

The Crooked River (49%), Werri Lagoon (31%), Moruya River (23%), Shoalhaven River (23%), Tuross Lake (18%) and the Bega River (12%) had the most adjacent land suitable for cultivation (Figure 8.53b). All other estuaries had less than 10% of adjacent land suitable for cultivation. All sections of ocean coast had less than 4% of adjacent land suitable for cultivation (Figure 8.54a).

Land capability for grazing

Currarong Creek (0%), Ulladulla Harbour (0%), Carama Creek (3%), Nelson Lagoon (11%), Jervis Bay (11%), Lake Tabourie (16%) and Termeil lake (17%) had the least adjacent land classed as suitable for grazing. All other estuaries had between 25% and 95% of adjacent land suitable for grazing (Figure 8.53c). Sections of coast between the Crooked River and Swan Lake and south of Pambula Lake had the least adjacent land suitable for grazing. All other sections had between 20 and 80% of nearby lands suitable for grazing (Figure 8.54b).

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[3] now within the NSW Department of Infrastructure, Planning and Natural Resources.

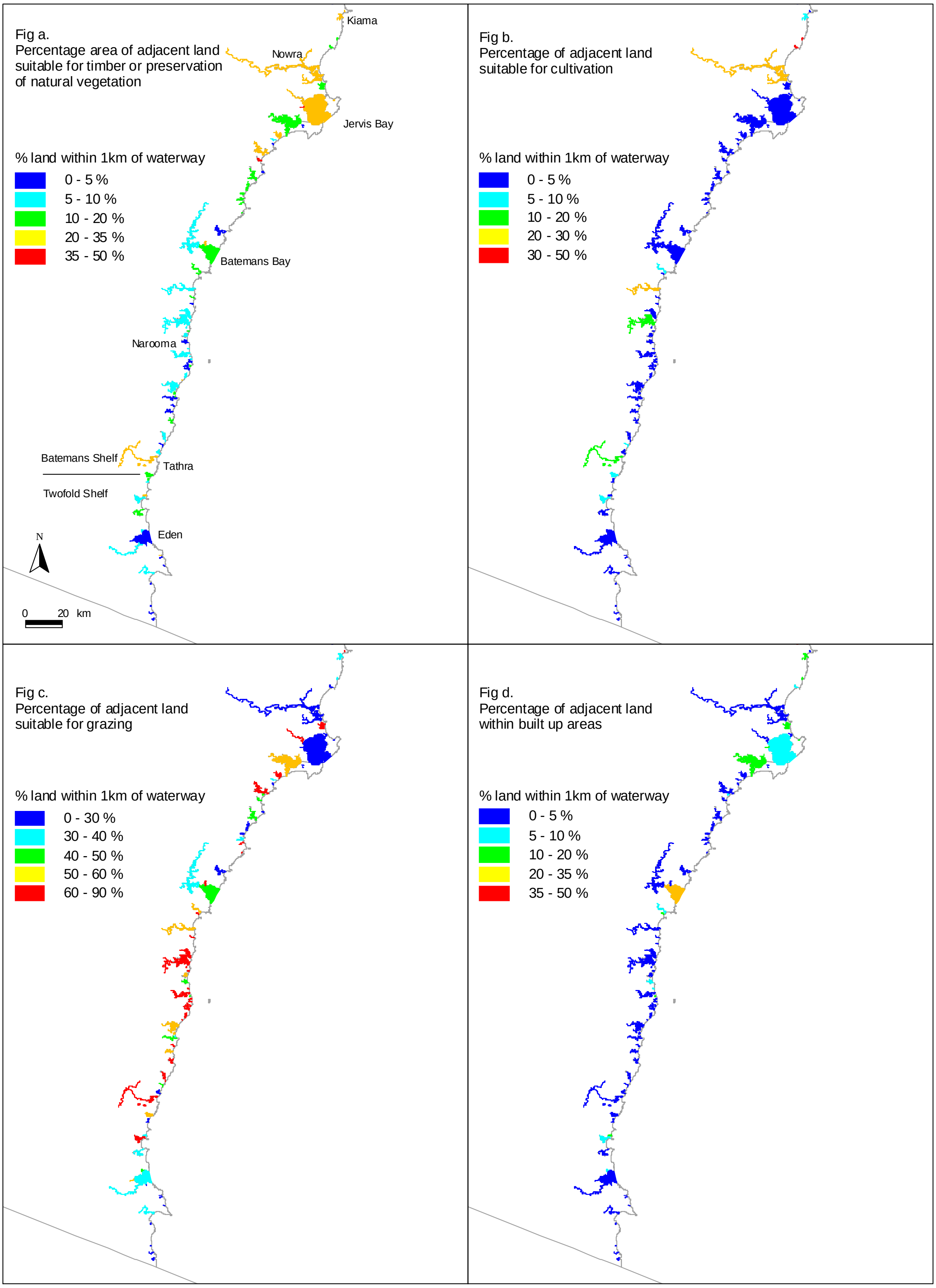

Figure 8.53. Percentage area of lands within 1 km of estuaries suited to different land uses and within built up areas in the Batemans and Twofold Shelf bioregions.

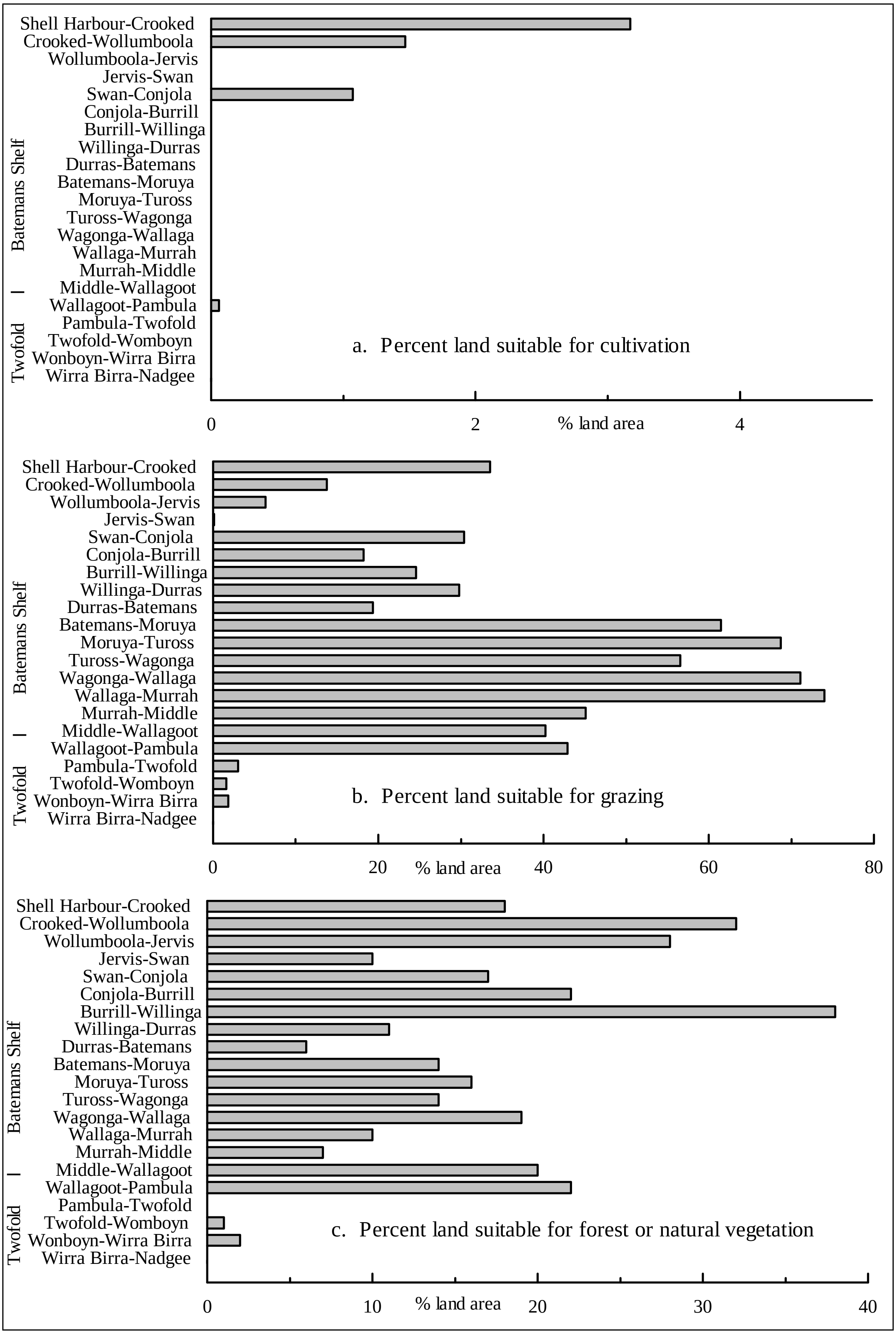

Figure 8.54. Percentage area of land within 1 km of coast in areas suitable for cultivation, grazing and timber or natural vegetation for the Batemans and Twofold Shelf bioregions.

8.4.30 Built-up areas

Data Source

1:250,000 topographic database held by Geoscience Australia

Data description

GIS layer of built up areas.

Criteria

Vulnerability, naturalness (condition) and human use.

Assessment measure

Percent of lands in built-up areas within 1 km of each estuary and each section of coast.

Assessment

In the Batemans Shelf bioregion, Ulladulla Harbour (53%), Batemans Bay (24%), Little Lake (19%), Minnamurra River (14%), Lake Wollumboola (14%), Currarong Creek, Candalagan Creek (13%), Moona Moona Creek (13%), Werri Lagoon (12%) and St Georges Basin (12%) had the greatest area within 1 km in built up areas. All other estuaries had less than 10% in built-up areas and 26 estuaries had no built-up areas within 1 km (Figure 8.53d).

For sections of coast in the Batemans Shelf bioregion, the Shellharbour-Crooked (26%), Conjola-Burrill (24%) and Crooked-Wollumboola (24%), Batemans-Moruya (13%) and Swan-Conjola (10%) sections of coast had the most adjacent land in built-up areas. All other sections had less than 10% of nearby land in built-up areas (Figure 8.52b).

In the Twofold Shelf bioregion, Back Lagoon (14%), Curalo Lagoon (7%), Merimbula Lake (6%), Twofold Bay (4%) and Pambula Lake (2%) were the only estuaries to have built-up areas within 1 km of their shores (Figure 8.53d).

For sections of ocean coast in the Twofold Shelf bioregion, the Wallagoot-Pambula section had 6% of adjacent land in built-up areas and all other sections had virtually no built-up areas within 1 km of the ocean shore (Figure 8.52b).

8.4.31 Acid Sulphate Soils

Data source

GIS maps of acid sulphate soils from the NSW Department of Land and Water Conservation[3].

Data description

Acid sulphate soil risk maps predict the distribution of acid soils based on an assessment of the geomorphic environment using 1:25,000 scale aerial photograph interpretation and field and laboratory soil analysis. Acid sulphate soils occur naturally and only become a threat when oxidised through exposure to the air. This occurs when either the water table is lowered artificially or sediments are excavated. Many estuaries in the Batemans and Twofold Shelf

[3] now within the NSW Department of Infrastructure, Planning and Natural Resources.

bioregions have acid sulphate soils present, but these sediments cause little harm while left undisturbed. The threat of acid release is related to inappropriate land use as well as the occurrence of the sediments themselves.

Criteria

Vulnerability.

Assessment measure

Percent of adjacent lands with high risk or disturbed acid sulphate soils within 1 km of each estuary.

Assessment

The Minnamurra River (47%), Werri Lagoon (41%), Crooked River (26%), Shoalhaven River (23%), Lake Brou (23%) and Currarong Creek (20%) had the most adjacent land with disturbed or high acid sulphate soils. All other estuaries had less than 20% of nearby land with disturbed or high acid sulphate soils (Figure 8.55a).

8.4.32 Australian river and catchment condition database

Data source

Australian rivers and catchment condition database. "The identification of wild rivers: methodology and database development" (Stein *et al*. 2000).

Data description

GIS grids (with a cell size of 250 m) for seven catchment and flow disturbance indices calculated from a wide range of distance weighted, topographic features (e.g. land use, roads, mines, weirs, pollution sources, vegetation etc.)

Criteria

Naturalness (condition) and vulnerability.

Assessment measures

Area weighted averages of grid values for lands within 1 km of each estuary and within 5 km of each section of exposed coast.

Assessment

Mean total river disturbance (RDI):

- Mean RDI was highest for the Shoalhaven River (0.23), Crooked River (0.24), Killalea Lagoon (0.19), Minnamurra River (0.18), Tilba Tilba Lake (0.16) and relatively low for most other estuaries (Figure 8.55b).
- For sections of ocean coast, mean RDI was highest for the Shellharbour-Crooked and Crooked-Wollumboola sections (Figure 8.57a).

Mean Catchment disturbance (CDI)

- Mean CDI was highest for the Crooked River, Killalea Lagoon, Tilba Tilba Lake, Middle Lagoon, Minnamurra River, Werri Lagoon and Ulladulla Harbour (Figure 8.55b).
- For sections of ocean coast, mean CDI was highest for Shellharbour-Crooked, Crooked-Wollumboola, Conjola-Burrill, Wagonga-Wallaga, Moruya-Tuross and Wagonga-Wallaga (Figure 8.57c).

Mean flow disturbance (FDI)

- Mean FDI was highest for the Shoalhaven River (0.45), Minnamurra River (0.1), Little Lake (0.10), Bega River (0.08) and Crooked River (0.07; Figure 8.55c).
- Mean FDI was not reported for sections of ocean coast, as this measure was more relevant to rivers and estuaries.

Mean settlement factor (SF)

- Mean SF was highest for St Georges Basin (0.09), Ulladulla Harbour (0.07), Burrill L. (0.07), Crooked R. (0.07), Shoalhaven R. (0.06) and Killalea Lagoon (0.05) (Figure 8.56a).
- For sections of ocean coast, mean SF was highest for Shellharbour-Crooked, Crooked-Wollumboola, Conjola-Burrill and Jervis-Swan (Figure 8.57c).

Mean land use factor (LUF)

- Mean LUF was highest for Killalea Lagoon, Crooked River, Tilba Tilba Lake, and Werri Lagoon (Figure 8.56b).
- For sections of ocean coast, mean LUF was highest for Shellharbour-Crooked, Crooked-Wollumboola, Conjola-Burrill, Moruya-Tuross and Wagonga-Wallaga (Figure 8.58a).

Mean infrastructure factor (IF)

- Mean IF highest for Werri Lagoon, Crooked River and Durras Lake (Figure 8.56c).
- For ocean coast, mean IF was highest for the Shellharbour-Crooked section (Figure 8.58).

Mean extractive industry/pollution point source factor (EF)

- Mean EF was highest for Mummuga Lake, Kianga Lake, Lake Wollumboola and Lake Brou (Figure 8.56d).
- For sections of ocean coast, mean EF was highest for Tuross-Wagonga and Crooked Wollumboola (Figure 8.58).

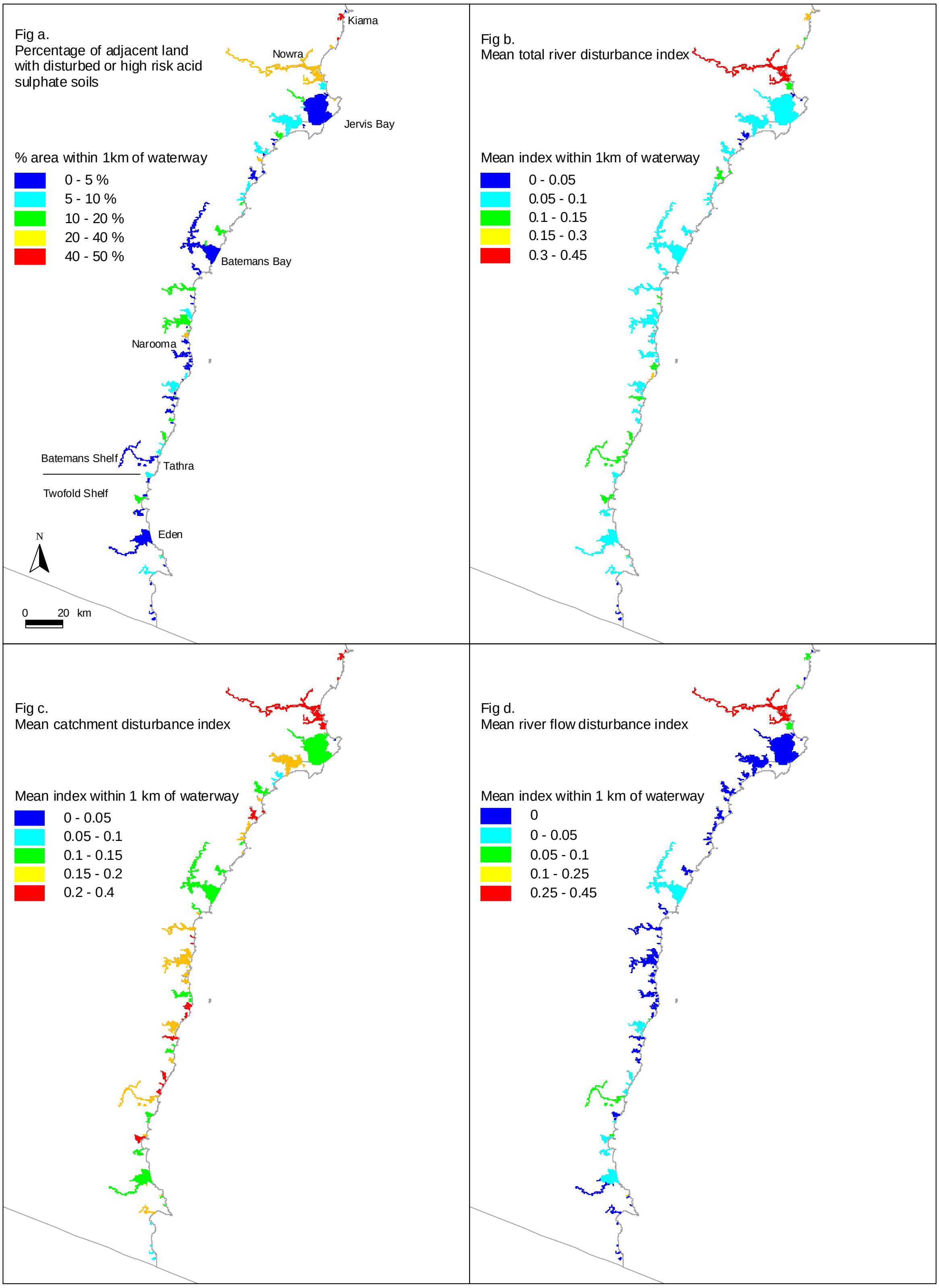

Figure 8.55. Percentage area of lands within 1 km of estuaries with disturbed or high risk acid sulphate soils and mean Australian river and catchment condition indices for estuaries in the Batemans and Twofold Shelf bioregions.

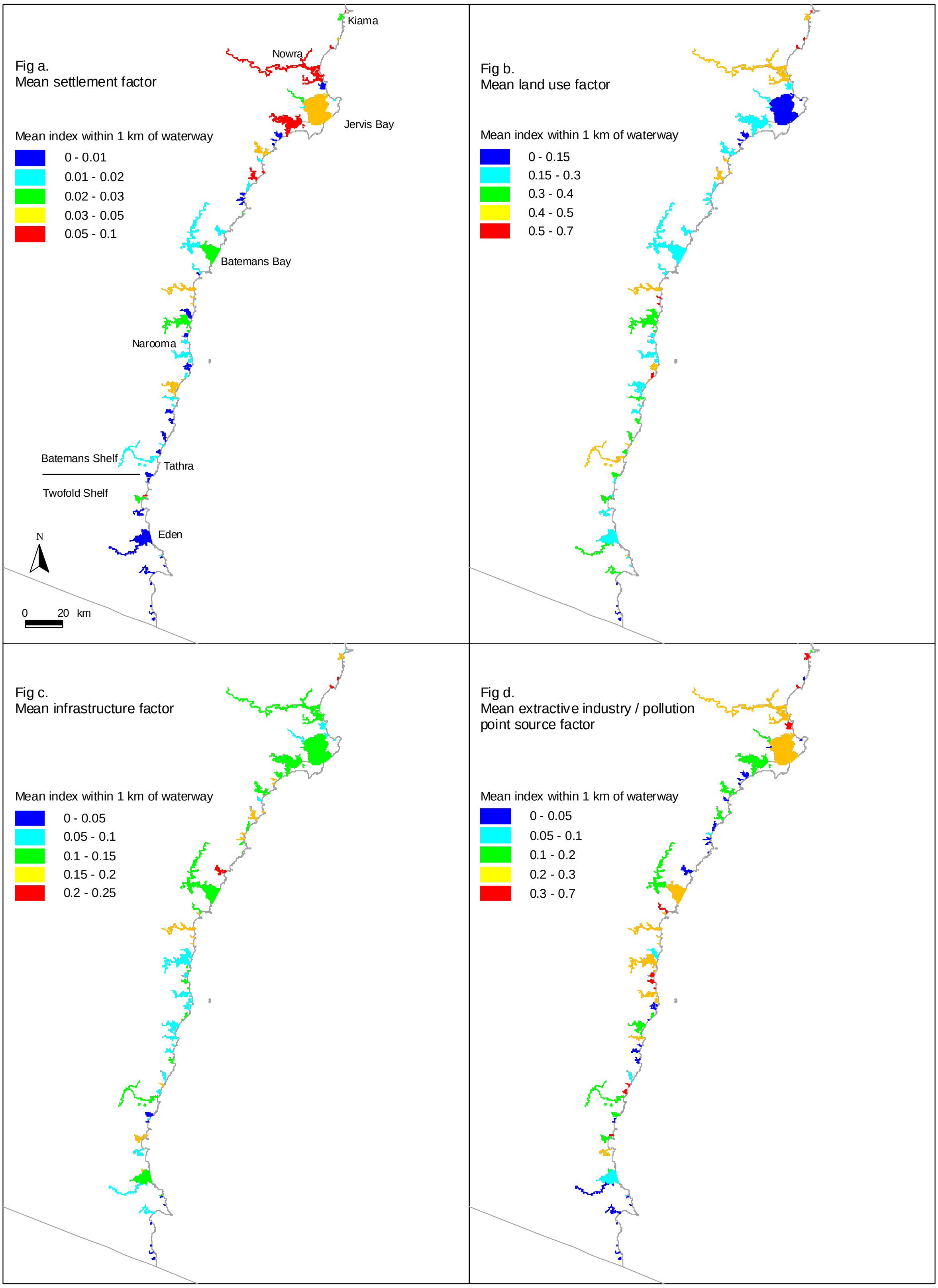

Figure 8.56. Mean Australian river and catchment condition indices (continued) for estuaries in the Batemans and Twofold Shelf bioregions.

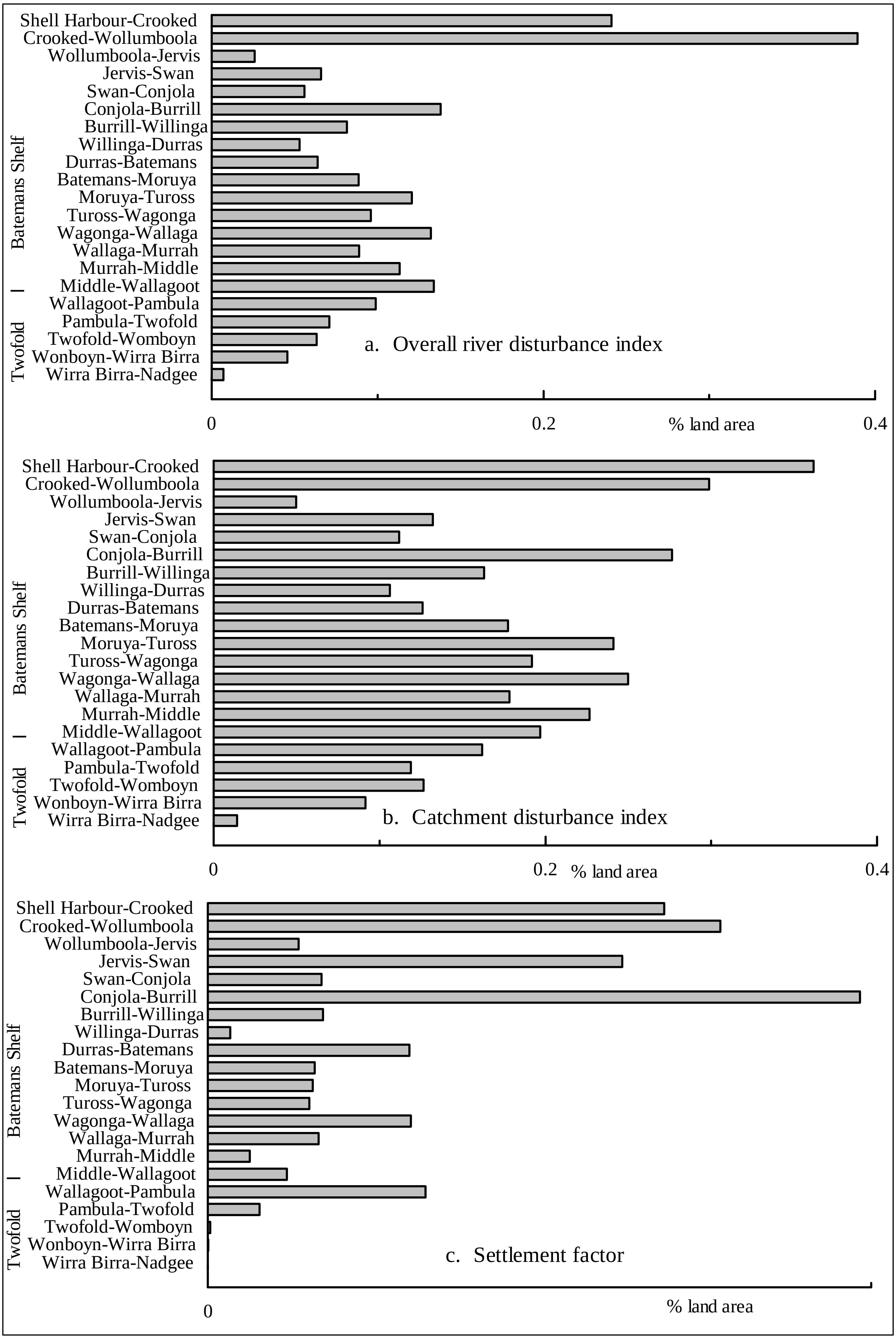

Figure 8.57. Mean Australian river and catchment condition indices within 5 km of coast for overall river disturbance, catchment disturbance and settlement for the Batemans and Twofold Shelf bioregions.

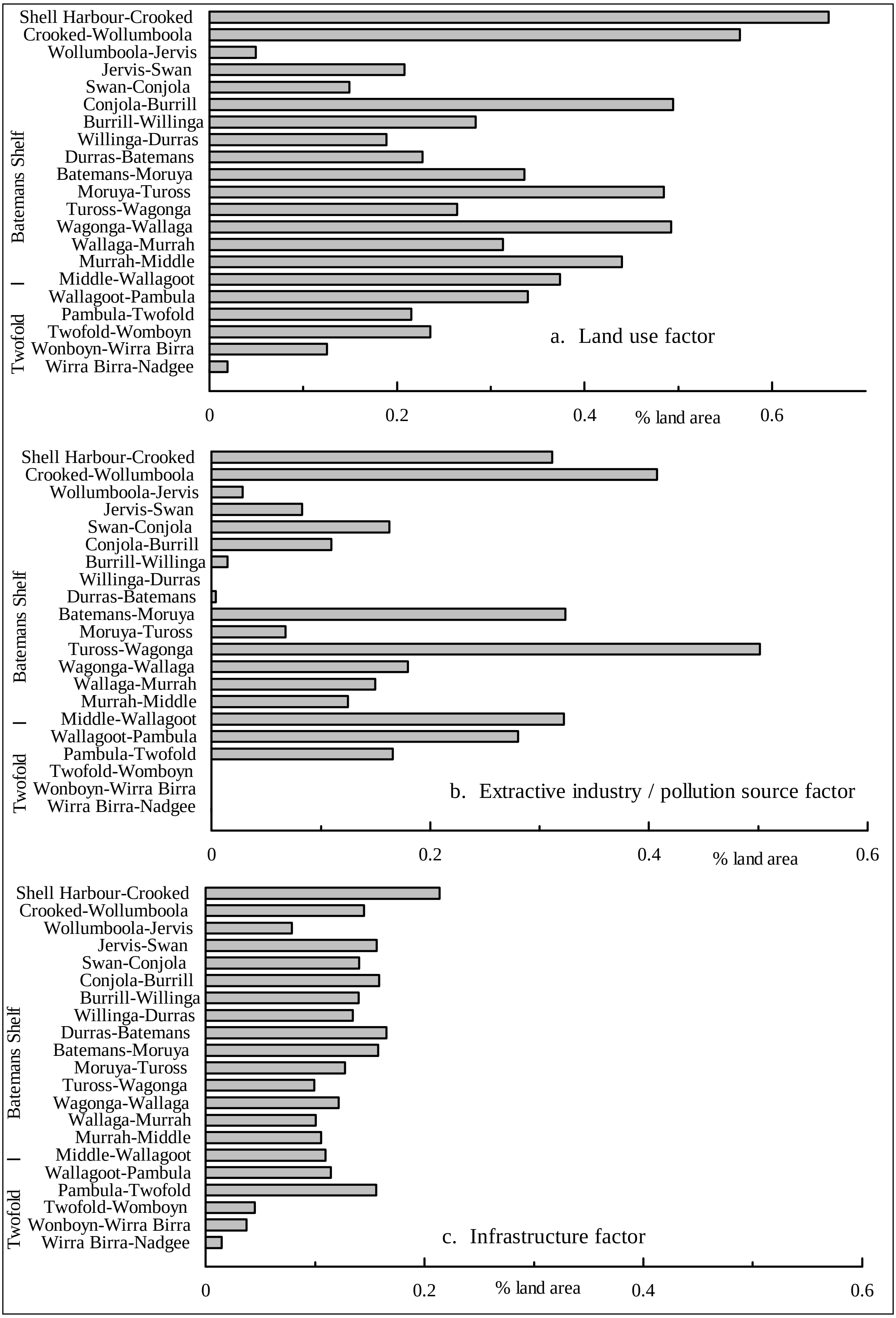

Figure 8.58. Mean Australian river and catchment condition indices within 5 km of coast for land use, extractive industries and pollution, and infrastructure for the Batemans and Twofold Shelf bioregions.

8.4.33 MPAs in the Victorian and Tasmanian sections of the Twofold Shelf bioregion

Data source

Department of Sustainability and Environment, Victoria.

Tasmanian Department of Primary Industry, Water and the Environment.

Data description

The locations and extent of Marine National Parks and Marine Sanctuaries in Victoria and Marine Reserves in the Tasmanian section of the Twofold Shelf bioregion.

Assessment

In 2002, Victoria established a system of 13 marine national parks and 11 marine sanctuaries which cover approximately 540 km^2 or 5.3 per cent of Victoria's marine waters. In all of these MPAs, marine life is protected from extractive activities such as fishing.

The Victorian section of the Twofold Shelf bioregion includes three marine national parks and one marine sanctuary (Figure 8.59 - Figure 8.63). These include sections of rocky coast, ocean beaches and offshore reef and sand but no estuarine ecosystems or habitats from the Twofold Shelf bioregion. The Cape Howe Marine National Park extends up the NSW border and out to the 3 nm limit to state waters.

Tasmania has marine reserves at Governor Island (50 ha), Maria Island (1,500 ha), Ninepin Point (60 ha), Tinderbox (45 ha) and Macquarie Island (74,715 ha). In February 2004, two new marine reserves were announced at Port Davey/Bathurst Harbour (17,000 ha) and the Kent Group of islands (29,000 ha).

The MPA in the Kent Group of islands is located in the eastern Bass Strait area of the Twofold Shelf bioregion. The reserve is a multiple use MPA with a sanctuary (no-take) zone around the western section of the island group (Figure 8.64). The islands are reported to be unusually rich in fish species having the highest diversity in Tasmania. They are subject to a range of influences including the East Australian current coming from NSW and the westerly influence of Bass Strait.

Figure 8.59. Victorian Marine National Parks – (11,12 and 13 are in Twofold Shelf bioregion).

1. Discovery Bay	2. Twelve Apostles	3. Point Addis
4. Port Phillip Heads	5,6,7. Western Port Bay	8. Bunurong
9. Wilson's Promontory	10. Corner Inlet	11. Ninety Mile Beach
12. Point Hicks	13. Cape Howe	

(Victorian Department of Sustainability and Environment).

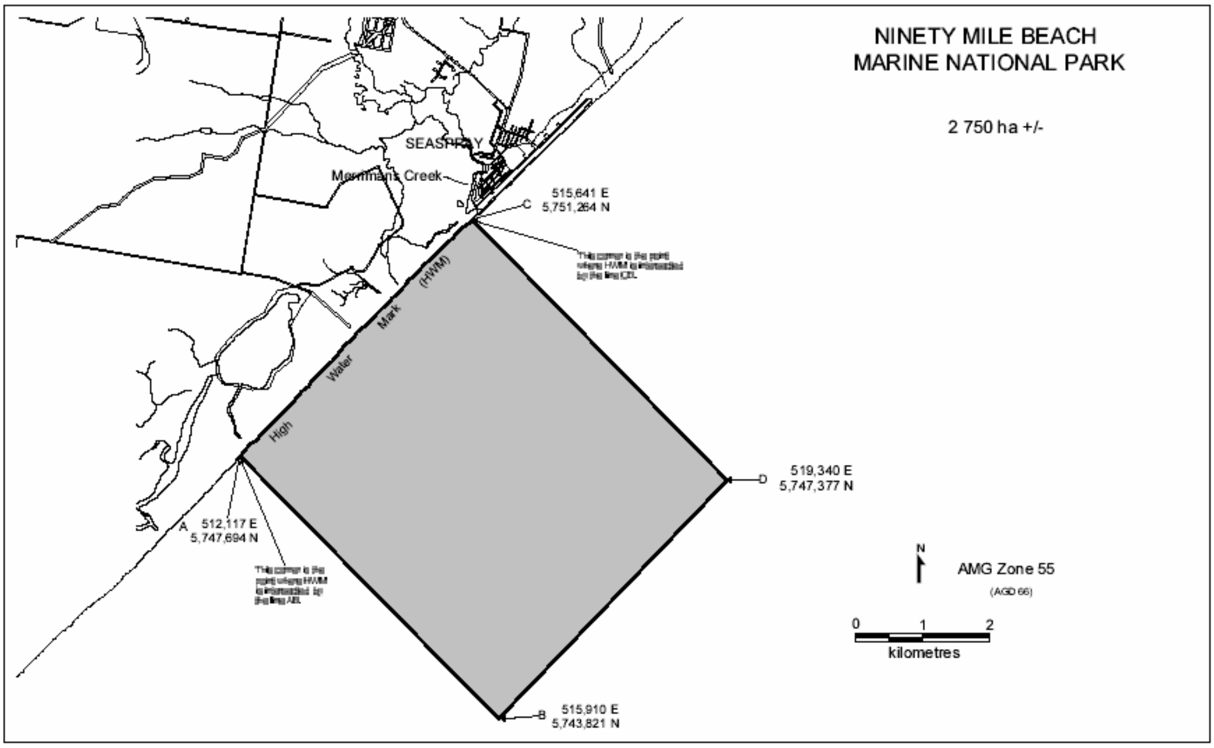

Figure 8.60. The Ninety Mile Beach Marine National Park in the Twofold Shelf bioregion, Victoria (Victorian Department of Sustainability and Environment).

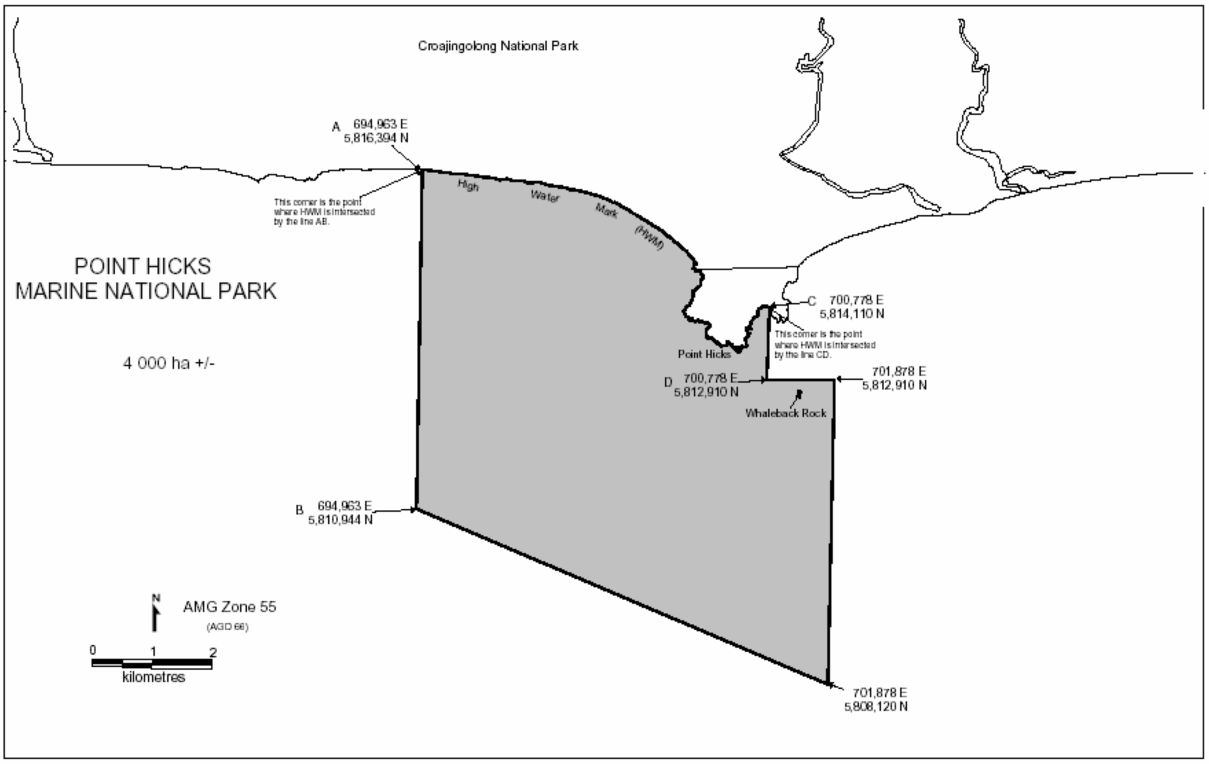

Figure 8.61. The Point Hicks Marine National Park in the Twofold Shelf bioregion, Victoria (Victorian Department of Sustainability and Environment).

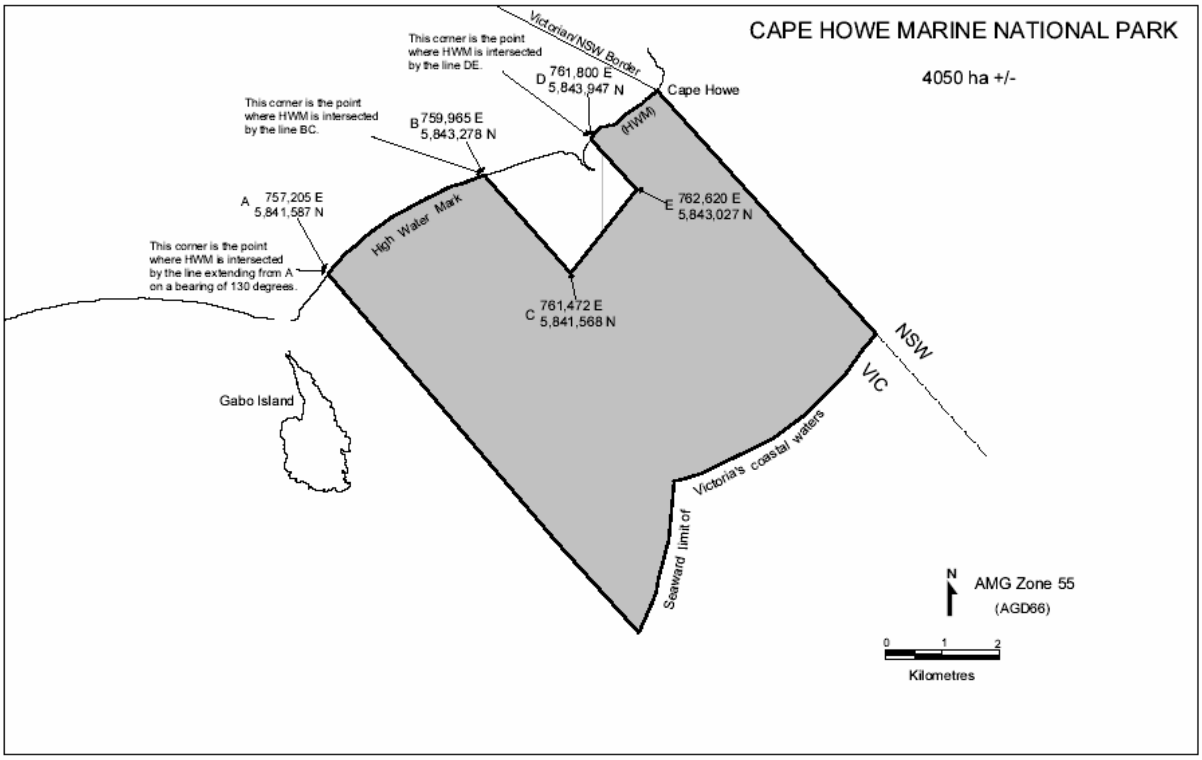

Figure 8.62. The Cape Howe Marine National Park in the Twofold Shelf bioregion, Victoria (Victorian Department of Sustainability and Environment).

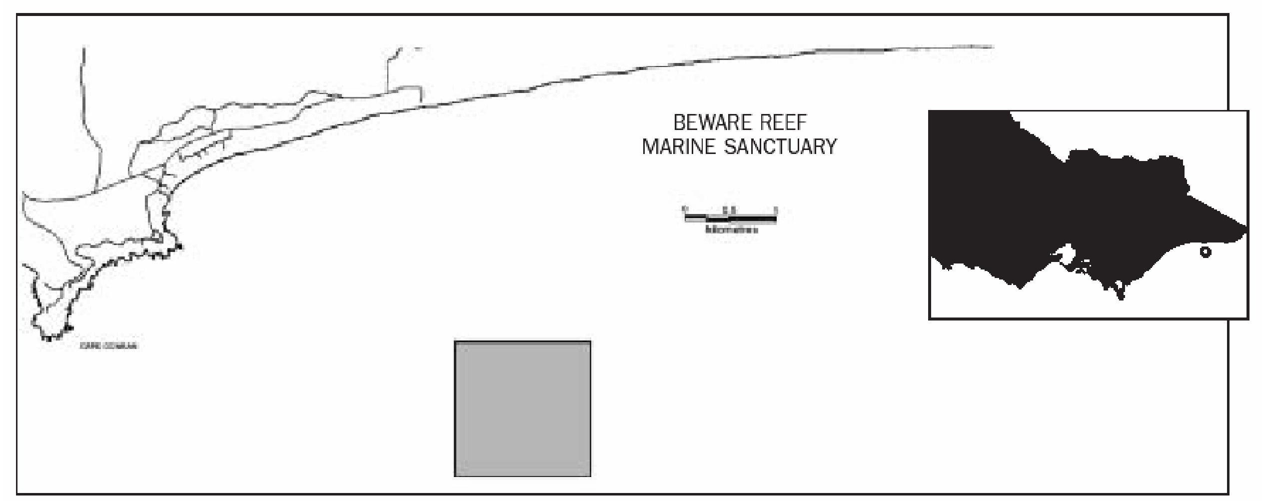

Figure 8.63. The Beware Reef Marine Sanctuary in the Twofold Shelf bioregion, Victoria (Victorian Department of Sustainability and Environment).

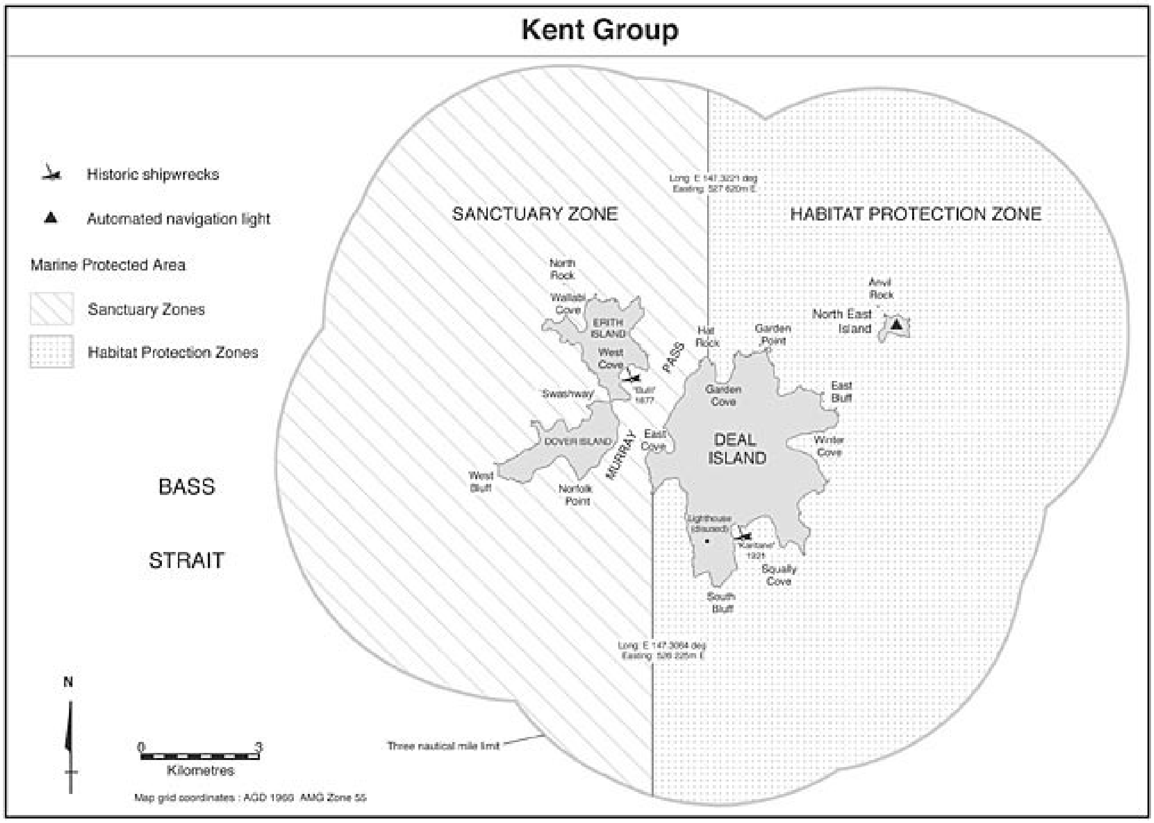

Figure 8.64. The Kent Group multiple use marine reserve in the Twofold Shelf bioregion, Tasmania (Tasmanian Department of Primary Industry, Water and the Environment 2004).

8.5 Discussion

This assessment provides information and methods to systematically examine options and help plan a system of marine protected areas in the Batemans and Twofold Shelf bioregions. Because of the scope of this task and the need for consistent information across areas as large as whole bioregions, approximate surrogates for biodiversity and other criteria have been used. However, even at the broad scale of this study, a number of patterns were evident.

Jervis Bay Marine Park already protects some of the most important areas in the Batemans Shelf bioregion for marine biodiversity and occupies an area of 224 km^2. However barrier and intermittent estuaries, deeper ocean ecosystems and mangrove and saltmarsh habitats are not well represented in the existing marine park.

Mangrove and saltmarsh habitats however, do occur in the marine and terrestrial components of national parks and nature reserves. These protected areas also include significant intermittent estuaries and areas of intertidal ocean beach and rocky shore. However, these areas can not, on their own, directly protect fish or marine invertebrates from fishing.

There is only one aquatic reserve in the Batemans Shelf bioregion protecting just four hectares of rocky shore, subtidal reef, sediments and rocky shore in Bushrangers Bay, near Shellharbour. In total, about 10% of coastal waters in the Batemans Shelf bioregion are currently included within some form of MPA. If Commonwealth waters beyond 3 nm of the coast are considered, this equates to 2.6% of the entire marine bioregion.

In the Twofold Shelf bioregion, there are no marine parks or aquatic reserves in NSW waters and 2 km^2 of estuary in national park and nature reserve. This represents 0.3% of coastal waters in the NSW section of the bioregion. If Commonwealth waters beyond 3 nm of the coast are considered, this equates to 0.075% of the waters off NSW for this bioregion.

Victorian and Tasmanian MPAs in the Twofold Shelf bioregion include additional areas of beach, rocky shore, subtidal reef, island and sediment habitats. However, estuarine ecosystems and habitats may not be well represented within MPAs in the Victorian or Tasmanian sections of the Twofold Shelf bioregion.

This assessment identifies a number of different areas of high conservation value and presents a few ways in which these areas could be included within a large, multiple use marine park. These are areas that tended to meet criteria for representing a range of ecosystems, habitats and species in locations with protected foreshores, catchments and waters relatively unaffected by human impacts.

8.5.1 MPA options for the Batemans and Twofold Shelf bioregions

The options for exactly where and how MPAs can be established are relatively flexible for all but a few criteria. Therefore, there is the potential to apply reserve design criteria to achieve more effective management, and to accommodate, and even promote, a range of sustainable human activities while still meeting conservation objectives.

For marine parks, the exact nature of the protection provided will depend on subsequent zoning to address different impacts and operational plans to regulate how activities are carried out. It is hoped that the information and techniques from this study prove useful in assessing these alternatives, and in providing a basis for future consultation, research and management.

The primary ecological identification criteria for MPAs adopted for this study were comprehensiveness, representativeness and adequacy of management. According to the environmental classification used, this means representation of each of the four major estuarine ecosystems, the four ocean ecosystems classified by depth, and the nine habitat surrogates (mangrove, seagrass, saltmarsh, subtidal sediment, beach, intertidal rocky shore, subtidal reef and island) within MPAs that can be effectively managed for the conservation of biodiversity.

In the Batemans and Twofold Shelf bioregions, there are many areas with high conservation values which may be relatively unaffected by human impacts. While some criteria are quite restrictive in what areas qualify (e.g. representation of drowned river valleys, ocean embayments and offshore islands) others are more flexible in the number of areas potentially suitable (e.g. representation of intermittent lagoons and barrier estuaries).

Each option, listed below, describes specific locations and values which might be included in different marine park proposals or alternatively, be included in other types of reserves in a MPA network to represent geographic variation in biodiversity throughout the bioregion.

Given the uncertainty involved in assessing biodiversity and the complex issues involved, a strong emphasis is placed on presenting information and methods to allow a range of alternatives to be examined. General boundaries are presented as an approximate indication of alternative locations, but areas could be included or excluded according to different priorities for a range of criteria.

The following options aim to meet criteria for comprehensiveness and representativeness for most mapped ecosystems, habitats and species. They have, in most cases: a high degree of naturalness and catchment protection; they include areas recommended from previous conservation assessments; they consistently score highly in quantitative analyses for a range of criteria; and they complement existing MPAs and conservation management strategies.

The options (A, B and C for the Batemans Shelf and D and E for the Twofold Shelf bioregion) are listed below from north to south and are examined in more detail in Appendix 4. For each option, approximate areas and percentages of different ecosystems and habitats within estuaries and coastal waters out to 3 nautical miles are shown in Table 8.12 and Table 8.13.

Option A. Shellharbour to Jervis Bay Marine Park.

Option B. Termeil Lake to the Moruya River.

Option C. Durras Lake to Wallaga Lake.

Option D. Middle Lagoon to Twofold Bay.

Option E. Twofold Bay to Nadgee.

	Marine Park & Aquatic Reserve		All existing MPAs		Shellharbour-Jervis		Termeil-Batemans		Durras-Wallaga		Total
Feature Name	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	km^2 in bioregion
Intermittent Estuary	**1.4**	0.5	**29.6**	11.3	**30.5**	11.7	**42.6**	16.4	**66.7**	25.6	38.4
Wave Dominated Estuary	**0.8**	1.1	**2.2**	3.0	**24.5**	32.8	**8.1**	10.8	**30.6**	41.0	133.8
Ocean Embayment	**75.7**	123.3	**75.7**	123.3	**75.7**	123.3	**99.7**	162.2	**99.7**	162.2	162.7
Tide Dominated Estuary	**0**	0	**0**	0	**0**	0	**100**	16.4	**100**	16.4	16.4
0-20 metres*	**12.7**	39.1	**12.8**	39.6	**35.3**	109.1	**32.0**	98.9	**41.3**	127.5	308.7
20-60 metres*	**4.9**	51.8	**4.9**	51.8	**26.9**	282.4	**21.6**	226.9	**38.2**	400.2	1048.8
60-200 metres*	**0.2**	1.2	**0.2**	1.2	**27.7**	151.5	**19.1**	104.3	**33.9**	185.3	546.9
Seagrass	**25.4**	9.3	**34.2**	12.5	**37.8**	13.8	**38.7**	14.1	**57.7**	21.1	36.5
Mangrove	**1.6**	0.2	**5.2**	0.7	**45.0**	6.0	**37.1**	4.9	**44.7**	5.9	13.3
Saltmarsh	**0.8**	0.1	**3.2**	0.3	**45.2**	4.4	**18.8**	1.8	**38.3**	3.7	9.7
Beach	**6.2**	0.6	**16.2**	1.5	**38.3**	3.5	**32.5**	2.9	**39.4**	3.5	9.0
Rocky Intertidal	**10.5**	1.0	**15.0**	1.4	**31.0**	2.9	**47.9**	4.4	**51.8**	4.8	9.3
Reef and shoal	**3.7**	2.8	**3.7**	2.8	**26.6**	20.4	**35.8**	27.4	**41.9**	32.0	76.5
Inshore sand	**8.8**	11.6	**8.8**	11.6	**24.4**	32.2	**32.5**	42.9	**49.5**	65.3	132.0
Islands	**23.6**	0.6	**23.6**	0.6	**25.3**	0.7	**56.4**	1.5	**70.8**	1.8	2.6
Total of bioregion (NSW)	**9.6%**	224	**10.4%**	242	**32.2%**	748	**28.3%**	657	**42.5%**	987	2322

Table 8.12. Area (km^2) and percentage of ecosystems and habitats in the Batemans Shelf bioregion that would be represented in a system of MPAs under scenarios that include: the existing NSW Marine Park, Commonwealth Marine Park and Aquatic Reserve only; all existing MPAs including the marine components of national parks and nature reserves; all existing MPAs together with either Options A, B or C for a large, multiple use marine park. Total areas and percentages of the bioregion for each scenario are provided below each column. * Percentages are for waters within 3 nm of the coast.

	Marine Parks & Aquatic Reserves		All existing NSW MPAs		Middle-Twofold**		Twofold-Nadgee		Total
Feature Name	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	**% in MPA**	km^2 in MPA	km^2 in bioregion
Intermittent Estuary	**0**	0	**49.7**	1.6	**100**	7.4	**100**	2.6	3.2
Wave Dominated Estuary	**0**	0	**0**	0	**74.8**	16.8	**44.6**	6.6	14.9
Ocean Embayment	**0**	0	**0**	0	**100**	30.8	**100**	30.8	30.8
0-20 metres*	**0**	0	**0**	0	**48.4**	46.0	**52.2**	35.5	68.0
20-60 metres*	**0**	0	**0**	0	**51.1**	230.5	**53.9**	166.4	308.4
60-200 metres*	**0**	0	**0**	0	**20.4**	53.2	**86.3**	172.5	199.9
Seagrass	**0**	0	**2.0**	0.1	**93.7**	5.4	**12.2**	0.5	3.9
Mangrove	**0**	0	**0**	0	**100**	1.1	**1.3**	0.01	0.8
Saltmarsh	**0**	0	**0**	0	**68.3**	1.8	**46.1**	0.7	1.6
Beach	**0**	0	**0**	0	**82.3**	3.0	**30.1**	0.9	3.1
Rocky Intertidal	**0**	0	**0**	0	**35.0**	1.8	**75.7**	3.2	4.2
Reef and shoal	**0**	0	**0**	0	**34.6**	4.9	**79.4**	6.9	8.7
Inshore sand	**0**	0	**0**	0	**51.2**	21.4	**58.5**	18.8	32.2
Islands	**0**	0	**0**	0	**59.9**	0.07	**87.7**	0.05	0.06
Total of bioregion (NSW)	**0**	0	**0.35%**	2.2	**44.4%**	282.8	**61.0%**	388.3	637.0

Table 8.13. Area (km^2) and percentage of ecosystems and habitats in the Twofold Shelf bioregion that would be represented in a system of MPAs under scenarios that include: existing NSW marine parks (none) and aquatic reserves (none); all existing MPAs including the marine components of national parks and nature reserves and; existing MPAs together with either Options D (Middle-Twofold) or E (Twofold-Nadgee) for a large, multiple use marine park. Total areas and percentages of the bioregion for each scenario are provided below each column. * Percentages are for NSW waters of the bioregion. **Areas for Option D include Batemans Shelf components but percentages are calculated only for the NSW section of the Twofold Shelf.

Option A. Shellharbour to Jervis Bay Marine Park (Batemans Shelf)

Some important features that Option A could include are:

- All estuary types except drowned river valley and extensive examples of estuarine habitats poorly represented in the existing Jervis Bay Marine Park.
- All ocean ecosystem depth zones and all marine habitats occurring within the bioregion.
- Jervis Bay, the largest ocean embayment in the bioregion, with the largest area of seagrass in the bioregion and largest area of *Posidonia* seagrass in NSW.
- The Shoalhaven River, the second largest barrier estuary, with the largest area of mangrove habitat, the second largest area of saltmarsh in the bioregion and the highest summed irreplaceability score for estuarine ecosystems and habitats. The river is one of the most important areas for shore birds in NSW supporting over 60 species including the endangered Little Tern and Beach Thick-knee and 27 bird species protected by international agreements. It was identified as a third priority candidate aquatic reserve in a previous NSW Fisheries[2] assessment for estuarine MPAs in the bioregion and is listed in the Directory of Important Wetlands.
- Lake Wollumboola, the largest intermittent estuary in the bioregion and a first priority candidate in a NSW Fisheries[2] assessment for estuarine aquatic reserves. The lake is the fourth largest and second most successful nesting area for the endangered Little Tern in NSW. It supports 11 threatened bird species, at least 24 JAMBA/CAMBA species, is listed in the Directory of Important Wetlands and has recently been included within national park.
- Killalea Lagoon, which supports vulnerable bird species, black swans, 17 JAMBA/CAMBA species and the endangered plant, Flat Spurge. The Lagoon is listed in the Directory of Important Wetlands.
- The Minnamurra River, an important wetland with significant mangrove and saltmarsh communities supporting vulnerable bird species and 7 JAMBA/CAMBA species.
- Bass Point, an aggregation site and declared critical habitat for the endangered Grey Nurse Shark and an area recognised for its marine biodiversity in the Register of the National Estate.
- Bushrangers Bay Aquatic Reserve on Bass Point is also noted for its marine biodiversity in the Register of the National Estate.
- Bombo Head and Bass Point, previously proposed as aquatic reserves by NSW Fisheries[2].
- Comerong Island Nature Reserve, Seven Mile Beach National Park and Jervis Bay National Park protect areas of coast and estuary in the south of this option. Areas to the north, however, are vulnerable to urban and industrial development.

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[2] now within the NSW Department of Primary Industry

Option B. Termeil Lake to the Moruya River (Batemans Shelf)

Some important features that Option B could include are:

- All estuary ecosystem types and substantial areas of estuarine habitats not represented in Jervis Bay Marine Park.
- All ocean ecosystem depth zones and significant examples of all mapped ocean habitats in the bioregion.
- Termeil, Meroo and Durras Lakes, intermittent estuaries with near pristine catchments protected in national parks and recommended for comprehensive protection by the Coastal Lakes Inquiry.
- Durras Lake, the fifth largest intermittent estuary in the bioregion. The lake was previously proposed as a candidate for an estuarine aquatic reserve, provides important habitat for threatened birds and migratory waders protected under JAMBA and CAMBA agreements and is listed in the Directory of Important Wetlands.
- The Clyde River, the only tide dominated, drowned river valley in the bioregion. The estuary includes the second largest area of mangrove habitat in the bioregion, large areas of saltmarsh, and has the second highest summed irreplaceability score (after the Shoalhaven) for estuarine ecosystems and habitats. Much of the river's catchment and shores are within state forest or national park and it is listed in the Directory of Important Wetlands.
- Batemans Bay, the second largest ocean embayment in the bioregion after Jervis Bay. The bay includes important offshore island and reef habitats and an important aggregation site declared as critical habitat for the endangered Grey Nurse Shark.
- The Moruya River, an example of a wave dominated barrier estuary with significant areas of saltmarsh listed in the Directory of Important Wetlands.
- The Willinga-Durras section of ocean coast with some of the largest areas of inshore reef and island habitat. It includes significant offshore habitats and had the second highest summed irreplaceability score for ocean ecosystems and habitats.
- Option B includes the most seabird breeding islands and the greatest diversity and abundance of breeding seabirds in the bioregion.
- Between 40 and 75% of the ocean coast and most islands in the sections of coast between Termeil Lake and Durras Lake are within national parks.

Option C. Durras Lake to Wallaga Lake (Batemans Shelf)

Some important features that Option C could include are:

- All ocean depth zones and the most extensive examples of mapped ocean habitats in the bioregion.
- All estuarine ecosystem types and substantial areas of estuarine habitats not represented in Jervis Bay Marine Park.
- The Clyde River, the only tide dominated, drowned river valley in the bioregion. The river includes the second largest area of mangrove habitat in the bioregion, large areas of saltmarsh and has the second highest summed irreplaceability score (after the Shoalhaven) for estuarine ecosystems and habitats. Much of its catchment and shores are within state forest or national park and the Clyde River is listed in the Directory of Important Wetlands.
- Tuross Lake, Wallaga Lake, Wagonga Inlet and the Moruya River, the largest barrier estuaries in the bioregion after the Shoalhaven River and St. Georges Basin.
- Coila Lake, the largest intermittent estuary in the bioregion and Durras, Brunderee, Tarourga, Brou, and Nargal Lakes, intermittent estuaries with near pristine catchments that have been recommended for comprehensive protection by the Coastal Lakes Inquiry.
- Coila Creek Delta, the Moruya River, Tuross River, Nargal Lake and Wallaga Lake are all listed in the Directory of Important Wetlands, include important mangrove and saltmarsh assemblages and provide habitat for threatened and migratory birds protected under JAMBA or CAMBA.
- Wallaga Lake, proposed as an estuarine aquatic reserve in an assessment by NSW Fisheries.
- Batemans Bay, the second largest ocean embayment in the bioregion after Jervis Bay. The bay includes offshore island and reef habitats and an important aggregation site and critical habitat for the endangered Grey Nurse Shark.
- Montague Island, the most northerly and only remaining haul out site in NSW for Australian fur seals, one of the most important sea bird breeding islands in NSW, the second largest breeding area in Australia for Little Penguins, and a breeding site for the threatened sooty oystercatcher (*Haematopus fuliginosus*). The waters adjacent to the island are also an important aggregation site and critical habitat for the endangered Grey Nurse Shark.
- The Wagonga-Wallaga section of ocean coast, which includes the largest area of rocky intertidal shores and offshore islands in the bioregion and the second largest mapped area of offshore reef in the bioregion.
- Wagonga Head, proposed as an aquatic reserve for intertidal rocky shores in an assessment by NSW Fisheries.
- Approximately 75% of the ocean coast between Durras Lake and Batemans Bay and 30% of the coast between Tuross Lake and Wagonga Inlet are included in national park as are parts of several other estuaries and sections of ocean coast.

Option D. Middle Lagoon to Twofold Bay (Batemans / Twofold Shelf)

Some important features that Option D could include are:

- All ocean depth zones and representative examples of all mapped ocean habitats from the NSW section of the Twofold Shelf bioregion.
- All estuary ecosystem types found in the NSW section of the Twofold Shelf bioregion and the substantial areas of estuarine habitat from the NSW section of the bioregion. These are estuarine habitats and ecosystems not represented in MPAs in the Victorian or Tasmanian sections of the Twofold Shelf bioregion.
- Pambula Lake, the largest barrier estuary in the NSW section of the Twofold Shelf bioregion. The lake has the second largest area of seagrass, the largest area of mangrove and the third largest area of saltmarsh in the NSW section of the bioregion. This estuary type occurs in the Victorian section of the bioregion but is not represented in MPAs. Areas upstream of the lake include channels, sand flats, mangroves, saltmarsh, and brackish and freshwater assemblages listed in the Directory of Important Wetlands.
- Merimbula Lake, the second largest barrier estuary in the NSW section of the bioregion. The lake includes the largest area of seagrass habitat, the second largest area of mangrove and the largest area of saltmarsh in the NSW section of the bioregion. The lake is the southern limit for River Mangrove (*Aegiceras corniculatum*) and includes a significant saltmarsh assemblage. The area provides habitat for endangered and vulnerable bird species protected under JAMBA and CAMBA and is listed in the Directory of Important Wetlands.
- Nelson Lagoon, proposed in a previous NSW Fisheries[2] assessment as an estuarine aquatic reserve and Bondi and Bournda Lagoons, all intermittent estuaries with near pristine catchments and slightly affected to pristine waters. All of these areas were recommended in the Coastal Lakes Inquiry for comprehensive protection. Nelson Lagoon is listed in the Directory of Important Wetlands and the area around the lagoon includes saltmarshes of significant conservation value. Bournda Lake is listed in the Directory of Important Wetlands and provides habitat for species protected under JAMBA and CAMBA agreements.
- Wallagoot Lake, on the border of the Twofold and Batemans Shelf bioregions. The lake is listed in the Directory of Important Wetlands and has extensive seagrass beds, including *Posidonia.* It supports endangered Little Tern and Hooded Plover, several vulnerable bird species and 17 species protected under JAMBA or CAMBA agreements.

[2] now within the NSW Department of Primary Industry

- Twofold Bay, the only ocean embayment in the Twofold Shelf bioregion (in NSW or Victoria). The bay and the four intermittent and barrier estuaries that flow into it are listed in the Directory of Important Wetlands. These and the sheltered rocky shores, beaches, reefs and deep water areas provide important habitat for fish, invertebrates, cetaceans and threatened and migratory birds.

- The Middle-Wallagoot section of ocean coast includes the largest area of islands between Bega and Victoria, and the rocky shores and subtidal reefs south of Tathra are important for their high diversity of marine algae and biogeographic significance. Tathra Head was also short listed by a community advisory panel in an assessment for intertidal aquatic reserves by NSW Fisheries[2].

- Bondi Lake and Bournda Lagoon are surrounded by national park and most of Nelson and Middle Lagoon, and about 40% of Pambula and Wallagoot Lakes are surrounded by national park. Over 60% of the ocean coast between Middle and Wallagoot Lakes, 30% of the coast between Wallagoot and Pambula and 95% of the coast between Pambula and Twofold Bay is within national park.

Option E. Twofold Bay to Nadgee (Twofold Shelf)

Some important features that Option E could include are:

- All ocean ecosystem depth zones within the NSW section of the Twofold Shelf bioregion and representative examples of mapped ocean habitats from the NSW section of the bioregion.

- All estuarine ecosystem types found in the NSW section of the Twofold Shelf bioregion and small areas of estuarine habitat from the NSW section of the bioregion. These estuarine habitats and ecosystems are not represented in MPAs in the Victorian section of the Twofold Shelf bioregion.

- Twofold Bay, the only ocean embayment in the Twofold Shelf bioregion (in NSW or Victoria). The bay and the four intermittent and barrier estuaries that flow into it are listed in the Directory of Important Wetlands. The sheltered rocky shores, beaches, reefs and deep water areas of the bay provide important habitat for fish, invertebrates, cetaceans and threatened and migratory birds.

- The Towamba and Wonboyn Rivers, representative barrier estuaries in a largely unmodified condition. Wonboyne Lake was recommended for significant protection by the Coastal Lakes Inquiry.

- Nine small, intermittent estuaries in national park. Saltwater, Woodburn and Bittangabee Creeks are entirely surrounded by Ben Boyd National Park. Wirra Birra, Table and Little

Creeks, Merrica River, Nadgee River and Nadgee Lake are entirely included in the Nadgee Nature Reserve and Wilderness area.

- The ocean coast between Twofold Bay and Wonboyn River includes the largest area of mapped inshore reef in NSW south of Tuross Heads. It includes small areas of inshore islands and rocks and the largest mapped area of intertidal rocky shore in the Batemans Shelf and the NSW section of the Twofold Shelf bioregion.
- Almost all the ocean coast between Twofold Bay and the Victorian border is included in national park or nature reserve and much of it is in the declared Wilderness area. These areas are therefore likely to be among the least disturbed coastal areas in NSW.
- This option would complement the Cape Howe Marine National Park in Victoria, which lies immediately south of the NSW border.

8.6 Conclusion

In April 2006, an 850 km^2, multiple use marine park was declared in the Batemans Shelf bioregion between Bawley Point and Wallaga Lake. The marine park encompasses most of the features in Options B *and* C described in Section 8.61 and includes 30 estuaries, coast, islands and ocean out to the 3 nautical mile limit.

After declaration, the NSW Marine Parks Authority conducted a detailed site assessment. This included multibeam and sidescan sonar and video mapping of subtidal habitats and communities, detailed mapping of estuarine habitats by NSW Fisheries (NSW Department of Primary Industry), social surveys of stakeholders and communities, social and economic assessments and over 90 consultation meetings.

After the release of a draft zone and further consultation a final zone plan was gazetted (Figure 8.65) which includes 19% of the marine park (161 km^2) in 32 ‘no-take’ sanctuary zones (pink),. The zone plan also includes 43% of the marine park in habitat protection zones (yellow), 37% of the park in general use zones (light blue) and small areas in special purpose zones (dark blue) for traditional indigenous use, aquaculture, commercial abalone harvest, marinas and other facilities.

The habitat protection zones permit recreational fishing and some forms of commercial fishing, while the general use zones permit most forms of commercial fishing except trawling, long lining and dredging which are not permitted anywhere in the park. To avoid displacement of commercial trawling to other areas, the government provided $2.2 million to buy out 14 commercial trawling licenses that previously operated in the region. Additional fishing restrictions apply in some estuaries and seasonal gear restrictions will be used at Montague Island to help protect endangered Grey Nurse Shark aggregations.

The marine park partly fulfils a commitment by the NSW Government to establish at least one large marine park in each bioregion. The multiple use design of the park is ideally suited to a scientifically assisted approach to adaptive management that aims to improve our understanding of how MPAs can be best used. Biological baseline and monitoring programs are now needed to test these predictions and evaluate the benefits and impacts of the new marine park.

No decisions have been made to establish other MPAs elsewhere in the Batemans Shelf or anywhere in the NSW section of the Twofold Shelf bioregion. Selection of MPAs will need to take into account the MPA planning already implemented in Victorian and Tasmanian waters and Commonwealth planning for offshore waters in the South East Regional Plan. Although there are important commercial fishing interests in the NSW section of the Twofold Shelf bioregion, this area may include some of most pristine and distinctive marine ecosystems in the state and therefore warrants a more thorough consideration of its conservation value.

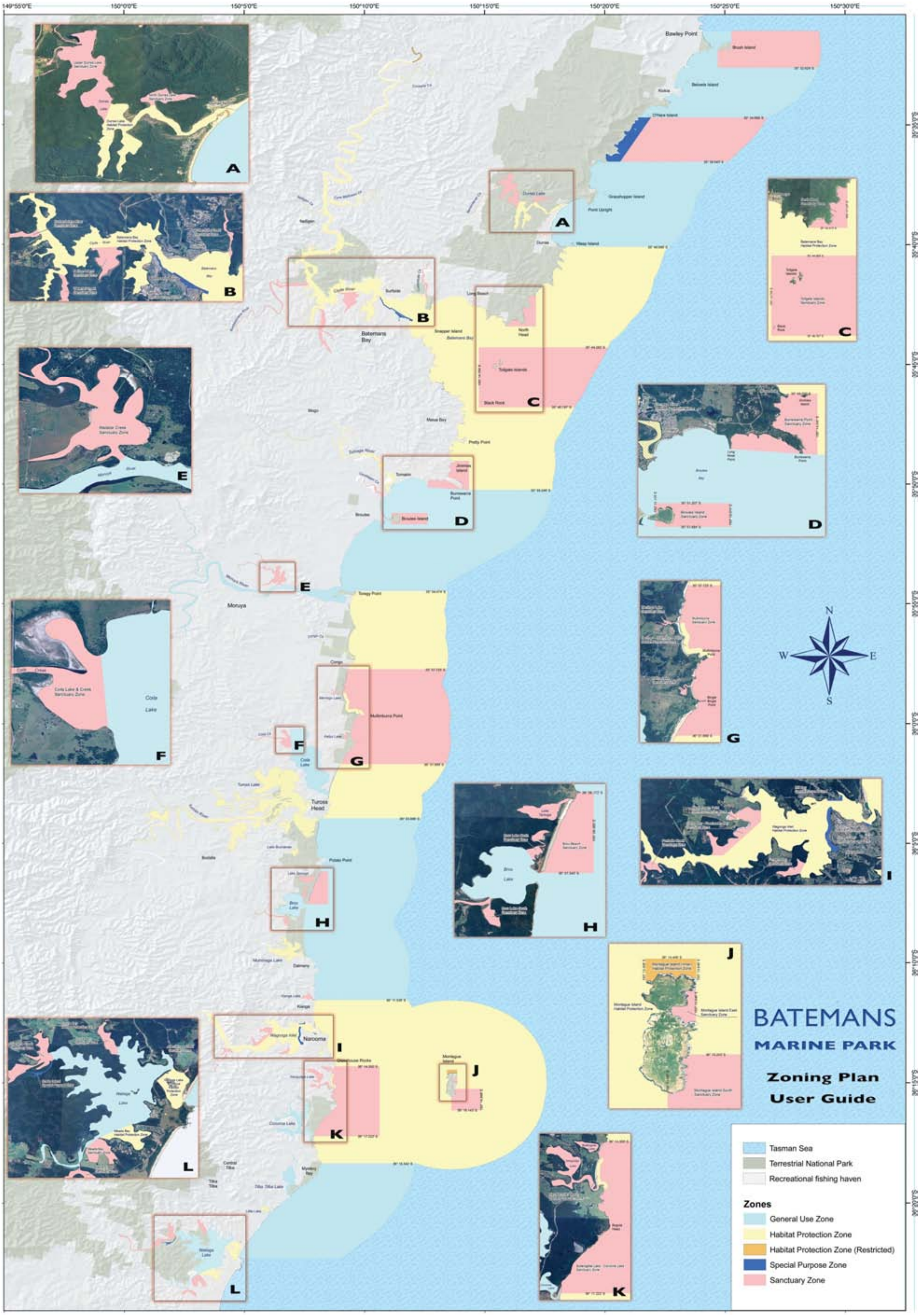

Figure 8.65. Final zone plan for the Batemans Marine Park implemented in June 2007 (www.mpa.nsw.gov.au).

9 Geographic Information tools for broad scale marine planning in NSW

9.1 Introduction

Marine protected areas are increasingly used as a tool to conserve marine ecosystems and plan for the sustainable use of the ocean. However the ecological and sociological issues that MPAs aim to address are complex and often controversial, with far reaching consequences for marine organisms and humans. The potential costs of mistakes are substantial and there are often only limited opportunities to establish MPAs. Once established, few MPAs are revoked. Therefore selecting areas of low value that return little benefit can risk large investments in time and resources and can waste opportunities to protect other areas. At a time when effective management is urgent, we are only just beginning to understand the extent and nature of marine ecosystems. It is therefore crucial that the best science available is applied and that opportunities to learn from practical management and research are exploited.

This chapter demonstrates how GIS (Geographic Information Systems) based conservation planning tools can integrate data and help provide a scientific basis for designing networks of MPAs. The models developed here for MPA selection and management use existing information. They provide a broad, but realistic and accessible knowledge base for informed marine planning. The models also provide a foundation for more detailed research and for a more adaptive approach to marine ecosystem research and management.

9.1.1 Previous assessments for marine protected areas in NSW.

The earliest marine protected areas in NSW were established incidentally as part of larger terrestrial national parks and nature reserves that extended partly below mean high tide (McNeill 1995). However MPA assessments and proposals specifically for marine conservation occurred as early as 1969 (Pollard 1997). Other state-wide assessments of marine and coastal environments include an "Inventory of estuaries and coastal lagoons in NSW" (Bell and Edwards 1980), a "Headland Survey" (Quint 1982), "Beaches of NSW" (Short 1993a), "Protection of coastal rock platforms of NSW" (Short 1995), an "Australian Estuarine Database" (Digby *et al.* 1998), a "Directory of Important wetlands in NSW" (NPWS 2000a), a "Register of the National Estate" and an "Independent inquiry into coastal lakes" (Healthy Rivers Commission 2002).

Parker (1995) identified a state-wide system of marine and estuarine protected areas on the basis of their conservation values. The report proposed an extensive system of large marine national parks and smaller marine reserves. Pollard *et al.* (1997) defined marine bioregions for NSW and outlined a process for establishing networks of MPAs within these regions to represent finer scale environmental classes. National funding provided support for assessments to select aquatic reserves in estuaries (Frances 2000), on rocky shores (Otway 1999, Otway and Morrisson in prep.) and for conservation of the endangered Grey Nurse Shark (*Carcharius taurus*).

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A committee from NSW Fisheries and the NSW National Parks and Wildlife then produced guidelines for the NSW Marine Parks Authority on *"Developing a representative system of marine protected areas - an overview"* (NSW Marine Parks Authority MPA Strategy Working Group 2001). Between 2000 and 2005, the NSW Marine Parks Authority and the Australian Department of Environment and Heritage then funded assessments to develop options for systems of marine protected areas (MPA) in each of the state's marine bioregions (IMCRA 1998, Avery 2000, Breen *et al.* 2003, 2004, 2005, 2006). These bioregional assessments aimed to provide information to establish a comprehensive, adequate and representative system of marine protected areas (MPAs) to conserve marine biodiversity and maintain marine ecosystem processes. The assessments developed conceptual multiple criteria models from national guidelines and criteria (ANZECC 1998a, 1998b, 1999), mapped a broad scale marine environmental classification and identified marine conservation values and options for MPAs.

The assessments used C-Plan, a GIS based, reserve selection tool developed at the NSW National Parks and Wildlife Service, to estimate the irreplaceability of small and large plan units within each of the Manning, Hawkesbury, Batemans and Twofold Shelf bioregions. These analyses mapped the conservation value of planning units according to their ability to represent areas of different 'ecosystem' (five estuary types and three offshore depth zones) and 'habitat' surrogates (seagrass, mangrove, saltmarsh, rocky shore, beach, reef and island). In the Manning Shelf bioregion, multiple criteria analyses were also used to assess the value of large plan units (estuaries and sections of coast) against measures of their suitability as MPAs. Chapters 6, 7 and 8, Avery (2000) and Breen *et al* (2003, 2004, 2005, 2006) provide descriptions of this work.

9.1.2 A Marine Geographic Information System for NSW

In this Chapter, I merge the information and tools from the bioregional assessments into one state-wide Geographic Information System for marine and coastal planning. The database includes over 60 different variables describing the extent and broad scale distribution of different marine bioregions, ecosystems, habitats and species assemblages as well as information on the condition and vulnerability of coastal waters and adjacent lands. This information is mapped for small (4 km^2) and large (10-100 km^2) estuarine and oceanic plan units in a spatial framework bounded by legal national and state boundaries, limits of tidal influence, high and low water marks and marine protected areas established by 2005. The database also includes adjacent freshwater systems, catchments, lands, tenures and terrestrial protected areas and adjoining commonwealth marine waters. This set of additional areas is excluded from the following analyses. However, the system is capable of including these components as part of an integrated analysis and can be readily extended to other marine and coastal applications.[1]

[1] Several measures for marine and estuarine condition and vulnerability were derived from analyses of these adjacent terrestrial ecosystems.

9.1.3 C-Plan

The GIS database is linked to computer assisted planning tools in C-Plan, Criterium Decision Plus and Marxan. C-Plan is a computer program extension for ArcView GIS developed by the NSW National Parks and Wildlife Service (NPWS 2001). C-Plan includes a range of functions and algorithms for creating scenarios of reserve systems and viewing how well these systems represent different conservation values while minimising costs (e.g. area of reserve). It aims to assess which areas contribute most towards meeting goals for representation of a given set of different conservation 'features.' The conservation features are typically areas or percentages of different environments, habitats or ecological communities or occurrences of different species. Cost is usually, but not necessarily, measured as the area or number of sites occupied by the proposed reserve system.

C-Plan calculates statistical estimates of 'irreplaceability' (Pressey *et al*. 1994, Ferrier *et al*. 2000). Irreplaceability represents the "complementary" value of a site to a reserve network. It is related not only to how a site may represent different features (e.g. species or habitats), but to how the features in a site can complement other sites in meeting conservation targets for a minimum cost. Links between C-Plan and ArcView GIS allow operators to quickly map the results of analyses and include or exclude potential sites to compare different designs for MPA networks. Including or excluding locations in a reserve network continually alters the potential value of remaining areas in meeting overall goals. C-Plan progressively recalculates irreplaceabilities to adjust for the features that new sites bring to the network. It interactively updates areas, percentages, irreplaceabilities and other summary statistics as scenarios evolve.

9.1.4 Marxan

Marxan is a computer program built by Ball and Possingham (2000) for the Great Barrier Reef Marine Park Authority (Day *et al.* 2002). The program aims to meet marine conservation goals while minimising costs. It is based on a program developed for terrestrial conservation (Spexan) written in the programming language 'C'. Spexan, itself, was derived from an earlier, less accessible version, SIMAN, written in FORTRAN at the Department of Applied Mathematics at Adelaide University.

Like C-Plan, Marxan works from a basic data matrix of values (areas, percentages, occurrences etc.) of conservation features (e.g. habitats or species) represented within sites or planning units and a table of associated costs. Marxan has the ability to influence the spatial arrangement of planning units selected by reserve design algorithms. This includes the capacity to:

- minimise boundary length to area ratios to generate a network of more compact reserves
- specify minimum reserve sizes, numbers of reserves and replication of features in reserves
- specify minimum separation distances between reserves for more independent replication and representation across geographic gradients.

Algorithms in Marxan aim to minimise an objective function (Equation 1) of the sum of the costs of the plan units in a reserve system and the sum of the penalties incurred for not meeting goals for conservation features.

Equation 1. $\sum_{sites} \text{Cost} + \text{BLM} \times \sum_{sites} \text{Boundary} + \sum \text{CFPF} \times \text{Penalty} + \text{Cost Threshold Value}_{(t)}$

The cost of a plan unit can be measured as the area occupied by reserves or by some other measure of cost such as fish catch. Cost can also be assigned to the boundary length (or any other boundary cost) of the reserve system. A coefficient known as the boundary length multiplier (BLM) adjusts the relative importance of minimising boundary length over other costs such as the area occupied. The Conservation Feature Penalty Factor (CFPF) is used to weight the relative importance of meeting targets for conservation features. The penalty is roughly the additional cost and modified boundary cost needed to represent features not already adequately represented in the reserve system.

A very small or zero value boundary length multiplier tends to generate a reserve system that is highly fragmented but efficient in terms of occupying a small area. A large boundary length multiplier aggregates plan units into larger clumps, but can increase the cost in area and where the CFPF is low, solutions my not meet all conservation targets. The cost threshold value is an optional feature that applies an additional penalty once a specified or time dependent threshold cost has been exceeded (Ball and Possingham 2000).

The program includes variations of different stepwise heuristic algorithms, an iterative improvement algorithm and a simulated annealing algorithm. The heuristic algorithms work by sequentially adding sites to a reserve network according to stepwise criteria until a stopping condition is met. Criteria include selecting those sites with the most un-represented features (greedy algorithm), the rarest features or the highest irreplaceability. Iterative improvement algorithms randomly add, subtract and/or swap plan units that improve an initial ‘seed’ network to find a local minimum.

Simulated annealing works in a similar manner to iterative improvement. However, in the early stages of simulated annealing, when a parameter described as the ‘temperature’ is set high, both ‘good and bad changes’ to minimise the objective function are accepted. As the algorithm progresses through a set number of iterations, the ‘temperature’ gradually decreases, and changes that do not decrease the objective function are rejected more frequently until only improvements in the solution are accepted. By randomly accepting many different plan units early in the algorithm, the program avoids local minima and can potentially identify a greater number of near optimal solutions.

9.1.5 Multiple criteria analysis

In this Chapter, I use Criterium Decision Plus to develop a multiple criteria model to compare nine different options for large marine parks that include different combinations of large estuarine and ocean plan units. These models interpret a single overarching goal or objective in terms of finer scale criteria and performance measures nested in a hierarchical “tree”. A single, primary goal is subdivided into broad criteria, which in turn are interpreted in terms of more specific criteria, until ultimately at the outer branches of the tree, measurable performance indicators can be assigned to evaluate a range of alternative decisions. The overall performance of these decisions against the primary goal, and for each level of sub-criteria, can then be assessed as the weighted average value of the standardised scores for all performance indicators.

All criteria may be weighted equally, or criteria at each level can be prioritised as to how much influence they have on the average score of the criteria above them in the tree and ultimately on the overall score for the primary goal. For example, particular measurements of areas of habitat, number of species, ecosystem condition or levels of human use may be weighted differently according to the importance given to these by different managers, stakeholders or communities or according to how reliable or useful the data are thought to be. Importantly, Criterium Decision Plus provides an interface to quickly alter these weights or priorities and view the effect this has on overall outcomes for each criteria and the primary goal. It also includes other tools including sensitivity and trade-off analyses to estimate the relative influence of individual criteria at different priorities.

9.2 Methods

9.2.1 Data

The analyses in this chapter rely on data collected and mapped in the previous bioregional assessments but standardised and delimited within a consistent system of planning units for all of NSW. These units are based on detailed legal boundaries to include all marine waters within the jurisdiction of the NSW State government. The selection of data is based on multiple criteria for national and state policy and legislation for MPAs and a hierarchical environmental classification developed in conjunction with the NSW Marine Parks Authority Research Committee and Ron Avery. The classification represents progressively finer scales of ecological variation within:

- IMCRA bioregions (IMCRA 1998)
- ecosystem classes based on estuary type and depth zone
- habitat classes (seagrass, mangrove, saltmarsh, rocky shore, beach, reef, island and sediment)
- community classes based on more detailed physical surrogates, dominant biota or species assemblages, and
- the estimated distributions and abundances of selected species and populations.

The bioregional classification was developed through the national IMCRA process (Pollard *et al* 1997) from analyses of a range of geological, oceanographic and biological information sources. This process identified three marine bioregions wholly within NSW (Manning Shelf, Hawkesbury Shelf and Batemans Shelf) and two bioregions (Tweed-Moreton and Twofold Shelf) which extended into waters managed by neighbouring states. These bioregions extend out to the edge of the continental shelf at the 200 m isobath. However, the assessments described here only address mainland waters within the jurisdiction of NSW out to three nautical miles from coast and adjacent islands.

The assessment for the Byron Bay Marine Park in the Tweed-Moreton bioregion extended the classification to ecosystem and habitat classes (Avery 2000) and these classes were refined in the Manning Shelf and other bioregional assessments (Chapters 5, 6 and 7 and Breen *et al*. 2003, 2004, 2005, 2006). The areas of these 'ecosystem' and 'habitat' surrogates within each bioregion provide the main target values for the following irreplaceability analyses in C-Plan and Marxan.

Multiple criteria analysis is however, able to accept a much wider range of qualitative and quantitative data. The multiple criteria analyses therefore include any available finer scale classifications of inshore and offshore islands, inshore and offshore reefs and microhabitats within rocky shores and beaches. They also incorporate species surveys for estuarine vegetation (West *et al*. 1985, R.J. Williams, NSW Fisheries, pers. comm.), juvenile fishes (R. Williams pers. comm.), intertidal rocky shores (Otway 1999; Otway and Morrison in. prep.) threatened

Grey Nurse shark (Otway and Parker 2000), mammals, seabirds, waders, commercial fish catches (Pease 1999, Tanner and Liggins 1999) and sightings databases kept by NSW Fisheries and the NSW National Parks and Wildlife Service.

The analyses were also able to incorporate irreplaceability values generated by C-Plan analyses and indices for condition, threat and vulnerability. The latter include the proportion of adjacent land occupied by terrestrial national parks and nature reserves, state forest, wetlands, wilderness, land capability, built-up areas, acid sulphate soils, and indices derived from the Australian river and catchment condition database (Stein *et al*. 2000). The results of previous conservation assessments for wetlands (ANCA 1996), estuaries (Bell and Edwards 1980, Digby *et al*. 1998, Frances 2000, Healthy Rivers Commission 2002), and rock platforms (Short 1995, Otway 1999) were also summarised and included in the multiple criteria model. Finally, the model included some simple costs defined as the total area of water included in the MPA and the estuarine and ocean fisheries catch for each MPA option.

9.2.2 Planning frame

ArcView 3.2 and ARCInfo 8 GIS were used to generate an overall planning frame for all NSW marine waters between the mean high water mark, the upper limits to tidal flow of all major estuaries and the 3 nautical mile offshore limit to state waters from the GIS data sets shown in Table 9.1. These boundaries were selected from a range of alternatives to meet specific ecological and administrative objectives and to be legally consistent with other state and national boundaries.

In particular, the state cadastre database was used to derive ocean and estuarine boundaries coinciding with other legal, council and land ownership boundaries along the coast. It provides a relatively detailed and accurate coastline and aligns well with orthorectified aerial photography. The resulting boundaries provide for realistic planning scenarios that a simplified grid based representation could not provide. These attributes are particularly important for interpretation during community consultation and for interpreting and enforcing legislation for development and other activities along MPA borders. While this boundary required checking and editing to remove bridges, dams, ports and various administrative features remaining from the original terrestrial data set, the new boundaries now provide a basis for a marine cadastre in NSW. The mean high and low water marks in the data set were useful in defining the extent of intertidal beaches and rocky shores and were required to accurately define the extent of MPAs in legislation that refers to both of these datums.

The upper limits of mapped saltmarsh and mangrove assemblages were used to optionally extend the limit of the marine planning frame as approximately 40% of the area of these habitats in NSW occurs above the mean high tide mark. The upper limits of tidal influence were used to define the upper extents of estuaries as Marine Parks and Aquatic Reserves in NSW are limited by legislation to marine waters.

The freshwater components of coastal rivers, adjacent coastal lands and catchment areas were included in the overall planning frame but identified so that they could be excluded from analyses where appropriate. This allowed the models to be extended beyond purely marine influences and include considerations such as land use, terrestrial protected areas and the requirements of diadromous species moving between marine and freshwater ecosystems.

The boundaries of the IMCRA bioregions were derived directly from the recommendations of Pollard *et al* (1997), as the national IMCRA GIS data set includes boundary errors from interpreting degrees and minutes of latitude as decimal degrees. Most of the marine protected area boundaries were derived and revised specifically for this study and related projects using advice from the agencies responsible (Avery 2000, Danielle Morrisson pers. comm. NSW Fisheries, Rodney James pers. comm., NSW National Parks). These boundaries are set to align with the other state data sets in Table 9.1, the boundaries of NSW National Parks and Nature Reserves and the specific legislation for each MPA.

Table 9.1 Data sets used to define the extent of marine areas used to identify potential MPAs.

Source	Geographical features	Data set
Geoscience Australia	3 nautical mile offshore limit to state waters, location and extent of islands	Australian Maritime Boundary Information System, Commonwealth of Australia (2002)
NSW Land & Property Information	Mean high water and low water marks and boundaries of MPAs	Digital Cadastre database
West *et al.* (1985), NSW Fisheries	Extent of estuarine vegetation above mean high water	Estuarine vegetation surveys
NSW Environmental Protection Agency	Upper limits to estuaries	Upper limits of tidal influence
Australian Department of Environment & Heritage Pollard *et al.* 1997	Boundaries of NSW marine bioregions	Interim Marine and Coastal Regionalisation of Australia
NSW Marine Parks Authority, NSW Fisheries, NSW National Parks	Boundaries of marine protected areas	This data set and associated agency data sets.

9.2.3 Planning units

To compare conservation values among different marine areas, several sets of different sized planning units were produced by dividing the overall planning frame into smaller areas. Several combinations of shape, size and analysis methods were trialled but the main units used were:

- broad scale plan units of whole estuaries and sections of ocean and coast between major estuaries. These ranged in size from a few square kilometres for some small estuaries to over 200 km^2 for large sections of open ocean. These readily recognised regions could be used to effectively summarise the major attributes of estuaries, coasts and sections of ocean. This approach assisted in developing a relatively simple set of measures that could be easily graphed or mapped for interpretation. Their major disadvantage was the disparity in size as larger units naturally tend to include more areas of different conservation features. These planning units were particularly useful for creating and evaluating options for large multiple use marine parks in C-Plan and Criterium Decision Plus where the ability to otherwise spatially aggregate smaller plan units was limited.

- medium scale planning units formed by intersecting a shape file of all marine waters in NSW with a grid of 4 km^2 hexagonal polygons created using the Patch Analyst (Rempel 1999) extension for ArcView. These units were most effective when using C-Plan and Marxan to create and compare customised options for MPAs at medium to broad scales. Each unit was generally large enough to potentially include several conservation features and therefore discriminate among areas of high and low irreplaceability. However, the units were small enough to discriminate individual sites during interactive analyses. The number of planning units of this size for NSW marine waters (~5,000) was also small enough to allow C-Plan to rapidly update irreplaceability values and run simulations in Marxan within a reasonable time.
- fine scale planning units formed by intersecting the GIS shape files of NSW marine waters with 1 km^2 and 10 hectare (0.1 km^2) hexagonal polygons. These planning units are not used in the analyses described here but were useful for interactively exploring fine scale options for MPAs and developing zoning plans within marine parks such as the Cape Byron and Port Stephens - Great Lakes Marine Parks. An example of their use is described in the following chapter.

9.2.4 C-Plan models for broad scale MPA planning in NSW

A broad scale C-Plan model was built to compute 'irreplaceability' for 349 broad scale planning units with the aim of representing examples of each marine ecosystem (i.e. five estuary types and three ocean depth zones) and habitat class (i.e. seagrass, mangrove, saltmarsh, rocky intertidal shore, inshore sand, beach, reef, and islands) within each bioregion. After allowing for the absence of some estuary types from some bioregions, the resulting data matrix included areas for 73 different conservation features. The model was used interactively explore alternative MPA networks for a range of feature targets and scenarios. This included calculating irreplaceability before, and after adding existing MPAs to the models and accounting for the features they included.

A fine scale C-Plan model was also built from approximately 5,000 hexagonal plan units each occupying up to 4 km^2 in area. This model was used to explore many medium to broad scale options using an experimental, “what-if,” scenario approach and to run “greedy” and other stepwise heuristic algorithms to automatically select reserve systems. Results from these particular studies are not described here as without parameters to limit boundary length, the algorithms tended to select very fragmented reserve systems. Irreplaceability values for these models are however shown in Chapters 6, 7 and 8 and the models were also used in management and community workshops to develop MPA options.

9.2.5 Simulated annealing to identify MPA options

The simulated annealing algorithm in Marxan is used to develop options for MPAs throughout the state and compare the results to those from the bioregional assessments. The algorithm is very flexible but requires many parameters to be set by the operator that can affect the results of the analyses. Some of the parameters are related to the objectives of the planning exercise and the relative weight or importance given to different goals, costs or considerations for reserve design. Others relate to more arbitrary factors such as the units and scales that costs, goals and boundaries are measured in, the number and nature of the planning units and the conservation features to be protected, and logistic requirements in computation time and computer memory.

In the following analyses, computation times for 1 million iterations of the algorithm on a 3.3 GHz Pentium 4 laptop with one gigabyte of ram took between 15 and 30 seconds. Marxan can also be set to run repeat runs of the algorithm and summarise and list detailed outputs for all runs in annotated files. Multiple instances of this entire process can also be run almost simultaneously (by repeatedly altering parameters and re-running the Marxan.exe file) or sequentially through a batch file which specifies different combinations of input parameters. This capacity was used to examine how the results of the annealing algorithm were affected by differences in the settings for initial and final temperatures, in the feature targets, in the size of the planning unit and in the size of the boundary length modifier.

Initial assessments were also made of the effect of altering the number of iterations, the number of runs of the algorithm and the effect of ignoring external boundaries when calculating boundary lengths of planning units. From this I determined that 1 million iterations and 10 thousand temperature decreases were sufficient for the algorithm to reach a minima and that for these planning units, external boundaries were best ignored if small estuarine plan units (with high boundary length to area ratios) were to be included in solutions.

Marxan simulations were then used to identify options for MPAs from 5,000 plan units created by intersecting 4 km^2 hexagons with all NSW marine waters. A range of initial and final temperatures and an adaptive temperature schedule were trialled with a simulated annealing algorithm followed by simple iterative improvement. The algorithm was run repeatedly to produce 100 near optimal solutions for each combination of five boundary length modifiers (0.001, 0.01, 0.1, 1 and 10) and five goals aiming to represent increasing percentages (10%, 20%, 30%, 40% and 50%) of all habitat and ecosystem classes in each marine bioregion. Boundary lengths between each pair of adjacent plan units were calculated using the “Marxan boundary file maker” extension for ArcView (Smith 2004).

The “best” solution and the number of times a planning unit was selected out of a possible 100 runs were mapped in ArcView GIS. Simulations were run while ignoring the contributions of existing MPAs and also after specifying that all existing MPAs must be included in the list of sites selected for any solution.

9.2.6 Multiple criteria analysis to assess Marine Parks for NSW

Multiple criteria analyses were used in the Manning Shelf bioregional assessment to compare conservation values among individual estuaries and among sections of coast and ocean (Chapter 6, Section 6.4.31). In this chapter, the Simple Multi-Attribute Utility Technique (SMART) is used to compare the overall conservation value of nine options for large, multiple use marine parks in the Hawkesbury, Batemans and Twofold Shelf bioregions (Figure 9.1 and Figure 9.2). This approach was deemed more proficient than assessing individual plan units given the large number of estuaries and coastal sections in these bioregions and the number of possible options for marine protected areas.

Each option includes enough adjacent large scale plan units to represent all ecosystem and habitat classes within a large marine park. The options are initially identified in Chapters 7 and 8 by graphically assessing the scores of individual variables and mapping the results of irreplaceability analyses from C-Plan. The areas and percentages of ‘ecosystem’ and ‘habitat’ surrogates within the options are provided in Chapters 7 and 8 in Tables 7.10, 8.12 and 8.13.

The conceptual models of MPA goals and criteria developed in Chapter 2 were used to develop a quantitative multiple criteria model to compare MPA options using the commercially available software Criteria Decision Plus 3.0 (InfoHarvest 2000). This model interprets the overall goal of selecting comprehensive, representative and adequate marine protected areas while allowing for sustainable use in terms of five levels of progressively more detailed criteria. These criteria are nested within the overall goal and culminate in 122 performance measures which evaluate each large marine park option using information collated by the assessments described in Chapters 7 and 8

Most of these measures relate to biodiversity values and reflect the scope and objectives of the bioregional assessments. However four simple measures of the potential cost in area and the commercial fish catch (Tanner and Liggins, 1999) are also included. These provide a very approximate measure of the possible impacts on human activities and demonstrate how the technique could be used to integrate biodiversity information with data on social, economic and cultural values.

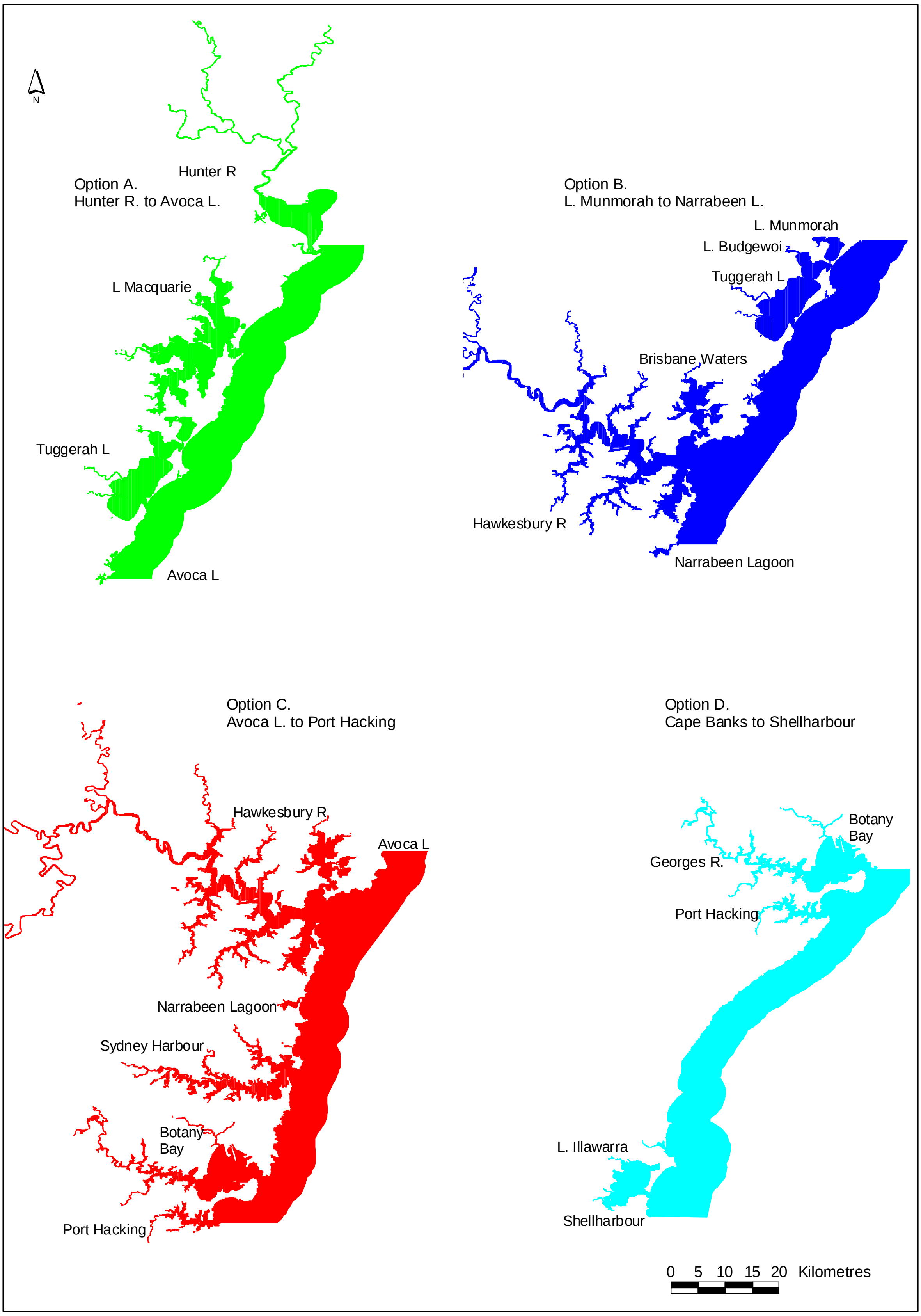

Figure 9.1. Four options identified for a large, multiple use marine park in the Hawkesbury Shelf bioregion.

Figure 9.2. Three options identified for a large, multiple use marine park in the Batemans Shelf bioregion (Options A to C) and two options for a large multiple use marine park in the Twofold Shelf bioregion (Options D and E).

9.3 Results

9.3.1 C-Plan models for MPA planning in NSW

C-Plan can rapidly calculate irreplaceability for different goals and sets of conservation features while including or excluding different areas from reserve networks. These are useful tools to use interactively, but difficult to demonstrate on printed media. Therefore in the following examples, an arbitrary 20% target is adopted for all ecosystem and habitat classes in each bioregion. Figure 9.3 and Figure 9.4 show site irreplaceabilities for large plan units in the state's northern and southern regions. These results are derived from the same C-Plan model, but mapped separately for greater clarity.

Irreplaceability values are calculated under two assumptions:
a.) that initially, all areas are equally likely to be included in a MPA network; or
b.) that existing MPAs must be included as permanent part of the MPA network.

In the Tweed-Moreton bioregion (Figure 9.3a), plan units with a high initial irreplaceability include the Clarence River and the area occupied by the Solitary Islands Marine Park. When currently existing MPAs are included within the modelled reserve network (Figure 9.3b) many sections of coast and ocean have a low irreplaceability but values for the Clarence River remain high. This occurs because sections of open coast and ocean, offshore islands, reefs, beaches and rocky shores are already represented within MPAs like the Solitary Islands Marine Park but barrier estuaries, seagrass beds, mangroves and saltmarshes remain underepresented even after the addition of the new Cape Byron Marine Park.

In the Manning Shelf marine bioregion (Figure 9.3a), the highest initial irreplaceabilities occur for the Myall River, Myall Lakes, Port Stephens and the areas immediately offshore. These scores reflect the uniqueness of the Myall Lakes as the only brackish water system in the bioregion and Port Stephens as the only drowned river valley. The scores also reflect the large areas of mangrove, saltmarsh, seagrass, rocky shore, inshore and offshore reefs and islands in and around Port Stephens. Wallis Lake also has a high irreplaceability as a large barrier estuary that includes the largest areas of seagrass in the state.

When existing MPAs are added to the model (Figure 9.3b), the Myall Lakes and large areas of mangrove and saltmarsh are included within several national parks and nature reserves (i.e. in Port Stephens, Camden Haven, Lakes Cathie, Lake Innes, Khappinghat Creek, the Hastings River and the Macleay River). However, only very small areas of other coastal conservation features are included in the 0.8 km^2 Fly Point/Halifax Aquatic Reserve and in the narrow coastal fringes of some national parks and nature reserves. Irreplaceability therefore remains high for the Port Stephens estuary and adjacent ocean, for Wallis Lake and for the section of coast north of the Manning River.

In the Hawkesbury Shelf bioregion, Botany Bay and the coast and ocean between Towradgi Creek and Shellharbour have the highest irreplaceabilities (Figure 9.4a). These scores reflect the uniqueness of Botany Bay as the only coastal embayment in the bioregion and the presence of offshore islands between Towradgi Creek and Shellharbour. Moderate irreplaceabilities also occur for the Hunter River, Lake Macquarie and the Hawkesbury River, and for the coast and ocean between the Hunter River and Tuggerah Lake, and between Stanwell Park and Towradgi Creek.

When features already protected in existing MPAs are taken into account (Figure 9.4b), scores for Botany Bay, the Hawkesbury River and Lake Macquarie decrease because areas of coastal embayment and seagrass are already protected in the 14 km^2 Towra Point Aquatic Reserve and Nature Reserve and because some seagrass beds and parts of drowned river valleys are already protected in the North Sydney Harbour Aquatic Reserve and in nature reserves and national parks in the Hawkesbury River and Sydney Harbour.

Irreplaceability scores however, increase for the large areas of mangrove and saltmarsh in the Hunter River barrier estuary. Scores also increase along the coast between the Hunter River and Lake Macquarie, between Lake Munmorah and Tuggerah Lake, between the Hawkesbury River and Avoca Lake, and between Stanwell Park and Shellharbour. The increases along the coast occur despite the existence of seven aquatic reserves on exposed rocky shores throughout the Sydney region, which in total, include only a small area (2.7 km^2) of exposed coastal habitat and ocean.

In the Batemans Shelf and the NSW section of the Twofold Shelf bioregion, initial irreplaceabilities are highest for the Clyde River estuary and for Twofold Bay (Figure 9.4a). This reflects the uniqueness of the Clyde River as the only drowned river valley in the Batemans Shelf bioregion and Twofold Bay as the only coastal embayment in the Twofold Shelf bioregion. Jervis Bay Marine Park also scores highly as the largest coastal embayment in the bioregion with the largest area of seagrass and significant offshore islands. The Shoalhaven River also scores highly as the second largest barrier estuary in the bioregion with the largest area of mangroves.

When existing MPAs are taken into consideration, irreplaceability decreases on the Batemans Shelf coast because of the protection of coastal areas in Jervis Bay Marine Park, in Bushrangers Bay Aquatic Reserve and within several national parks and nature reserves (Figure 9.4b). However, scores remain high for the Clyde River estuary and the Shoalhaven River, despite the protection of some parts of these estuaries in national parks and nature reserves.

Although the initial irreplaceabilities of sections of coast and ocean in the Twofold bioregion Shelf are high (Figure 9.4a) and increase in value when existing national parks and nature reserves are considered (Figure 9.4b), this can not be interpreted easily without consideration of the areas of this bioregion represented in Victorian and Tasmanian state waters (see Chapter 8).

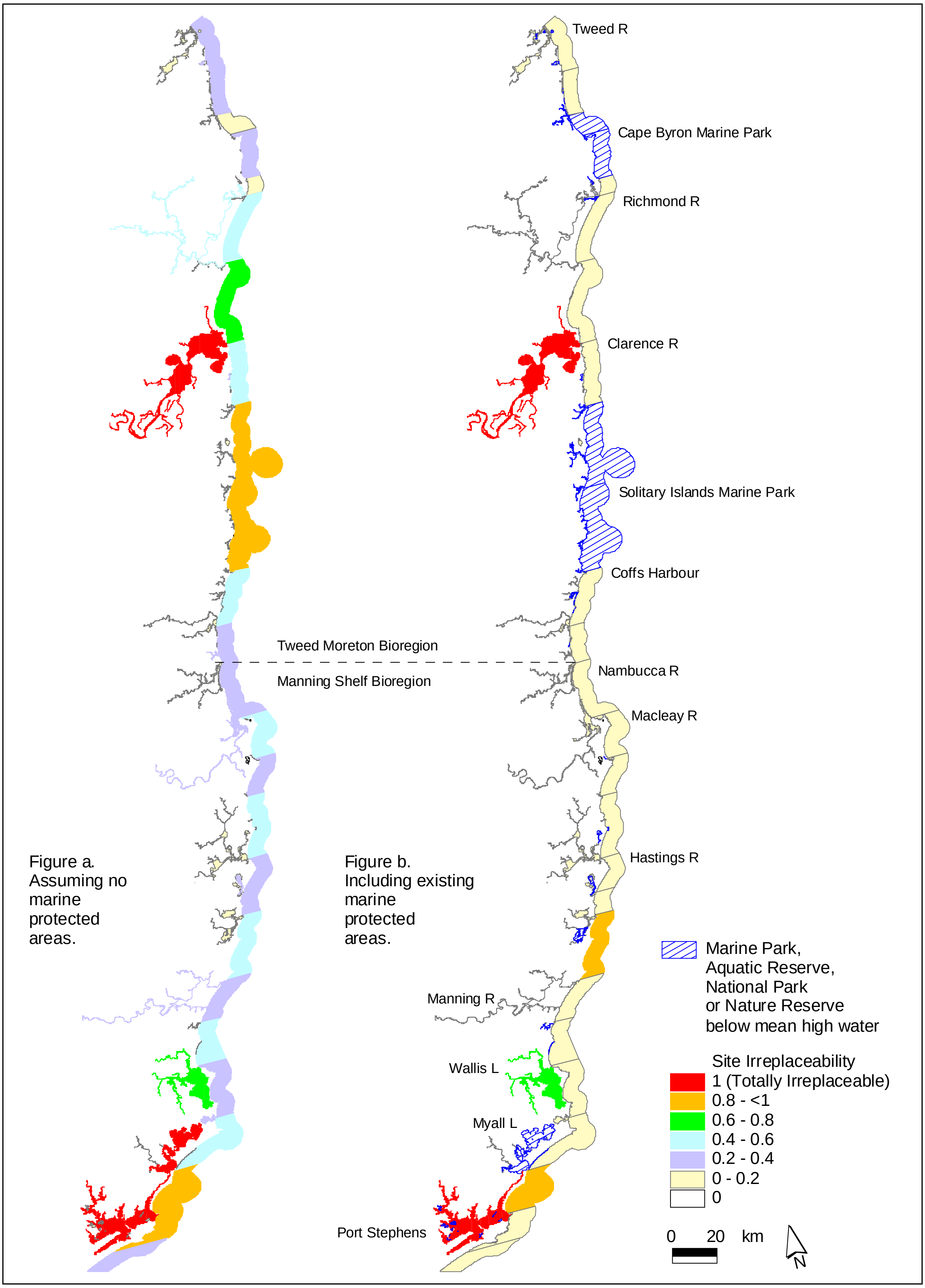

Figure 9.3. Site irreplaceability for large scale plan units in northern NSW state marine waters calculated using C-Plan reserve design software (NPWS 2001). The two particular scenarios shown aim to represent 20% of the area of each of eight 'ecosystem' types and eight 'habitat' types in each marine bioregion assuming a. no existing marine protected areas and b. marine protected areas present in June 2005.

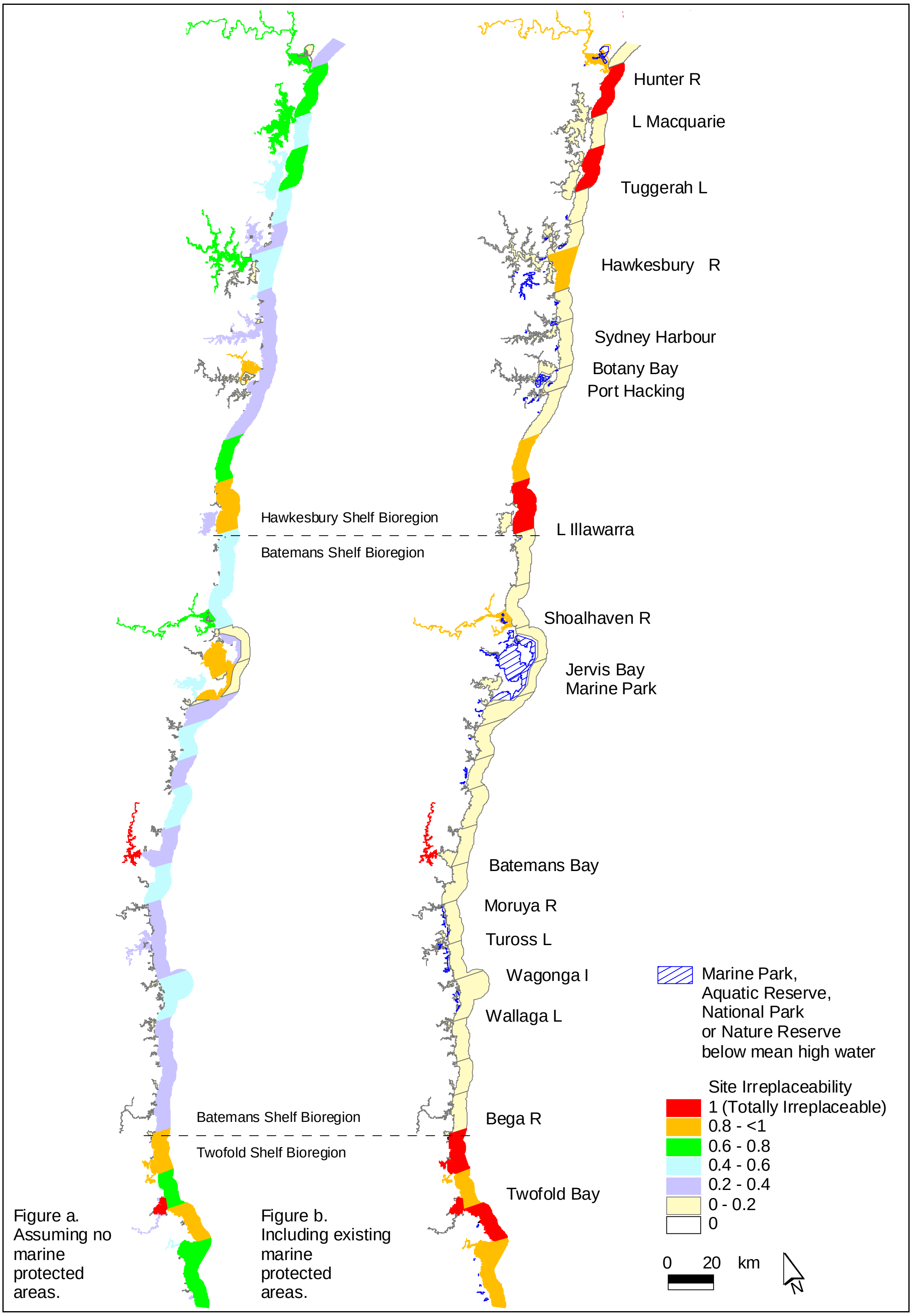

Figure 9.4. Site irreplaceability for large scale plan units in southern NSW state marine waters calculated using C-Plan reserve design software (NPWS 2001). The two particular scenarios shown aim to represent 20% of the area of each of eight ‘ecosystem’ types and eight ‘habitat’ types in each marine bioregion assuming a. no existing marine protected areas and b. marine protected areas present in June 2005.

9.3.2 Simulated annealing to identify MPA options

The initial and final temperatures of the simulated annealing schedule can be set manually or by an adaptive method where the program chooses temperatures after first sampling the problem (Ball and Possingham 2000). Running the algorithm for ~5,000 plan units in NSW marine waters at a range of initial (12 to 1,000,000) and final (1 to 0.001) temperatures produced small improvements in minimizing the value of the objective function (Figure 9.5). However using the programs adaptive schedule provided the best results of all (Figure 9.5) and this practice was adopted in all subsequent runs.

Figure 9.6 and Figure 9.7 indicate that the total boundary length for a model of the NSW marine protected area system can be reduced substantially while meeting almost all conservation feature targets if a boundary length modifier of 1 is used. Boundary length and cost in area can be reduced further, but only by reducing the species penalty factor (to spf = 0.8) and subsequently failing to meet some targets for representation of ecosystems and habitats in each bioregion. A boundary length modifier of 1 was therefore used in all subsequent runs of this particular model.

If existing MPAs are ignored, and all areas are treated as equally likely to be included in the reserve system, the total boundary length ranges from less than a 1,000 km to just over 4,000 km for feature targets ranging from 10 to 50% of each habitat and ecosystem class in each bioregion (Figure 9.6). However, if the existing MPA system is included, boundary lengths increase substantially to between 2,500 km and almost 6,000 km respectively, for targets between 10 and 50% (Figure 9.7).

The total area covered by the modelled reserve system also increases if existing MPAs are required in solutions, and this tendency is more pronounced for lower feature targets. For targets of 10% of each ecosystem and habitat in each bioregion, the total area of reserve required increases from 1,000 km^2 to almost 2,000 km^2 if existing MPAs must be included. However, to meet feature targets of 50% of all ecosystems and habitats, the area required by a MPA network is only slightly higher (at around 5,000 km^2) if existing MPAs are included.

This suggests a systematic approach to selecting MPAs could represent conservation values within a smaller area than could be achieved with the existing network of MPAs. However, the similar areas covered with and without existing MPAs at higher feature targets, indicates that area costs can be reduced if systematic planning is adopted for subsequent MPA planning.

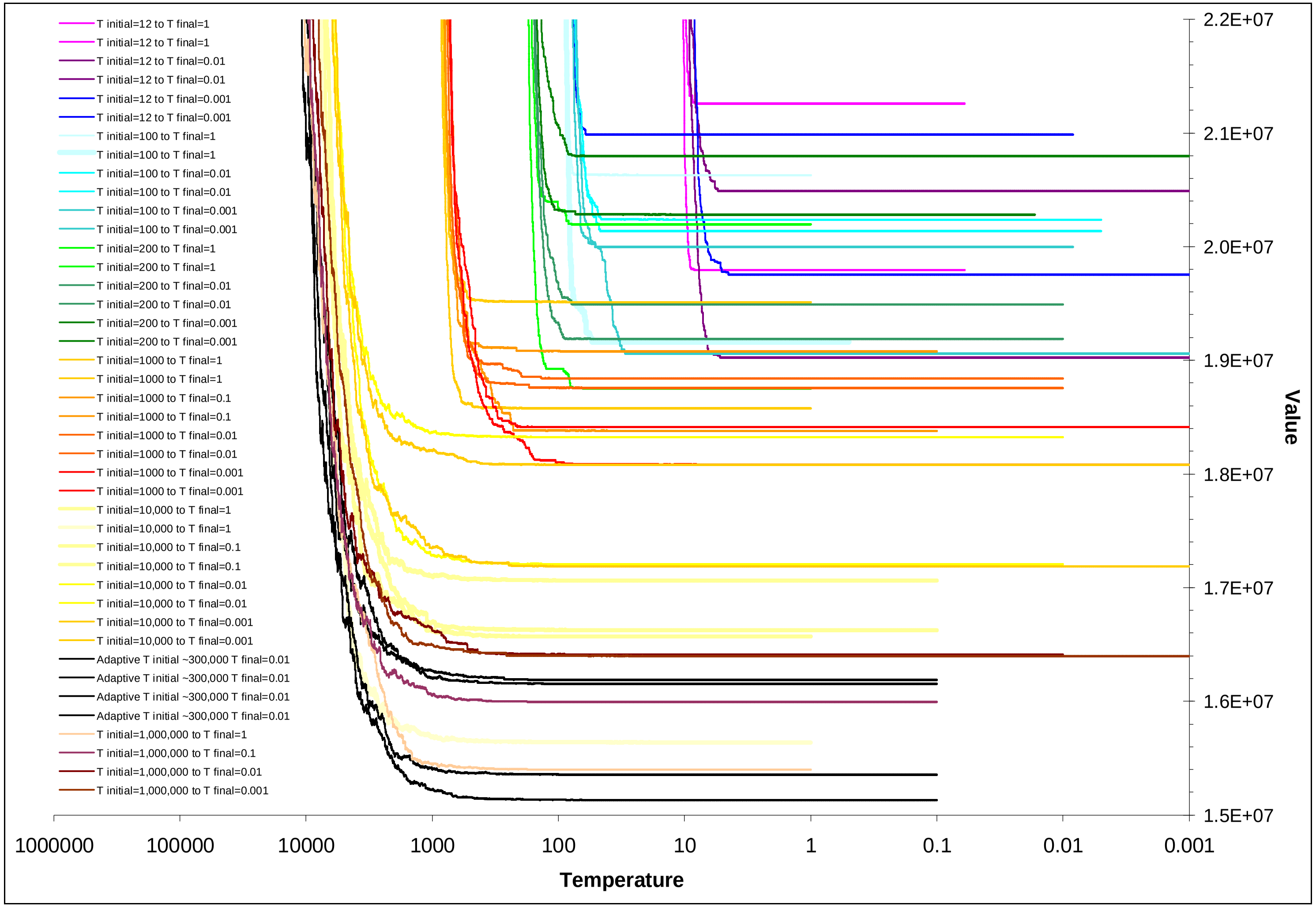

Figure 9.5. Curves showing the final stages of improvement in Marxan simulated annealing solutions. Objective function values decrease from an initial high "temperature" (T initial) where many alternative 'good and bad' changes to a hypothetical reserve system are accepted to a final cool temperature (T final) where only good changes are accepted. Curves are shown for a range of initial and final temperatures. The simulations aim to represent 20% of each of the eight "ecosystem" and eight "habitat" types in each marine bioregion by selecting from among 5,000 small scale plan units in NSW state marine waters while minimising cost in area and boundary length. Each simulation involves 1,000,000 iterations and 10,000 temperature decreases.

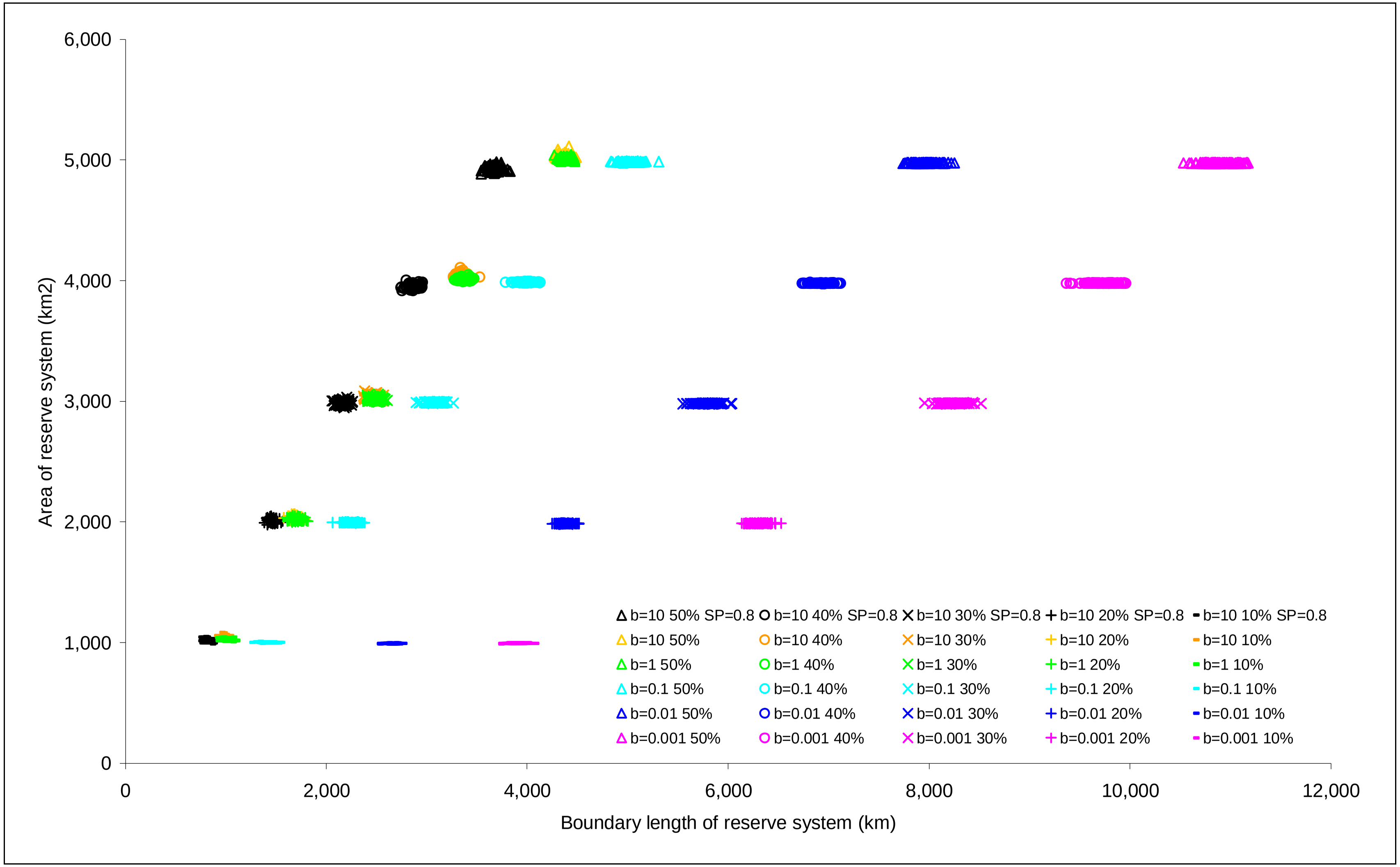

Figure 9.6. Areas of hypothetical reserve systems from simulations *ignoring* existing MPAs and aiming to represent of all environmental classes in each marine bioregion using Marxan simulated annealing and iterative improvement with ~5,000 medium size (>4 km2) planning units for all NSW waters. Each point represents the solution reached after 1,000,000 iterations with 10,000 temperature decreases. 100 replicate simulations are plotted for each combination of percentage goal (10-50%) and boundary length modifier (b=1 to 1,000).

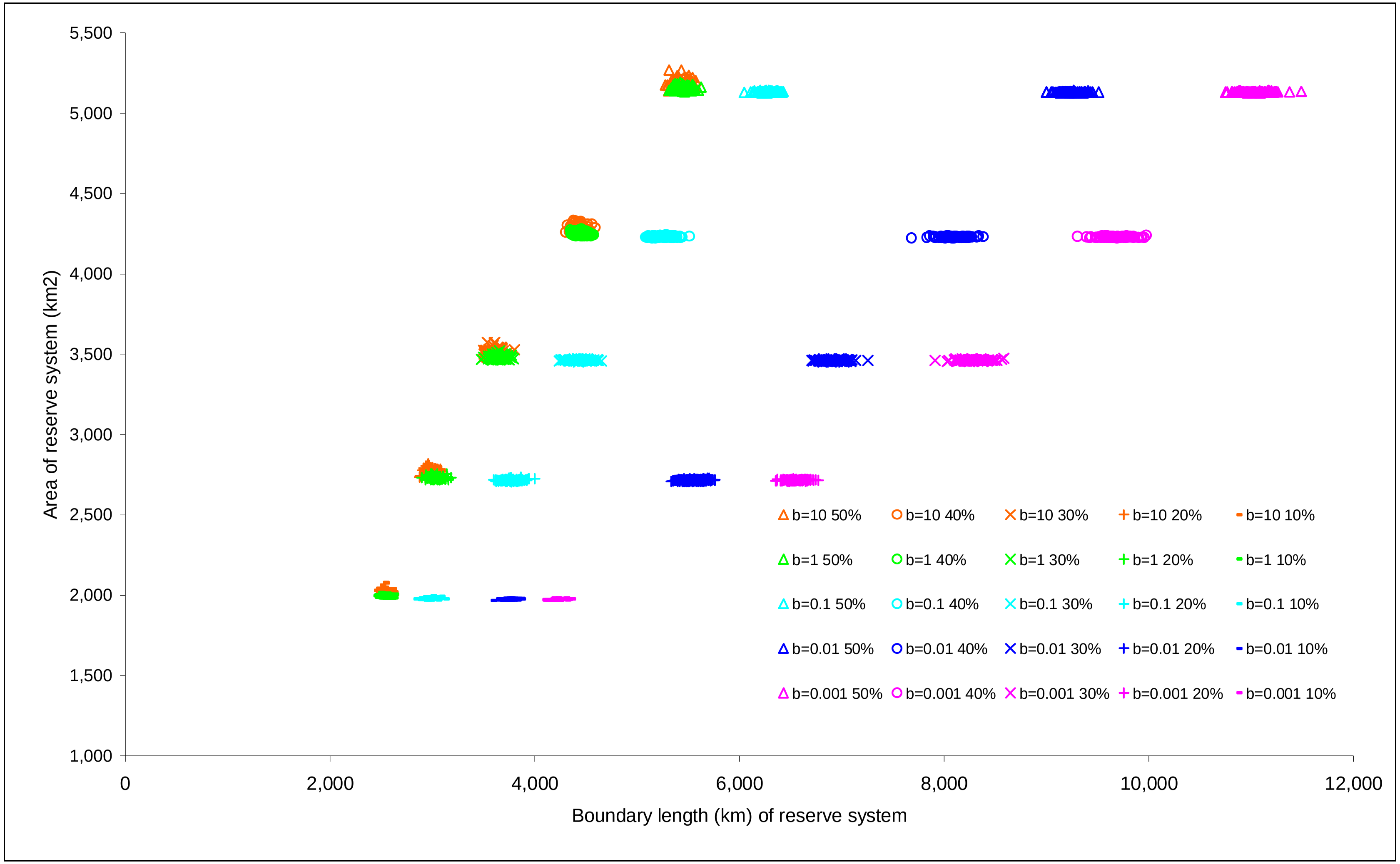

Figure 9.7. Areas of hypothetical reserve systems from simulations *including* existing MPAs and aiming to represent of all environmental classes in each marine bioregion using Marxan simulated annealing and iterative improvement with ~5,000 medium size (>4 km2) planning units for all NSW waters. Each point represents the solution reached after 1,000,000 iterations with 10,000 temperature decreases. 100 replicate simulations are plotted for each combination of percentage goal (10-50%) and boundary length modifier (b=1 to 1,000).

Marxan is capable of producing many near optimal solutions in a relatively short period of time. This can be an advantage as exploring a variety of network designs can provide the flexibility to meet a range of other reserve design and social and economic goals. To map each of these solutions here is impractical. However, Figure 9.8 to Figure 9.11 map the number of times a plan unit occurs in 100 solutions derived from running the simulated annealing algorithm repeatedly. This relative measure of irreplaceability is shown for targets aiming to represent between 10 and 50% of all ecosystem and habitat classes in each bioregion.

For example, a planning unit coloured red, is selected in an MPA system in between 75 and 100 of all 100 runs of the algorithm. The annealing models included all bioregions in NSW, but again, for clarity, the northern and southern halves of the state are mapped separately.

In Figure 9.8, areas such as the Broadwater and Lake Woolaweyah in the Clarence River estuary, and areas in Wallis Lake, Lake Innes and the Richmond River are selected in many solutions even when targets are set at 10%. At targets of between 20 and 40%, large areas in, and offshore of Port Stephens and smaller areas north of Wallis Lake and in Camden Haven are frequently selected. At targets between 40 and 50%, large areas of the Solitary Islands Marine Park and other areas including south of the Macleay River and parts of the far north coast are also selected frequently.

Figure 9.9 shows the same simulations run after including existing MPAs as a mandatory component of all solutions. In the Tweed-Moreton bioregion, where two large marine parks, an aquatic reserve and several national parks and nature reserves already include large areas of marine habitat, most other areas occur only rarely in solutions. The major exceptions are in the Clarence River, a major barrier estuary with significant areas of seagrass, because these features are still currently underepresented in the existing system of MPAs.

In the Manning Shelf bioregion, including existing MPAs in all solutions does not significantly alter the high irreplaceabilities of planning units in Port Stephens, Wallis Lake, Camden Haven and the Macleay River. The large areas of national park and nature reserve in these areas may, in fact, increase the selection of adjacent plan units as the algorithm seeks to reduce boundary length (Figure 9.9).

In the Hawkesbury Shelf marine bioregion (Figure 9.10), areas that are selected most frequently occur in, and offshore of, major estuaries including Lake Illawarra, Botany Bay, Sydney Harbour, the Hawkesbury River, Tuggerah Lakes, Lake Macquarie and the Hunter River. Taking into account the existing MPAs in the Hawkesbury Shelf bioregion does not appear to influence these results significantly (Figure 9.11). This may be because most existing MPAs are small and scattered throughout the bioregion.

In the Batemans Shelf bioregion (Figure 9.10), the areas selected most frequently occur in and around Jervis Bay Marine Park (including the Shoalhaven River, St Georges Basin and areas to the south), between the Moruya River, Montague Island and Wallaga Lake, and in the Clyde River estuary. These areas include relatively irreplaceable sites for coastal embayments and seagrass (Jervis Bay), drowned river valleys (Clyde River), offshore islands (Montague Island) and numerous barrier and intermittent estuaries (between the Moruya River and Wallaga Lake). If existing MPAs, (e.g. Jervis Bay Marine Park and Eurobodalla National Park) are taken into account, this pattern, if anything, becomes more pronounced.

In the Twofold Shelf bioregion, selected areas occur most frequently around Twofold Bay, Merimbula Lake and Pambula Lake. Twofold Bay is the only coastal embayment in the NSW section of this bioregion. Merimbula and Pambula Lakes are the largest barrier estuaries and include the largest areas of seagrass in this section of the bioregion. However, these results should be interpreted with regard to the MPAs established in Victorian and Tasmanian state waters (see Chapter 8).

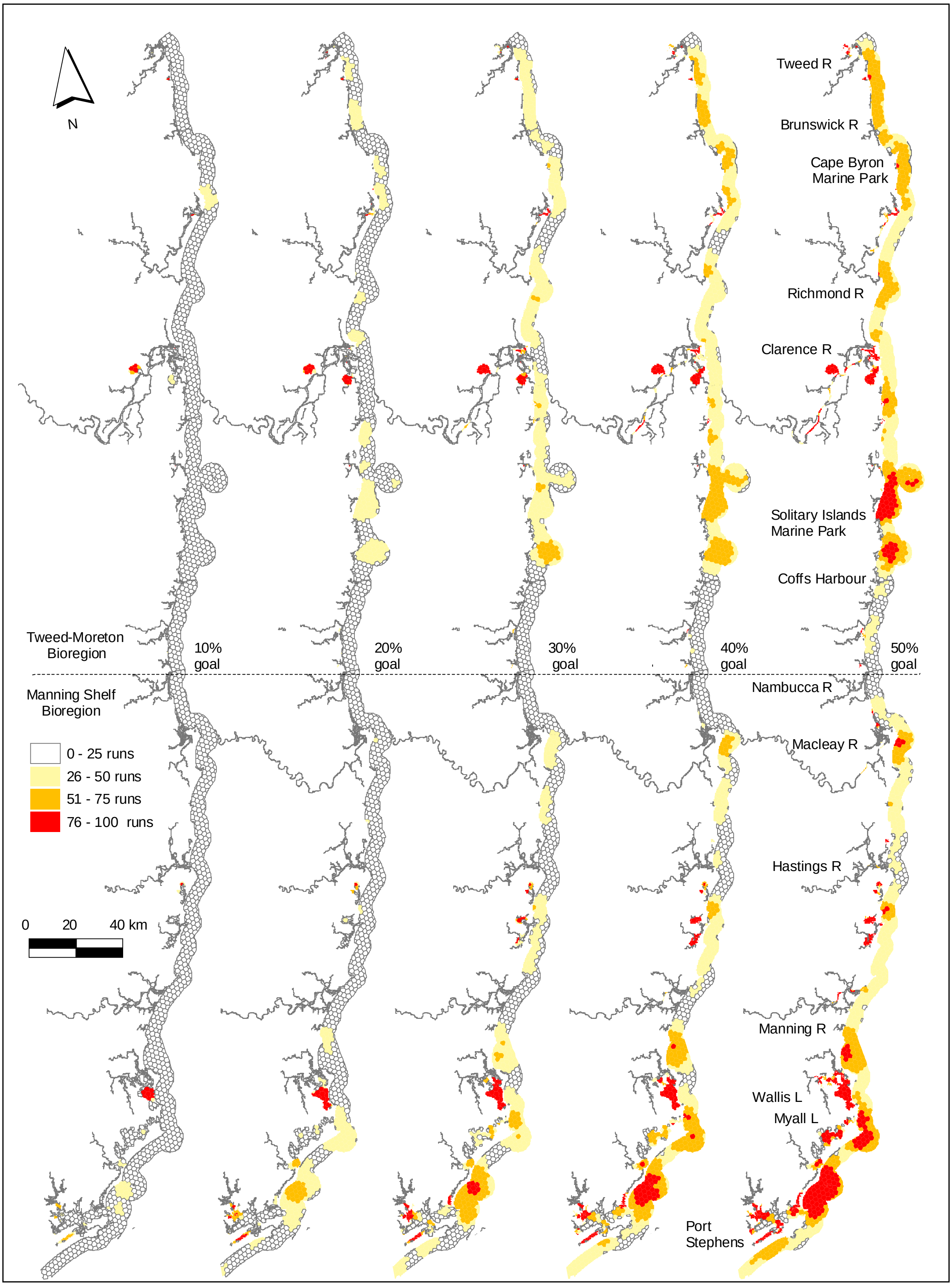

Figure 9.8. Irreplaceability of small scale plan units for northern NSW marine waters within 3 nautical miles calculated using Marxan reserve design software while ignoring marine protected areas already present in October 2005. Colours indicate the number of times a plan unit is selected out of 100 Marxan simulation runs aiming to represent 10, 20, 30, 40 and 50% of all marine ‘ecosystem’ and ‘habitat’ classes for each marine bioregion in a reserve system while minimising the cost in the total area and boundary length.

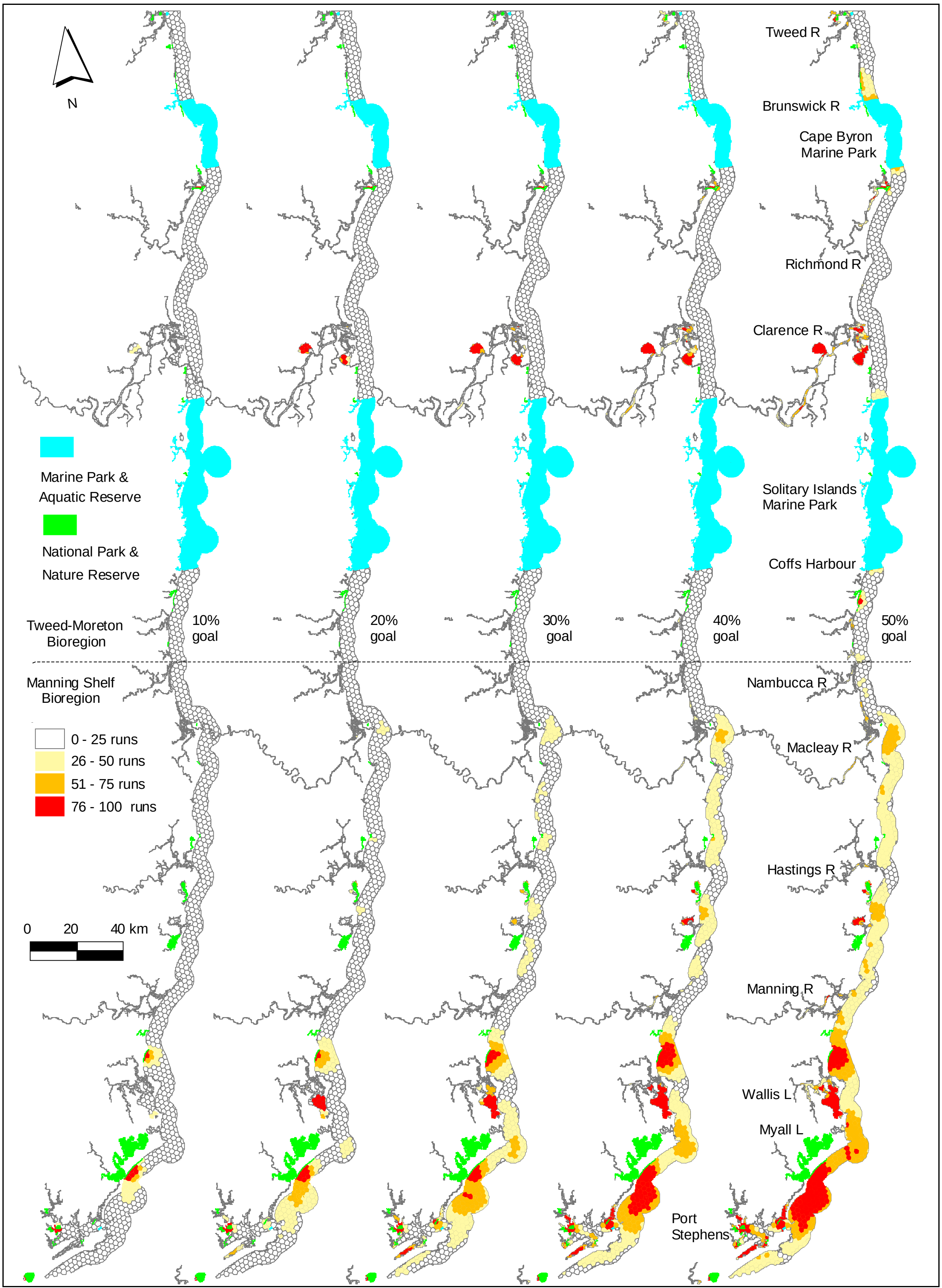

Figure 9.9. Irreplaceability of small scale plan units for northern NSW marine waters within 3 nautical miles calculated using Marxan reserve design software while including marine protected areas present in October 2005. Colours indicate the number of times a plan unit is selected out of 100 Marxan simulation runs aiming to represent 10, 20, 30, 40 and 50% of all marine 'ecosystem' and 'habitat' classes for each marine bioregion in a reserve system while minimising the cost in the total area and boundary length. Note that these areas do not indicate the extent of any MPA system, only the degree to which areas are likely to represent all environmental classes in the smallest, most compact space.

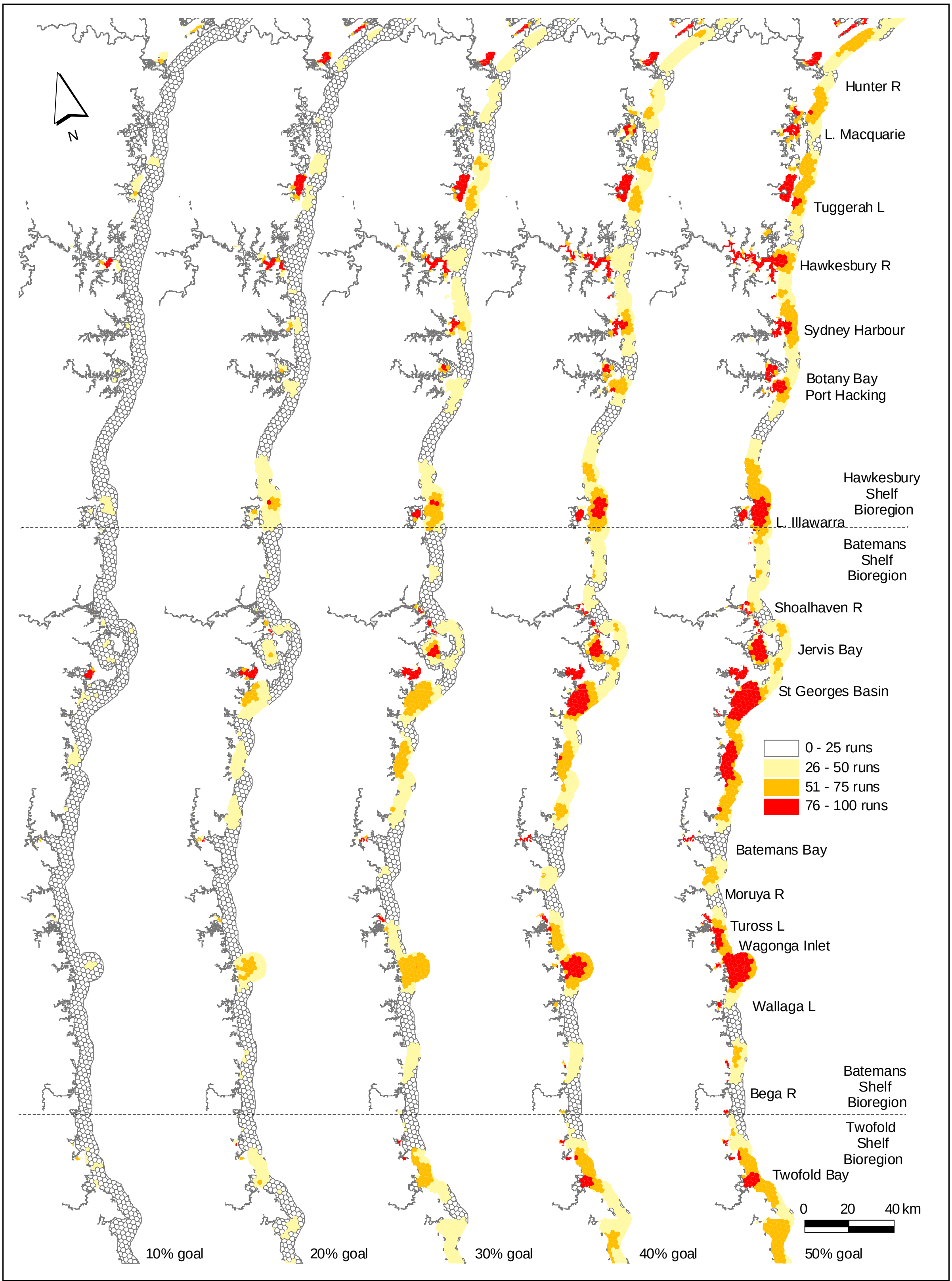

Figure 9.10. Irreplaceability of small scale plan units for southern NSW marine waters within 3 nautical miles calculated using Marxan reserve design software while ignoring marine protected areas already present in October 2005. Colours indicate the number of times a plan unit is selected out of 100 Marxan simulation runs aiming to represent 10, 20, 30, 40 and 50% of all marine ‘ecosystem’ and ‘habitat’ classes for each marine bioregion in a reserve system while minimising the cost in the total area and boundary length.

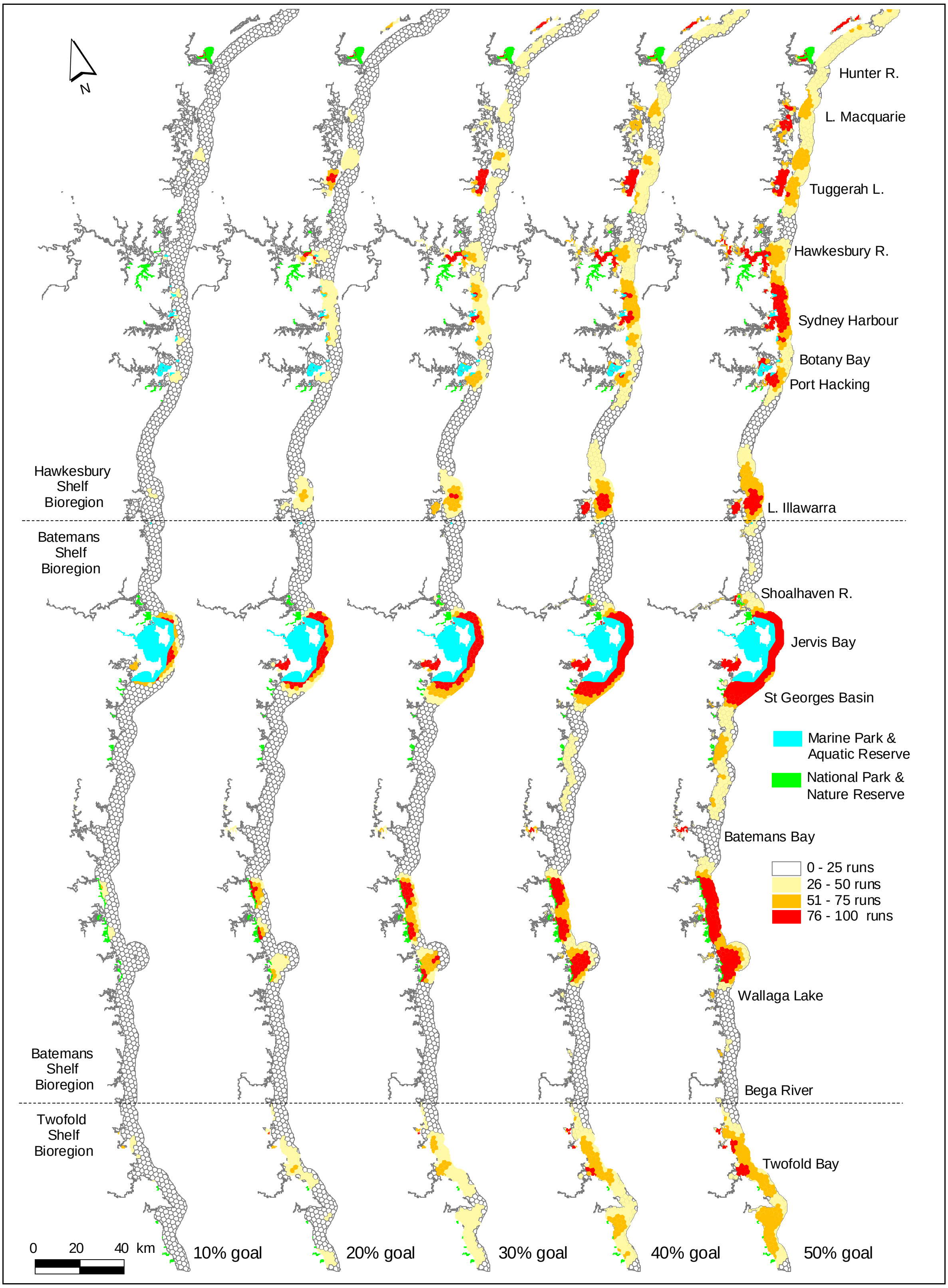

Figure 9.11. Irreplaceability of small scale plan units for southern NSW marine waters within 3 nautical miles calculated using Marxan reserve design software while including marine protected areas present in October 2005. Colours indicate the number of times a plan unit is selected out of 100 Marxan simulation runs aiming to represent 10, 20, 30, 40 and 50% of all marine ‘ecosystem’ and ‘habitat’ classes for each marine bioregion in a reserve system while minimising the cost in the total area and boundary length. Note that these areas do not indicate the extent of any MPA system, only the degree to which areas can contribute to representing all environmental classes in the smallest, most compact space.

9.3.3 Multiple criteria models for MPA planning in NSW

Figure 9.12 - Figure 9.14 show the hierarchical structure of a multiple criteria model built to assess options for marine parks in the Hawkesbury, Batemans and Twofold Shelf marine bioregions. The model assesses MPA goals as a function of criteria, priorities and performance scores for nine hypothetical, large marine parks using the data sets described in Chapters 6, 7 and 8 and in Breen *et al* (2003, 2004, 2005,2006). For clarity, the entire model is displayed over three separate pages for the major criteria of comprehensiveness, representativeness, adequacy and potential costs for alternative human activities.

Comprehensiveness (Figure 9.12) is measured (according to definitions stated in Chapter 2) as the extent of different 'ecosystems' and 'habitats' in each marine park option expressed as area in square kilometres and as a percentage of the bioregion. Each option is also scored by the highest site irreplaceability for the whole estuaries and sections of coast and ocean in each option.

Representativeness (Figure 9.13) is assessed as a function of a range of measures for endangered Grey Nurse Shark, commercially caught fish species, juvenile fishes surveyed by seine net from estuary shores, threatened species, shorebirds, seabird breeding colonies, rocky shore biota and scores from various previous conservation assessments.

Adequacy (Figure 9.14) is estimated from the results of previous conservation assessments and indices of condition based primarily on the condition and use of adjoining lands, catchments and river systems.

The potential cost (Figure 9.14) to alternative human activities is defined very approximately as the area of each option, the percentage of the total area of the bioregion, and as the total ocean or estuarine commercial fish catch for the ports and estuaries in each option.

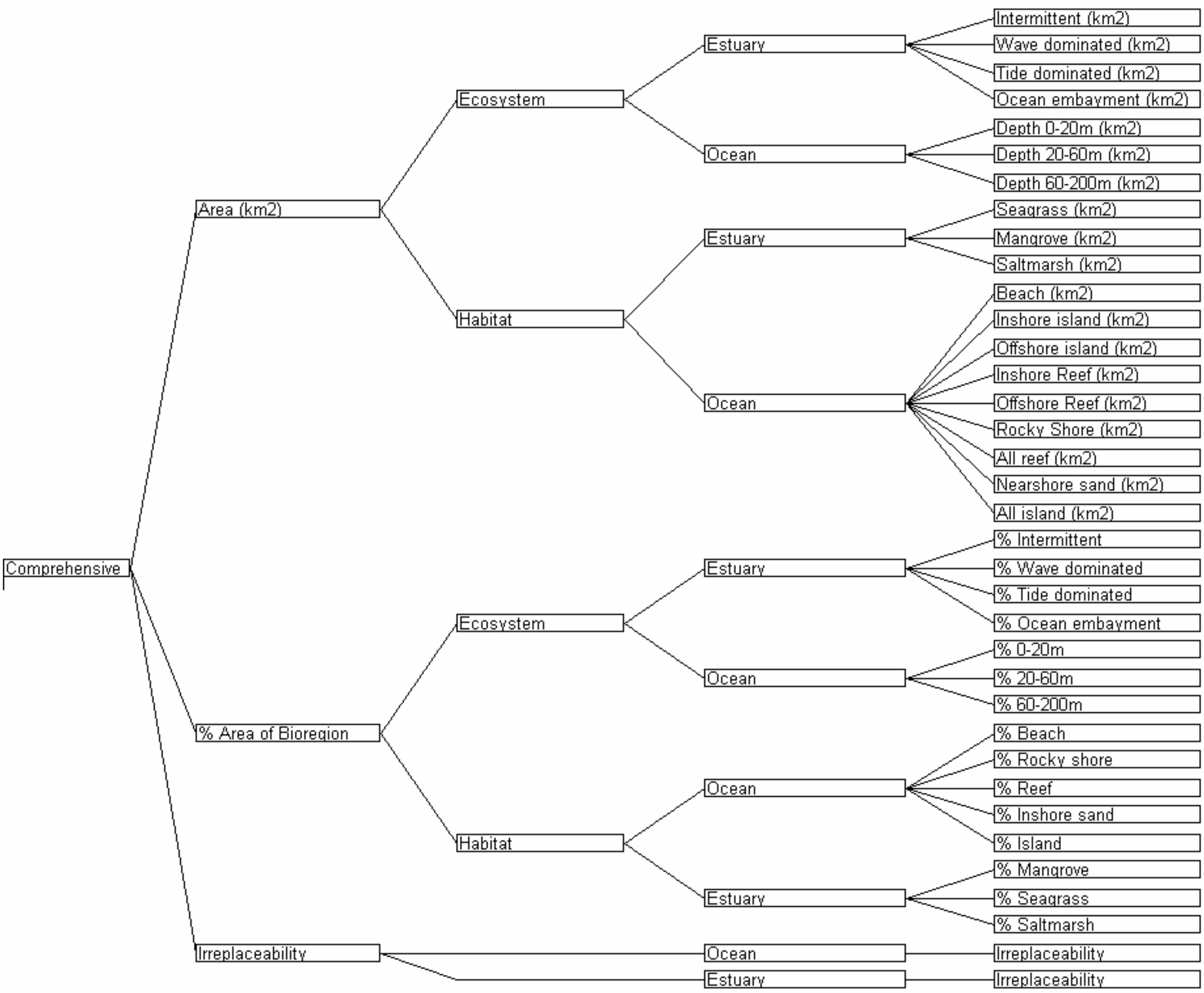

Figure 9.12. A multiple criteria model representing broad marine protected area goals (left hand side), intermediate criteria (centre) and detailed performance indicators with attached data scores (right hand side) to assess the ‘comprehensiveness’ of nine options for large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions. The model was built using the software Criterium Decision Plus™ (InfoHarvest 2000).

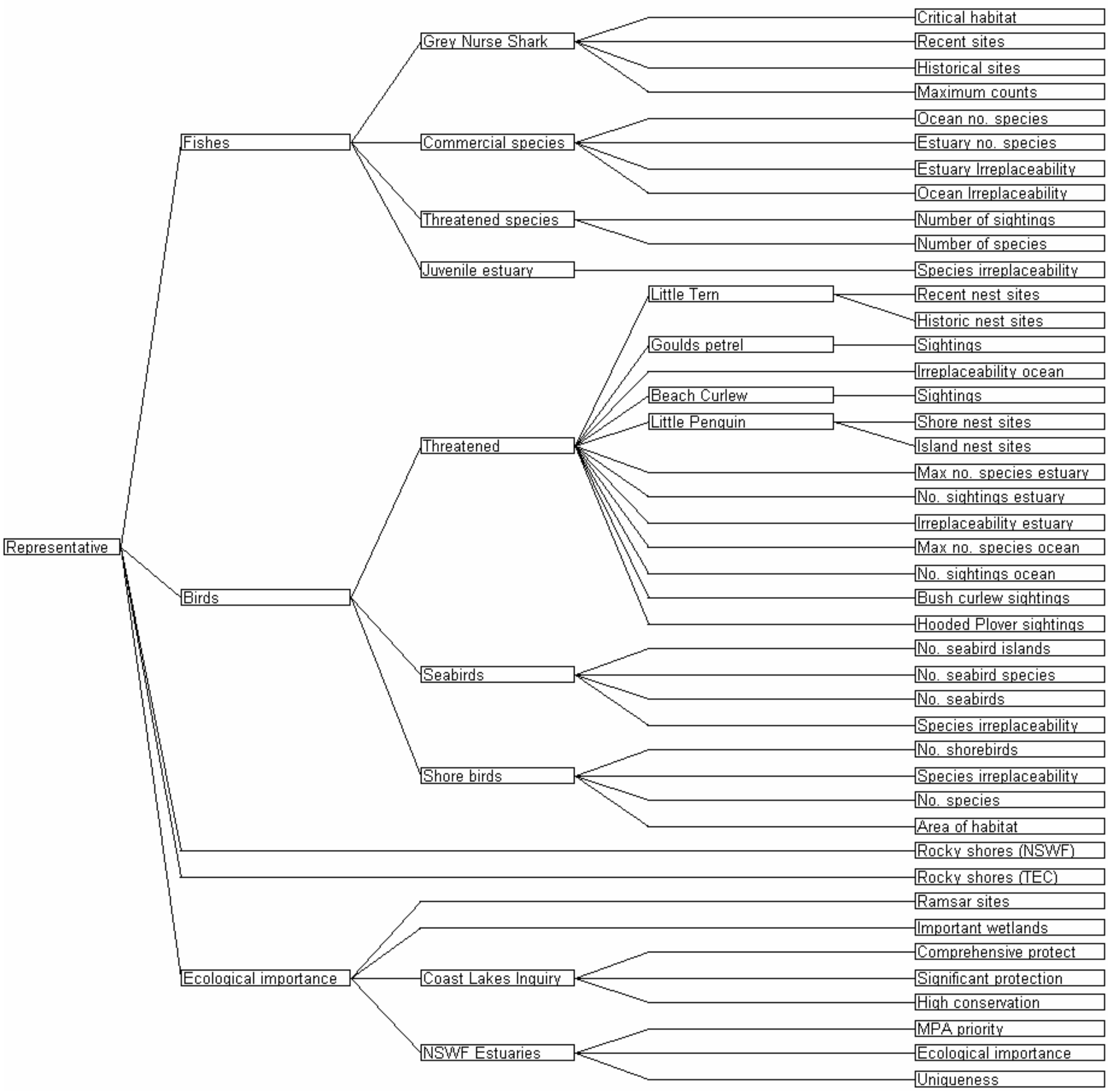

Figure 9.13. A multiple criteria model representing broad marine protected area goals (left hand side), intermediate criteria (centre) and detailed performance indicators with attached data scores (right hand side) to assess the 'representativeness' of nine options for large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions. The model was built using the software Criterium Decision Plus^{TM} (InfoHarvest 2000).

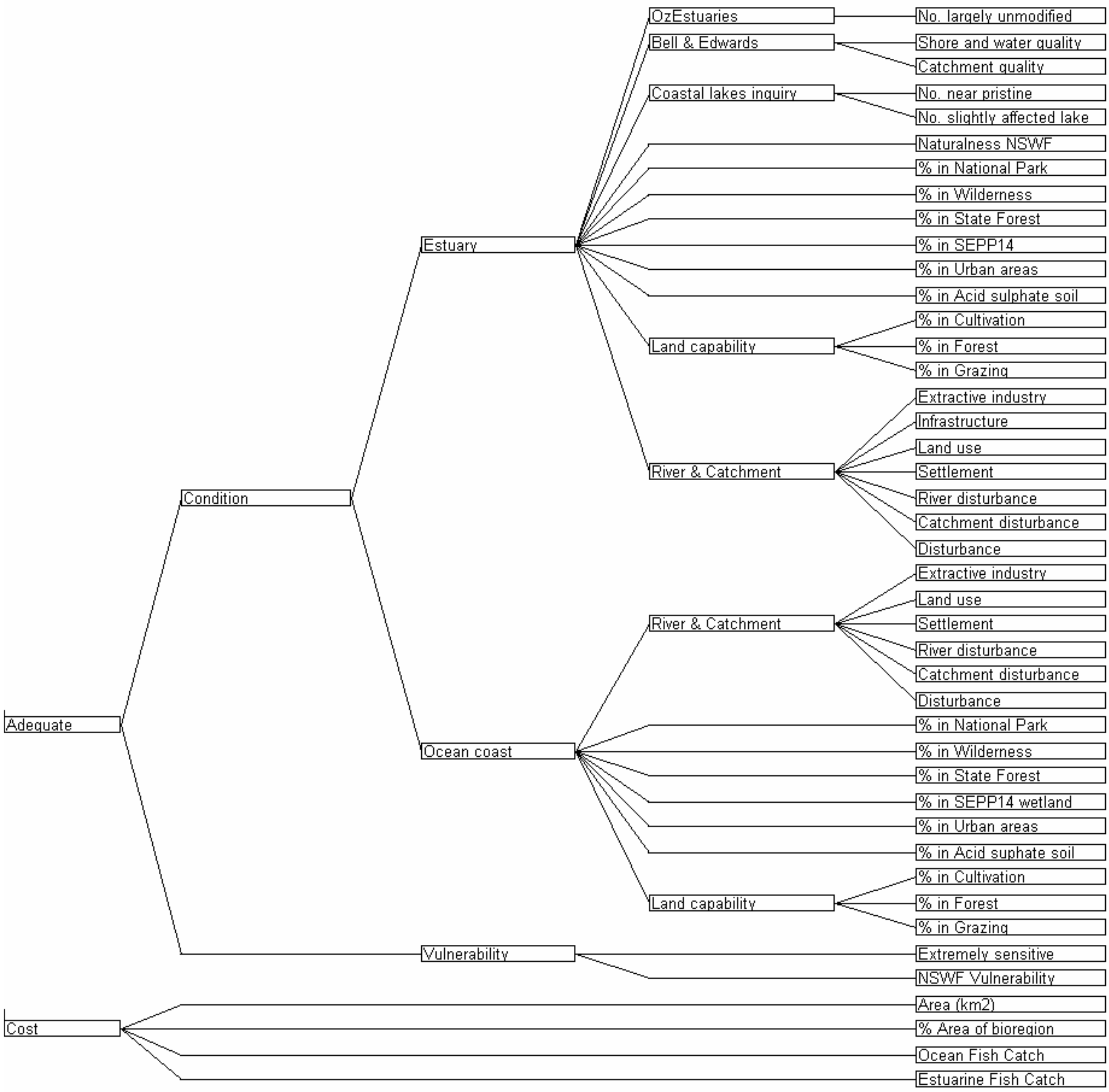

Figure 9.14. A multiple criteria model representing broad marine protected area goals (left hand side), intermediate criteria (centre) and detailed performance indicators with attached data scores (right hand side) to assess the 'adequacy' and 'cost' of nine options for large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions. The model was built using Criterium Decision Plus™ (InfoHarvest 2000).

It is possible to weight the importance of all criteria and data in the models according to different opinions or estimates of the reliability or relevance of the data. However, for simplicity, only results for a few scenarios are displayed here. Options for the marine parks were assessed with all criteria weighted equally (Figure 9.15) and for scenarios in which the four main criteria were weighted separately to exclude the influence of the other main criteria.

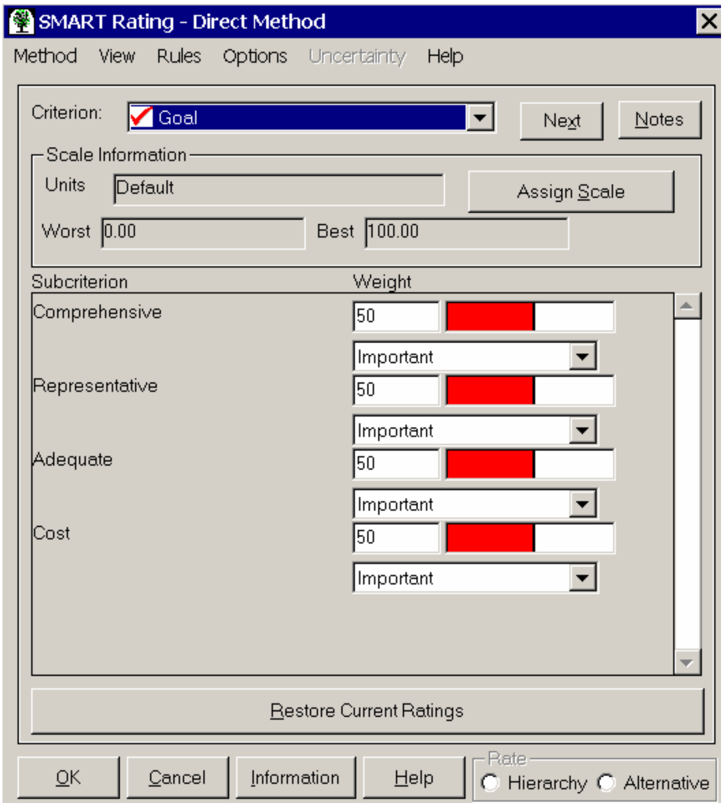

Figure 9.15 Interactive priority weighting for the four main MPA selection criteria in Criterium Decision Plus with all criteria weighted equally.

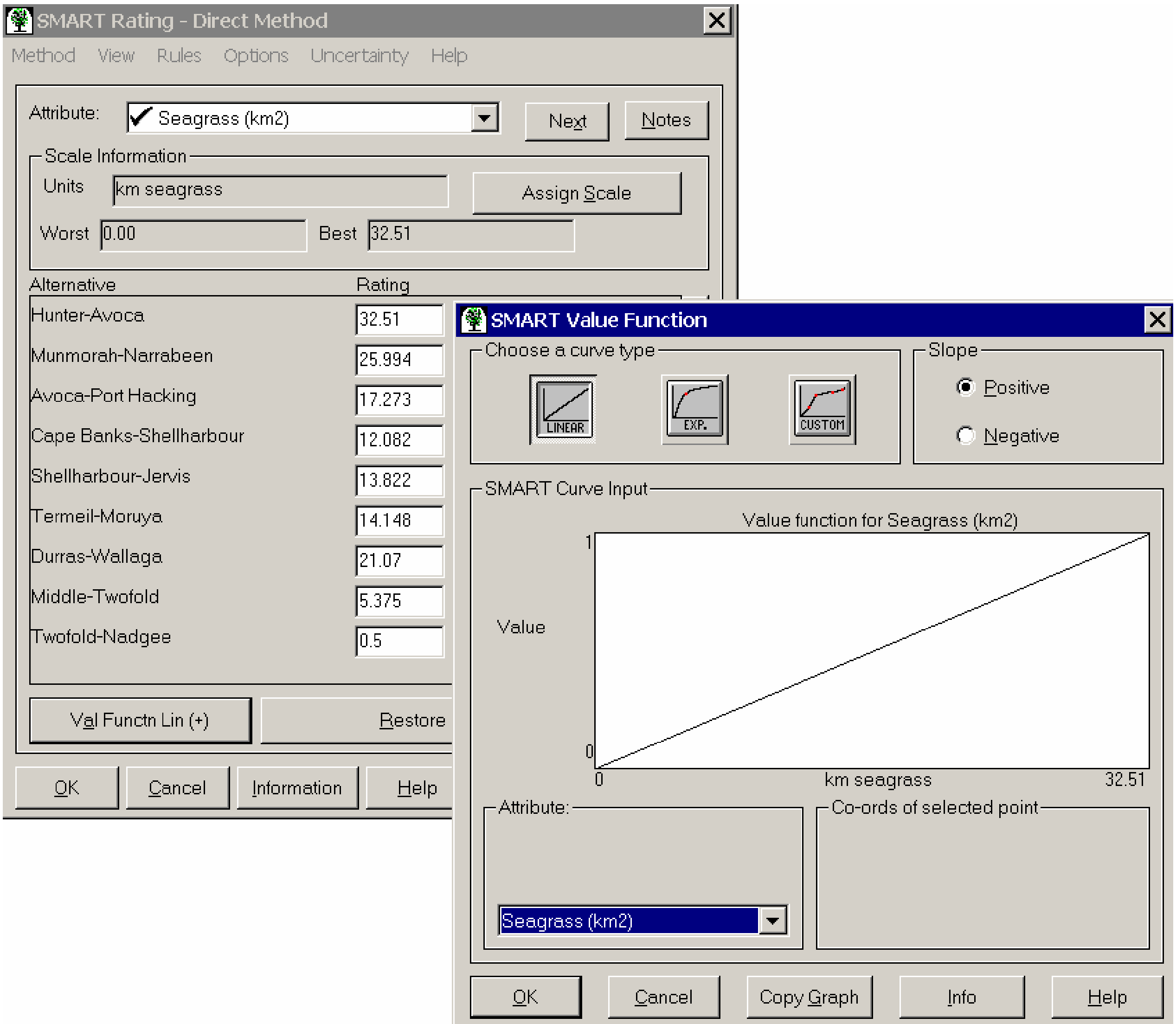

Figure 9.16. Individual scores for each marine park option assessed against area of seagrass in Criterium Decision Plus, with the measure modelled as a linear value function. Where appropriate measures can also measured as other exponential, custom or negative (e.g. cost) functions.

Figure 9.17 shows some aggregate multiple criteria scores for nine marine park options in meeting the primary goal of selecting a comprehensive, representative and adequate marine park while providing for sustainable use. In the Hawkesbury Shelf marine bioregion, all scores are similar, although the L. Munmorah to Narrabeen L. option scores highest.

These aggregate scores however, mask tradeoffs between estimated cost and biodiversity values. The Hunter R. to Avoca L. option scores highest for comprehensiveness (Figure 9.18) and the Avoca L. to Port Hacking scores highest for representativeness (Figure 9.19). Both of these options also score higher for adequacy (Figure 9.20). The Cape Banks to Shellharbour option however scores least for these criteria but scores best for estimated cost (Figure 9.21) as it occupies less area and its ports have smaller commercial fisheries.

In the Batemans and Twofold Shelf marine bioregions, the Durras L. to Wallaga L. option scores highest overall (Figure 9.17) and for comprehensiveness (Figure 9.18) and second highest for adequacy (Figure 9.20) after the Twofold to Nadgee option. However, this comes at a greater potential cost in area and in the size of the reported commercial catches landed in the area (Figure 9.21).

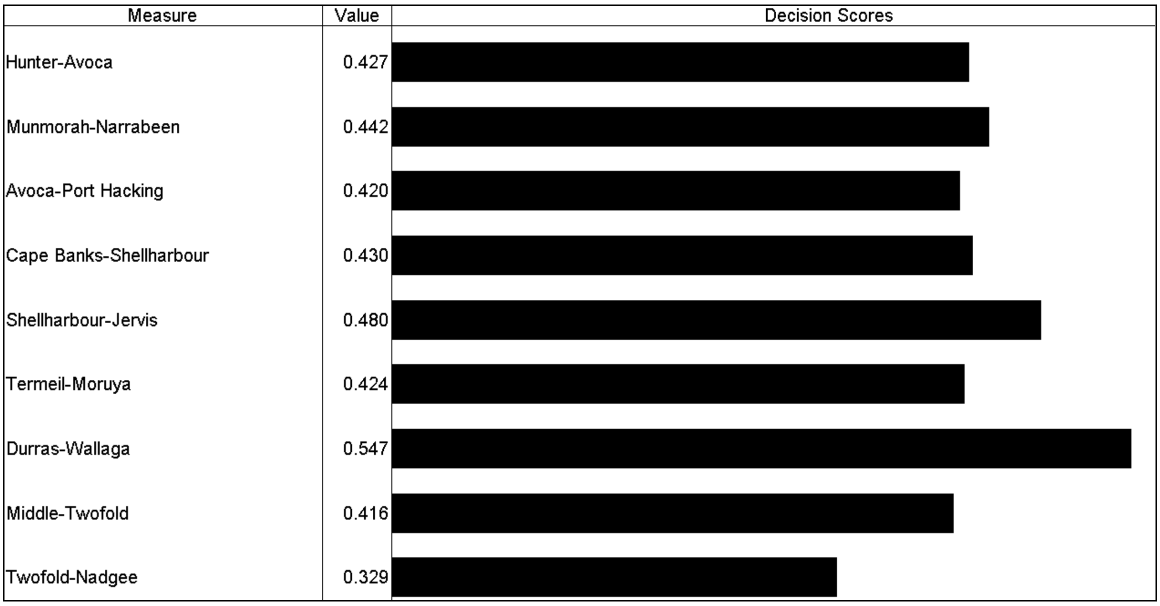

Figure 9.17. Multiple criteria scores for candidate large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions with the main criteria and all sub-criteria weighted equally for comprehensiveness, representativeness, adequacy and cost.

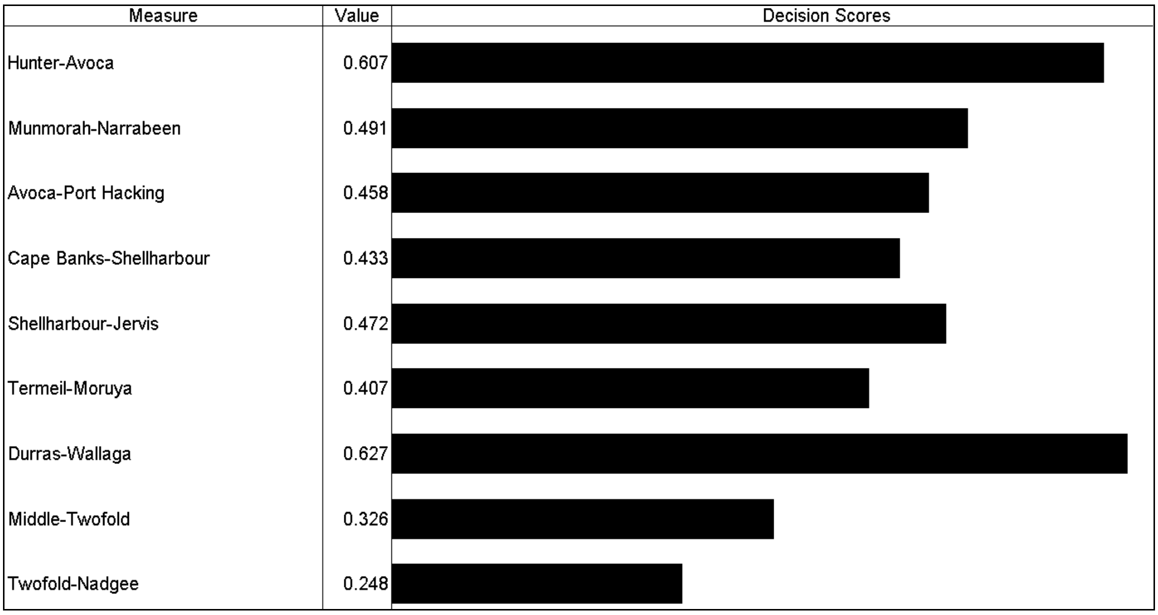

Figure 9.18. Multiple criteria scores comparing options for large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions weighted only for comprehensiveness.

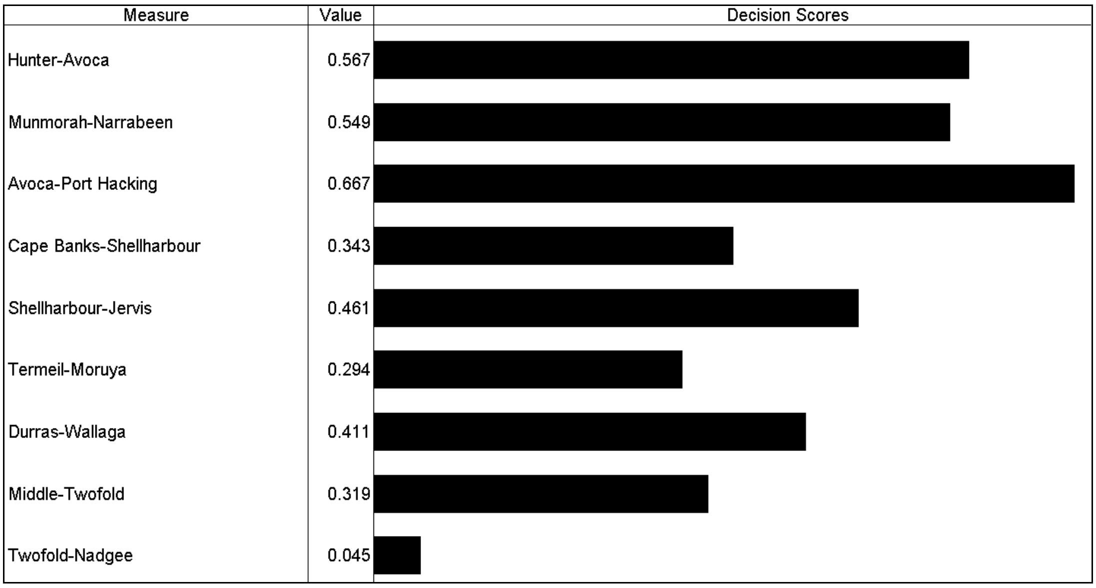

Figure 9.19. Multiple criteria scores for candidate large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions weighted only for representativeness.

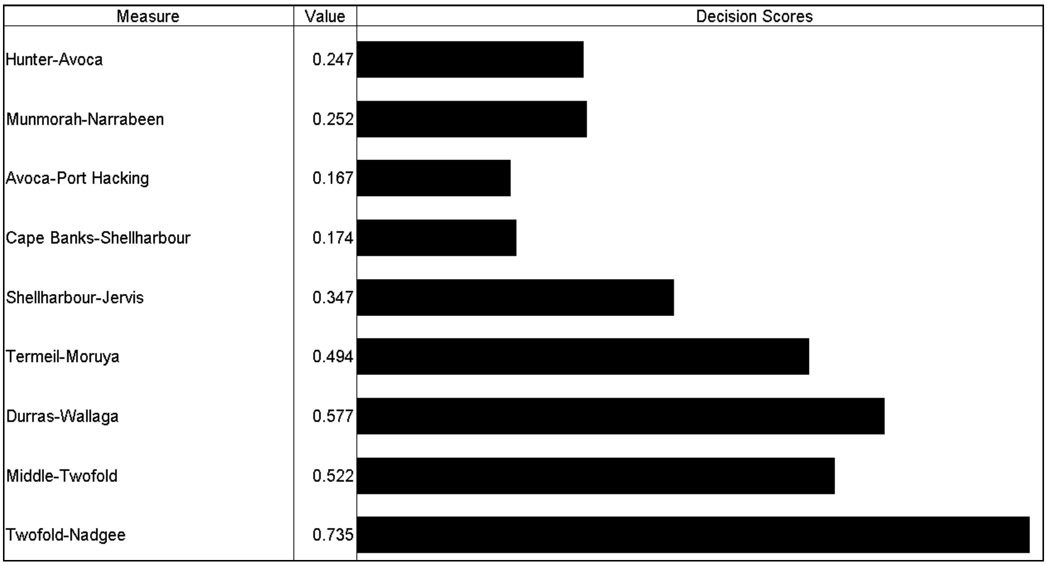

Figure 9.20. Multiple criteria scores for candidate large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions weighted only for adequacy.

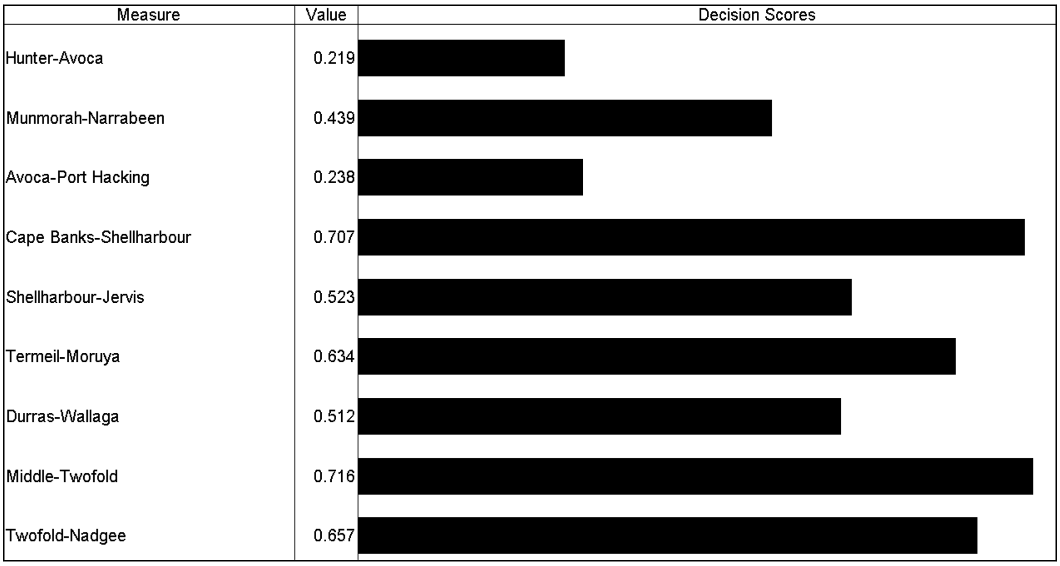

Figure 9.21. Multiple criteria scores for candidate large marine parks in the Hawkesbury Shelf, Batemans Shelf and Twofold Shelf Marine bioregions weighted only for cost.

9.4 Discussion

In this chapter, I integrated many different ecological data sets within ArcView GIS and used C-Plan, Marxan, and Criteria Decision Plus to demonstrate how these models can be used to systematically explore and assess planning options for marine protected areas throughout NSW. A major outcome of the previous bioregional assessments was to identify options for large marine parks. The models developed here provide additional support for the areas proposed and provide another means of selecting and fine-tuning exactly where these and other MPAs are best located.

The C-Plan and Marxan models for NSW marine waters clearly show which areas would most readily increase the representation of ecosystems and habitats within MPAs. In all bioregions, the current system of MPAs fails to meet an arbitrary target of 20% representation for each type of estuary, offshore depth zone and habitat.

The high irreplaceability values in C-Plan and Marxan for the Solitary Islands and Jervis Bay confirms the suitability of these sites for the marine parks established there. It is interesting that similar results were derived from quite different selection approaches and information. The analyses in this study were based solely on broad scale environmental surrogates, while the initial identification of these marine parks were also driven by observations at a species and community level.

Both C-Plan and the Marxan simulated annealing algorithm identify the Clarence River as highly irreplaceable, even when existing MPAs are taken into consideration. This reflects a bias in the selection of MPAs in the Tweed-Moreton bioregion that underepresents barrier estuaries and estuarine habitats such as seagrass beds. This is surprising given that large barrier estuaries are one of the most characteristic features of this northern region. Two large marine parks have now been established in the bioregion, but only the relatively small Brunswick River and some other areas in national park and nature reserve are protected in MPAs. One reason for the underepresentation of barrier estuaries may be the importance of commercial and recreational fishing in these areas. Whether MPAs or other strategies are used, problems with catchment management, acid sulphate runoff, development and the potential for over-fishing indicate that a greater level of estuarine management may be required here.

The high irreplaceability values in C-Plan and Marxan for areas around Port Stephens, Batemans Bay, and Twofold Bay support the MPA options recommended from the bioregional assessments. Large multiple use marine parks have now been established for the Port Stephens - Great Lakes and Batemans Bay areas identified. Options for Twofold Bay however, need to assessed within the context of MPAs established throughout the Victorian and Tasmanian sections of this bioregion.

The high irreplaceability values for several areas in the Hawkesbury Shelf bioregion support the results of the bioregional assessment which recommends a range of different options throughout this bioregion. The simulated annealing simulations also highlight other areas recommended from the assessments including south of the Macleay River, Lake Innes/Cathie, Wallis Lake, several areas throughout the Hawkesbury Shelf bioregion, areas offshore of Jervis Bay Marine Park and the area between the Moruya River, Montague Island and Wallaga Lake .

The multiple criteria analyses in Criterium Decision Plus summarise information for wide range of criteria and highlight the trade-offs in the Hawkesbury and Batemans Shelf bioregions between representing larger and more extensive examples of habitats and ecosystems, representing areas presumed to be in better condition and occupying areas important to interests such as commercial and recreational fishing.

Assessments and proposals have been made for MPAs previously in NSW (Pollard 1980, Parker 1995, Otway 1999, Francis 2000) but few have been as comprehensive in the range of different ecosystems and regions assessed or as systematic in relating objectives to data and planning tools. However, it is likely that the previous studies were based on many years of personal observation and experience with the marine biota of these areas. Pollard identified priority areas for MPAs in NSW and many of these were implemented as aquatic reserves and as the first marine parks in the state. Parker (1995) identified a comprehensive system of marine and estuarine areas that includes large marine national parks and smaller marine nature reserves. Both of these studies used similar information to that available for the bioregional assessments together with many field observations.

There are two major differences between the bioregional assessments and these previous studies. The first is that all the objectives and data used in the recent assessments were explicitly documented and recorded in electronic map formats that could be reviewed, modified and augmented with new data as it becomes available. The second difference is the use of computer based, systematic reserve selection tools to support decisions by presenting alternative planning scenarios and potential outcomes for a range of ecological variables. The differences between this and previous studies are therefore mainly in formatting goals, information and decisions in a framework that can potentially, be accessed by a wider audience that includes future managers, researchers and community interests.

It is therefore not surprising, that Pollard and Parker previously identified many of same areas that rate highly as MPA sites in the bioregional assessments and in the C-Plan, Marxan and multiple criteria analyses. Areas such as the Solitary Islands and Jervis Bay identified by Pollard that are now marine parks include some of the most irreplaceable sites in the state. The similarity in these conclusions, using different sources and techniques, tends to confirm the suitability of these areas as MPAs. However more research into the effects of the established MPAs is required to assess their performance in conserving biodiversity and managing for sustainable use.

The bioregional assessments identified some options for large marine parks. For many areas, implementing these parks will be a major step in establishing a comprehensive network of marine protected areas. However, a fully representative system of MPAs may also require other MPAs to address gaps in protection and protect threatened species, special sites and other local conservation values. The broadscale assessments identified a number of such areas. Other MPAs may also be required to support sustainable fisheries and protect local educational, recreational and cultural values.

As marine parks are established, they are zoned into sanctuary areas where all habitats and species are fully protected, as well as habitat protection and general use zones where a range of fishing and other activities are permitted. It likely that analyses of detailed, fine scale information for ecological, social, economic and cultural values will also be needed here. As more is understood about linkages among and within MPAs and different environments, other sites may also be required to support functioning MPA networks and address new threats. As MPAs are progressively established, the priorities for protecting different habitats and ecosystems will change as a result.

Future marine conservation planning will therefore need to take into account these changes, and continually assess and review progress as MPAs are implemented. The state-wide models developed here can be used to systematically assess the potential impact of new MPAs and estimate how these changes effect priorities for different marine ecosystems, habitats, species and coastal communities. The models can also be used to incorporate new and more detailed information for biodiversity and for social, economic and cultural values.

These systems can also be applied to other related marine and coastal resource management problems including planning for sustainable aquaculture, commercial and recreational fisheries, biosecurity, coastal development and catchment management. There is in fact, an urgent need for a coordinated approach to planning for these often overlapping and competing interests. The integrated systems developed here provide a way to objectively and systematically evaluate different options for competing marine use and to prioritise future research.

The spatial structure of the planning frame and the hierarchical classification of environments provides a foundation on which to build more detailed models of fine scale habitats, species assemblages, human activities and the functional ecosystem processes which link these features. Understanding how MPAs perform and interact with ecological processes and human activities is a challenge rarely addressed in NSW, or elsewhere. However, information and techniques to do this are becoming increasingly available. The virtual landscapes developed here can be used as a foundation for models that explore how ecological processes and reserve networks interact and to design management experiments to test the predictions of scientists and managers.

These spatially explicit marine ecosystem models also provide a realistic platform for community consultation, participation and education. Data for ecosystem, habitat and condition surrogates have already been used in consultation and can be accessed directly from websites designed for this purpose (www.canri.nsw.gov.au).

9.5 Conclusion

The ecosystem and habitat variables used here as surrogate measures of spatial patterns in biodiversity are crude estimates and do not include specific values for the diversity of organisms and processes that make up 'real' ecosystems. The algorithms also do not take into account the many other goals and criteria for MPA design that may be difficult to quantify in numerical analyses. Regardless of how sophisticated these techniques are, they can only interpret the information they are provided with. The analyses should therefore be used cautiously with support from more detailed studies that incorporate a wider range of knowledge, intuition and priorities.

All of examples presented here using C-Plan, Marxan and Criterium Decision Plus are only static "snapshots" from tools designed to interactively recalculate values as different areas are experimentally added or excluded from hypothetical reserve networks. They are exploratory tools that can be used with participation by different users with different points of view. The full potential of this work will only be realised through the use of these tools in consultation with managers, stakeholders and communities. "Participatory GIS" is an approach that has been applied in planning for terrestrial (Pressey 1998) and some marine protected areas (Day *et al.* 2002, Scholz *et al.* 2004, Fernandes *et al.* 2005, Bruce and Eliot 2006, Close and Hall 2006). The following chapter describes a trial of this technique used to assist in developing a draft zone plan for the Cape Byron Marine Park.

10 Geographic Information Tools for Fine Scale Planning in the Cape Byron Marine Park

"How do you know how much to pay if you don't know what it's worth?"

Peter Carey (2006) 'Theft.' Random House, Sydney, Australia.

10.1 Introduction

Planning for marine conservation often involves many ecological and social objectives. Multiple use, marine protected areas (MPAs) aim to manage for many different species, ecosystem processes and human activities. An open and accountable planning process aims to use the best available scientific information to address these goals and to fully involve the knowledge and input of local communities. However collecting and making use of such information is challenging, especially for a wide audience of managers, stakeholders and communities.

The previous chapter discussed a systematic approach to plan the establishment of a broad scale network of MPAs in the state of NSW, Australia. This chapter describes how systematic assessments and participatory GIS (Geographic Information Systems) were used in fine scale planning for the Cape Byron Marine Park. GIS and decision support tools are used to assist community representatives communicate and interpret information on ecological, social, economic and cultural values and select areas in the marine park for different levels of protection. The software tools ArcView, C-Plan, and Marxan are used to integrate information from diverse scientific and anecdotal sources and assist managers and community representatives to develop draft zoning boundaries for the park.

Marine parks in NSW are zoned for multiple use. The zoning aims to manage a range of sustainable human use while protecting some areas from extractive activities like commercial and recreational fishing. Once a multiple-use marine park is declared in NSW, a zoning plan is required to define highly protected 'no-take' sanctuary zones where all fishing and collecting is prohibited, habitat protection zones where some forms of fishing are allowed, and general use zones where most sustainable forms of fishing are allowed. This zoning aims to spatially segregate conflicting uses, manage or exclude some of the more potentially damaging activities, create buffers around fully protected zones, and provide a regionally integrated approach to managing networks of marine protected areas.

The location of the Cape Byron Marine Park was identified using information from a broad scale biodiversity assessment of the Tweed–Moreton marine bioregion conducted by Avery (2000). The study, like the bioregional assessments for the Manning, Hawkesbury, Batemans and Twofold Shelf bioregions (Breen *et al.* 2003), relied predominantly on broad scale data for estuary types, ocean depth zones, habitats and some information on species, coastal condition and adjacent land use. The bioregional assessments aimed to identify options for new MPAs on the basis of ecological criteria alone (Breen *et al*. 2003, 2003, 2005, 2006). They were conducted on the assumption that a separate selection process would be required before implementing protection. This would involve a detailed site assessment and consultation with the community to consider social, economic and cultural criteria (NSW Marine Parks Authority 2001, Breen *et al*. 2003, 2004, 2005, 2006).

After the Cape Byron Marine Park was established in 2002, a zoning plan was required to be developed as soon as was practicable. An initial meeting of a Marine Park Steering Group (consisting of officials from the Marine Parks Authority, NSW Fisheries and the NSW National Parks and Wildlife Service) reviewed C-Plan planning models in ArcView using broad scale habitat data. The group agreed to trial these techniques at the fine scales relevant to local planning decisions.

It was however, evident that existing data sources were not detailed enough to assess biodiversity or social, economic or cultural values at the scale required for zoning. This chapter describes how several projects were instigated to collect data at this scale and how this information was integrated within systematic planning tools, and used in participatory GIS workshops by local community representatives and managers.

10.2 Methods

10.2.1 Planning Units

The planning area for the marine park was clipped from the state-wide model of NSW marine waters developed in Chapter 8 using the newly declared northern and southern boundaries of the marine park. An additional boundary to the south was also investigated in relation to a proposed extension to the park. Initial trials were conducted with fine scale (maximum sizes[1] of 1 km^2 and 10 ha) hexagonal planning units in the ‘C-Plan’ conservation planning software (NPWS 2001).

The trial aimed to identify ‘no take’ sanctuary zones representing various percentages of broad scale ‘ecosystem’ (estuary types and ocean depth zones) and ‘habitat’ classes (seagrass, saltmarsh, mangrove, reef, island, rocky shore, beach and subtidal sediments). The planning units used were substantially smaller than the 4 km^2 planning units used in the broad scale bioregional assessments as the Cape Byron Marine Park Steering Committee indicated that smaller units would be required to model fine scale planning decisions within the park.

These exercises provided approximate models of irreplaceability throughout the marine park and an initial opportunity to model different scenarios for zone plans. The models were also useful in subsequent negotiations when community representatives requested estimates of levels of representation within a bioregional and state-wide context. Ultimately, even these fine scale plan units were too coarse to accurately define detailed zone boundaries for community representatives and detailed editing of vector-based polygons was required during workshops.

[1] Size is a maximum as planning units adjoining the coast and other marine park boundaries are only parts of hexagons.

10.2.2 Biodiversity surrogates

Initial community consultation indicated that the broad scale data collected for the bioregional assessments were not sufficiently detailed to designate zones within the marine park and that information collected at finer spatial and taxonomic scales would be required. It was also apparent that there were gaps in the coverage of mapped habitats in offshore areas where reefs well known to commercial and other fishers existed (Figure 10.1).

The park's management therefore contracted scientists from the Coastal and Estuarine Cooperative Research Centre (Bickers 2004) to survey offshore benthic habitats and assemblages throughout the entire park using a combination of sidescan sonar and dropped underwater video camera. Recent maps were also available for a detailed classification of shoreline types (S. Banks and D. Scotts pers. comm.), fine scale aerial photograph interpretations of near shore reef (Avery 2000) and estuarine vegetation recently digitized from orthorectified aerial photographs (G. West and D. Morrison pers. comm.)

Attributes from the survey of shoreline types were transferred from an original linear coverage to the intertidal polygons derived from the state cadastre for the broad scale models of NSW waters. All of these GIS coverages were then merged and clipped within the marine park boundaries derived from the digital model for state waters developed in Chapter 8. Any overlaps between the data sets were eliminated with priority given to land over intertidal areas, intertidal areas over near shore reefs and near shore reef over offshore areas. This process produced a continuous map of mutually exclusive, fine scale environmental surrogates to represent general patterns in the distribution of biodiversity throughout the marine park (Figure 10.2).

This map provided the primary biodiversity data for consultation and decision making but was supplemented with other more specific data on birds, sharks (Otway and Parker 2000, Otway *et al.* 2003), mammals, reptiles, fishes (R.J. Williams pers. comm.) and invertebrates (Harriot *et al.* 1990).

Measures reflecting the potential condition and vulnerability of areas in the marine park were also made available to decision makers. These were derived primarily from information on adjoining terrestrial areas and included the proximity of adjacent terrestrial national parks and nature reserves, state forest, wetlands, wilderness, land capability, built-up areas, acid sulphate soils, and indices derived from the Australian river and catchment condition database (Stein *et al*. 2000). The results of previous conservation assessments for wetlands (ANCA 1996), estuaries (Bell and Edwards 1980, Digby *et al.* 1998, Frances 2000, Healthy Rivers Commission 2002), rock platforms (Short 1995, Otway 1999) and coastal management plans were also summarised and related to MPA identification and selection criteria.

Many individual research papers, reports and theses for particular sites, species and assemblages in the marine park were also made available (e.g. Smith and James 2003). This information was provided directly to managers and community representatives in digital and paper formats and to the broader community through the marine park website and background documents prepared by Marine Park's staff (NSW Marine Parks Authority 2003). Members of the advisory committee also provided supporting documents including a comprehensive review of the benefits of marine protected areas written by a conservation representative (D. Pugh, unpublished report to the NSW Marine Parks Authority).

10.2.3 Socioeconomic information

Planning for the zone plan also required consideration of social, economic and cultural values. While some information on commercial fisheries, recreation and tourism was available at regional scales, there was very little quantitative information available on the distribution and nature of human activities within the park itself. However, during consultation it was evident that anecdotal information was available from the many stakeholders and communities that frequently used the area.

Recreational users and commercial fishers were therefore surveyed as part of the consultation process for the zoning plan. Maps within the surveys were used to obtain information on the nature and spatial distribution of different activities. The Marine Park's staff circulated surveys for recreational users through all regional newspapers and through many regional clubs, businesses, mail lists and community information meetings. Those communities most likely to have a direct interest in planning the marine park were targeted. As the survey was likely to underepresent people less likely to be directly involved in consultation, random telephone surveys were conducted (CDM Telemarketing) to estimate the types and levels of use in the marine park for all people living in the region. Other independent studies (Boykett in prep., Wellington in prep.) estimated recreational use at different locations and times using visual surveys at different locations in the park.

Surveys mailed to recreational users included a section on demographics, a detailed map of the marine park and room to comment freely on issues of concern. On the map, respondents were asked to draw where they participated in different activities (e.g. fishing, horse riding, and swimming) and indicate how frequently they used these locations.

All commercial fishers licensed to fish in the area were mailed a survey which included a map on which they were asked to draw where different types of fishing were carried out, the types of gear used, the species taken and the approximate average annual catch taken over the last 10 years. This survey was required to supplement the commercial catch data (e.g. Tanner and Liggins 1999) available from mandatory catch reports routinely returned to NSW Fisheries for each legal fishing license. This data is, unfortunately, only reported for zones of one degree of latitude (60 nautical miles). As the marine park spans only 16 nautical miles of latitude, catch records for the area therefore included commercial catch from inside and outside of the marine park. In the voluntary survey, fishers were therefore asked to estimate what proportion of their catch was caught inside the marine park and to map which areas were regularly used. This information was used to identify the fisheries licenses most affected by proposed sanctuary and habitat protection zones and estimate the cost of *ex gratio* payments to ‘buy-out’ commercial fisheries and prevent the displacement of fishing pressure to other areas.

Hand drawn maps from the commercial fishing surveys were digitised by selecting and assigning survey codes and answers to 10 hectare hexagonal planning units in ArcView GIS 3.2 and Microsoft Access using customised macros, Arcview scripts and selection tools. The planning units were identical to those used to represent ecological values in C-Plan and Marxan and this enabled both of these data sets to be linked spatially within the same grid and database. Ecological values and commercial fishing costs could then be integrated in reserve selection algorithms that aimed to represent biodiversity values and minimise ‘buy-out’ costs and impacts on commercial fishing.

10.2.4 Analysis

All data were stored in Microsoft Access relational databases and ArcView GIS shape files. Data on recreational use were linked to medium scale plan units comprised of sections of beach, rocky shore, estuary and major depth zones. Data for broad scale and fine scale biodiversity surrogates, and data from the surveys administered to commercial fishers were linked to 2,580 fine scale, 10 hectare hexagonal plan units.

The NSW National Parks reserve selection software ‘C-Plan’ (NPWS 2001) was used to estimate irreplaceability for plan units linked to areas of different broad scale and fine scale biodiversity surrogates. Irreplaceability estimates ‘the likelihood that an area will be required as part of a conservation system that achieves a set of given ‘feature targets’ (Pressey *et al.* 1994). It represents the ‘complementary’ value of a site to a reserve network and is related not only to the area of different features (e.g. species or habitats) a site includes, but to how that site can complement the range of features already represented in the network.

Marxan, the simulated annealing software adapted for the Great Barrier Reef Marine Park Authority (Ball and Possingham 2000, Day *et al.* 2000) was trialled during planning workshops by Matthew Watts (then NSW National Parks and Wildlife Service). I then later used this software to explore the range of different scenarios presented here in this chapter. Marxan was used to model reserve networks representing targeted percentages of each environmental class in a zone while minimising boundary length and costs measured as square metres of reserve or the number of commercial fishery entitlements reporting use of a planning unit.

As the results of combining different parameters and coefficients are sensitive to the units used, trials were run for a range of different targets and coefficients. The algorithm was run one hundred times for each combination of percentage targets (10%, 20%, 30%, 40% and 50%) and boundary length modifiers (blm) for cost measured as the area in m^2 (for blm=1, 10, 100, 500, 1000) or cost measured as the number of fishing commercial licenses (for blm=0.001, 0.01, 0.1, 1, 10).

Each run involved 1 million iterations with 10,000 temperature decreases using the adaptive cooling schedule provided in Marxan and a species penalty factor of 1. Boundary length modifiers were selected that minimized boundary lengths and costs while meeting at least 90% of each environmental target by assessing:

- scatter plots of cost against boundary length (adapted from McDonnell *et al.* 2002)
- maps of the 'best' solution of plan units and
- maps of how frequently plan units occurred in near-optimal solutions generated from 100 repeated runs of the algorithm.

Simulations were then run 100 times for each set of biodiversity targets (10, 20, 30, 40 and 50%) and for cost modelled as area (m^2), cost as the number of licenses for all types of commercial fishing and costs as the number of licenses for each individual fishery including: prawn trawling; spanner crab trapping; line fishing; purse seining (live bait for tuna fishing); and beach hauling. The frequency with which different planning units occurred in 100 solutions for each target and cost were then mapped in ArcView GIS.

10.2.5 Community workshop

Data and printed maps were provided to stakeholder and community representatives and to the general community during consultation. Technical assistance with data and GIS tools was provided to community representatives to manipulate and display information, and to help draw maps of initial zoning options. Objectives and criteria, information sources, decision support tools and the zoning process were discussed at several advisory committee meetings for the marine park. This committee aimed to provide advice to the Marine Park Authority and to the NSW government to represent the views of commercial and recreational fishers, conservationists, divers, tourism, local councils, marine scientists, indigenous interests and other users.

A two day workshop with the Cape Byron Marine Park Advisory Committee was then held with the aim of developing joint options for a draft marine park zoning plan. The workshop was chaired by an independent facilitator and additional technical input was provided, on request, by observers from NSW Fisheries, the NSW National Parks and Wildlife Service, NSW Marine Parks and from individuals with special experience in local fisheries, conservation, diving, tourism, science and the interests of indigenous people.

The facilitator defined clear objectives and terms of reference, coordinated processes to develop and examine options and helped maintain the rights of members to freely express their opinions and ideas in an atmosphere conducive to open discussion and cooperation. Independent facilitation played a major role in the workshop and was necessary to maintain discussion when arguments became contentious.

Data layers, reserve design software and zoning options were displayed on screens and whiteboards in the main workshop using a data projector. Separate rooms with GIS operators were also provided for groups to develop specific planning options. As options and compromises became more detailed, different approaches to mapping and assessing options were required. The context for representation ranged from within the marine park, to within the bioregion and within all state and commonwealth waters. The planning units used included 1 km, 10 ha and 1 ha hexagons. However, during the latter stages of the workshop, GIS operators were required to directly edit individual vector polygons to map and assess detailed zoning options defined at scales of a few metres.

10.3 Results

10.3.1 Fine scale environmental surrogates for Cape Byron Marine Park

Figure 10.1 shows the broad scale environmental surrogates available at the time of the park's declaration. Figure 10.2 shows the fine scale classification developed to help plan zones in the new multiple use marine park. In particular, Figure 10.2 shows detailed maps of offshore reef and sediment habitats provided by Andrew Bickers (Bickers 2004) and Katrina Baxter using sidescan sonar and underwater video surveys.

This technique was used to sample, within a few days, an almost continuous coverage of seabed types within the Cape Byron Marine Park and some surrounding areas. It detected many areas of reef that had not been mapped previously, accurately defined substratum boundaries and identified a diversity of physical and biological features on hard and soft substrata. Drop video surveys within acoustically defined substrata were able to identify distinct biological assemblages and classify surrogate categories within offshore subtidal environments (Bickers 2004). The surveys also identified significant areas of reef to the north and south of the declared marine park (Bickers 2004) that might have been useful in designating the original park boundaries.

The inshore areas of reef in Figure 10.2 are mapped from detailed aerial photo interpretation carried out by Ron Avery as part of the bioregional assessment process. Figure 10.2 also includes data from projects underway at the same time as the zoning process. Over fifteen different intertidal beach and rocky shore classes were identified by Banks and Scotts (pers. comm.) and recent, detailed maps of estuarine seagrass, mangrove and saltmarsh (G. West pers. comm.) were used to update information for these habitats that had last been collected over 20 years ago (West *et al.* 1985).

The continuous coverage and level of precision in these data sets meant that this information could be combined to provide a single, holistic overview of marine environments for the entire marine park. Features in this fine scale environmental classification include:

- seagrass, mangrove and saltmarsh habitats in the Brunswick River and other smaller estuaries
- extensive near shore reefs in Byron Bay and around Cape Byron, Broken Head and Lennox Head
- extensive rocky reefs at a range of depths and coarse sediments around Julian Rocks
- small islands and rocks at Julian Rocks and off Broken Head
- rocky pinnacles between 35 and 50m to the north of Cape Byron
- boulder, platform and rocky cliff areas at Cape Byron, Broken Head and Lennox Head

- an enclosed oceanic lagoon at Lennox Head
- beach types at Brunswick, Belongil, Byron, Tallows, Broken Head and Seven Mile beaches
- tongues of coarse sediment offshore of Tallow and Seven Mile Beaches
- offshore coarse sediment and scattered rocky reef at depths greater than 50m
- extensive fine sand throughout the majority of the marine park (Figure 10.2).

Many of these features were either not evident or only mapped at a limited resolution in previous work (e.g. Figure 10.1). Most of the new data were mapped as a result of recent projects for marine biodiversity conservation (G. West pers. comm., S. Banks and D. Scotts pers. comm.), for the bioregional assessments conducted by the Marine Parks Authority (Avery 2000) or for the Cape Byron Marine Park planning process (Bickers 2004).

10.3.2 Recreation in the Marine Park

Over 1400 volunteers responded to the questionnaire on recreational use of the marine park. Most (93%) were resident in the region. Maps summarising the number of respondents involved in activities at different locations in the park were used to help identify competing recreational, commercial, cultural and conservation interests and develop zoning options to mitigate conflicts. Independent observational surveys by Boykett (in prep.) and Wellington (in prep.) confirmed the spatial patterns in recreational use at the locations where these studies were carried out.

The random telephone survey however reported much lower percentages of respondents using the marine park than indicated by the voluntary questionnaire returns. This difference was apparent for all activities but most evident for activities including whale and dolphin watching, snorkelling and bait collecting (Figure 10.3). This result indicates that the voluntary questionnaire sample may have been biased towards returns from individuals actively using the marine park and reflects more a subset of the local community rather than the general population.

The most frequently reported activities in the marine park were swimming, walking and running, beach going, whale and dolphin watching, surfing and recreational fishing (Figure 10.3). Swimming occurred throughout the marine park but was especially common on beaches in Byron Bay (Figure 10.4), while SCUBA diving was strongly focused around Julian Rocks (Figure 10.5).

Figure 10.6 shows high numbers of recreational fishers reporting use of areas in, and south of the Brunswick River, and at Broken and Lennox Heads. These areas were also identified as locations with high conservation values. As a result, consultation to zone these areas was contentious and required particular attention to meet conflicting demands.

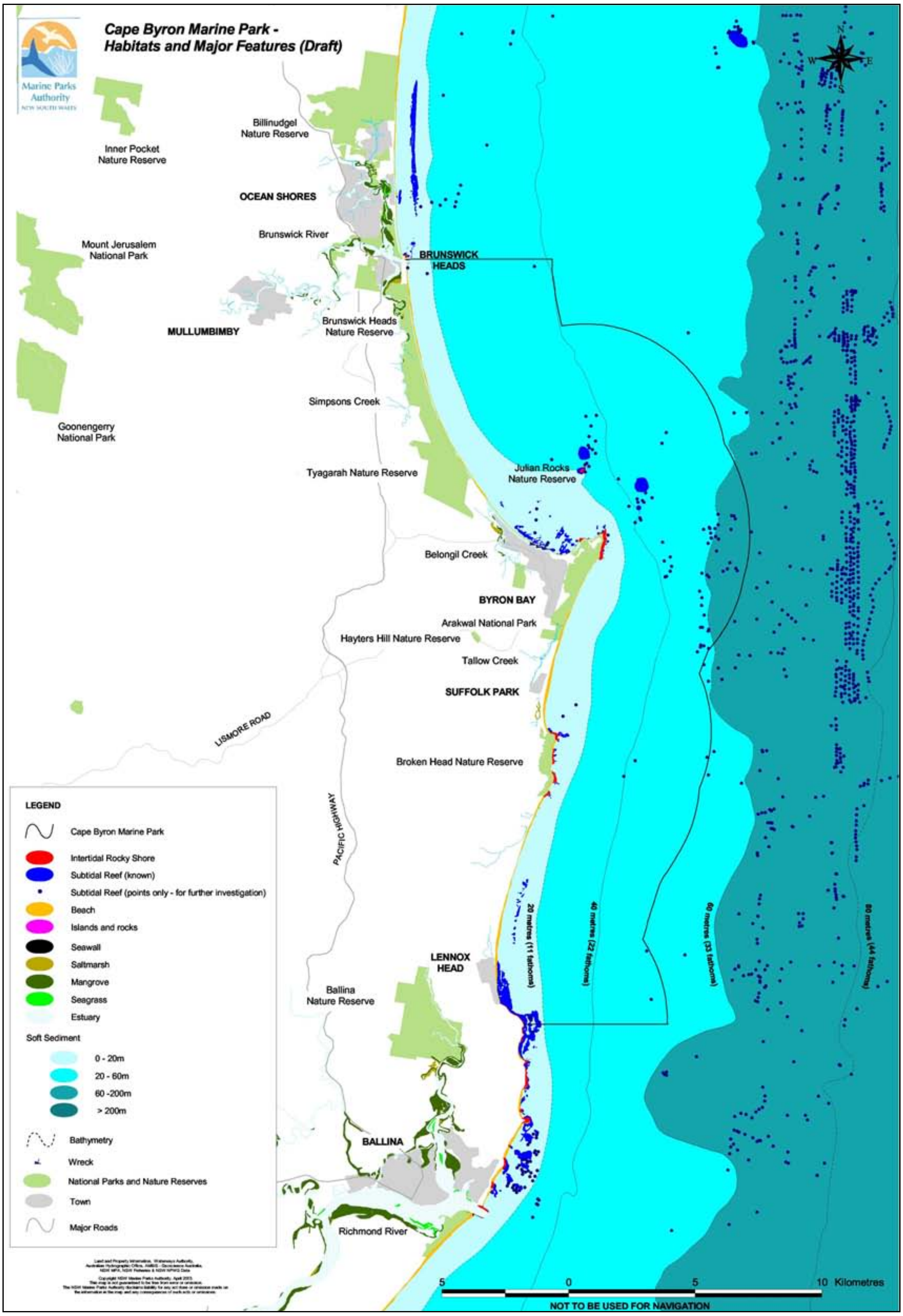

Figure 10.1. Broad scale marine environmental classes in Cape Byron Marine Park. Inshore reefs mapped from aerial photographs by Ron Avery (NSW National Parks). Estuarine vegetation mapped from West *et al.* (1985). Intertidal beaches and rocky shores identified from NSW Land and Property cadastre by Dan Breen and Natalie Taffs (NSW Fisheries). Offshore depth zones from NSW Waterways. Points for hard substrata provided to NSW Marine Parks by local commercial fishers. Map by Vanessa Mansbridge (NSW Marine Parks).

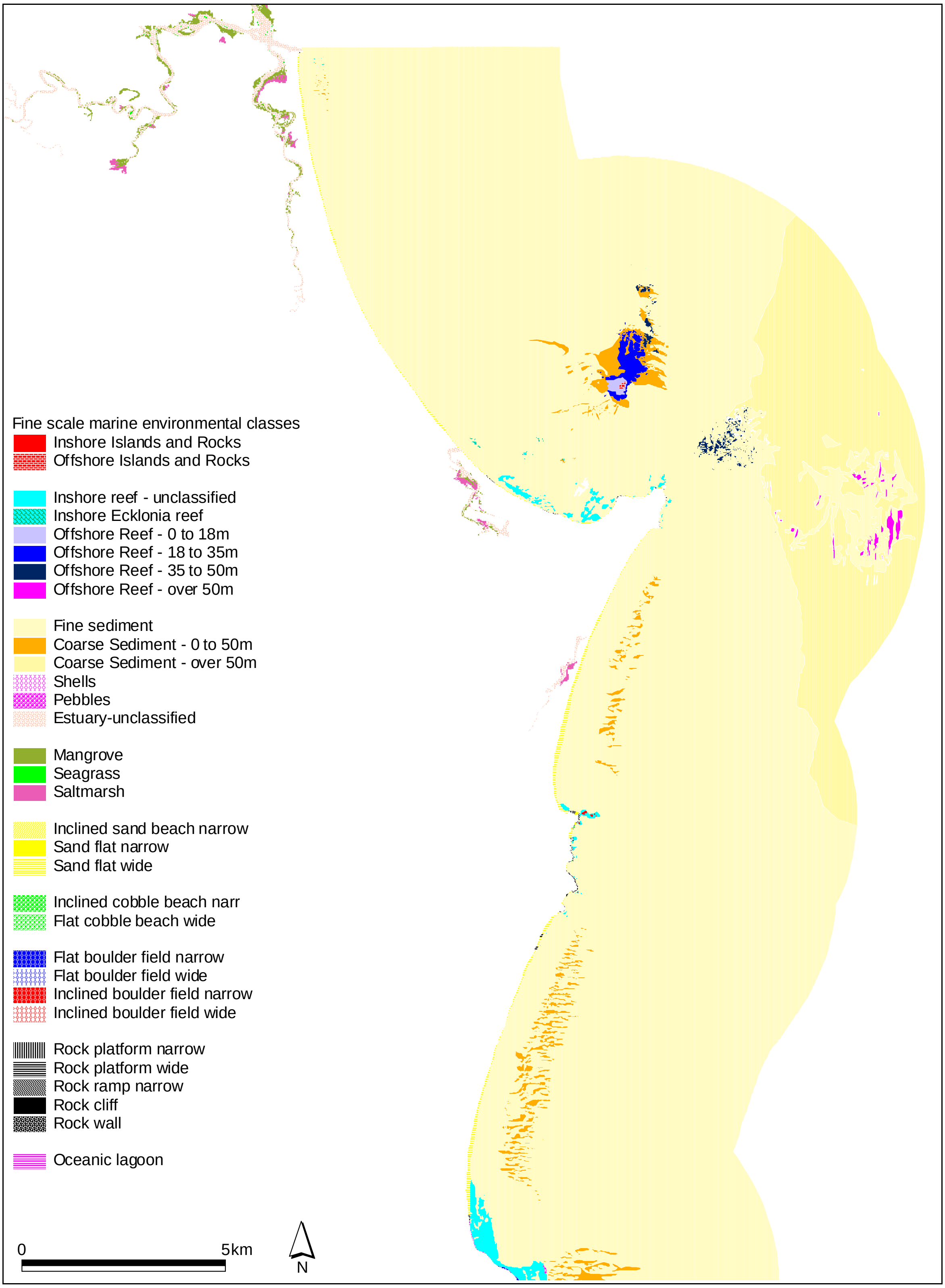

Figure 10.2. Fine scale marine environmental classes in Cape Byron Marine Park. Nearshore reefs were mapped from aerial photographs by Ron Avery (NSW NPWS). Other seabed types were mapped from sidescan sonar, differential GPS and dropped underwater video by Andrew Bickers (University of Western Australia) and Katrina Baxter (University of Melbourne). Shorelines were classified by Simon Banks and David Scotts (NSW National Parks) as line shape files and transferred to polygons of the intertidal zone (D. Breen) derived from NSW Land and Property Information cadastre data. Estuarine vegetation was mapped from aerial photographs by Greg West and Danielle Morrison (NSW Fisheries).

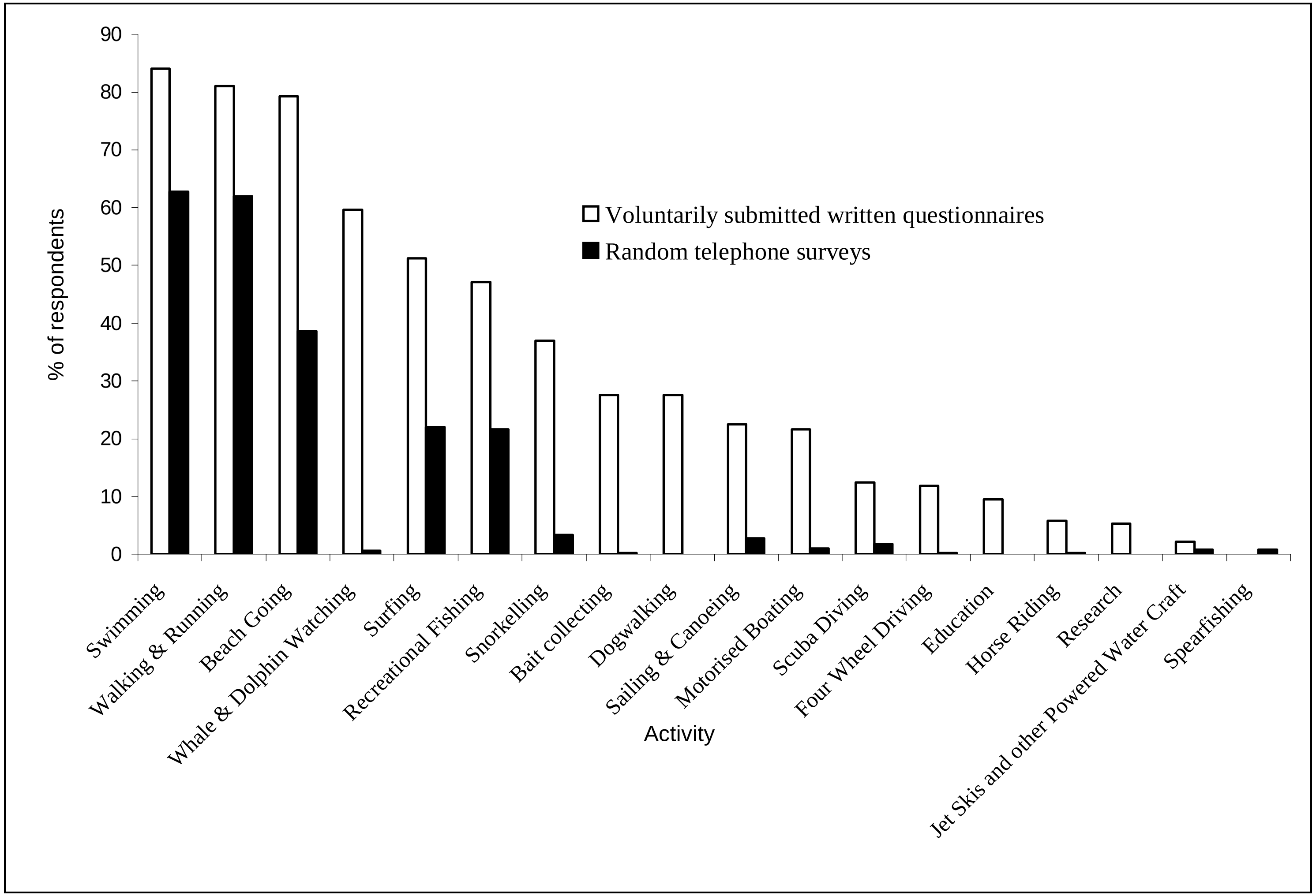

Figure 10.3. Percentage of respondents using the Cape Byron Marine Park for various activities according to a written questionnaire returned voluntarily by respondents (white) and to a random telephone survey of residents in the region (black). Note that percentages add to over 100% as respondents can reply for more than one activity (Telephone survey from CDM Telemarketing, questionnaire data collated by Kellie Lobb and staff of Cape Byron Marine Park).

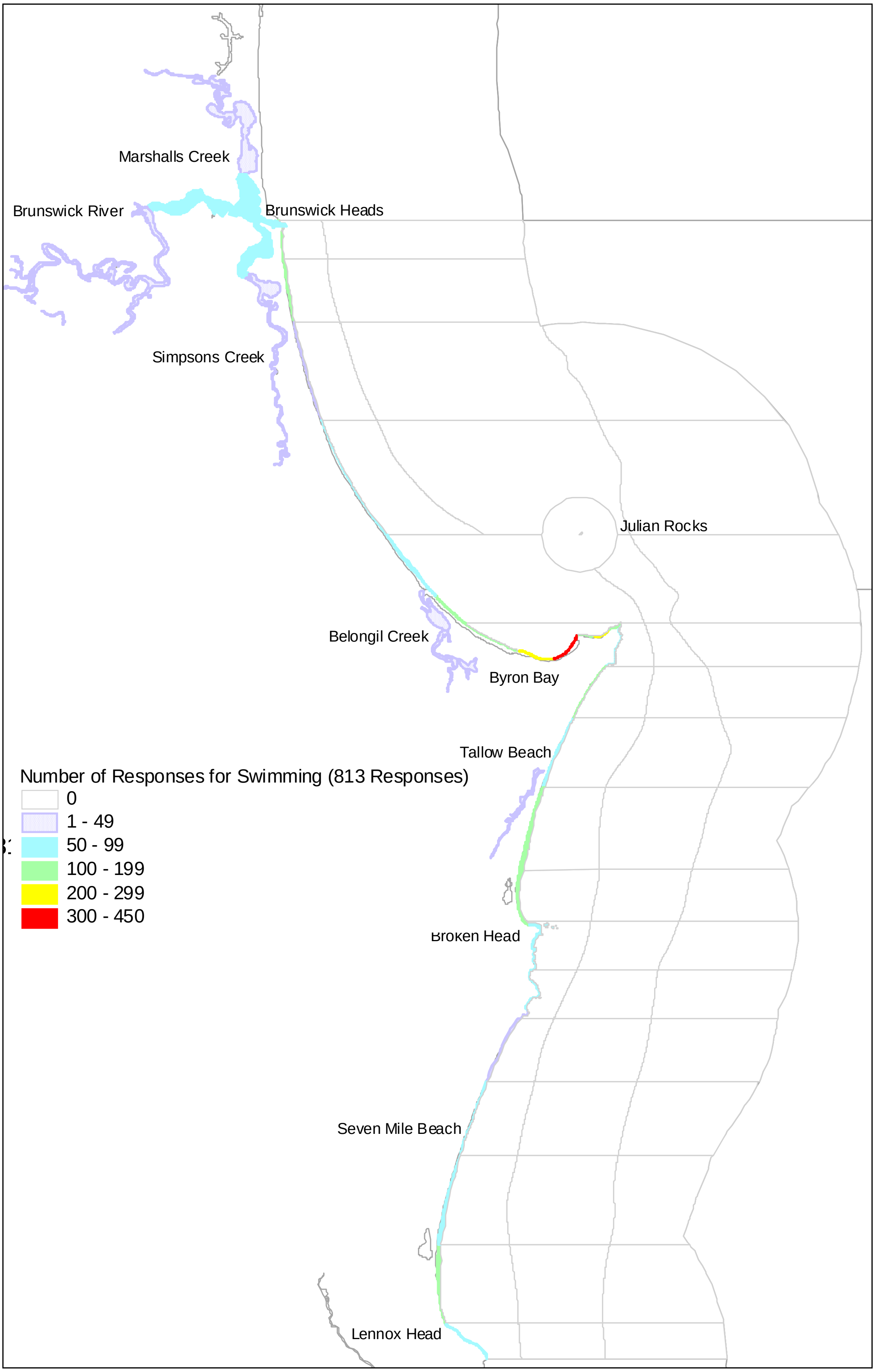

Figure 10.4. Number of questionnaire respondents reporting use of different areas of Cape Byron Marine Park for swimming (map by Kellie Lobb and Dan Breen).

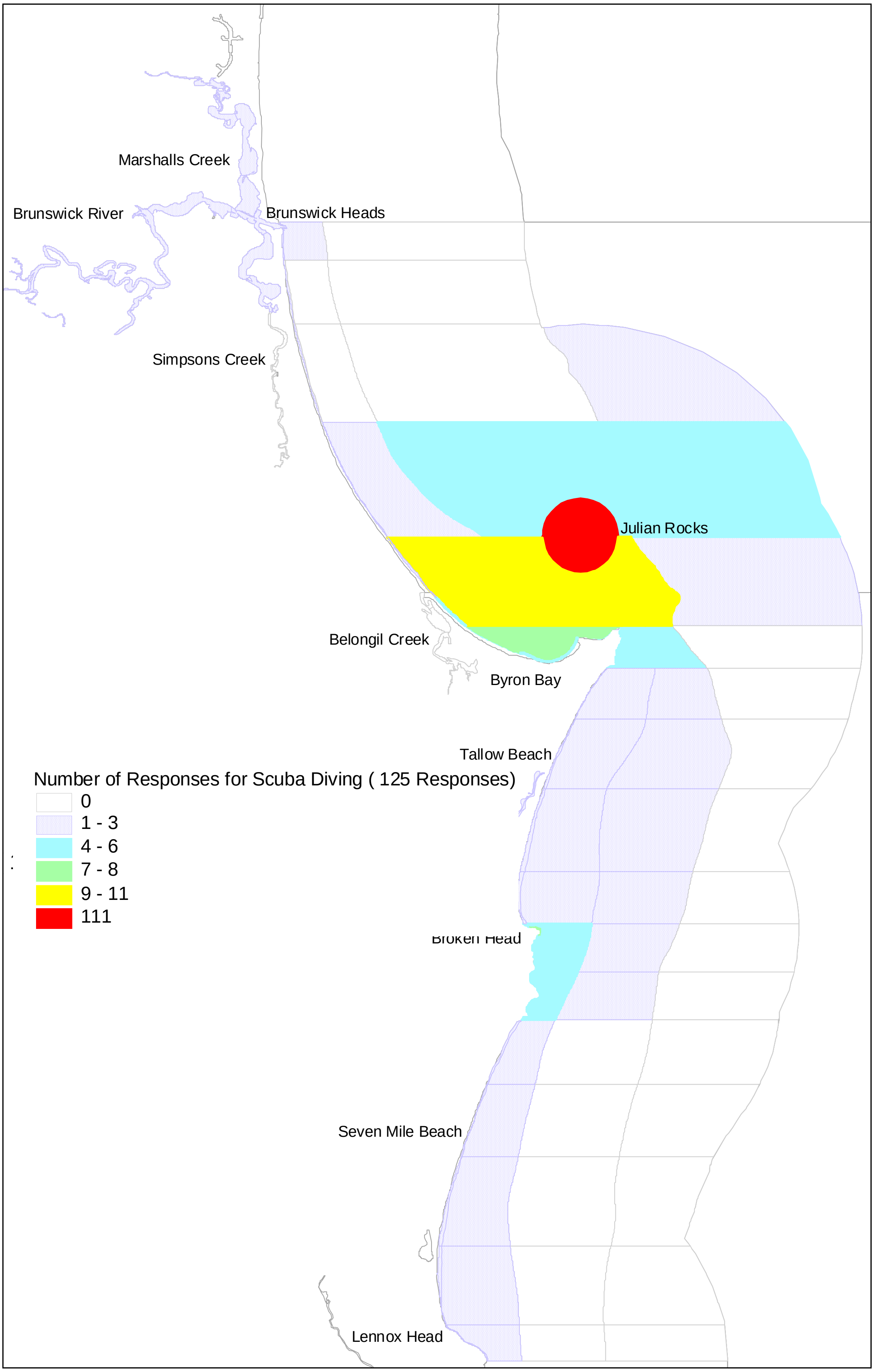

Figure 10.5. Number of questionnaire respondents reporting use of different areas of Cape Byron Marine Park for SCUBA diving (map by Kellie Lobb and Dan Breen).

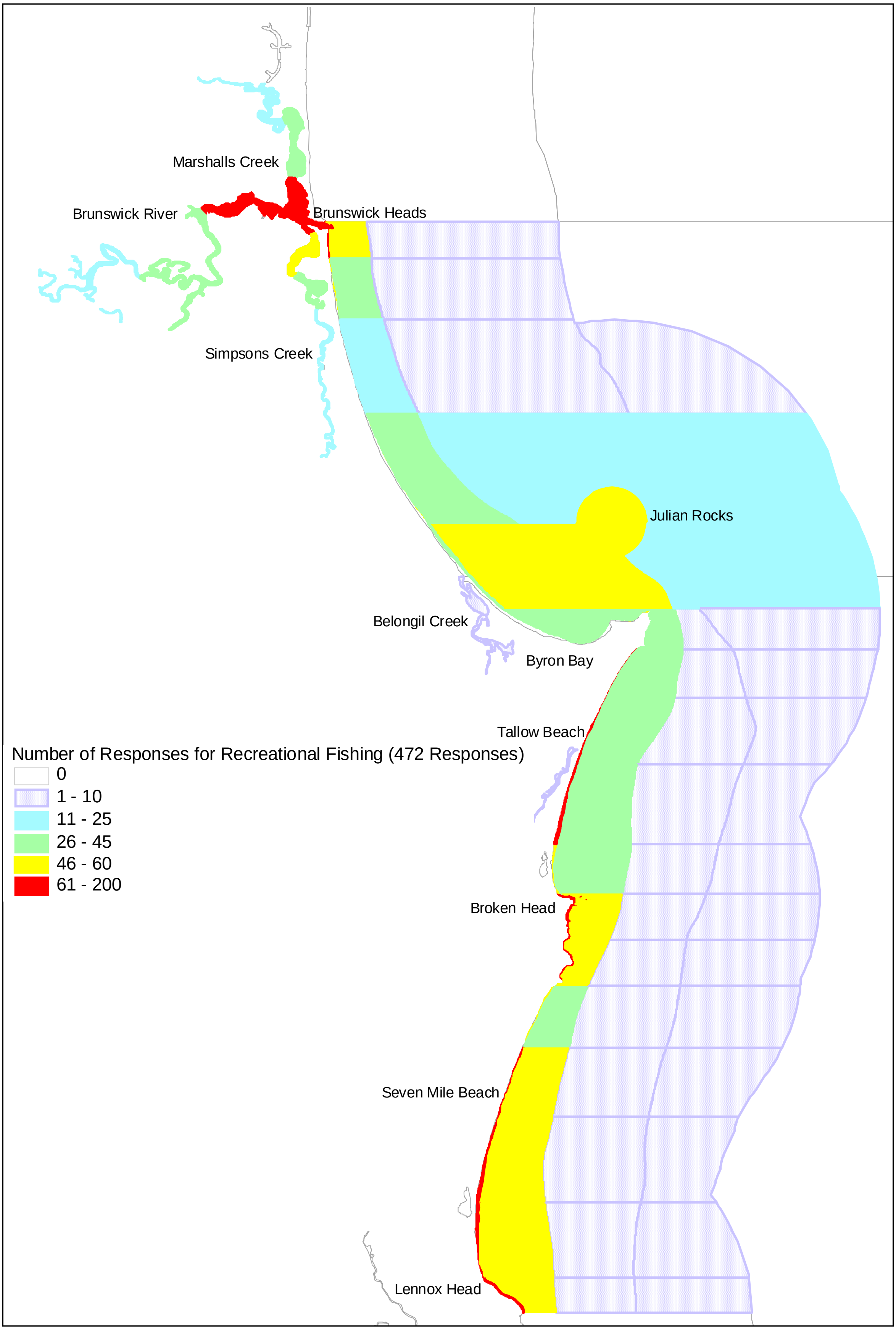

Figure 10.6. Number of questionnaire respondents reporting use of different areas of Cape Byron Marine Park for recreational fishing (map by Kellie Lobb and Dan Breen).

10.3.3 Commercial fishing in the Marine Park

Figure 10.10a to Figure 10.15a show the number of commercial fishing licenses reporting use of different areas in the marine park for prawn trawl, spanner crab, purse seine (live bait for tuna), line fishing, beach hauling and for all fisheries combined. The total for all fisheries also includes licenses to collect pipis (shellfish), mud crab, eels and lobster. Only a few licenses for the latter fisheries operated in the marine park and these are not mapped here.

It is evident that different fisheries favour different locations and habitats in the marine park according to the occurrence of the target species and the methods of fishing. Prawn trawling (Figure 10.9a) and trapping for spanner crabs (Figure 10.10a) occurred most frequently in offshore areas south and north of Cape Byron. Purse seining (Figure 10.11a) for live bait occurred mainly in sheltered inshore areas to the north of major headlands, and especially in Byron Bay. Line fishing (Figure 10.12a) occurred mostly on inshore reefs and hauling (Figure 10.13a) occurred mostly on beaches. Other fisheries were also restricted to specific locations. Eel and mud crab trapping occurred only in estuaries and lobster trapping focussed on particular areas of reef.

These data and the fisher's estimates of the proportion of their catch caught within the marine park were used with mandatory catch return data for the region by Doug Chapman (NSW Fisheries) to assess the cost of buying out commercial fishing licenses in the marine park. The assessments included estimating the cost of buying commercial fishing licenses affected by different zoning options and the allocation of *ex gratia* payments to fishers that might otherwise be displaced to surrounding areas.

The maps of commercial fishing licenses were also used in Marxan simulated annealing simulations as relative measures of the potential impact of different reserve designs on different commercial fisheries. They provided an alternative to using the area occupied by highly protected areas as the sole indicator of the relative cost of different reserve systems. The use of these values had significant effects on the reserve network designs described in Section 10.3.5.

10.3.4 Irreplaceability analyses in C-Plan

Figure 10.8a shows a map of site irreplaceability calculated using the C-Plan conservation planning software to represent 30% of the area of each environmental biodiversity surrogate. The low irreplaceability values throughout the park indicate that for most conservation features there is a high degree of flexibility in the number of potential areas that could be selected to meet feature targets. The exceptions are for small areas around Julian Rocks, Cape Byron, Broken Head and Lennox Head. In each case, these areas include environmental classes (offshore island, inclined boulder field, inshore island, oceanic lagoon and pebbles) that are found at only a few locations in the marine park.

C-Plan allows an operator to easily add and subtract plan units to and from hypothetical reserve systems while immediately seeing the effect of these changes on irreplaceabilities, percentage goals and the areas included for different conservation features and sites. C-Plan was used throughout the planning process with managers and community representatives to provide rapid estimates of the areas of different environmental classes included in alternative reserve network options. C-Plan also provides tools to build heuristic iterative algorithms to automatically select candidate reserve systems that meet a set a feature targets while minimising costs. However, at the time of the draft zoning process, C-Plan had no way to easily aggregate plan units into larger reserves. Without specific rules to preferentially select adjacent units, solutions tended to include planning units scattered over a wide area. The following section describes solutions produced by the simulated annealing algorithm in Marxan which is able to minimise reserve boundary length and generate reserve networks of more compact clusters of planning units.

10.3.5 Simulated annealing in Marxan

Using a range of boundary length modifiers in the Marxan simulated annealing algorithm produced reserve network solutions with plan units aggregated to varying degrees between widely dispersed and tightly clustered. Figure 10.7 is a scatter plot of total cost in area plotted against total boundary length for reserve networks aiming to meet targets of between 10 and 50% of all fine scale environmental classes using boundary length modifiers that range between blm=1 and blm= 1,000.

Each point represents a simulation of 1,000,000 iterations with 10,000 temperature decreases and 100 replicate simulations of each point are plotted for each combination of percentage goal and boundary length modifier. Points towards the right hand side of the x-axis are solutions with relatively large total reserve boundary lengths made up of many scattered plan units, while points to the left, represent solutions with progressively smaller boundary lengths and larger, more compact reserves of aggregated planning units.

For each combination of boundary length modifier and feature target, the algorithm generated a range of solutions (n=100) with relatively little variation in boundary perimeter or cost in area. As expected, area costs increased with the size of the percentage feature target and the boundary perimeters of reserve networks decreased as the boundary length modifier increased.

However, there was almost no increase in area cost with boundary length modifier until blm=1,000 and the greatest reductions in boundary perimeter occurred at less than blm=500. Therefore targets could be met within a relatively compact network of reserves without necessarily increasing the total area protected.

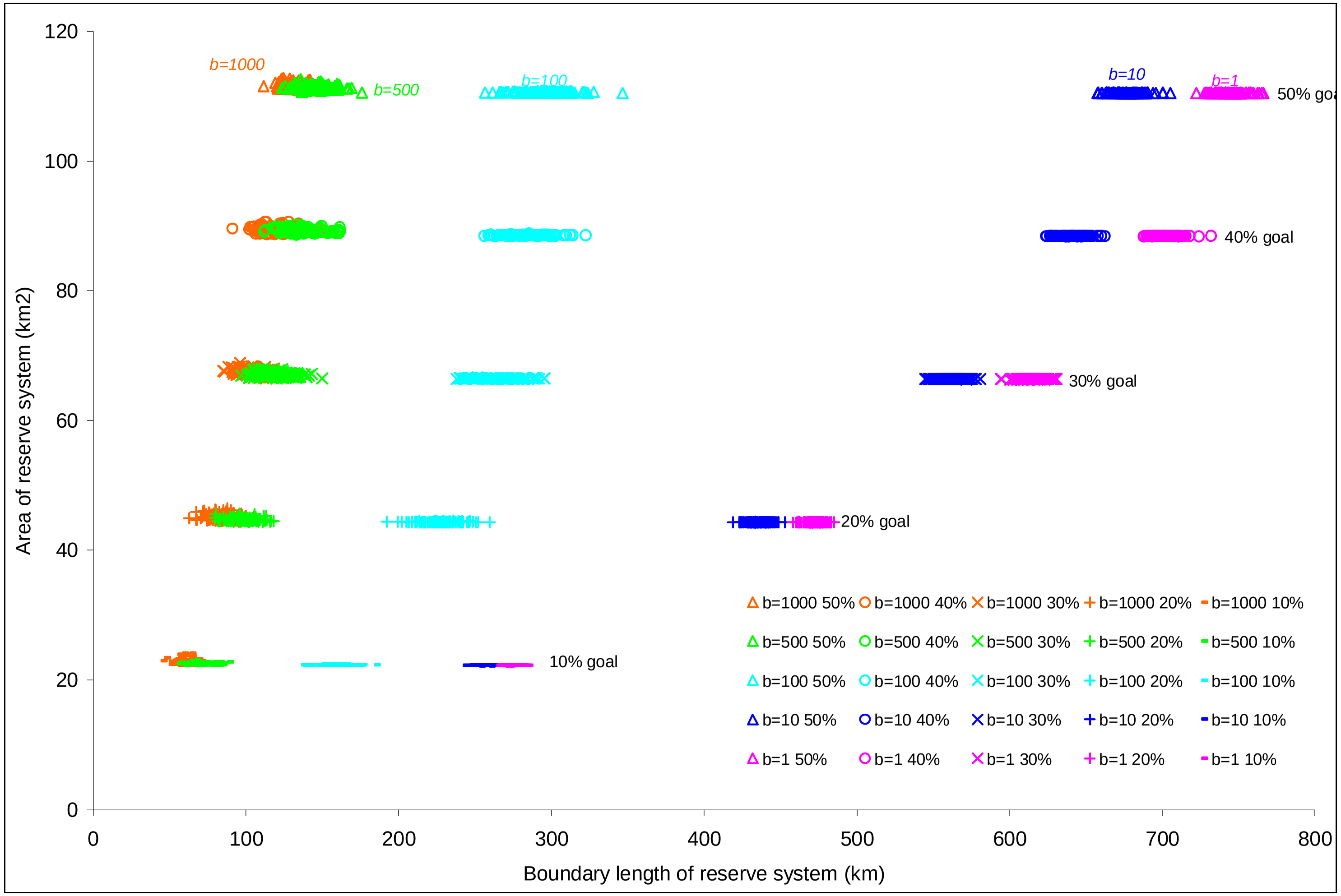

Figure 10.7. Areas of hypothetical reserve systems aiming to represent between 10 and 50% of all environmental habitat classes in Cape Byron Marine Park for a range of boundary length modifiers (blm=1 to 1,000) using Marxan simulated annealing and iterative improvement (Ball and Possingham 2000). Each point represents a simulation of 1,000,000 iterations with 10,000 temperature decreases. 100 replicate simulations are plotted for each combination of percentage goal and boundary length modifier. Total area of the marine park is approximately 224 km^2.

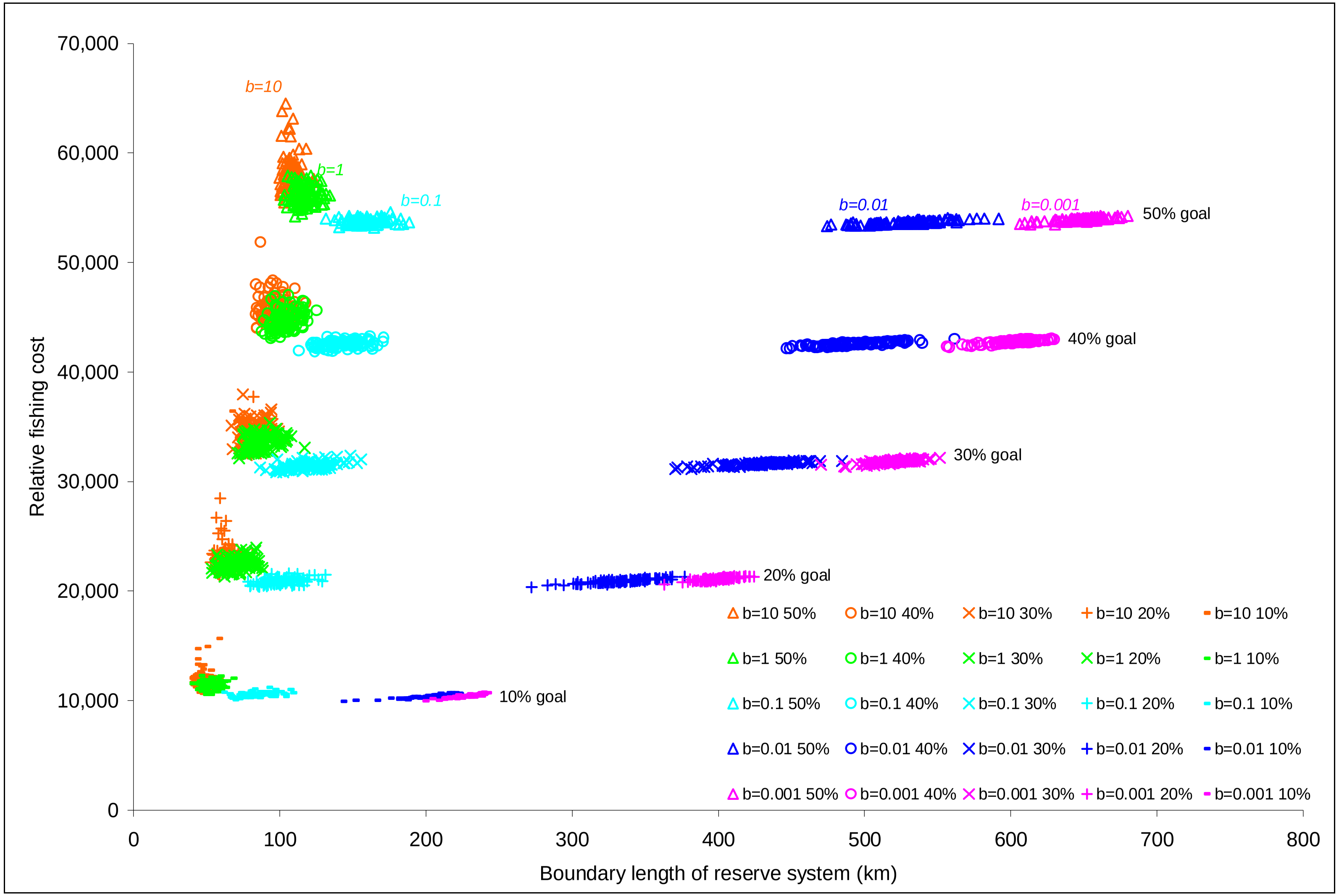

Figure 10.8. Relative impact on commercial fishing grounds (derived from how frequently plan units were used by fisher's) in Cape Byron Marine Park of reserve systems aiming to represent between 10 and 50% of all environmental habitat classes for a range of boundary length modifiers (blm=0.001 to 10) using Marxan simulated annealing and iterative improvement. Each point represents a simulation of 1,000,000 iterations with 10,000 temperature decreases. 100 replicate simulations are plotted for each combination of percentage goal and boundary length modifier.

A similar pattern occurred when using commercial fishing as a cost (Figure 10.8). Cost increased with the size of the target and boundary length decreased as the boundary length modifier increased, but again, there was no substantial increase in cost until the boundary length modifier became greater than 1. When using either area or commercial fishing use as a cost, the total area occupied by each solution (e.g. Figure 10.7) was not substantially greater than the area met for each individual feature target. Therefore for each scenario, a range of reserve network options were available that achieved targets within reduced boundary perimeters without substantially increasing the total area occupied by reserves or the relative impact on commercial fishing.

This information, and maps of the ‘best’ and the ‘most frequently selected’ planning units from 100 replicate runs were used to select boundary length modifiers to generate networks of reserves with a relatively high degree of insulation from external influences, and which could be feasibly enforced, while still providing geographic replication throughout the marine park. A boundary length modifier of blm=500 was chosen for simulations using area as the reserve cost (Figure 10.7) and a boundary length modifier of blm=1 was used for simulations using the frequency of commercial fishing (Figure 10.8) as a cost.

Figures 10.9b - Figure 10.15 show maps of different costs, and of irreplaceabilities mapped as the frequency of each planning unit in solutions from 100 runs of the Marxan simulated annealing algorithm. Each individual result from the algorithm is a ‘near optimal’ solution which represents all environmental classes at a specified percentage target (between 10 and 50% of the area of each fine scale environmental class) while minimizing cost in boundary length and cost as either area or commercial fishing use. Irreplaceabilities are presented for a range of percentage targets as the size of these targets was a topic of debate among managers and community representatives. This range of targets identifies potential sites for highly protected, ‘no-take’ sanctuary zones but can also be used to identify potential locations for other levels of protection such as habitat protection zones where most commercial fishing is excluded.

If area is used as a cost (Figure 10.9b-f), Marxan irreplaceabilities for representation of 10% of all environmental classes resemble the irreplaceabilities calculated by C-Plan (Figure 10.8a). The sites most frequently included in solutions occur in the Brunswick River, and at Julian Rocks, Cape Byron, Broken Head and Lennox Head. As goals increase towards 50%, additional sites around these areas are added to the reserve systems. Most selected sites occurred in an arc linking the inshore reefs of Byron Bay with the diversity of habitats around Julian Rocks (offshore island, reef 0-18m, reef 0-35m) and the reef pinnacles (35-50m) and scattered deep reef and coarse sediment (>50m) offshore of Cape Byron.

If cost is calculated as the number of prawn trawlers using a site, the solutions are quite different. The algorithm tends to avoid the ‘high cost’, heavily trawled areas that occur south of Cape Byron and approximately 2 km out from the coast (Figure 10.9a). Instead, the sites most frequently selected for protection occur between Cape Byron and the Brunswick River and out to the 3 nautical mile limit and along a narrow band of inshore sites on the coast between Broken Head and Lennox Head (Figure 10.9b-f).

Marxan solutions for the commercial spanner crab fishery show a similar pattern with sites selected most frequently between Cape Byron and the Brunswick River and along a narrow inshore band north of Lennox Head. However, for the spanner crab fishery, there is a more pronounced concentration of fishing licenses in the narrow passage between Cape Byron and the deep reef to the east. This is reflected in a gap in selected reserve sites to the east of Cape Byron in Figures Figure 10.10b-f. This area is known to commercial fishers as the ‘mad mile.’ This location and areas to the south were identified during consultation as some of the most important areas for commercial fishing. The importance of the ‘mad mile’ is also evident in the gap at this location in the initial draft sanctuary zone proposed by commercial fishers (Figure 10.15a).

The areas used for purse seining (Figure 10.11) and line fishing (Figure 10.12) and the resulting Marxan solutions are different again. These fisheries favour the protected inshore areas to the north-west of Cape Byron and Broken Head. The annealing algorithm avoids selecting these areas with the exception of small areas of habitat that can not be found anywhere else. Instead it builds reserve systems around offshore examples of reefs and sediments.

Hauling operations are usually shore based and fishing is reported most frequently from beaches in the marine park (Figure 10.13). The resulting Marxan selections are therefore different again. They resemble the solutions using area as a cost, except that the algorithm avoids including beaches within the reserve system.

When the total frequency of all types of commercial fishing licenses is used to represent cost (Figure 10.), the Marxan solutions include several of the features described for the individual fisheries above. These include the large area of selected sites between Cape Byron and Brunswick River, the inshore band of selected sites between Cape Byron and Lennox Heads and the gap in protection midway between Cape Byron and the deep (>50m) offshore reefs.

These general solutions allow for the maintenance of the larger prawn trawl and spanner crab fisheries in the Marine Park. However, they do not necessarily allow for smaller fisheries such a purse seining and line fishing in the sheltered areas of Byron Bay or for hauling along the ocean beaches. This indicates that treating all commercial fisheries as the same may not provide a reliable indication of the potential impacts for the different types of fisheries. Unless fisheries are assessed individually, the larger fisheries may drive the selection algorithm towards general solutions that favour particular areas. These solutions may however, impact on the grounds of fisheries with fewer licenses.

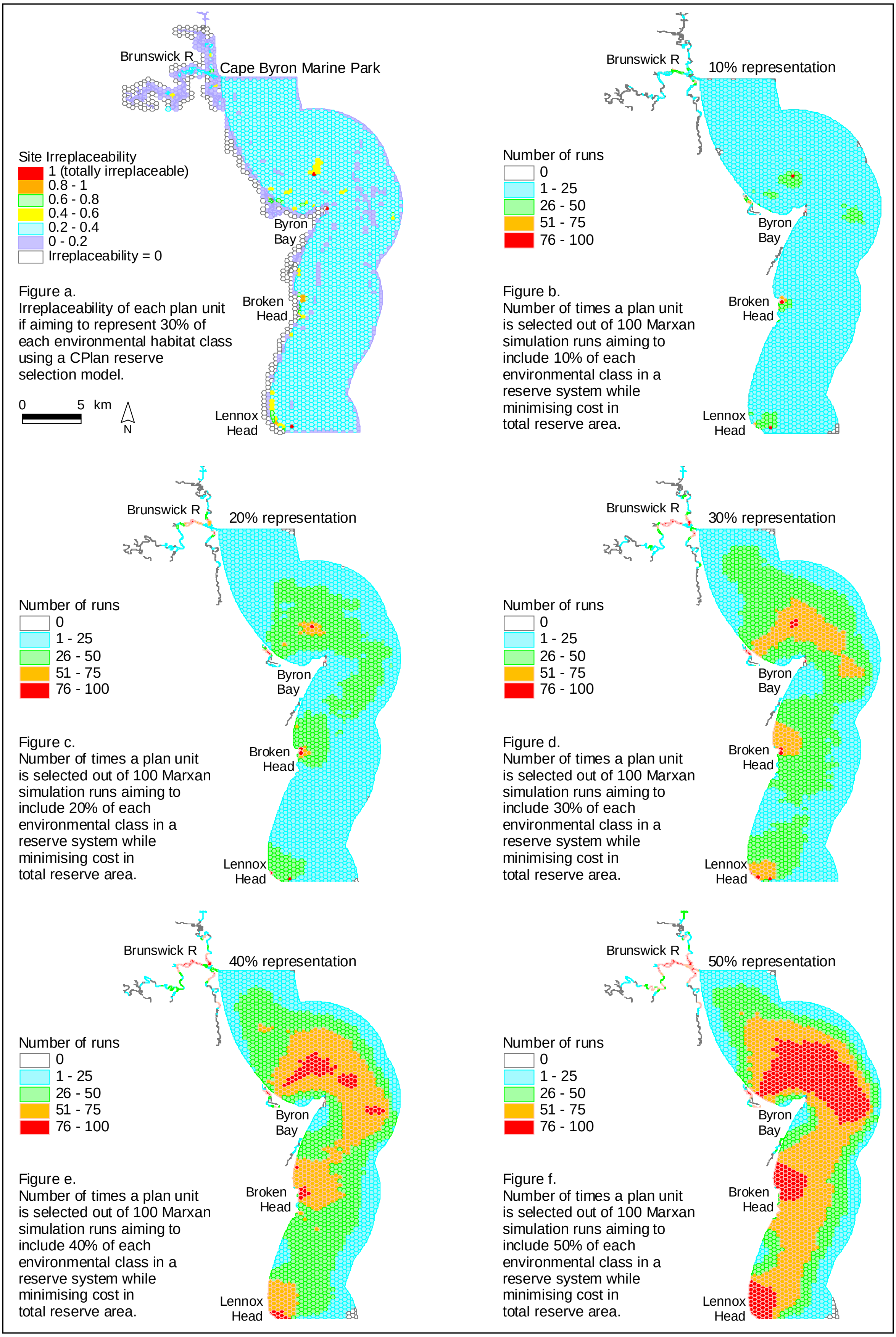

Figure 10.8a. Site irreplaceability for representation of 30% of each environmental class in Cape Byron Marine Park calculated using C-Plan (NPWS 2000). Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising their total area and boundary length.

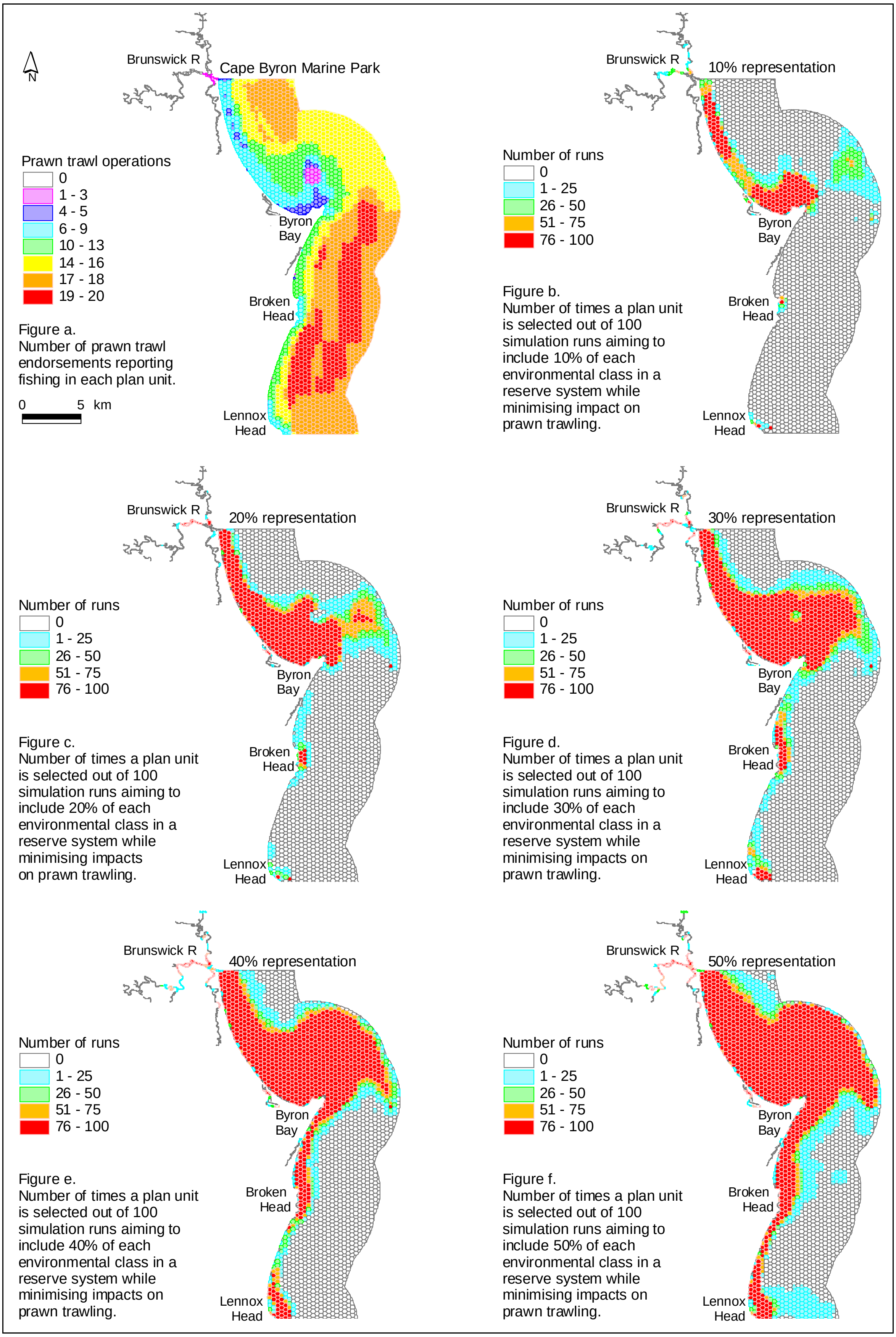

Figure 10.9a. Number of prawn trawl licenses reported in Cape Byron Marine Park. Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on prawn trawling.

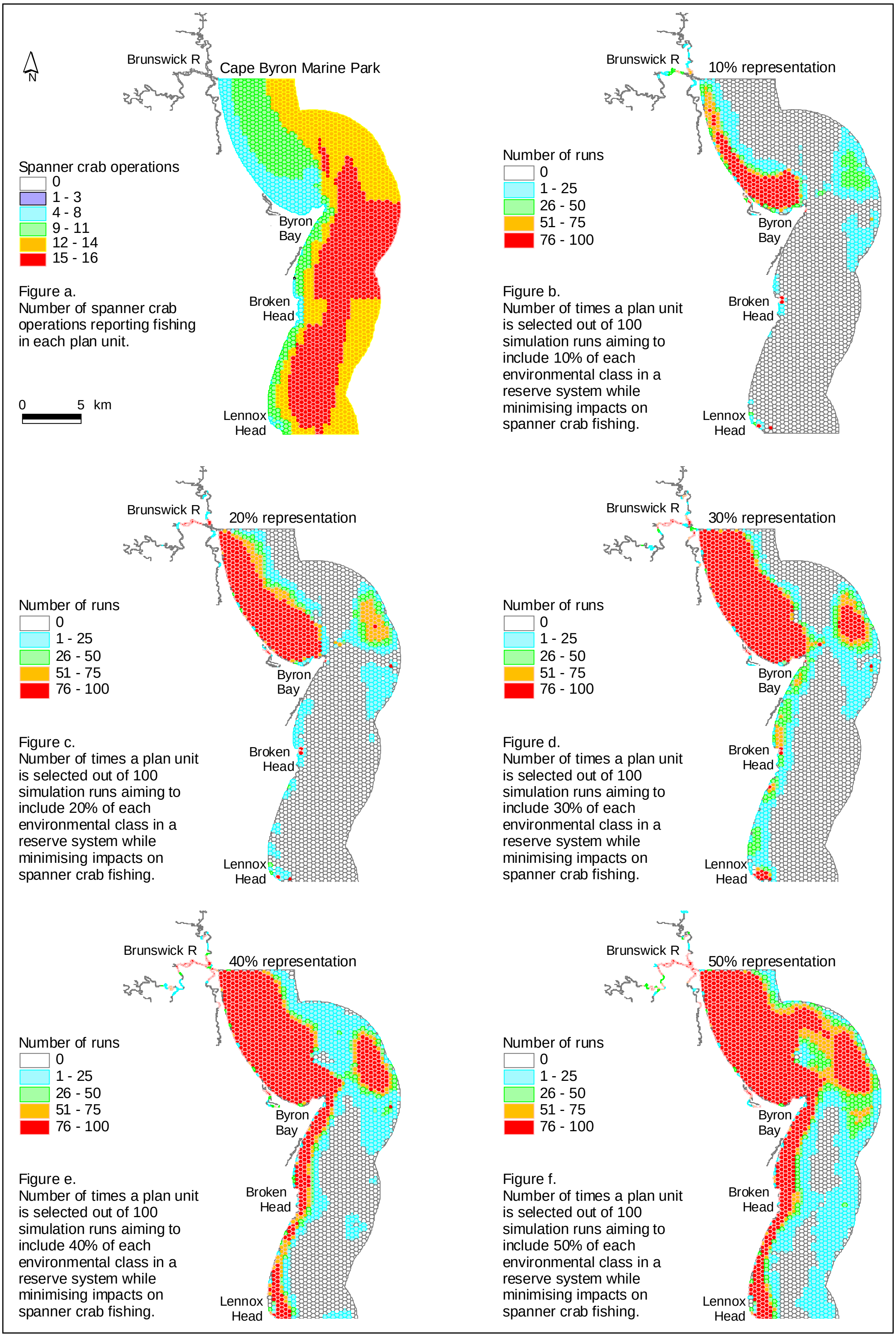

Figure 10.10a. Number of spanner crab licenses reported in Cape Byron Marine Park. Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on commercial fishing for spanner crabs.

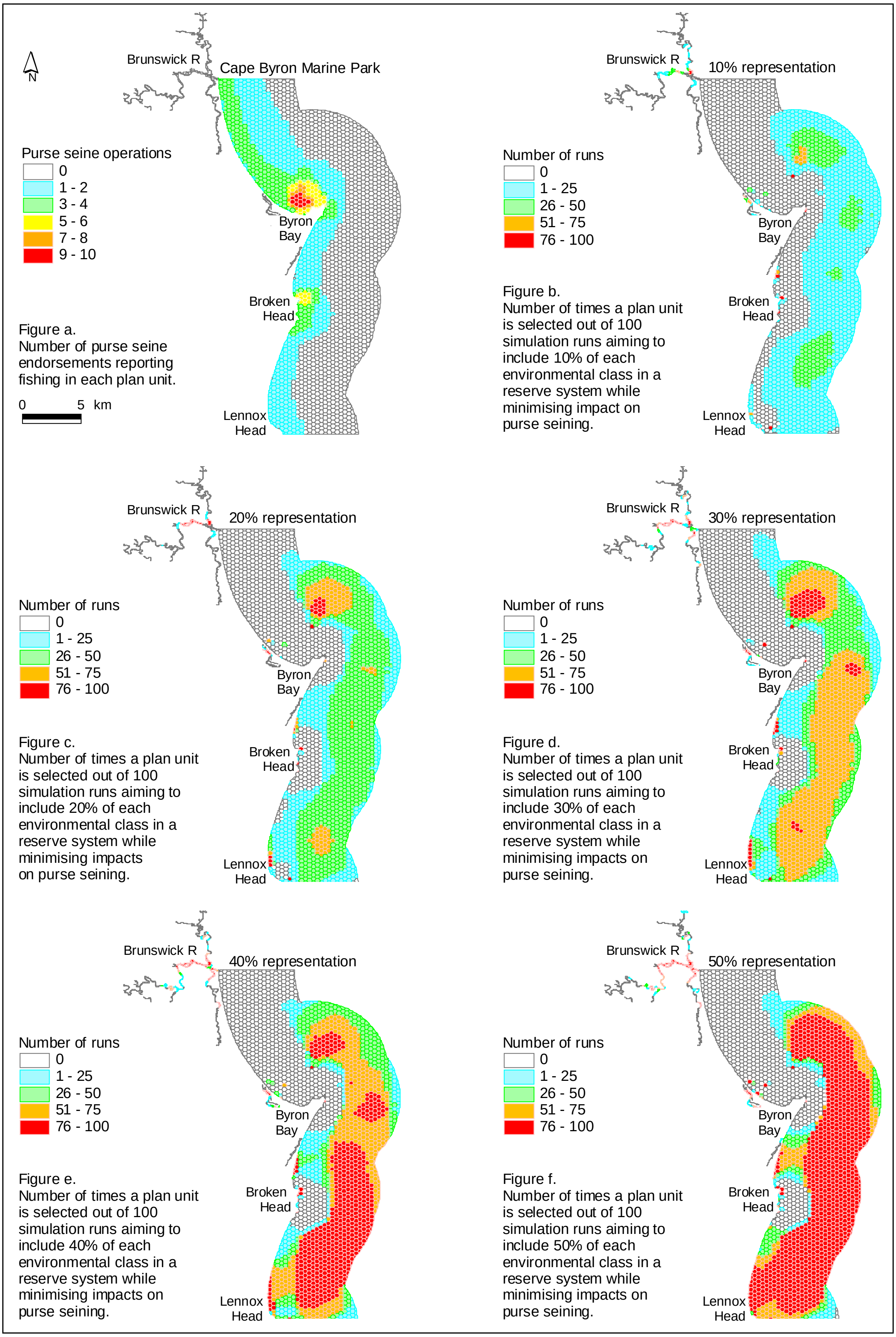

Figure 10.11a. Number of purse seine licenses reported in Cape Byron Marine Park. Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on purse seining.

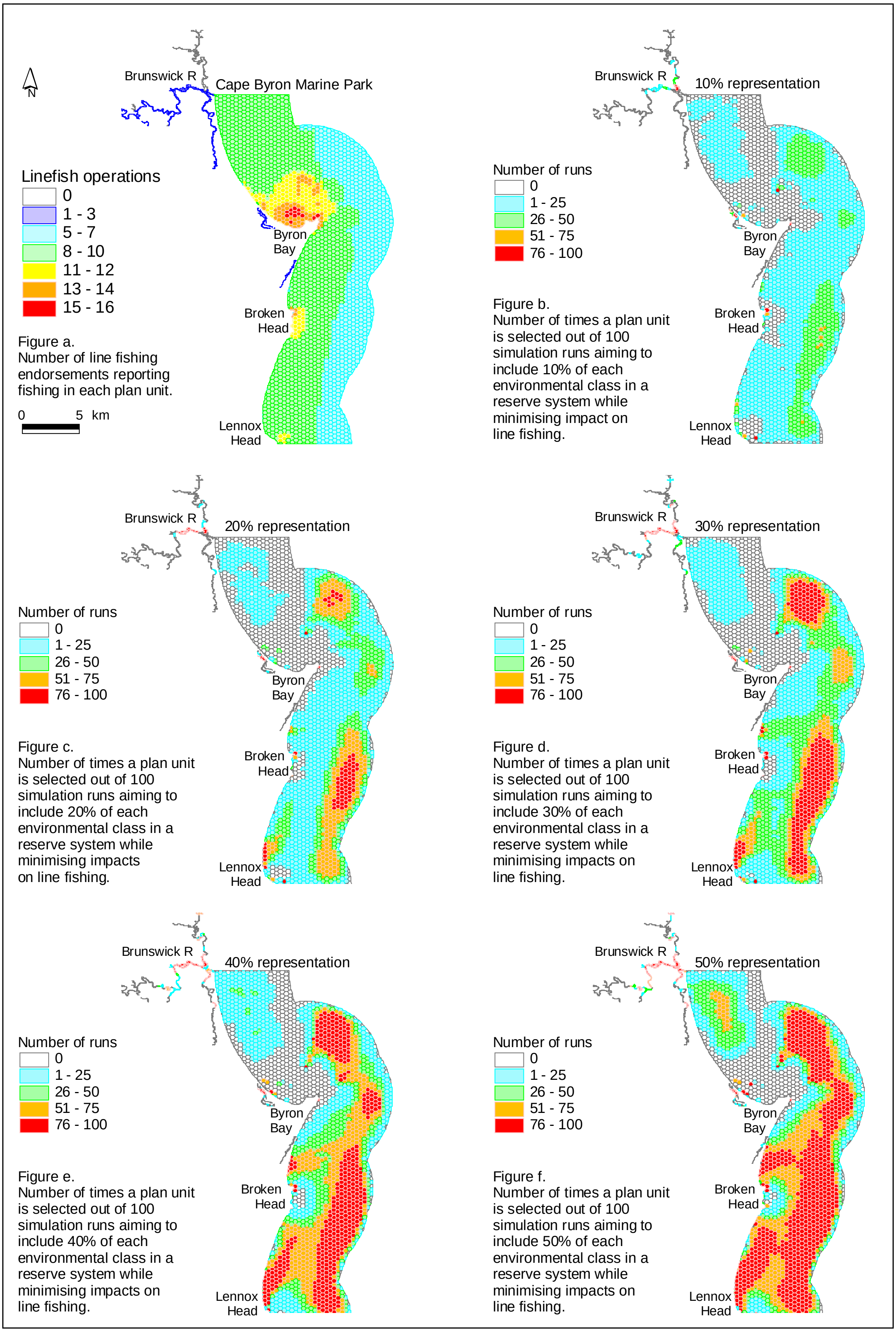

Figure 10.12a. Number of commercial line fishing licenses reported in Cape Byron Marine Park. Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on commercial line fishing.

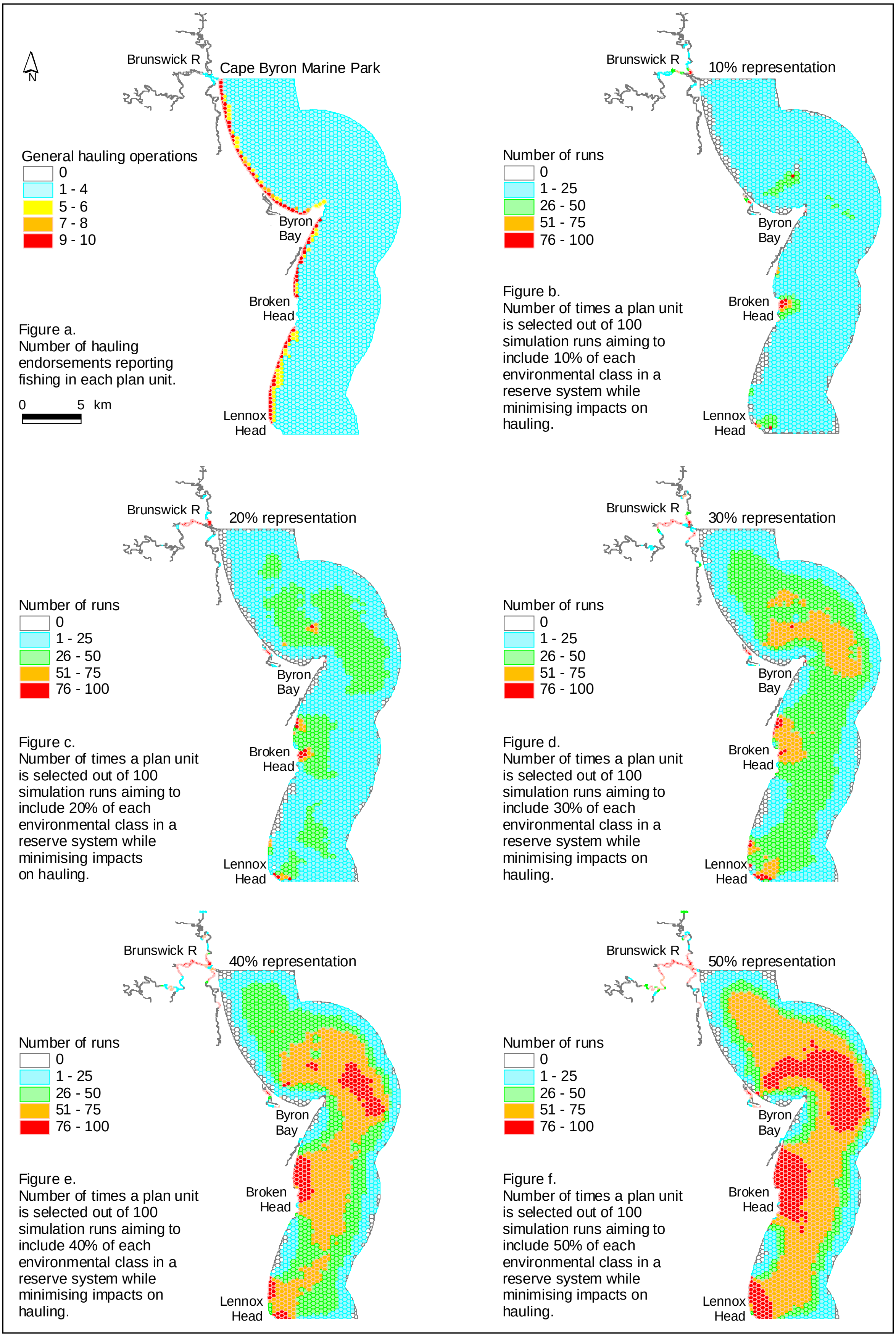

Figure 10.13a. Number of commercial hauling licenses reported in Cape Byron Marine Park. Figures b-f. The number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on commercial hauling.

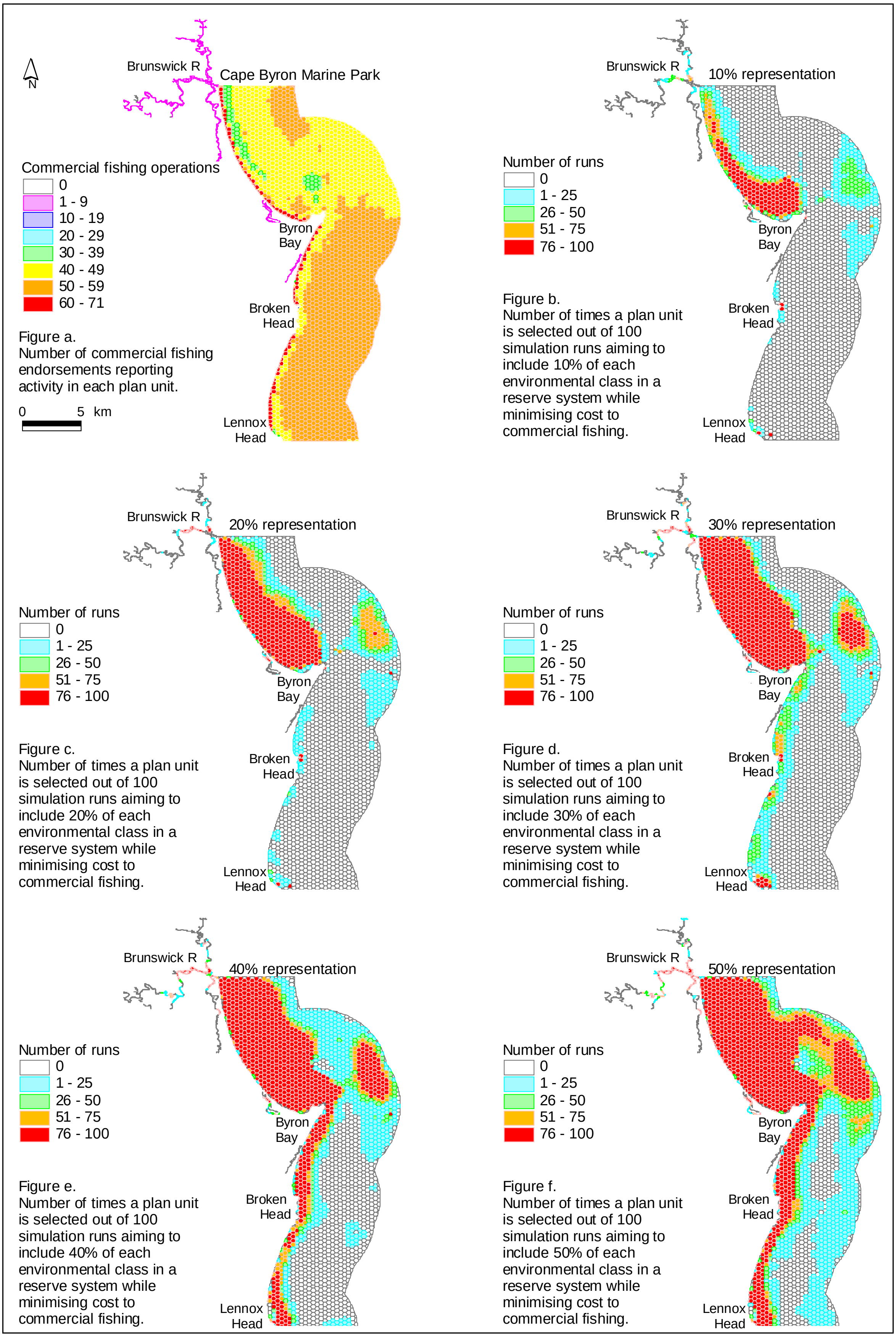

Figure 10.14a. Total numbers of reported commercial fishing licenses for Cape Byron Marine Park. Figures b-f. Maps of the number of times a planning unit is selected out of 100 Marxan simulations (Ball and Possingham 2000) aiming to represent between 10 and 50% of all environmental classes in highly protected zones while minimising total boundary length and impacts on commercial fishing.

10.3.6 Advisory committee and draft zoning workshop

The early involvement of the Cape Byron Marine Park Advisory Committee allowed time for the Committee to request and receive data and information tools, and to provide feedback and develop independent GIS maps of zoning options (Figure 10.15ab). Consultation during this time also provided management with detailed information on conservation and recreational values. This included local knowledge of offshore areas (e.g. GPS points for the offshore reefs in Figure 10.1) and other information that was not available from existing datasets.

Reviews of existing data by the community and the Advisory Committee also provided support for marine parks managers to commission more detailed surveys on environments in the marine park and their use. Early consultation also allowed time to develop and assess objectives and options for the draft zone plan and prepare materials, terms of reference and support staff for a two day workshop.

At the workshop, discussions among stakeholders, community and management frequently focused on opposing options. However compromises were often negotiated between extremes, although most of these occurred for relatively small areas (e.g. to provide access for recreational fishing or protection of other values at specific sites). Figure 10.15a, b, c and d show how the designs proposed by fishing and conservation interests retained most of their initial features with minor modifications for particular areas.

Most discussion focussed on the location and extent of ‘no-take’ sanctuary zones. Conservation and fishing interests tended to favour designs with respectively, more or less area, in these ‘no-take’ areas (Figure 10.15). Conservation representatives argued strongly for networks of large sanctuary zones which included a range of entire habitats and provided protection for species such Grey Nurse Shark and shorebirds. Sanctuary zones (coloured pink in Figure 10.15) prohibit all forms of fishing, collecting or other extractive use and prohibit anchoring over reef. Conservation representatives advocated for sanctuary zones as the only meaningful form of protection in the marine park and on several occasions proposed designs that ignored lesser forms of protection such as habitat protection zones because of their alleged inadequacy (Figure 10.15d).

Habitat protection zones in the marine park (coloured yellow in Figure 10.15) permit most forms of recreational fishing but prohibit many commercial fishing activities, including trawling. Recreational fishers proposed various forms of habitat protection zone within larger sanctuary zones to maintain access to specific fishing sites. Much effort during the workshop went into drafting small, localised habitat protection zones to provide access for recreational fishing from specific headlands, reaches of estuaries, and beaches (Figure 10.16, Figure 10.17, Figure 10.18 and Figure 10.19).

More complex planning arrangements included habitat protection zones with restrictions that are seasonal (e.g. when endangered Grey Nurse Sharks are most abundant, Figure 10.16), species based (e.g. permitting only recreational fishing for pelagic fishes on inshore reefs that supply bait, Figure 10.16) or prohibit collecting, but allow recreational line fishing (Figure 10.19).

Commercial fishing representatives provided substantial input into the extent and location of habitat protection zones, and how these excluded trawling off Cape Byron, restricted the movements of vessels travelling along the coast and limited trawling to offshore areas of the park. General use zones (coloured blue in Figure 10.15) permit most commercial and recreational fishing (including trawling) in this marine park but exclude setline, dropline, longline and purse seine fishing activities which are prohibited throughout the marine park.

Special purpose zones were also drafted to provide for restoration activities, protect indigenous cultural values (Figure 10.16), allow existing aquaculture leases and port facilities to continue (Figure 10.17) and permit special access to fishing for the disabled (Figure 10.19). Figure 10.15 shows just six draft zone plans from the many alternatives developed and reviewed before, during and after the workshop and draft planning process.

Figure 10.15e and f are draft and final plans developed by the Marine Park Authority in consultation with community groups and managers from NSW Fisheries and the NSW National Parks and Wildlife. It is apparent from comparisons with the designs submitted by community representatives that these represent compromises between the extremes. The draft zone plan in Figure 10.15e for example includes 27.5% of the marine park in sanctuary zone, a percentage precisely halfway between options negotiated by management agencies to include either 25% (NSW Fisheries) or 30% (NSW National Parks) of the park in sanctuary zones.

The total area in sanctuary zone appears to be determined by government agencies negotiating among extremes proposed by conservation and fishing interest groups while attempting to represent approximately equal proportions of each fine scale environmental class. However, the individual locations and boundaries of zones were determined primarily through negotiation among the stakeholder groups to select those areas most important to their particular interests.

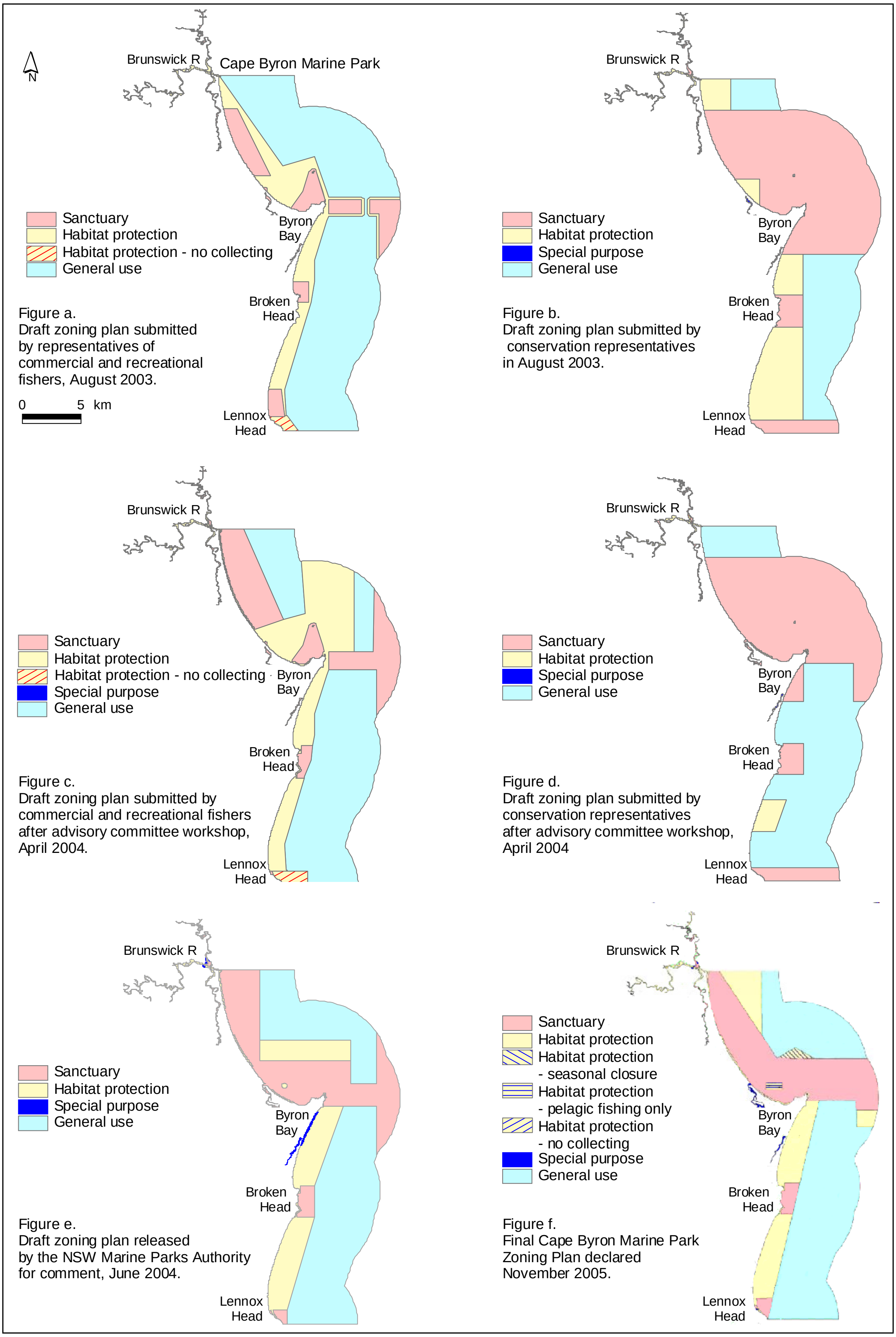

Figure 10.15. Draft zoning plans for Cape Byron Marine Park submitted by fishing (a and c) and conservation (Figures b & d) representatives before and after an advisory committee workshop and the draft (e) and final (f) zoning plans accepted by the NSW Marine Parks Authority (Maps a, b & f by Vanessa Mansbridge NSW MPA).

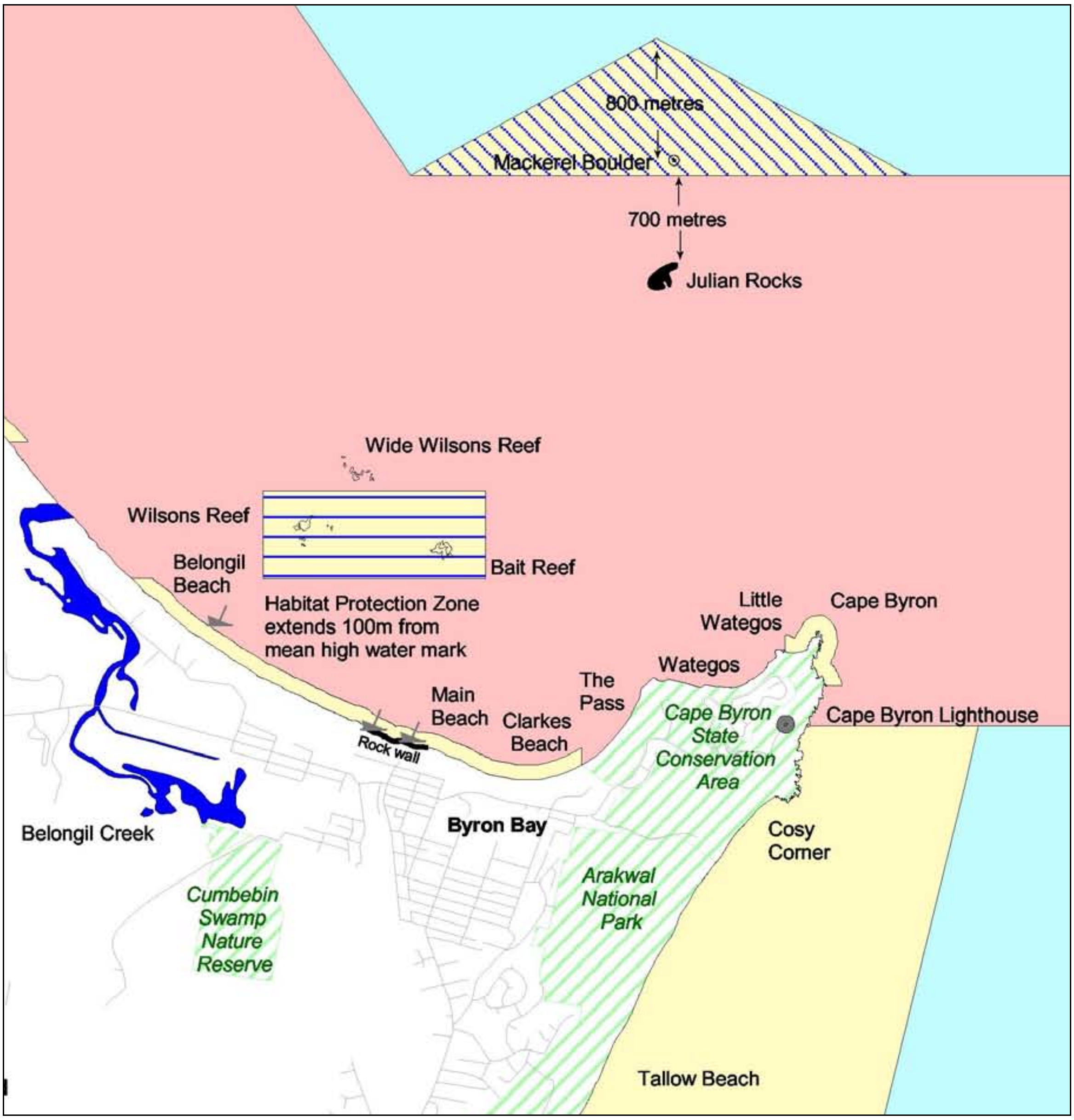

Figure 10.16. The 'no-take' Sanctuary zone (pink) offshore of Byron Bay and around Julian Rocks and Wide Wilsons Reef. Within this area, there are smaller Habitat Protection zones (yellow) within 100 m of the mean high water mark on Belongil Beach, Main Beach, Clarkes Beach, Little Wategoes Beach and Cape Byron. These zones permit most recreational fishing activities but prohibit spear fishing and commercial netting. A much larger Habitat Protection zone (yellow) extends south of the Cape Byron Lighthouse. This zone prohibits commercial trawling along Tallow and Broken Head Beaches but permits recreational fishing. A Habitat Protection zone (yellow with blue hatching) around Mackerel Boulder prohibits all fishing between the 1st of May and the 31st of December to help protect endangered Grey Nurse Sharks (*Carcharias taurus*). Another Habitat Protection zone around Wilsons Reef and Bait Reef allows only recreational fishing for certain pelagic fishes. Belongil Creek is zoned as Special Purpose to allow for recovery of this area and indigenous cultural activities. (Adapted from a map of the Cape Byron Marine Park final zoning plan produced by Vanessa Mansbridge, NSW Marine Parks Authority, www.mpa.nsw.gov.au).

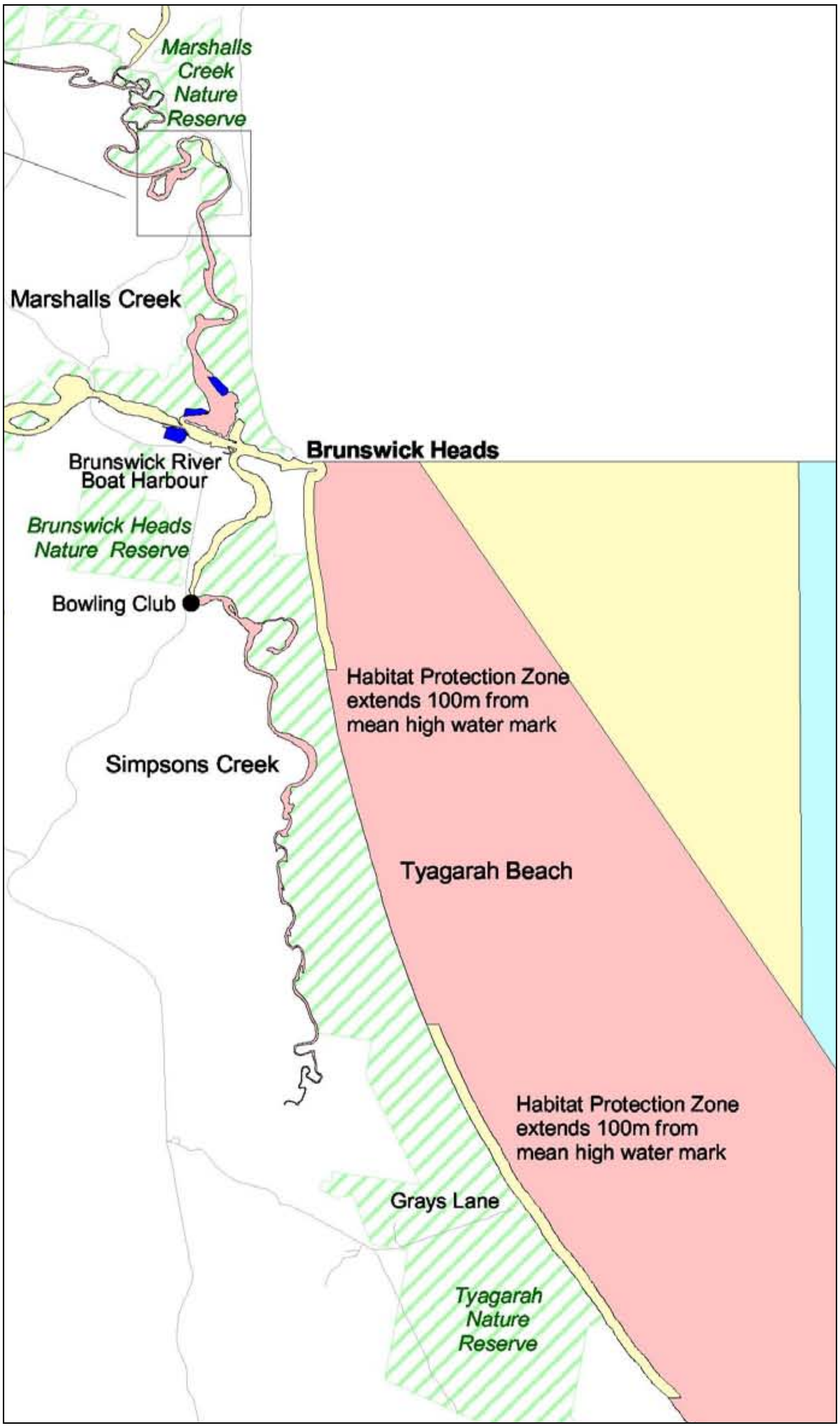

Figure 10.17. The 'no-take' Sanctuary zone (pink) extends north from Cape Byron to the northern wall of the Brunswick River mouth with the exception of two Habitat Protection zones (yellow) that permit recreational fishing and commercial collecting within 100m of the mean high tide mark. Sanctuary zones (pink) in Marshalls and Simpsons Creek prohibit all fishing in these tributaries but recreational fishing is allowed within the Habitat Protection zone (yellow) of the main Brunswick River. Special purpose zones (dark blue) allow for port activities in the Brunswick River Boat Harbour and existing oyster leases in Marshall Creek. The area adjoins Marshalls Creek Nature Reserve and Tyagarah Nature Reserve. (Adapted from a map of the Cape Byron Marine Park final zoning plan produced by Vanessa Mansbridge, NSW Marine Parks Authority, www.mpa.nsw.gov.au).

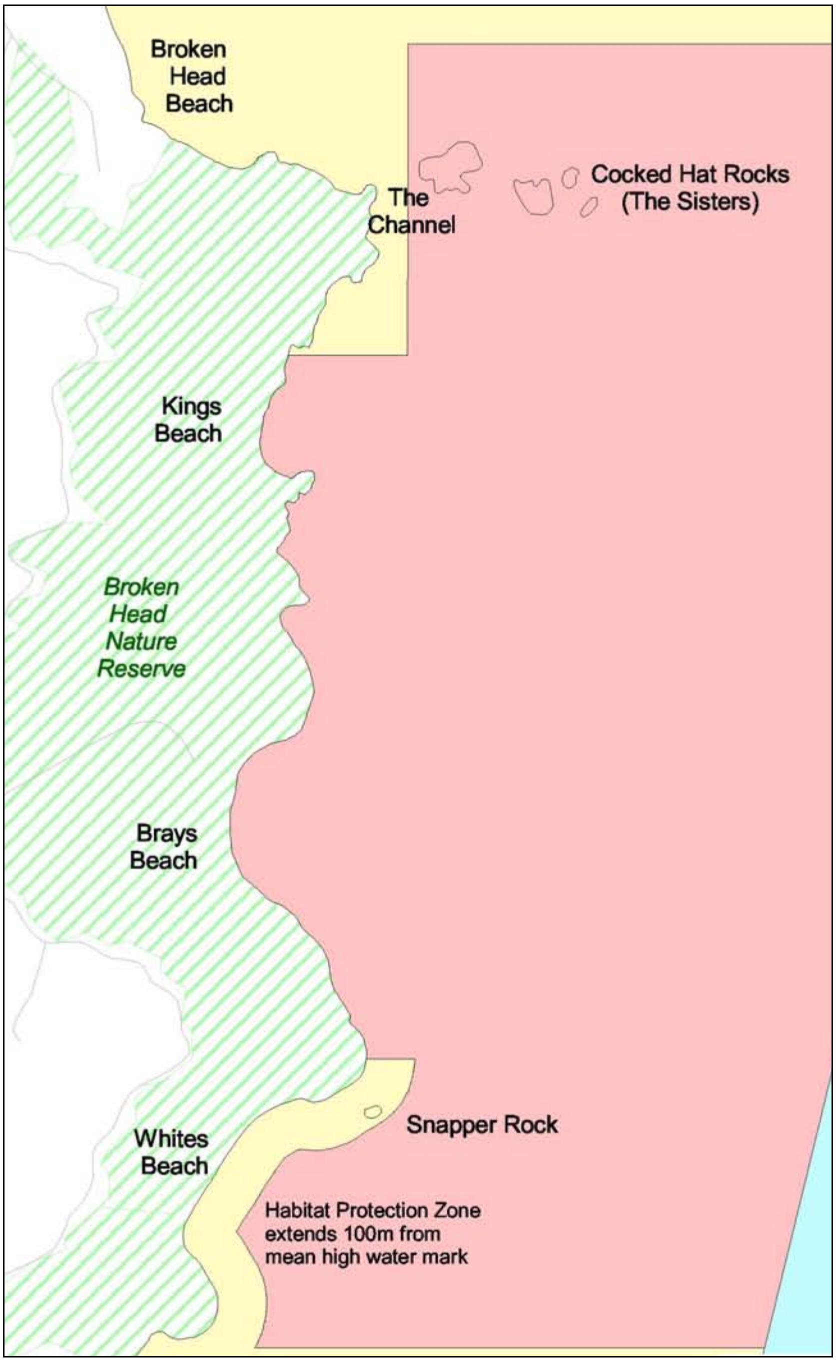

Figure 10.18. A 'no-take' Sanctuary zone (pink) offshore of Broken Head with Habitat Protection zones (yellow) where recreational fishing is allowed within 100 m of the mean high water mark at Broken Head (inside Cocked Hat Rocks), Whites Beach and Jews Point. The area adjoins the Broken Head terrestrial nature reserve (green diagonal hatching). (Adapted from the Cape Byron Marine Park final zoning plan maps produced by Vanessa Mansbridge, NSW Marine Parks Authority, www.mpa.nsw.gov.au).

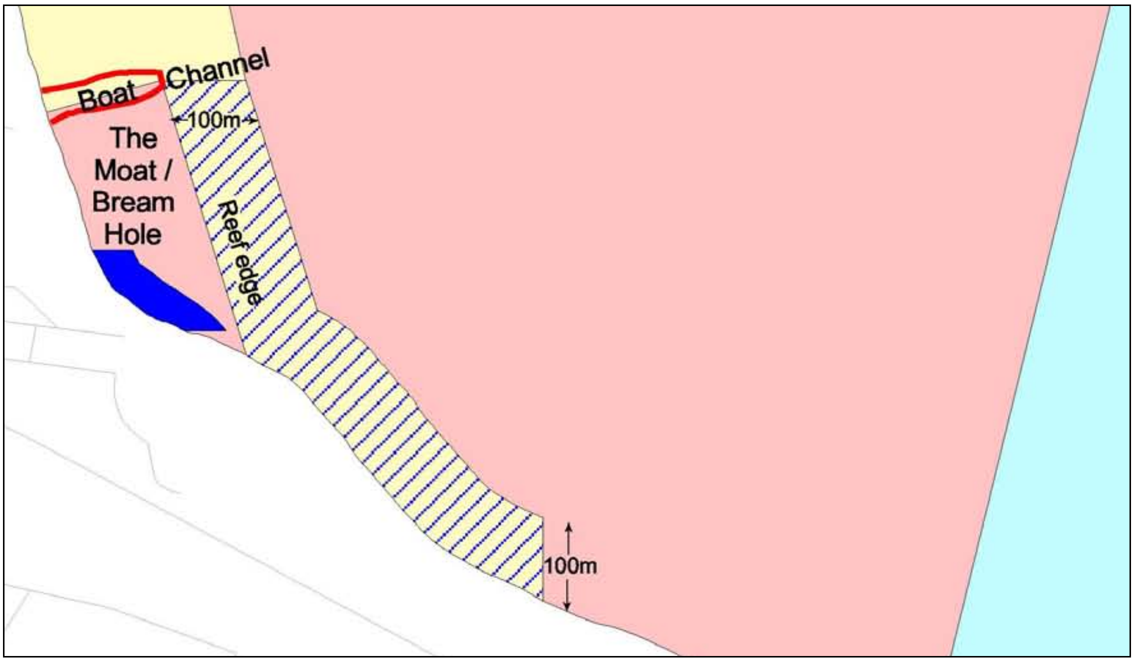

Figure 10.19. 'No-take' Sanctuary zones (pink) off Lennox Head and in 'The Moat' or 'Bream Hole' (oceanic lagoon) and a Habitat Protection zone (hatched area) which permits recreational line fishing within 100 m to seaward of the reef edge of 'The Moat' and the boulder foreshore of Lennox Head but prohibits collection of invertebrates or algae. A Special Purpose zone (dark blue) allows recreational fishing within 50 m of the Lennox Head boardwalk for those with a disability permit issued by the Marine Parks Authority. Trawling and other commercial fishing is permitted in the General Use zone offshore (light blue). (Adapted from a map of the Cape Byron Marine Park final zoning plan produced by V. Mansbridge, www.mpa.nsw.gov.au).

10.4 Discussion

Explicit goals and criteria and the systematic use of information provided an accountable and repeatable framework to guide the Cape Byron Marine Park planning process. The generic goals and criteria developed for the bioregional assessments provided direction and priorities for information gathering and a protocol to assess alternative zone plans.

Broad scale data from the bioregional assessment were useful in providing a state-wide context for planning but were not detailed enough to accurately assess values and assign boundaries within the marine park. This exercise demonstrates however, that it is feasible to collect reasonable data on fine scale habitats and species assemblages within an MPA of this size (224 km^2). This was made possible largely through the use of remote sensing methods.

Sidescan sonar proved to a highly efficient tool. Scientists from the Estuarine Cooperative Research Centre (A. Bickers and K. Baxter) used this method to acoustically map seabed textures in continuous swathes extending up to hundreds of metres each side of the survey vessel's path. The high resolution acoustic images that were returned were then classified using a dropped or towed underwater video. Within a relatively short time, and for a reasonable cost, this method provided an almost continuous map of subtidal habitats in the marine park and mapped many previously undescribed features at a range of depths (Bickers 2004). High resolution (1:8-12,000) aerial photographs were also used to provide accurate, continuous maps of near shore reef (Avery 2000) and estuarine vegetation (G. West and D. Morrisson pers. comm.) and field surveys provided detailed maps of rocky and sandy intertidal habitats (Banks and Scotts unpublished data., Banks *et al.* 2005)

Each of these surveys is distinctive in that outlines of major features were mapped directly, rather than interpolated between widely spaced samples. Although the habitats mapped are relatively broad, they now provide a stratified seascape to guide more detailed surveys of species composition. Combining this information into one almost continuous, seamless map provided an important resource for planning discussions and the basic data for reserve selection models. This cooperative exercise demonstrates how communication among managers, stakeholders and scientists can benefit from, and promote, cooperative progress in applied conservation research and management.

Recreational and commercial values were identified as an important social and economic consideration in the planning of the marine park. Approximately 1,752,000 tourists annually create $306 million in business for the local economy (Byron Shire Council 2002, NSW Marine Parks Authority 2003). The voluntary surveys provided a useful indicator of where community concerns were focused. However, they should be used cautiously, and only as a relative index of use. Respondents returning voluntary surveys were more likely to be individuals and organisations with particular interests affected by the zoning. It was also evident that responses for some activities and areas were affected by political organizing to influence returns. However, in the absence of site specific information on recreational values, the survey maps provided reasonable data that reliably predicted those areas and issues of most concern to different sectors of the community. More objective estimates of use can be derived from observational studies like those of Boykett (in prep.) and Wellington (2003) and from random, statistical census techniques.

Questionnaire returns from registered commercial fishers provided approximate information on the amount and type of catch landed from different areas inside the marine park. This information was used to assess the voluntary 'buy-out' of commercial fishing licenses in the marine park under different zoning scenarios and to determine the allocation of *ex gratia* payments to buy out fishers that might otherwise be displaced to surrounding areas. Voluntary descriptions of the commercial fishing catch within the marine park were of variable quality but most provided basic descriptions of the areas most frequently used. Assessments of this data in workshops and in reserve selection simulations indicated that the information was reasonably realistic. Perhaps most importantly, it provided an opportunity for commercial fishers to provide direct input into the process and for managers to understand something of how fisheries operated in the area.

Both C-Plan and Marxan provided similar maps of irreplaceability that focussed on those habitats found at a limited number of locations. Both tools indicated high irreplaceabilities for the areas between Byron Bay and Julian Rocks, in the Brunswick River estuary and for distinctive rocky shore types at Cape Byron, Broken Head and Lennox Head. Marxan was however, able to effectively aggregate planning units into larger zones and generate a range of different reserve designs that minimised impacts on different commercial fisheries. What was surprising were the major differences between reserve designs produced using cost data for different fisheries, while still meeting conservation targets. This indicates that designs that aim to accommodate different commercial and other activities need give consideration to the individual differences among patterns of use. Unfortunately, because of time constraints, Marxan was only used to a limited degree in the workshops. The results however provided useful insights into the range of zoning options available and the potential impacts for different fisheries.

The reserve selection tool C-Plan, had a useful role in planning before, during and after the workshops. The program is a powerful 'participatory GIS' tool that enables managers and community representatives to interact directly with the goals, data and the spatial boundaries of proposed reserves. The program also saves a significant amount of time for operators and technical staff, in building and analysing GIS coverages for alternative proposals. The models developed here were used throughout the Cape Byron Marine Park draft zoning with managers and community representatives to assess options within the context of the marine park and within wider bioregional and state contexts.

However, three issues arose in relation to the use of this kind of software. The first is in regard to the use of targets. Another is in regard to the use of planning units of a fixed size and shape. The third is in providing appropriate time, resources and expertise to develop, apply and assist in using the models. Targets of specified percentages of area, or the absolute areas targeted for each conservation feature are necessary for the computation of irreplaceability. While many proponents of these methods recommend that these targets should be pre-agreed among stakeholders at some fixed level, there are few definitive guidelines for where these should be set, and having different sectors of the community agree to these would be difficult.

The required level of representation is also dependent on the context of the target. For example, is a target calculated as a proportion of the multiple use marine park, a proportion of the bioregion, or of the entire state. The required area or proportion might also differ significantly for different features and should reflect the ecology of different conservation features, their vulnerability, condition, connectivity and other goals detailed in Chapter 2. The main problem with targets, among managers and stakeholders involved in the zoning process, was a preoccupation with meeting specific, sometimes arbitrary percentages and this tended to obscure the many other criteria important for an effective MPA (listed in Chapter 2). Examples of this include neglecting issues of reserve design, monitoring and enforcement issues and altering the location of whole reserves in order to achieve incremental increases of less than 0.1% of the park's area.

A related difficulty is in presenting results as static 'snap shots' from a limited number of simulations for a few different scenarios. This can be misleading where many different parameters can be applied and where, potentially, many alternative reserve networks can satisfy these goals. Ideally, these simulations should be run interactively with input from experts in marine ecology, reserve design and the human activities undertaken in the marine park. The next best thing is to present results for several different targets and scenarios but ensure that these results are interpreted as only indicative of the kinds of solutions possible.

During the latter stages of negotiations, very precise boundaries were required to represent stakeholder suggestions. At this stage, even the fine scale 10 hectare planning units were too coarse to accurately record proposed boundaries and the advisory committee required zones to be mapped through the exact editing of vector shape files. Examples here include extending 100 metre buffer zones from a rocky shore to include an inshore rock, but exclude the outermost rocks of a group of islands used for spear fishing. This level of detail precluded the use of reserve planning software (although theoretically, even smaller planning units could be used) and required many hours of high speed editing for GIS operators to keep up with the many proposed changes. A major improvement in the reserve planning tools would be to base simulations on polygons that could be rapidly edited while simultaneously updating databases of the conservation values they include.

The draft zoning process allowed for additional staff, resources and time to collect additional data, develop reserve selection models and assist the advisory committee before, during and after the workshops. Even so, there was only sufficient time to develop and run only basic models and the use of Marxan in these circumstances was limited. The workshop demonstrated that using an information based, 'participatory GIS' is a feasible and potentially powerful tool for community based planning. However, future exercises need to ensure that adequate resources, time and trained staff are made available for this work.

While a single mutually acceptable draft zone plan was not finally agreed upon, there was significant ‘give and take’ among interest groups and a variety of detailed design options were examined for specific locations throughout the marine park. A simple ‘for and against’ model of participants and arguments did not accurately represent the viewpoints of all stakeholders or agencies. The advisory committee included not only recreational and commercial fishing interests, but also representatives for diving (including spear fishing and SCUBA interests), tourism, local councils, indigenous people, scientists and local communities.

These groups did not automatically support or condemn fishing or conservation positions but expressed a range of views depending on the particular issue and location. Even advisory committee members and agencies within fishing or conservation interests had variable positions on different options and opposing interests were often able to work together to reach some compromise. The biggest impediment to progress in workshops appeared to be the polarising of debate around fixed ideas from conflicting points of view. A major disadvantage of this was that other, less strident views were marginalised and received less weight in decision making. In particular, values for general recreation, science and indigenous values were sometimes ignored.

At several specific locations, there were direct conflicts between protecting conservation values and maintaining access for commercial and recreational fishing. Boundary options for these areas were often complex and reflected the importance of small changes to include either local conservation values or accommodate very specific patterns of use. Local experience from the advisory committee and other community members was crucial in representing these issues. Compromises were often only achievable through small changes in boundaries at spatial scales less than hundreds of metres.

Consultation with, and among community groups was contentious and a complete consensus on one mutually acceptable zone plan was never reached. However agreement did occur for several individual sites in the plan and most decisions represented a compromise between, what were initially, diametrically opposing views. The tools and information had an important role in clarifying goals, presenting objective evidence for specific sites and allowing community representatives to contribute local knowledge, draw zone boundaries and view possible effects on a range of conservation, economic and social values.

By making decisions more transparent and accountable, the techniques inspired a greater degree of community ownership and cooperation. The open exchange of information, and the ability to readily view data as maps also created support for proposals to collect new and more detailed information. Most importantly, allowing representatives to directly participate in analyses and the drafting of boundaries helped to divert arguments away from general political stances and towards specific zoning decisions.

These techniques should have an increasingly important role in other marine planning and consultation processes. However, there are a number areas in which consultation and the use of this technology could be improved. Understanding the diversity of scales, information, tools, processes and people that can assist in resolving issues can help improve decisions. It also needs to be recognised that the information tools are there to support, not replace participatory decision making and that these tools should be used explore alternatives, rather than simply confirm preconceived ideas. Most importantly, sufficient time and resources to collect, explore and share information with communities must be allocated if it is to be done successfully. While broad scale surveys and general MPA proposals may serve to identify broad areas of interest, detailed research and direct community involvement is needed for planning at scales relevant to local ecological and human communities.

10.5 Conclusion

GIS based tools with good ecological and social data provided a very useful foundation for the draft zone plan and workshop. In particular, this approach allowed managers and community members to reach compromises through directly exploring the possible outcomes of a range of specific zoning options, rather than becoming locked in polarised debate over general issues or designs. The information systems were invaluable in integrating information from many different sources and formats and in recording and developing options among stakeholders. However the most challenging problems were not scientific or technological, but in how to coordinate balanced discussions among competing interests and develop joint management options.

11 General Discussion

"you can't depend on anything…you need a bus load of faith to get by"

Lou Reed, "New York", Sire Records 1989.

Marine protected areas have an important role in how we manage and understand marine ecosystems. However there is much uncertainty in how they should be applied and what outcomes might be expected for different species, environments and human activities. There are no automatic solutions to problems in marine conservation and MPAs are only one way to help maintain marine ecosystems. Establishing marine protected areas on their own and without careful consideration of the ecosystems and human activities will not guarantee protection and understanding how to manage our use of marine ecosystems is no simple task.

In this thesis, I demonstrated how the systematic use of ecological, social and economic information can help address these complex or so called "wicked" problems in ecosystem conservation and research. However, while the use of spatially explicit, decision support tools has received much attention in recent applications of this approach, these tools are not a completely necessary or sufficient component of a systematic conservation planning process. Knight *et al.* (2006) define systematic conservation assessment as the "technical, often computer-based, identification of priority areas" and conservation planning as these technical assessments "coupled with processes for the development of an implementation strategy and stakeholder collaboration."

Despite this, decision support tools are one way to bring many of the diverse components of conservation planning to focus on specific problems and possible solutions. The tools add value to conservation planning by applying planning principles in a structured, analytical environment. An environment where real planning problems can be confronted in a transparent and repeatable process and where alternatives can be critically assessed using the best available information.

Figure 11. 1 highlights systematic conservation planning tools as one technique to unite many different elements of conservation planning. In the overall scheme of conservation and research, decision support tools require only a portion of the total effort, resources and attention involved. However, to get to the point where these tools can be used requires the systematic organisation of all the resources in the 'pyramid' in Figure 11. 1. The greatest strength of these tools may therefore be in helping to coordinate a central, strategic approach to planning and research. Systematic conservation planning and management relies on the coordinated integration of many interdependent scientific, social and political components. The following discussion highlights the relatively small, but pivotal role of these tools, and emphasises how they are dependent on many other factors for success.

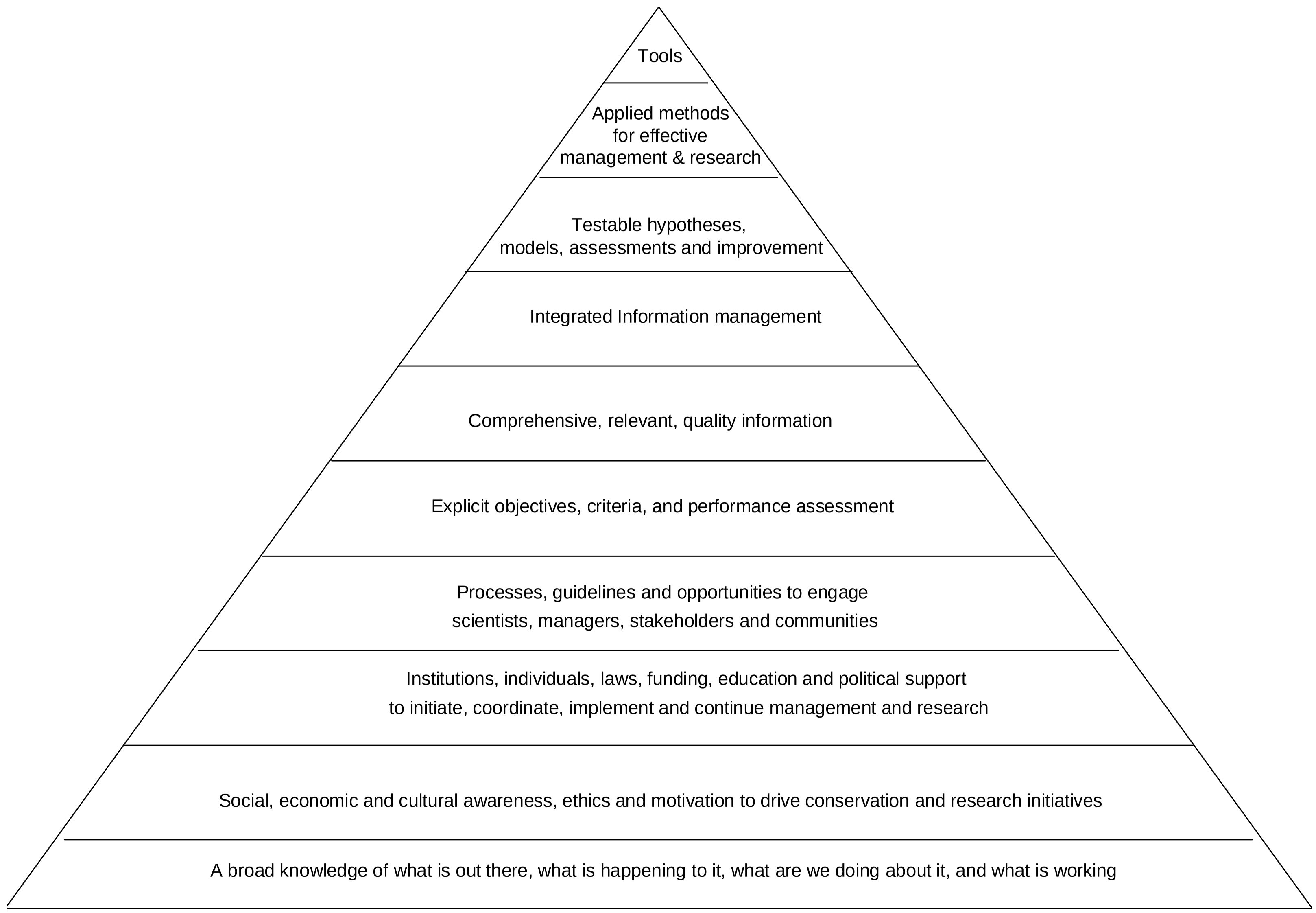

Figure 11. 1. The support required for systematic conservation tools to be effective.

11.1 What is out there? What is happening to it? What are we doing ? Is it working?

These four questions summarise the core knowledge requirements for environmental management. The questions provide the context for the assessments in this thesis and the starting point for any environmental study. If these questions are considered, it is evident that our knowledge although increasing, is limited. An initial recognition of this is a reasonable first step towards planning for a more informed basis for management. For at least some marine locations, there is a reasonable knowledge of what is 'out there' in terms of broad habitat types, some of the more obvious processes and those conspicuous species that may be of special importance to us. However, for most species, habitats and processes, relatively little is known.

Knowledge of what is happening to these systems is even less and a matter debated by many. However, there is a general consensus that for many locations, undesirable changes are occurring in marine systems and in the products and values they provide for human societies. Given that this knowledge of biodiversity is limited and that measuring change is arguably even more difficult, it is quite possible that predictions of 'what is happening?' are underestimates. MPAs are an important tool for understanding the extent and nature of these impacts. For example, comparisons inside and outside of marine reserves demonstrate that fishing can cause significant direct and indirect effects on marine environments (Langlois and Ballantine 2005).

Research associated with MPAs has also had an important role in assessing other impacts such as the effects of run off on sedimentation and water quality (Furnas and Brodie 1996, Koop *et al.* 2001), climate change (Berkelmans and Oliver 1999, Berkelmans *et al.* 2004), tourism (Harriot *et al.* 1997, Breen and Breen 1994ab, Breen *et al.*1997ab) and development (Kelleher and Kenchington 1986, Smith and Rule 2001).

MPAs are however, just one way to help understand and manage impacts. For management to be effective, a range of strategies need to be considered together. MPA management must be considered within the context of sustainable fishing practices, catchments, coastal development, aquaculture, biosecurity, climate change, human demographics, social welfare and politics. The use of different types of MPAs (IUCN 1994, 2000) and combinations of these within large multiple use MPAs, is one way in which integrated management can be achieved.

This thesis aims to integrate marine management and research by reviewing basic, regional knowledge of what marine biodiversity and ecosystems exist, how these resources might be managed in a network of MPAs and identifying where more research is needed. However, it contributes very little towards understanding what may be happening to marine environments, or towards knowing how effective management efforts are.

It does however, provide a foundation on which to design appropriate monitoring programs, and aims to establish MPAs to support this work. The goals, criteria and information presented provide a basis for future evaluation of MPAs as well as other marine conservation strategies. The biodiversity assessments should therefore be considered as only a first step in a process to identify and protect conservation values, compare the effects of this management with outcomes achieved through other strategies and then adapt management accordingly. The sites selected for MPAs in his thesis are essentially management hypotheses based on existing information. Research is now required to ground truth these predictions and to assess whether the MPAs established achieve the goals they were designed to meet (Walters 1986, Underwood 1998, Walters and Holling 1999, Hockings 1998, Creese and Breen 2003, Day *et al.* 2003).

11.2 Awareness, education and motivation

Support for conservation strategies ultimately requires a political and social awareness of the need for management and confidence in the ability of management to achieve its goals. This support is critical if options for MPAs are even to be considered, proposed or assessed and if the resulting MPAs are to be adequately resourced. An awareness of the benefits of MPAs is most important where, as is often the case, there are competing uses such as commercial, recreational or subsistence fishing.

For these reasons a community driven approach to MPA identification and establishment is often recommended (Christie *et al.* 1994, Gilman 1997, Krausse 1998). However this approach can also incorporate a systematic, information based component (Elwood and Lietner 1998, Harris and Weiner 1998, Lewis *et al.* 2003, Close and Hall 2006). MPA processes often incorporate either one or the other of these components, but the approaches complement each other well and when used together, can provide more effective solutions. An information based approach provides structure and direction for community consultation by integrating ecological and social goals and providing access to better information. Communities in return can help develop and refine goals and criteria, validate scientific surveys with their own observations and provide information of their own, particularly for areas they regularly use.

Providing reliable data directly to communities helps increase their awareness of conservation issues, bolsters their confidence in management and empowers them to make their own informed decisions. There are many ways in which consultation can be enhanced through advisory committees (Vasseur and Renaud 1997), community meetings, information sessions, displays, the media and through the availability of staff for public communication. Effective consultation encourages public confidence and a sense of ownership and contributes to the effectiveness of MPAs in adequately conserving marine biodiversity.

In NSW, information was provided through published electronic and hard copy reports and summaries, through internet based map applications and through the direct supply of GIS data to user groups. The provision of information on MPAs in NSW and elsewhere is increasing, but remains an opportunity to support marine conservation that is under-exploited. Without community awareness, motivation and political support, it will become increasingly difficult to establish MPAs and even harder to enforce, fund and maintain these areas. Providing readily understood, well researched information on the values that MPAs protect and the benefits they provide for ecosystems is one of the best ways to ensure that MPAs continue to receive support.

11.3 Institutions, individuals and political support

Promoting marine conservation issues requires dedication from individuals and institutions. Institutions require people to establish, maintain and ultimately make the decisions that create and manage MPAs. It often also individuals who lobby and work to establish MPAs in the absence, or in spite of, institutions for this purpose. In many areas, it is still local communities and individuals who bear most responsibility for establishing and maintaining MPAs.

Institutions however, organise the efforts and resources of many individuals beyond a single working lifespan and can establish the ‘law or other effective means’ (IUCN 1994) required to give MPAs a degree of permanence. Institutions can also help coordinate the development of regional networks of MPAs to meet goals for many different ecosystems, habitats, species and communities. The role of government in this area has lead to the steady, coordinated development of national networks of MPAs and increasing funding for their management. At a global level, international organisations like the IUCN help to promote, coordinate and support the development of MPAs across whole regions.

The way that institutions operate and interact is now recognised as a major factor determining the effectiveness of regional conservation strategies and this topic now has a scientific literature of its own (Imperial 1999, Kinzig 2001). The establishment, for example, of the Great Barrier Reef Marine Park Authority in 1975 was a major step for marine conservation in Queensland, but also provides a model and support for MPA management and research elsewhere. The Authority works closely with several scientific and educational institutions on coral reef studies including a cooperative research centre specifically dedicated to reef research and industry involvement. The Representative Areas program described in Chapter 3 benefited from the expertise and support of scientists and managers from many of these institutions and its success was due in no small part to their cooperation.

Similarly, the NSW Marine Parks Authority is one of the smallest government departments in the state, but it exploits the resources and expertise of the Fisheries, National Parks and Premier’s departments as well as several other departments with a role in marine and coastal management. The latter include the NSW Department of Waterways, the NSW Department of Infrastructure and Planning, the NSW Land Information Centre, Ports Authorities and councils.

Among this many institutions, there is much potential for duplication of effort and resources, but also many opportunities to share resources and information. The assessments in this thesis made use of information and advice from many of these departments and the assessments themselves promote a wider awareness of this knowledge. The decision support tools used in this thesis were also provided freely by individuals supported by other government and educational institutions. These resources are available to agencies and communities through internet sites developed for this purpose (e.g. www.canri.nsw.gov.au). Such cooperation however depends on those individuals within institutions willing to promote data sharing and encourage informed planning and management.

Cooperation among institutions has been important factor in planning for MPAs throughout Australia. The assessments described in this thesis, for example, are just a few of the many joint projects carried out between state agencies and the Marine Protected Areas Program at Environment Australia.[1] More recently, the Commonwealth has sought support from state agencies to develop regional plans which include options for MPAs in offshore waters. The plans and the MPAs proposed will address marine ecosystems adjacent to state waters and therefore cooperation among Commonwealth and state agencies will be required for success.

11.4 Processes to engage scientists and communities

While it is important to inform communities of marine conservation issues and their management, it is also necessary to build processes that allow people, other than conservation managers, to participate in decision making. It may seem expedient to involve fewer participants, particularly where there are opposing views. However this can lead to perceptions that consultation is a pretence, that decisions have already been made and that public comment is only sought to satisfy legislative and political requirements.

Davey (1998) lists eleven reasons why MPAs fail, six of which involve stakeholder input.

- they do not address key issues
- they fail to involve stakeholders
- they rely too much on external experts and fail to involve local people
- they are weak on implementation
- they fail to raise political support for protected areas as a worthwhile concern
- they are poorly publicised.

To engage properly with communities requires that consultation begin early in the MPA planning process rather than towards the end. To do this requires consultation guidelines and

[1] Now the Commonwealth Department of Environment and Heritage.

processes to be established, preferably by law. The *NSW Marine Parks Act (1997)*, for example, requires that an advisory council of stakeholder and community representatives be established to provide recommendations on all marine parks. A local advisory committee is also required to provide specific advice to the government on each individual marine park and a minimum period of consultation is required for each draft and final zoning and operational plan.

At the start of the Manning Shelf bioregional assessment, information sessions on the assessment process were held at regional centres throughout the bioregion. Community forums were also conducted in the Port Stephens and Great Lakes area by a non-government organisation, the Marine and Coastal Community Network. These occurred six years before declaration of the Port Stephens–Great Lakes Marine Park. The report on the "Broad scale biodiversity assessment of the Manning Shelf Marine Bioregion" was made available on the internet and as hard copies, and meetings with representatives of interest groups occurred before the declaration of the park.

However, there were few other opportunities for stakeholders, communities or scientists to provide direct input into selecting boundaries for the park. It could be argued that this approach avoided political debate and further delays (after five years) in establishing the park. However, while general plans for a park were well known, this approach did not encourage trust from the community and the process may not have benefited from all the information that stakeholders could have contributed. Although a Marine Parks Scientific Advisory Committee of four scientists from NSW Fisheries and NSW National Parks oversaw the assessment process, there was little direct input from the broader marine science community. Input from the scientific sector into the zoning process for Cape Byron was also limited to letters in the public submission process and a representative on the Marine Parks Advisory Council and on the Cape Byron Advisory Committee.

This situation contrasts strongly to Great Barrier Reef Marine Parks Representative Areas Program where a multi-disciplinary Scientific Steering Committee with representatives from several scientific and tertiary education institutions provided guidance for the whole process. Interviews were also conducted with over 70 different experts in tropical marine animal and plant ecology, oceanography, geology and reserve design. Expert workshops were also held to interpret the data collected, develop bioregions, and establish reserve design guidelines to zone the marine park. This scientific input covered a broad range of marine ecosystem science on topics including fishes, invertebrates, algae, seagrasses, mammals, birds, reptiles, water quality, oceanography, geology and social science (Day *et al.* 2002). This input provided much additional information to that available from scientific literature and databases. The support of so many scientists with experience in the region also generated a high degree of confidence in the plan and a greater appreciation of the conservation values involved.

Community consultation to develop a zoning plan for the Great Barrier Reef Marine Park then collected submissions from over thirty thousand people through meetings, phone calls and surveys where individuals could map areas that were important to them for different interests (Innes 2004, Fernandes *et al.* 2005). Similar techniques were also used to analyse responses to previous plans for the Cairns, Whitsundays and Cooktown areas of the Great Barrier Marine Park and to map social and ecological values (Bollard-Breen 2006). This method was adopted in Chapter 10, for the Cape Byron Marine Park Draft Zoning process, and for the subsequent Port Stephens – Great Lakes Marine Park draft zone plan. In this way, the views and concerns of local communities could be systematically considered in zoning options and managers could make use of community information that might not otherwise have been available.

In Chapter 10, I also demonstrated how community workshops and reserve planning software could integrate this social data with ecological information to interactively design a system of MPAs using a participatory GIS approach. Similar community workshops have been conducted elsewhere with some success for terrestrial (Pressey 1998) and marine protected areas using tools such C-Plan, Marxan and multiple criteria analysis (Fernandes 1996, Villa *et al.* 2002). However, their use in MPA processes is often limited or included too late in the planning process. Adequate time and resources are required for this approach to be effective and informed workshops need to be scheduled as a mandatory component of the planning process.

An area where this approach could be of special value is in the ecological design of MPA networks. A workshop of scientists with expertise in biology, modelling, connectivity, fisheries and experimental design would be able to make the best use of the more advanced spatial features of reserve planning tools. They could also provide direct input on the likely outcomes of alternative designs and how predictions could be tested. The effects of different MPA network designs on protected and surrounding marine ecosystems is one of the most pressing issues in MPA science and management but practical attempts to address this question are few (Sale *et al.* 2005). Large, multiple use marine parks in NSW are ideal candidates for this type of study as they effectively establish whole regional networks of highly protected reserves and other MPAs simultaneously. Management is also required to monitor and review the performance of these MPAs every five years. However, so far, the direct input of scientists into MPA design in NSW has been limited and this approach needs to be carefully explored. Scientists need to be included not just as stakeholders with an interest in permitted research, but as experts that can contribute substantially to the design, management and functioning of MPAs.

11.5 Objectives, criteria and performance assessment

I used multiple criteria models to explicitly model the relationships among policy goals, criteria and the measures used to assess locations for MPAs. These presented a systematic, unified summary of the various guidelines, policies and legislation that verbally define how MPAs are to be identified by the NSW Government. In developing and prioritising the multiple criteria models, other studies have relied on input from managers, stakeholders and the community (Fernandes 1996, Villa *et al.* 2002). In this study, there was little opportunity to involve stakeholders and community directly in developing the models. However, comments from initial community meetings and documents summarising many years of consultation and experience were incorporated in many of the criteria.

The models are broadly applicable elsewhere and can be easily modified to accommodate new goals and criteria, alternative priorities and new information. In a more comprehensive consultation process, input from other sources could be used to develop alternative models.

It is important to distinguish between the conceptual (Chapter 2) and applied multiple criteria models developed (Chapters 5-9). The conceptual models were developed to represent the many potential goals portrayed in policy and legislation. The applied models were based on the conceptual models but constrained by the information available at the time. A comparison between the conceptual models and their actual application in the assessments clearly shows what information was available and where more information may be required. These goals and criteria also provide the logical basis to assess in the future, how well the MPAs perform in meeting their objectives.

11.6 Comprehensive, relevant and useful data

Models and decision support tools can assist in interpreting and summarising data from many different sources. However, support for decisions should ultimately be founded on direct observations and not just on derived indices. Models and indices are a powerful way to summarise data, but they can obscure the individual influences of many contributing factors and under-represent the weight of evidence provided by a range of independent information sources. An index may indicate that a site has high conservation value, but only the underlying data will reveal which particular value, or values are important and what is the appropriate management action. Individually identified sources of evidence are also more readily understood, evaluated and trusted by communities and scientists.

When interpreting an analysis it may be prudent to “not believe it, unless you can see it, and then, still don’t believe it” (B. McArdle pers. comm.). For this reason, the assessments in this thesis provided individual descriptions of all data sources, their limitations and features of the data likely to contribute to a site’s suitability as a MPA. A deliberate attempt was made to represent each measure in a format that was easily understood by simply mapping and graphing data. In this way, all interested parties could assess for themselves the values that occur at a site for any given criteria, rather than relying solely on aggregate mathematical scores or subjective interpretations.

Several studies have examined the effectiveness of using a limited set of biodiversity surrogates to represent a wider range of perhaps more detailed biodiversity values (Ferrier and Watson 1997, Ward *et al.* 1999, Buxton 2005). However to assess the validity of a particular surrogate requires independent data for verification and where this data is available, it should then also be presented, particularly if it provides additional support or new interpretations.

The assessments in this thesis relied primarily on a broad scale environmental classification applied at several spatial scales with surrogate classes ranging from bioregions, ecosystems, habitats, and communities to species. The hierarchical nature of the classification, and the classes chosen in each level, significantly influenced which locations were identified as potential locations for MPAs.

The decision to establish representative MPAs, including at least one marine park, in each of five different bioregions immediately constrained choices about where MPAs should be located. Criteria also required the inclusion of each estuary type in each bioregion within MPAs. This constrained choices further, especially where only a few locations were able to meet these criteria. At the habitat surrogate level, the locations of rarer features such as islands, reefs and the larger complexes of seagrass, mangrove and saltmarsh again strongly influenced which sites were identified as MPAs. For zoning within the limited area of the Cape Byron Marine Park, these features, and finer scale classes such as boulder shores and reefs in different depth zones, were a major influence on where sanctuary zones were established.

A basic assumption here, is that the surrogate bioregion, ecosystem and habitats actually correlate with patterns in biodiversity. While general justifications for all of these categories were available from the scientific literature, there were few comprehensive data sets of species distributions throughout the state available to test the overall performance of this classification.

It was therefore considered prudent to assess whatever other information on biodiversity values was available to supplement these choices. This was reasonable given the uncertainty in many data, the approximate nature of the surrogates, the complexity of the systems studied and the range of different questions and criteria to be addressed. This approach was also consistent with a philosophy to provide information for decision making, rather than simply impose decisions through an *a priori* selection or exclusion of information. Confronting alternative decisions with different data sets provides more opportunities to compare and question alternative choices for MPAs. Although it may require more time to assess a wide range of information, the time required to implement and consult for MPAs can be considerably longer, particularly where the justification for the MPA is questioned. The weight of evidence provided by many data sources was therefore considered a reasonable and convincing approach given the circumstantial nature of much of the information available.

Constraints on funding and time often limit applied marine biological research to short term studies at a few selected locations. Surveys are often opportunistic and information for whole regions is often fragmented into many different data sets, collected at different times by a range of different methods. It is possible to aggregate data from many similar studies. This has been done, for example, for bathymetry (Buchanan 1998) and seabed sediment data sets (Jenkins 1997, 1999ab, Roy and Boyd 1996, Boyd *et al*. 2004). However this approach requires many data points and adjustments to produce an even coverage that avoids biases in site selection, methods and units of measurement.

For most areas, biological data sets only provide a sparse and uneven distribution of species records. The Great Barrier Reef Marine Park Representative Areas project was to a degree, an exception to this. Although by no means a complete coverage, several systematic data sets were available across large regions for many species of fishes, hard and soft corals, algae, seagrasses, sponges and other benthos. This region has been the subject of extensive research programs for several decades. It includes relatively calm, warm, shallow waters, is important for tourism and fishing, includes conspicuous and attractive biodiversity and is adjacent to an affluent population with government agencies that are relatively well resourced. For these reasons, the region is relatively ‘data rich’ when compared to many other areas.

However, even here, very few, if any, data sets extend over the entire region of interest and all the data required at least some level of interpolation. The major issue, however, was not whether data existed, but whether it was accessible to planners, managers and scientists in an integrated form that could be used in decision making.

In NSW, marine environments have also been the subject of many years of research, but deeper, colder and more exposed conditions and a focus on the ocean as a resource (or dumping ground) have constrained research on marine biodiversity to greater degree. For inshore NSW, there were few systematic surveys of species distributions at broad spatial scales. Data collections for commercially fished species (Pease 1999) and museum specimens (Avery 2001) provided information for some areas but were biased by the intent and scope of the original research. However, other systematic surveys of intertidal organisms (Otway 1999), threatened sharks (Otway *et al.* 2003), estuarine fishes (R. Williams pers. comm.), birds (NPWS 1999abc, 2000bcd), and wetlands (NPWS 2000a) provided important data for the assessments.

Many other detailed studies were not included in the assessments because they were limited to a few locations. These could, in the future, be aggregated with other similar data, or used in planning for specific sites. A systematic process to review these data and address gaps in our knowledge of marine ecosystems is greatly needed. At a general level, the assessments in this thesis provide a starting point for this process.

Comparisons between the ideal goals and criteria defined in Chapter 2 and the actual measures used in Chapters 5-8 clearly show the approximate nature of the surrogate measures used and they highlight information gaps for many regions, habitats, taxa and other criteria. It was recognised in the assessments that more detailed information for fine scale habitats, individual species and social, economic and cultural values would be necessary to implement any options for MPAs and the assessments emphasise these information gaps.

In particular, the assessments identify the need for more detailed surveys of:

- subtidal environments, particularly offshore but also in estuarine areas
- finer scale biodiversity surrogates, especially for less well studied flora and fauna
- condition, vulnerability and changes in marine environments and populations
- ecological processes, connectivity and MPA designs to support these processes
- human activities and values and how these interact with marine ecosystems and MPAs
- comprehensive ground truthing of data and testing of assumptions and outcomes.

Vast areas of subtidal reef and offshore sediment throughout the state remain poorly mapped. Many of these areas are probably well known to fishermen and this knowledge has been used to produce detailed, scientifically verified maps of seabed and benthos for the continental shelf off the southern NSW and Victorian state border (Williams and Bax 2003). There is also the potential to aggregate existing geological seabed data (Jenkins 1997) and Boyd *et al.* (2003), for example have now developed a broad scale model of the entire NSW continental shelf. Multibeam (A. Jordan pers. comm. NSW Marine Parks), sidescan sonar (Bickers 2004) and video methods are also being used to map subtidal habitats in marine parks in NSW.

However the relationship between coarse scale surrogates and the community structure of different species assemblages is still poorly understood. As this link is a major assumption of assessments, and because biodiversity at the species level is a primary concern for conservation, it is important that research to assess these assumptions is planned and supported.

Another challenge for MPA research and management is to understand the ecological processes that link species populations, habitats and regions and how these processes respond to different management strategies. The importance of such relationships for designing a functioning MPA network is well recognised and acknowledged in the goals and criteria adopted for MPA identification and elsewhere (Sale *et al.* 2005). However, actually assessing criteria for these process is complex, given that our knowledge on how organisms respond to different MPA network designs is mainly theoretical. These aspects of reserve design have not been adequately addressed in this thesis. However, research linking marine ecosystem dynamics and MPA performance has been developing through a steadily growing body of observations (Sale *et al.* 2005), theory, mathematical models and workshops. Empirical studies of migration, reproduction, dispersal, recruitment, growth and survival have been made for an increasing number of species. There has also been a greater recognition that larvae and juveniles are not passive particles but influence their dispersal through directed behaviours (Leis 2003).

Research of this kind can be used to inform theoretical models and simulations with biological parameters relevant to the organisms that MPAs are designed to conserve. Some studies have used geographically realistic models to simulate ecological processes for specific regions and locations. James *et al.* (1990, 1998, 1999) simulated larval dispersal on the Great Barrier Reef using mathematical models of the interaction of tides, winds and currents with complex reef structures throughout the Cairns region. Wolanski *et al.* (1996) simulated the behaviour of propagules at smaller scales using three dimensional models of individual reefs and current fields. Trophic mass balance models have been used to integrate data on biomass and energy flows among different species, trophic levels and environments which include spatially explicit models of MPAs (Mackinson *et al.* 1997, Guenette and Pitcher 1999, Watson *et al.* 2000). Parnell *et al.* (2006) used models developed for 20 species and five habitats to help select the best location for a marine reserve near La Jolla, California.

Many terrestrial studies have also investigated the role of ‘corridors,’ habitat patch size, separation and configuration in maintaining ecological processes (Rouget *et al.* 2005). The mathematics of ‘graph theory’ provides a potentially useful way to evaluate how connectivity changes as habitats are included or excluded from a network (Bunn *et al.* 2000). For habitat and species data stored in GIS, many relevant parameters such as patch size, distance, and connectivity can be easily estimated or simulated. The spatially explicit, object oriented nature of these databases also provides an environment to build individual-based models (Hinckley *et al.* 1996) with realistic habitats, populations and management interventions. Reserve selection algorithms now also incorporate spatial reserve design parameters for size, spacing and replication and organism occurrence, dispersal and persistence.

The virtual ‘seascapes’ developed in the assessments described here could now be used to explore dynamic ecosystem models that use spatially realistic data for habitats, species and systems of MPAs. The potential to model processes using mapped objects of real environments and management interventions, could be a highly effective tool for future marine planning. Specific predictions from these models could then be rigorously tested in carefully designed monitoring programs.

Among the most neglected areas of research for MPAs is an understanding of their social, economic and cultural values. These values are usually considered as part of a consultation process, but are rarely included in any preceding systematic data collection or analysis of options. Such values were recognised in the conceptual MPA goals and criteria in Chapter 2, but were not considered within the scope of the broad scale bioregional assessments. In Chapter 9 however, I showed how surrogate measures for some social and economic values could be estimated from surveys and interviews and how this data could be integrated with ecological data in reserve selection algorithms and community workshops. While social, economic and cultural issues are complex, MPA programs can still benefit from adopting a systematic approach to collecting and analysing data on these issues as part of wider selection, management and monitoring strategies.

While identifying may MPAs require research, the reciprocal contribution of MPAs in initiating, supporting and continuing research can be even greater. MPAs highlight the conservation values of particular locations, and marine ecosystems in general, to a wide political, social, economic and scientific audience. They also serve to showcase the research of scientists working within MPAs. MPAs often generate increased resources for more detailed research on biodiversity, ecological processes and human values.

The Great Barrier Reef Marine Parks Representative Areas program, for example, provided support and recognition for existing research programs, initiated additional studies and supported more detailed analyses of data collected previously. This included the mapping and statistical analysis of data for seagrasses, fishes, corals, algae, sponges, *Halimeda* bioherms and seabed morphologies.

Assessments in NSW and the Great Barrier Reef Marine Park successfully transcribed many data sets from verbal, written, paper or other media into digital GIS formats. The assessments had an important role in archiving information and expert knowledge that might otherwise be lost or forgotten.

Initial reviews of both these projects indicated that very little information for either of these regions would be available and that very simple measures or an *ad hoc* approach would be more realistic. While less data were available in NSW, both assessments were however able to collect substantial amounts of information to inform planning.

Without these assessments, the MPA identification and selection processes could have relied on *ad hoc* or subjective decisions or very coarse scale, physical predictors of biodiversity. It is therefore important, that processes and structures are in place to maintain and develop a collective knowledge of marine ecosystems. This should include not just the verbal documents which the scientific literature relies upon, but also the data that underpins this work.

11.7 Integrated data management

Figure 11.1 highlights the importance of integrated data management in systematic conservation planning. Human impacts occur at many scales for many different ecosystems, habitats, processes and species. Impacts can be complex and involve cumulative, synergistic and emergent effects that are not easily predicted or understood. For these reasons, ecosystem wide management, modelling and research must take a holistic view that is able to integrate information from many different disciplines and sources.

Once goals and criteria are identified, conservation assessments need to identify what information is available and bring this information into a common environment where different data sets can be stored, documented and analysed together. GIS have an important role here because of their ability to join and query different data sets on the basis of spatial locations common to otherwise disparate tables. GIS now combine the capabilities of relational databases with powerful tools for spatial analysis and data visualisation. These tools are readily integrated with other scientific and management databases (Fernandes *et al.* 2005), internet programs (www.spatialvision.com.au, http://chrisweb.dpi.qld.gov.au/CHRIS/), statistical packages (Day *et al.* 2002, Bollard-Breen 2006, www.splus.com) and bibliographic databases.

Data integration requires a central repository for data storage. This may be as simple as a dedicated file server or directory for a project. There are also centralised databases on the internet for many agencies, regions and fields of interest and directories that provide links to information with global repositories increasing rapidly in number and scale (Grassle 2000, www.marine.csiro.au/datacentre, www.canri.nsw.gov.au). The GBRMPA Representative Areas Program and the assessments in NSW relied heavily on initial internet searches of these sources. Community based assessments such as described in Chapter 10 for the Cape Byron Marine Park can also make use of these data. In NSW, for example, the marine environmental classification and other measures in this thesis were mapped in an internet GIS application (www.nratlas.nsw.gov.au) and community representatives were able to download shape files and metadata (www.canri.nsw.gov.au/download) to help develop independent options for zoning.

Protocols and agreements associated with centralised approaches to data management can help ensure the assumptions and limitations of data are recognised and that ownership and intellectual property is protected without necessarily excluding other users. While detailed information for many areas and subjects may not yet exist, systematic approaches to data collection, storage and documentation can help ensure that existing information is not lost, that research effort is not duplicated unnecessarily and that the best available information is readily available to all scientists, managers and community. These data collections also serve to highlight gaps in data availability and identify where further research is required.

11.8 A scientific approach to develop and test marine management hypotheses

The initial selection and much of the management of MPAs depends strongly on an integrative approach to ecology as there is often little opportunity to experiment at a scale that addresses the range of issues involved. However, research and management for MPAs can benefit greatly from adopting a rigorous, scientific approach to collecting and assessing evidence and ensuring that the results of scientific research are directly used by environmental decision makers.

Repeated assertions of the effectiveness of MPAs, without scientific support, are not in the best interests of conservation. In the long run, it is worth recognising uncertainty and aiming to reduce the role of *ad hoc* decisions by making the best use of what information is available and seeking to test and improve this knowledge.

In the assessments in Chapters 5-8, quantitative planning tools and a range of different data were used to generate alternative hypotheses about how well different MPA networks were likely to represent marine biodiversity. In the Cape Byron draft zoning process, this approach provided a flexible way for managers and community representatives to assess alternative MPA networks and how these might affect different human interests. In both these processes an iterative modelling approach was used to propose, test and then improve MPA designs while using only existing data and “local” knowledge. However, as MPA networks develop, decisions will become more complex and costs to competing activities will create more dispute. Much of the current evidence to guide and support the design of MPA networks is circumstantial. The MPAs recommended in this thesis are effectively predictions about how well different areas are likely to conserve a representative sample of marine biodiversity. Where possible, alternative options, and tools to explore other options were provided to encourage ongoing testing and refinement of MPA designs.

In NSW, initial improvements were readily apparent as many unique and previously unprotected ecosystems, habitats and species were successively included in MPAs. However, at a local level, scrutiny of available data by the Cape Byron Marine Park Advisory Committee identified significant gaps and provided the impetus for more detailed surveys including sidescan sonar and video surveys of subtidal environments, updated maps of estuarine vegetation, more detailed classifications and studies of intertidal shores and surveys of recreational and commercial activities (NSW Marine Parks Authority 2003, Bickers 2004, S. Banks and D. Scott pers. comm., D. Chapman pers. comm., G. West pers. comm.)

We can also attempt to model the uncertainty in proposed MPA models. However, with many parameters, data sets and sources of error this could become a very complex task. In most cases, there has simply not been enough data to quantify systematic or random sources of error.

However, techniques that may assist here are being explored. Halpern *et al.* (2006), for example, compare estimates of uncertainty derived from traditional statistics and modelling with techniques in probability bounds analysis, interval analysis and info-gap theory. They apply these methods to the problem of modelling optimal reserve separation based on the estimated dispersal distance of a single fish species. These approaches, even applied at such a simple level, could provide at least cursory tests of the many assumptions implied in the design of reserve systems and the spatial and ecological information provided in this thesis and related research would greatly assist in doing so.

Ultimately however, the true test of an MPAs lies in how effectively it achieves its goals for conservation and sustainable use. This can only be assessed by rigorous monitoring of predicted outcomes and at least some consideration of experimental design in designating MPAs. This is also the only reliable way in which choices about reserve size, spacing and configuration can eventually be made. Many studies have documented changes within MPAs. However, the more subtle effects of spill over, recruitment and other benefits to surrounding areas, although frequently espoused, have rarely been tested. Examining how existing and newly established MPA networks perform in these areas would provide a better foundation for future networks.

There are many design requirements common to robust MPA networks and rigorous scientific research designs (Table 11.1). Much of the work required for both these tasks is complementary and can best be carried out using MPAs as quasi-experimental units. The zoning of multiple use MPAs where different levels of management are allocated to different areas provides an ideal opportunity to test these and other hypotheses about surrogates, representativeness and the various effects of MPAs. However, this framework is rarely taken advantage of, and research and monitoring for MPAs is often applied inconsistently, even within the same network and jurisdiction (Creese and Breen 2003).

This thesis has demonstrated that it is possible to learn a lot about marine ecosystems at broad spatial scales from existing information and a relatively simple, desktop mapping and iterative modelling process. MPA management and research should however, aim to integrate the results of these types of studies with an experimental approach to network development. The assessments should be regarded as just the first step, in an ongoing cycle of adaptive management and research where conclusions from finer scale experiments are applied and tested at a broader ecosystem level.

Table 11. 1 Similarities and differences between MPA and experimental designs (based on Kingsford 1999).

Management of MPA systems	**Research methods**
Need to assess effects of reserving (or not reserving) areas against a background of natural change.	Need to assess the effects of treatments against a background of natural change.
Selectively sample MPAs from sets of candidate sites.	Randomly sample from statistical populations of interest.
Need to understand natural patterns and processes and how they interact with humans.	Need to understand natural patterns and processes and how they interact with humans.
Findings used to evaluate initial management strategies, improve management model, and reassess.	Findings used to evaluate hypotheses, improve scientific models and test new hypotheses.
Need to assess effects of reserving (or not reserving) areas against a background of natural change.	Need to assess the effects of treatments against a background of natural change.
Selectively sample MPAs from sets of candidate sites.	*Randomly* sample from statistical populations of interest.
Need to understand natural patterns and processes and how they interact with humans.	Need to understand natural patterns and processes and how they interact with humans.
Findings used to evaluate initial management strategies, improve management model, and reassess.	Findings used to evaluate hypotheses, improve scientific models and test new hypotheses.

11.9 Real world applications of systematic marine planning and decision support tools.

Systematic assessments and decision support tools can only achieve real outcomes and be fully evaluated if they are applied to real planning situations and the results are used to guide and support management and research programs (Knight *et al.* 2006a). It is critical that they are not merely academic exercises in ecological mathematics. Their application to 'real-world' problems is therefore emphasised at the ninth level in Figure 11.1. Knight *et al.* (2006b) caution that conservation assessments alone, "do not deliver the actions necessary to conserve nature, they merely generate data to support the planning and implementation of conservation interventions. They cite that "between 1980 and 2000 at least 245 published studies employ selection algorithms" but caution that the fascination of many planners with the incremental improvement of assessment techniques has drawn the focus away from the real goal – directing conservation actions – because relatively few assessments published in peer reviewed literature actually lead to nature conservation (Prendergast *et al.* 1999, Faith *et al.* 2003, Knight *et al.* 2006b).

Managers have been slow to adopt systematic methods despite steadily increasing access to sophisticated ecological research, decision support and information management tools. A number of reasons may have been responsible for this. Firstly, there are fears that numerical, and particularly computer based methods usurp human decisions with 'black box' methods that produce arbitrary or unrealistic results beyond the control of decision makers.

Secondly, decision making is politically influenced and driven by administrative expediency with strict limits on time and resources. In these situations, simple methods and answers are the most readily trusted. Methods that complicate issues, require additional skills and resources, question assumptions or generate alternative views are regarded as obstacles to progress.

Thirdly, while systematic conservation planning and decision support may be based on policy and accepted principles, advanced theories and applied methods in ecology, mathematics and computing are unfamiliar to many people. These techniques may be mistrusted by managers and communities, particularly if they must rely on specialists for interpretation.

As a result, many conservation agencies still make only limited use of ecological data and spatial information technologies and provide only minimal resources to support systematic, science based, ecological planning. With some important exceptions, the majority of this work is done by external research or educational institutions or by contractors as isolated projects rather than within strategic, mainstream, corporate priorities. Without ongoing, dedicated maintenance by employed ecological analysts, much of the work actually done in setting up ecosystem information systems is often undone, forgotten or made obsolete when short term projects end. Effort is then duplicated by repeating these exercises from start, for each new problem. It is therefore critical, that practical applications of these methods are shown to be a realistic and cost effective part of a wider, and ongoing business strategy and not just experimental trials for isolated test cases.

To achieve this, is perhaps more challenging than the science itself. It requires planning for the development and refinement of tools that can be reliably used by, or at least with, managers and community members. It also requires: an increased awareness of these methods; an acceptance of their role in supporting and not replacing human decisions; the time, resources and opportunities for their use; and a professional capacity that includes staff familiar with these methods (Rodriguez *et al.* 2006).

The best way to do this is through practical examples that directly engage scientists, managers and communities and carefully planned and structured communication with these groups. The following sections compare the application of these methods in this thesis with previous assessments in NSW and elsewhere.

In Australia and elsewhere, systematic planning for terrestrial reserves has assisted in developing extensive systems of terrestrial protected areas and highlighted gaps where new reserves are most needed (Csuti *et al.* 1997, Margules and Pressey 2000, Cowling *et al.* 2003). This planning approach has involved extensive surveys and mapping of environments, flora and fauna (Margules and Stein 1989, McKensie *et al.* 1989, Margules *et al.* 1994), assessments of surrogates for biodiversity (Ferrier and Watson 1997) and the development of decision support tools now used around the world (Margules and Pressey 2000).

Planning for the conservation of marine environments in NSW has been less systematic. There have been many surveys of marine habitats and species, but with some exceptions (West *et al* 1985, Short 1995, Andrew *et al.* 1997, Williams *et al* 1998), most were limited to a few locations. There have also been studies of biodiversity surrogates (Ward *et al.* 1999) and trials of reserve planning tools (Pilav-Savic *et al.* 1996, Gladstone 2002). Broad scale assessments and proposals for networks of MPAs in NSW have been made previously (Pollard 1980, 1997, Pollard *et al.* 1997, Parker 1995) and finer scale assessments have been made for specific areas, habitats or species (Otway 1999, Frances 2000, Avery 2001, Gladstone 2001, Otway *et al.* 2003). The assessments in this thesis share many similar sources of information with these studies. This study however, differs in the range of criteria and locations assessed and the extent to which systematic planning tools were used to integrate, analyse and communicate information.

Pollard (1997) identified priority areas for MPAs and many of these were eventually implemented as aquatic reserves and the first marine parks in the state. The systematic analyses in this thesis support the selection of many of these sites including the large marine parks established at the Solitary Islands and Jervis Bay. Parker (1995) also identified a comprehensive system of marine and estuarine protected areas that included large marine national parks and smaller marine nature reserves. This proposal was not included explicitly in the bioregional assessments in order to keep the more recent studies as independent as possible. However, in retrospect, there are many similarities between Parker's proposals and the recommendations of the bioregional assessments in this thesis. The assessments include many of Parker's recommended areas within options for the large marine parks described in Chapters 6, 7 and 8 and within other smaller areas recommended for protection.

Otway (1999, Otway and Morrison, in prep.) identified several sites for MPAs on rocky shores in the Manning, Hawkesbury and Batemans Shelf bioregions using fine scale habitat predictors and surveys of species richness. Again, many of these sites are included in proposals for MPAs selected using broad scale biodiversity surrogates in Chapters 6, 7 and 8. Frances (2000) employed an expert panel and similar criteria to this study to identify sites for estuarine aquatic reserves. Once more, many of these sites are included in the MPA options described in the broad scale assessments.

It would be surprising, if these studies reached markedly different conclusions. However the similar recommendations, from different sources and using different approaches, tend to confirm the suitability of these areas as MPAs. Although not entirely independent, the studies provide convincing evidence that supports conservation management at these locations.

Two of the recommended options (Port Stephens - 972 km^2 and Batemans Bay - 850 km^2) are now established as the largest MPAs in the state. Options for a third large marine park in the Hawkesbury Shelf bioregion are also proposed. Figure 11.2 shows the progressive implementation of a network of MPAs in NSW, which now includes over 35% of state waters. Less than a third of this area is closed to all fishing within highly protected 'no-take' areas. However, all of the MPA sites are to be managed for the conservation of biodiversity.

It is difficult to completely distinguish the relative influence of systematic assessments in establishing these MPAs. Other factors such as increasing levels of institutional support, and a wider political and community awareness are an essential part of the process. These, and other factors listed in Figure 11.1 have provided fundamental support for the assessments and the authority to implement these changes. Other *ad hoc* opportunities have also influenced outcomes, sometimes more than is commonly appreciated. However, systematic assessments can provide guidance and support under all of these circumstances and a basis for ongoing management.

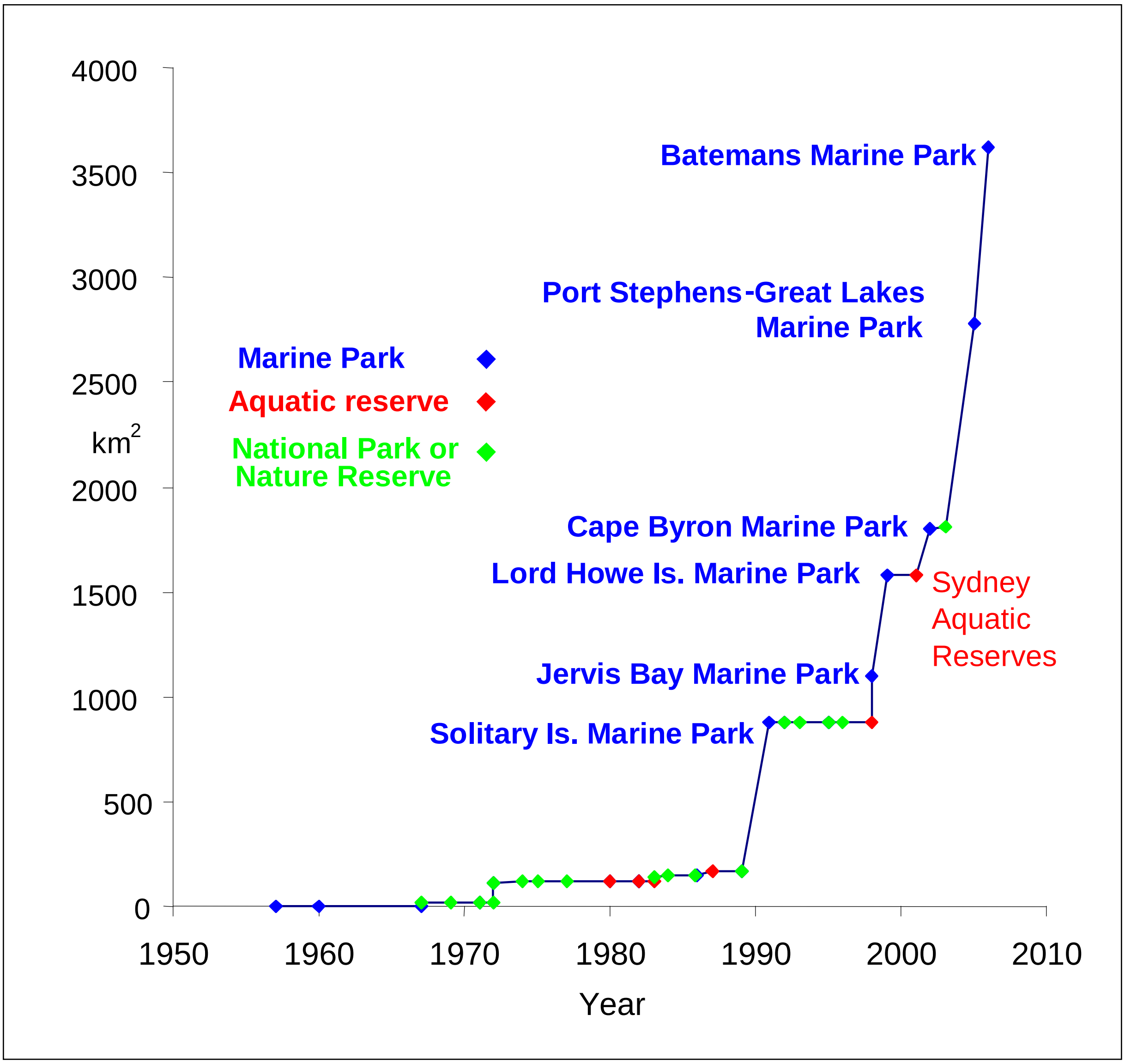

Figure 11.2. Increasing area (km^2) of MPAs in NSW.

11.10 Application of decision support tools for other MPAs

The use of a systematic approach and decision support tools has had significant outcomes for marine conservation and research elsewhere. For many years, the Great Barrier Reef Marine Park Authority maintained a GIS capability and supported extensive research and monitoring programs within the department and through associated research and educational institutions. Planning at the Authority also benefited from clearly defined objectives, comprehensive consultation processes and extensive education programs.

This work provided an important foundation for the Authority's Representative Areas program. This process incorporated a GIS based biodiversity assessment with ecological and social guidelines, decision support tools (Ball and Possingham 2000 and De'Ath 1999) and consultation with scientists, stakeholders and communities. The program also benefited from a high level of government and community support.

The resulting zoning plan increased the area of highly protected 'no-take' zones in the Great Barrier Reef Marine Park from less than 5 % to 33 % of its total area (345,000 km^2). The resulting network of fully protected areas, each at least 20-40 km in diameter, included a minimum of 20 % of the area of 70 biologically distinct regions (Fernandes *et al*. 2005).

Similar systems are being used to inform planning for marine protected areas in Queensland (Banks *et al.* 2005, Buxton 2005), South Australia (Stewart *et al.* 2002, Stewart and Possingham 2003, 2005), and at locations in Florida (Leslie *et al.* 2003, Cowie-Haskell and Delaney 2003), California (Airame *et al.* 2003), Maine and New England (Cook and Auster 2005), Wales (Richardson *et al.* 2006), and the Mediterranean (Villa *et al.* 2002). Some of these projects have been more successful than others in implementing MPAs, which suggests that assessments are not sufficient on their own to establish effective MPAs. All have however, provided critical assessments of existing networks and informed recommendations on what additional measures are required.

In New Zealand, for example, commercial fishing representatives (Deepwater Stakeholder Group 2006) proposed to close 31 % (1. 2 million km^2) of the country's Exclusive Economic Zone (EEZ) to bottom trawling. However, other forms of trawling and fishing would be allowed throughout these areas and the proposal required the repeal of regulations protecting seamounts in 18 areas currently closed to all fishing.

In addition, the proposal called for a signed accord with the government to consider the contribution of these proposed "Benthic Protection Areas" (BPAs) when assessing "the need for any marine protected areas" or "the need for, and funding of, research relating to any need for any such closed areas." The accord also sought agreement from the Minister for Fisheries to not "intend to close any further areas…to bottom trawling." However, a systematic evaluation of the distributions of trawled fish species by Leathwick *et al.* (2006b) using the reserve planning software Zonation, revealed that the proposed areas coincided with areas of low biodiversity value and would result in only a minimal loss of fishing opportunity. The timing of this proposal coincided with a bill to amend the New Zealand Marine Reserves Act 1971 to allow fully protected marine reserves to be established in the EEZ beyond territorial waters (beyond 12 nautical miles of the coast).

Without independent, objective and systematic assessments, proposals such as the accord threaten to trade existing and future MPAs for management that may not adequately represent or protect marine biodiversity. A failure to carry out reliable assessments can therefore result in even existing levels of protection being removed and in compromising future opportunities to develop effective MPA.

11.11 Systematic marine conservation planning and decision support tools

Several different decision support tools were used in the assessments for NSW. While some differences were evident, all of the tools produced broadly similar results. Most variation appeared to be due more to the data, planning units, targets, priorities and reserve design parameters used. While studies assessing the efficiency of a range of numerical tools (Csuti *et al.* 1997, Pressey *et al.* 1997, Cabeza and Moilanen 2001) often focus on differences in performance, it is frequently the similarities in solutions that is most evident.

In Figure 11.1, the particular choice of tool used is less likely to influence final planning and conservation outcomes than any other level in the hierarchy. What is important is that at least some form of systematic approach or tool is used (Knight *et al.* 2006b). The tools used in this thesis, although similar, had slightly different, but complementary uses.

C-Plan (NPWS 2001) was particularly useful in providing an almost instant statistical assessment of irreplaceability under changing scenarios of different targets, data and the selection or exclusion of planning units. The use of relatively large plan units in the bioregional assessments overcame constraints in aggregating small units into large reserves and provided easily interpreted, multivariate measures of conservation value for whole estuaries and sections of coast. The additional use of smaller (10 hectare to 4 km^2) plan units allowed for more detailed, interactive MPA design. The ability of C-Plan to update conservation priorities makes it a useful ‘hands on’ tool for conservation planning with scientists, managers and communities. The tool was used in this way with managers for the bioregional assessments and with community representatives in the Cape Byron Marine Park draft zoning process. However, a more open planning process would permit a much wider use of this capability.

Marxan (Ball and Possingham 2000) provides a flexible and powerful tool for goal oriented reserve design with options that include spatial aggregation, replication and configuration of reserve options. The tool is flexible in that repeated use of the simulated annealing algorithm can provide a range of MPA options. Marxan was used to develop options for a range of conservation targets throughout NSW and designs to minimise impacts on commercial fishing costs in the Cape Byron Marine Park. Marxan was also recently used to assess zoning options for the newly declared Port Stephens – Great Lakes Marine Park using ecological, recreational and commercial data..

Unlike C-Plan, Marxan, Worldmap, Zonation and other similar tools, the multiple criteria models built in Criterium Decision Plus (InfoHarvest 2001) do not inherently take into account the complementarity of sites in contributing towards conservation targets. However, this tool was able to integrate previously calculated estimates of irreplaceability from C-Plan with over 60 other quantitative and qualitative measures in a hierarchically structured tree of MPA goals, priorities and scores for alternative sites. This tool also provided a way to assess alternative sites according to varying priorities provided by different individual users.

The decision support tools applied employ relatively sophisticated techniques. However, these assessments have explored only part of their full potential and new techniques continue to be developed. The C-Plan reserve planning software has been modified to link with Marxan and now incorporates spatial criteria for advanced reserve design. The Zonation algorithms developed in Finland (Moilanen and Cabeza 2002) are now being used to incorporate design criteria for population persistence, uncertainty and dispersal. Other methods that incorporate uncertainty, decision theory, risk, ecological modelling and social science in new ways are also being applied (Ferrier and Watson 1997, Faith *et al.* 2003, Wintle *et al.* 2006, Halpern *et al.* 2006, Leathwick *et al.* 2006b).

The objective framework, data and models in this thesis provide some raw materials to apply these techniques in NSW. However their success will require opportunities and support from managers, scientists and the community. Finally, almost all depend on the use of GIS to integrate information. The capabilities of these systems are summarised in the following draft from a national workshop in 2005, to develop MPAs in the United States.

“Geographic Information Systems are considered to be an ideal tool for decision makers and conservation planning due to functionalities that allow the integration of physical, biological, and socioeconomic data into a single spatial frame of reference. The GIS platform also allows for the integration of data with different spatial and temporal scales, the application of a broad suite of software tools including statistical packages, and the visual representation and manipulation of data through user interfaces. Developing a participatory approach to mapping human activities in support of MPA planning and management is important for a number of reasons. Human dimensions of MPAs are the keys to the success of MPA design and management. Participatory methods can empower people and provide a platform for voicing diverse needs, concerns, and perspectives. Participatory research can increase the legitimacy of the planning process in which the data collection efforts are embedded, foster greater cooperation and consensus building, and increase the long-term viability of the management decisions. Methods that encourage participation can also facilitate future commitment to monitoring and evaluation, and may yield valuable local and experience-based knowledge that would otherwise remain untapped" (National Marine Protected Areas Centre 2005).

11.12 Conclusion

This thesis has adopted a holistic, ecosystem approach to planning and research that aims to provide a foundation for more detailed studies. The methods are based on explicit goals and comprehensive reviews of available information, but ultimately depend on the need to rigorously test conclusions and outcomes in an ongoing process. The spatially explicit way in which data are integrated and displayed provides an intuitive way for broad sections of the community to understand and participate in marine conservation. However, a key requirement of these approaches, is a spirit of cooperation among individuals, institutions and communities. Overcoming this segregation is a major challenge, but one that can be met by dedication to better communication. Prendergast *et al.* (1996) suggest that the main reason for a lack of success in conservation planning is that people are simply unaware of 'what science can contribute to practical conservation' and that 'low levels of funding, lack of understanding about the purpose of these tools and a general antipathy toward what is seen as a prescriptive approach to conservation all play a part.' They call for a closer dialogue between theoreticians and practitioners in conservation biology.

Science may also need to be more flexible in adapting methods to the ecological problems at hand, if the impact of research is to be felt outside the profession itself. Robinson (2006) suggests that "conservation biology must generate answers even when full knowledge is lacking and must structure scientific knowledge around policies and debates that influence what we value as conservationists, go beyond the certitude of biological sciences into the more contextual debates of the social sciences, engage scientifically with human-dominated landscapes, and address the question of how conservation can contribute to the improvement of human livelihoods and the quality of human life. "

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Appendices – Table of Contents

Appendix 1.
Ecological Reserve Guidelines to identify MPAs in NSW

(from Ron Avery in Breen *et al*. 2004)

Ecological viability requires consideration of reserve design including size, shape, replication and the configuration of reserves within a network. Reserve design criteria aim to ensure that individual MPAs and the overall reserve system remain ecologically viable. Marine reserve design guidelines frequently cited in the scientific literature include the following.

Establish clear objectives

The primary objectives of any MPA need to be stated clearly. A reserve's location, design and management should reflect its intended purpose. Reserve design for fisheries management, sedentary organisms, birds and whole ecosystems may differ considerably (Agardy 2000, Planes *et al*. 2000, Roberts and Hawkins 2000, Salm *et al*. 2000).

Select, design and manage the MPA in line with these objectives

The biology of the target organisms including their life cycles, movements, feeding, behaviour and physiology all need to be considered in reserve design. Even where a range of biodiversity is targeted, careful consideration should be given to the ecology of the organisms the MPA is designed to protect.

Conduct site assessments

Once candidate MPA sites have been identified at a regional level, more detailed site studies are required to assess the validity of broadscale predictions, collate any detailed information available and specifically assess local patterns of biodiversity, threats and issues for future management.

Use natural boundaries and include whole ecosystems and habitats

Where possible, the natural limits of ecosystems or habitats should be used to help define marine protected area boundaries (Salm *et al*. 2000). Where an entire ecosystem or habitat is important for conservation, all of its area should be protected (Roberts and Hawkins 2000, Salm *et al*. 2000). Reservation of an entire system is likely to enhance protection by:

- taking advantage of the unit's natural isolation from threatening processes
- inhibiting excessive spill over of mobile organisms from the reserve
- protecting the full range of variation occurring within a unit.

Use core and buffer zones

Highly protected core conservation areas should be surrounded by an appropriate buffer zone to avoid sudden transitions from highly protected areas to areas with relatively little protection. High value conservation sites that are vulnerable to human use should be protected in core protection zones. Buffer zones may also be used to provide important corridors between areas.

Use highly protected areas

The concept of minimum or optimum MPA size should be applied to core sanctuary zones, not to the total extent of a multiple-use MPA (Salm *et al*. 2000). Most evidence of the beneficial effects of MPAs is related to core sanctuary (or 'no take') areas where extractive use is prohibited.

Ensure adequate size and number of reserves

There are few general rules for determining the best size and arrangement of MPAs as biologies and life histories vary widely among species and with season and location (Roberts and Hawkins 1997, Crosby *et al.* 2000, Roberts 2000, Salm *et al*. 2000). However, protected areas should be as large as possible and should not be smaller than the average size for a given habitat type (Salm *et al*. 2000).

Where MPAs target particular species, and where sufficient data exist, attempts can be made to estimate an appropriate MPA size and configuration. MPA size may also be determined by examining the percentage of species richness represented with increasing reserve size (Salm *et al.* 2000), or through fisheries and other modelling techniques (Crosby *et al.* 2000).

One trend however, persists: the larger the MPA, the more species that will be represented, and the more likely their populations are to survive disturbances (Salm *et al*. 2000).

Maximise habitat complexity

Representation of species and habitat diversity can be enhanced by establishing MPAs in locations with a wide range of physical environments (e.g. estuaries, islands and headlands with significant depth gradients and both protected and exposed aspects). Different organisms associate with different marine structures and high habitat complexity is often associated with high species diversity. For example, the species richness of rocky reef fish communities is greatest in areas with high habitat complexity (Garcia-Charton *et al*. 2000).

Maximise the connection between neighbouring habitats

Many species selectively use different habitats at different times, seasons or stages in their life history. Protection of organisms in one habitat may be compromised unless other locations on which they depend are also managed for conservation (Salm *et al*. 2000).

Complement existing MPAs

Reserve design should consider the role of individual MPAs in contributing to the overall complement of biodiversity represented in reserves and should also consider the role of MPAs in the ecological functioning of the reserve system (Crosby *et al.* 2000, Salm *et al*. 2000).

Coordinate management across marine and terrestrial environments

Coordinated management of marine and terrestrial systems can help conserve ecosystem function and mitigate against catchment based threats. Increasing urban development and inappropriate land use in coastal catchments are recognised as major threats to marine biodiversity in New South Wales. With the population in the non-metropolitan coastal areas of NSW increasing by 45% between 1981–1991, the terrestrial reserve system and improved integrated planning are seen as key mechanisms for conserving marine and coastal biodiversity (NSW Government 1997).

Build a network of MPAs for all ecosystems, communities and species to:

- represent the full regional range of marine biodiversity
- insure against risk through replication
- ensure connectivity between ecosystems and populations
- provide scientific reference sites
- intersperse replicate study sites for research, monitoring and adaptive management
- promote ‘spill over’ effects to surrounding areas
- provide for the recovery of damaged environments
- provide opportunities for understanding, sustainable use and enjoyment
- provide opportunities for community input and stewardship.

Exercise risk management and the uncertainty principle

Information for management of marine biodiversity will never to be perfect and identification and selection criteria can only hope to approximate ideal objectives and goals. In setting and implementing criteria, the NSW Government has adopted a precautionary approach to managing MPAs i.e. ‘Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation’ (National Strategy for Ecologically Sustainable Development 1992).

Appendix 2. Options for MPAs in the Manning Shelf Marine Bioregion

2.1 A multiple-use marine park in the Manning Shelf Bioregion

The primary identification criteria for comprehensiveness and representativeness are most easily met, and for some features can only be met, in the region between Stockton Beach and Wallis Lake. Under the adopted criteria, comprehensiveness requires conserving examples of 'the full range of marine ecosystems and habitats across the marine environment'. According to the environmental classification adopted for the study, this means representation of each of the five major estuary ecosystems, the four ocean ecosystems classified by depth, and the nine habitat surrogates (mangrove, seagrass, saltmarsh, subtidal sediment, beach, intertidal rocky shore, subtidal reef and island).

Each of these ecosystems and habitats can be represented in the region between Stockton Beach and Wallis Lake, in many cases by the most extensive examples of their type in New South Wales. This represents an opportunity to manage within one area, conservation of some of the state's most important resources for marine biodiversity and sustainable use.

For reserve design, including many interrelated features within one MPA means the potential to conserve whole ecosystems, processes, communities and populations throughout the duration and spatial extent of entire life cycles. This may help to maintain connectivity among different ecosystems and their diverse components, and provides for greater control over threatening processes operating from within and outside MPAs.

The region not only includes the largest areas of most ecosystem and habitat types, but also a greater number and variety of often larger features. This replication of habitats in different areas is likely to include a greater diversity of life forms and provide better protection against disturbance. Having many features spread over broader areas also provides for greater flexibility in multiple-use zoning with more opportunities to provide for a range of conservation values, sustainable use and stakeholder interests.

There are also practical advantages in focusing broad-scale ecosystem management strategies in an area with so many important features. There are compliance benefits for more efficient monitoring and surveillance, in simplifying education, and in better communication generally. A large marine park of national and international significance will also promote widespread awareness of the area's values and the benefits MPAs can have for biodiversity and sustainable use.

The outstanding natural features of the estuaries, coast and ocean between Wallis Lake and Stockton Beach that identify it as a candidate site for a large multiple-use marine park are as follows.

- Port Stephens (tide-dominated drowned river valley) and the Myall Lakes (brackish barrier lake ecosystem) are the only major examples of their ecosystem type in the Manning Shelf Bioregion and the largest of their type in New South Wales.
- Port Stephens includes the largest area of mangrove forest in New South Wales (27 km^2 or 21% of the state total), the largest area of saltmarsh in the state (14 km^2 or 13% of the state total), and the second largest area of seagrass in the bioregion (8 km^2 or 5% of the state total).
- Myall Lakes connects with Port Stephens via the Myall River, which has the highest proportional cover of seagrass (71% of open water) in the bioregion and forms a unique link between brackish and marine estuarine ecosystems.
- Smith's Lake is the largest example of an intermittent coastal lagoon in New South Wales and lies immediately between Myall Lakes to the south and Wallis Lake to the north.
- Wallis Lake is the largest example of a tide-dominated barrier estuary in the Manning Shelf Bioregion. The lake includes the largest area of seagrass (31 km^2 or 21% of the state total) and the northern most beds of *Posidonia* in the state, as well as extensive areas of saltmarsh (4 km^2 or 7% of the state total).
- In ocean ecosystems, the sections of coast and ocean between Wallis Lake and Stockton Beach include all offshore depth zones including the 60–200 m depth zone within the state 3 nm limit.
- The sections of coast between Wallis Lake and Stockton Beach also include:
  1. more inshore and offshore islands
  2. more inshore and offshore subtidal reef
  3. more intermediate, reflective and estuarine beach habitat
  4. more rocky intertidal habitat with more sites representing all five identified 'community' types (boulder, cobble, platform, crevice, pool).
- Summed irreplaceability for a hypothetical 20% representation of each ecosystem and habitat type was highest for Port Stephens, Wallis Lake, Myall Lakes and the coast and ocean sections between Myall Lakes and Stockton Beach.
- The numbers of species of juvenile fishes and invertebrates caught in surveys by NSW Fisheries were high for Wallis Lake and Port Stephens and summed irreplaceability for representation of each species was highest for these estuaries.
- The numbers of commercial fish and invertebrate species in NSW Fisheries catch return records for 1997–98, and the summed irreplaceabilities for representation of each species were highest for Port Stephens and Wallis Lake.
- Port Stephens, Wallis Lake and Myall Lakes have large areas of important bird habitat for threatened species, species protected under JAMBA/CAMBA international treaties and for other native species. The ocean coast between Smiths Lake, Myall Lake, Port Stephens and

the Hunter River supported the most area of important bird habitat for threatened, JAMBA/CAMBA and other species.

- On average, 38% of Grey Nurse Sharks sighted in surveys of all New South Wales between 1998 and 2000 were recorded between Wallis Lake and Port Stephens at the Pinnacle, Latitude Rock, Seal Rocks and Broughton Island.
- The endangered Gould's Petrel (*Pterodroma leucoptera*) breeds only on Cabbage Tree and Boondelbah Islands off the coast of Port Stephens and has been sighted near Wallis Lake.
- The endangered Little Tern (*Sterna albifrons*) has significant nest sites at Wallis Lake and has been sighted at Myall Lakes and Port Stephens.
- The endangered plant, coastal spurge (*Chamaesyce psammogeton)* has been found growing on the main sandbar at the entrance of Smiths Lake (Webb *et al.* 1998).
- RAMSAR wetlands of international importance have been identified for Myall Lakes National Park including:
  - Myall Lakes
  - Yaccaba Headland, Fame Cove and Corrie Island Nature Reserve in Port Stephens
  - the southern shores of Smiths Lake
  - the ocean coast between Smiths Lake and Port Stephens.
- Wallis Lake, Myall Lakes and Port Stephens are included in the ‘Directory of Nationally Important Wetlands’.
- From 10–20% of lands adjoining Port Stephens and Myall and Wallis Lakes are classed as SEPP 14 important coastal wetlands. Corrie, Swan and Wirrung Islands and several wetlands surrounding the Port Stephens estuary are listed as SEPP 14 coastal wetlands. In Wallis Lake, SEPP 14 coastal wetlands include part of Regatta, Yahoo, Big, Snake, Goodwin and Wallis Islands and areas surrounding the lake and its tributaries to the north and west. Several areas within Myall Lakes National Park have been listed as SEPP 14 coastal wetlands.
- Port Stephens estuary is on the Interim list for the Register of the National Estate. The Fly Point – Halifax Bay area within the Port Stephens estuary supports a high diversity and abundance of sedentary marine animals, particularly sponges (Australian Heritage Commission 1998) and is listed on the Register of the National Estate.
- Myall Lakes National Park is registered on the National Estate. Wallis Lake is listed as an indicative place on the Register of the National Estate and Bandicoot Island Nature Reserve, Yahoo Island Nature Reserve and Wallis Island Nature Reserve are all listed on the Register of the National Estate.
- There are a number of areas of particular conservation significance in the Port Stephens estuary system due to the presence of mangrove, seagrass, saltmarsh and wetland complexes with relatively natural or protected subcatchments. These include the lower Myall River, the Corrie Island area, Kore Kore Creek system, Fame Cove and Creek, Bundabah Creek

(North Arm), Deep Creek system (Karuah River), Reedy Creek, Swan and Worimi Island complex, the northern shores of Big Swan Bay, Twelve Mile Creek system, Tilligerry Creek, Fenninghams Island Creek, Wallis Creek complex and Cromartys Bay.

- The *Independent Inquiry into Coastal Lakes* (Healthy Rivers Commission 2002) recommends Myall Lakes for significant protection, Smiths Lake for significant protection and Wallis Lake for secure 'healthy modified conditions'.
- Myall Lakes and the Myall River are the only estuaries in the bioregion classified with a very low degree of disturbance in the 'Environmental inventory of estuaries and coastal lagoons' (Bell and Edwards 1980).
- Short (1995) recommends four intertidal rock platforms between Wallis Lake and Stockton Beach for protection.
- The only rock platform in the Manning Shelf Bioregion recommended for protection by Griffiths (1982) is Bald Head, near Smiths Lake.
- The area includes Sugar Loaf Point (Seal Rocks), a major separation point for the East Australian Current (Godfrey *et al*. 1980, Cresswell 1983 and 1998) and also includes a range of sediment types identified by Colwell *et al*. (1981).
- Catchments for Myall Lakes, Port Stephens and Smiths and Wallis Lakes are largely undisturbed when compared with the heavily cleared catchments of the main branches of the Macleay, Hastings, Manning and Hunter River estuaries.
- Estuarine waters in Myall Lakes, Port Stephens and Smiths and Wallis Lakes are in relatively good condition, although problems with blue green algae in Myall Lakes and sewage contamination in Wallis Lake indicate how seriously this situation can change. The above areas are not, however, as affected by flood mitigation works. In particular, the drainage of acidic water to estuaries from 'reclaimed' wetlands is not as serious as has occurred in the Macleay, Hastings, Manning and Hunter River estuaries.
- All of the Myall Lakes (the largest MPA in New South Wales managed by NSW National Parks), some adjacent exposed coast and several locations in Port Stephens are already marine protected areas under the *National Parks and Wildlife Act* but this legislation, on its own, does not provide protection for fish or aquatic invertebrates from fishing.
- Most adjacent lands around the Myall Lakes, the major offshore islands, the coast and many areas around Port Stephens and Smiths and Wallis Lakes are managed as national park or nature reserve. Wallis Island is partly dedicated as nature reserve and Yahoo, Regatta and Bandicoot Islands are dedicated as nature reserves. These adjoining terrestrial reserves help provide protection from land-based threats and may also provide an indication of the condition of adjacent waters.
- Local and state agencies and infrastructure already exist in the region to provide support for management, research and education for marine conservation.

- Because of its natural attractions, proximity to major urban centres, improvements in transport and access, and its development as a tourism, holiday and residential area, the region is increasingly vulnerable to impacts from high levels of use and development.
- A large, multiple-use marine park would provide for more comprehensive management of these important marine areas and the increasing levels of human activity in the region.

Significant areas in relatively unimpacted, small estuaries

2.2 Khappinghat Creek

Khappinghat Creek is the largest intermittent creek in the bioregion and contains small areas of seagrass and extensive areas of sand, mud flats and rocky shores. The creek system includes large areas of *Casuarina*, *Melaleuca* and *Juncus* wetlands protected under SEPP 14. Areas of littoral rainforest near the creek entrance are protected under SEPP 26. The extensive reef systems occurring offshore are unusual for the northern half of the Manning Shelf Bioregion which is often dominated by large expanses of sand and limited nearshore reef.

All of the Khappinghat Creek estuary, most of the shores, and 57% of lands within 1 km are already protected within Khappinghat Nature Reserve. Prior to declaration of the nature reserve in 1993 the area was managed as state forest and some sand mining for minerals occurred. However the catchment, waters and intermittent entrance appear to remain in a relatively natural condition and there are few neighbouring built-up areas or disturbed acid sulphate soils. The *Australian River and Catchment Disturbance* indicators show little disturbance to flow or catchment. Khappinghat Creek may be the only opportunity in the bioregion to protect an estuary for which both waters and surrounding lands have been left relatively undisturbed.

2.3 Lakes Innes & Cathie

The estuary is the second largest intermittent lagoon in the bioregion and after Port Stephens and includes the second largest area of saltmarsh (6 km^2). Saltmarsh occupies 51% of the estuary area including the largest single patch of saltmarsh (3.2 km^2) in the bioregion.

The site provides outstanding opportunities for the scientific study of coastal geomorphology and wetlands processes, particularly in relation to the study of ecological succession during the process of estuary infilling. The site contains coastal wetlands, including extensive areas of saltmarsh and adjoining wet heath, *Melaleuca*, *Casuarina* and rainforest. The area is particularly diverse in terrestrial fauna and provides habitat for twenty threatened fauna species including Ospreys and Australasian Bittern.

The estuary was rated by the *Inventory of Estuaries and Coastal Lakes* (Bell and Edwards 1980) to have waters, shore and catchment in good condition, and by the *Australian Estuaries Database* to be only slightly affected by human activity. Land capability of surrounding areas is generally most suitable for forest or undisturbed natural vegetation and least suitable for cultivation or grazing. Australian River and Catchment Disturbance indices are generally low to medium for surrounding areas. The *Independent Inquiry into Coastal Lakes* recommends Lake Innes for ‘significant protection’ and Lake Cathie for ‘secure healthy modified condition’.

Almost all of the Lake Innes and Lake Cathie estuary and most of adjacent lands (59% within 1 km) are included within Lake Innes Nature Reserve. Much of the nature reserve is designated under SEPP 14 as protected coastal wetland and it may represent one of the few major wetlands on the NSW coast which is not affected by flood mitigation and drainage schemes (NPWS 1995).

2.4 Camden Haven River, Queens Lake, Watson Taylors Lake and Gogleys Lagoon

After Wallis Lake and Port Stephens, Camden Haven includes the third largest area of seagrass (6.3 km^2) in the bioregion and the seventh largest area of seagrass in New South Wales. Queens Lake contains the most extensive seagrass beds, while smaller amounts of seagrass, mangrove and saltmarsh are distributed throughout the estuary system.

Watsons Taylors Lake and the Crowdy Bay National Park wetland system are listed in the *Directory of Important Wetlands* and Gogleys Lagoon near the mouth of the Camden Haven River is considered to be a geomorphically significant feature (Eric Claussen pers. com.). The lagoon contains mangrove, saltmarsh and littoral rainforest communities, and provides important habitat for migratory waders (David Scott pers. comm.). The close proximity to the subtidal habitats of Perpendicular Headland provide an immediate connection between estuarine and ocean habitats.

The Camden Haven estuary is rated by the *Australian Estuaries Database* to have high fisheries value and a ‘slightly affected’ ecological status. Land capability for surrounding lands is low for cultivation and Australian River and Catchment Condition indices for disturbance are low to medium. The *Independent Inquiry into Coastal Lakes* recommends Queens Lake for ‘significant protection’ and Watson Taylor Lake for ‘secure healthy modified condition’.

Most of Watsons Taylors Lake is included in the northern end of the Crowdy Bay National Park but Queens Lake and several of the major tributaries lie outside the national park and are subject to increasing development pressures. Queens Lake is subject to a long-standing reserve proposal including areas of vacant Crown lands.

2.5 Korogoro Creek

The significance of Korogoro Creek lies in its hydrological relationship with extensive fresh water wetlands of the Swan Pool swamp (listed as an important Australian flood plain wetland), and the transition between freshwater and estuarine vegetation communities.

Korogoro Creek supports limited areas of estuarine vegetation including a low mangrove forest of *Avicennia marina* and isolated *Aegiceras corniculatum*. Saltmarshes in areas of infrequent tidal inundation include *Sporobulus virginicus* and *Sarcocornia quinqueflora*. Further up-stream the sedge *Baumea juncea* and maritime rush *Juncus kraussii* give way to swamp forests dominated by *Casuarina* spp. (NPWS 1998a).

Hat Head National Park includes wetlands behind the frontal dune systems of Smokey and Killick Beaches, fresh water wetlands of the Swan Pool (swamp) to the west of Hat Head Village, and the beach dunal systems (NPWS 1998a). The park provides important habitat for many species of wader birds for feeding and resting on sand and mud flats, rock platforms and beaches, including at least ten JAMBA/CAMBA species (NPWS 1998a).

The upper reaches of Korogoro Creek and 57% of adjoining lands within 1 km are included within Hat Head National Park.

2.6 South West Rocks Creek

For its size, this small creek system has a relatively high proportion of its area covered by mangrove (67%), saltmarsh (18%) and seagrass (20% of open water). Although most of the area is protected by SEPP 14 zoning there are currently no MPAs in the estuary, no adjoining national parks or nature reserves and 20% of land within 1 km is in built-up areas.

2.7 Saltwater Creek and Saltwater Lagoon

Both Saltwater Creek and Saltwater Lagoon are protected by SEPP 14, while NSW National Parks estate includes the whole of Saltwater Lagoon and part of the immediate catchment of Saltwater Creek. Built-up areas within the small catchment pose a potential threat to the condition of the creek and lagoon. The *Independent Inquiry into Coastal Lakes* describes the lagoon as having an extreme natural sensitivity and has recommended that the lagoon be secured in a ‘healthy modified condition’.

2.8 Killick Creek

Killick Creek has no MPAs, 17% of adjoining land within 1 km inside Hat Head National Park and 26% of lands within 1 km classed as SEPP 14. The proximity of built–up areas poses a potential threat to the condition of the creek and there has been extensive catchment clearing in the immediate area.

2.9 Unamed Creek (Big Hill Point)

Unamed Creek has no MPAs but 49% of lands within 1 km lie within SEPP 14 areas and Limeburners Creek Nature Reserve. A further 40% of adjacent lands are classified as wilderness, with no mapped built-up areas, low land capability for cultivation or grazing, and low disturbance from settlement, land use or extractive industry (ARCCD). Despite these apparently favourable indicators there is little natural riparian vegetation with clearing for a camp ground, golf course and low-density tourist development.

Significant areas in less impacted parts of the major estuaries

2.10 Limeburners Creek and Saltwater Lake – Hastings River

The wetlands of the Limeburners Creek area have been listed in the Directory of Important Australian Wetlands and the nature reserve is registered on the National Estate. Much of the lower Limeburners Creek system including the extensive estuarine vegetation lie outside the protected areas but are worthy of marine protection.

Much of the area (51%) has been designated as a coastal wilderness by independent state and national wilderness assessments, and the lake is identified as one of the most natural coastal lakes on the NSW coast. It is listed as 'near pristine' by the Healthy Rivers Commission and is the only coastal lake in the bioregion recommended for comprehensive protection by the *Independent Inquiry into Coastal Lakes.*

The *Environmental Inventory of Estuaries and Coastal Lagoons* (Bell and Edwards 1980) rates disturbance to shore, waters and catchment as low. Mean *Australian River and Catchment Disturbance* indices for the subcatchment are generally low for settlement, land use, infrastructure and extractive industry. There are few built-up areas adjacent to this section of the estuary but a high percentage of high risk or disturbed acid sulphate soils within 1 km.

Species listed under JAMBA and CAMBA which use the nature reserve include the nationally endangered Little Tern (*Sterna albifrons*).

The terrestrial conservation values of the site include the presence of a wide range of landforms providing evidence of past and present coastal processes. These landforms support a very extensive mosaic of vegetation communities including littoral and subtropical rainforest, mangrove forest and woodlands, wet and dry sclerophyll forests, shrublands, swamps, coastal heathland, saltmarsh and dune grasses. Extensive wetlands drain into the Saltwater Lake and Limeburners Creek estuary. During prolonged periods of rain the generally saline Saltwater Lake becomes brackish to fresh. The area supports a diverse range of wildlife communities including threatened species and birds protected under international agreements (NPWS 1998b).

During the Pleistocene period (~60,000 years ago) Point Plomer, Big Hill and Queens Head were islands separated from the mainland. They have since merged with the mainland as a consequence of sand deposition. An unusual limestone outcrop at Big Hill Point (including a natural arch and sea cave) is a record of the coral reefs that once existed along the ancient NSW coast.

Most of the upper reaches and land within 1 km of Limeburners Creek and Saltwater Lake are included within Limeburners Creek Nature Reserve (58%) and SEPP 14 wetland (70%).

2.11 Kooragang Island and Fullerton Cove

The Hunter River estuary includes the second largest area of mangrove habitat (15.5 km^2) after Port Stephens and the third largest area (5 km^2) of saltmarsh in the bioregion. Much of this vegetation is found in the Kooragang Island–Fullerton Cove area.

Fullerton Cove is a large shallow embayment north of Kooragang Island. It has a depth of two to three metres at its centre and at low tide, large areas of mudflats are exposed. Kooragang Nature Reserve (including Fullerton Cove) is recognised as a nationally and internationally important wetland (listed by the *Directory of Important Wetlands* and RAMSAR) providing habitat for many species of migratory waders and species listed as endangered at a national level including the Little Tern (*Sterna albifrons*). Species which are considered vulnerable at a state level include the Freckled Duck (*Stictonetta naevosa*), Pied Oystercatcher (*Haematopus longirostris*), Mongolian Plover (*Charadrius mongolus*), Large Sandplover (*Charadrius leschenaultii*), Black-tailed Godwit (*Limosa limosa*), Terek Sandpiper (*Xenus cinereus*), Great Knot (*Calidris tenuirostris*) and Broad-billed Sandpiper (*Limicola falcinellus*).

In general the area has undergone significant manipulation. Kooragang Island originally consisted of several smaller islands or bars. Several attempts to control deposition and siltation of the Newcastle port area resulted in the agglomeration of these islands into a smaller number of larger units by the artificial filling of channels and the construction of training walls. In 1970, a levee bank was built around Fullerton Cove in an effort to ameliorate flooding in low-lying areas of Newcastle, downstream of Kooragang Island. Drains were installed to reclaim the significant wetland areas behind the levees for agriculture (*Directory of Important Wetlands of Australia* 1996).

Past filling has destroyed up to 10 km^2 of estuarine wetlands, but remaining wetlands remain in a healthy condition. The estuarine herb *Zannechellia palustris*, considered endangered at a state level has been recorded immediately adjacent to the western end of the reserve. This herb is found in New South Wales only in the Newcastle/Lake Macquarie area and along Ironbark Creek (*Directory of Important Wetlands of Australia* 1996).

After Myall Lakes, Kooragang Nature Reserve is the second largest MPA in New South Wales managed by NSW National Parks.

2.12 Macleay River Delta and Macleay Arm

This area includes Clybucca Creek downstream of Clybucca, Macleay River downstream of Rainbow Reach, Macleay Arm and associated intertidal wetlands. The area is listed on the Directory of Important Australian Wetlands and contains five categories of wetland including subtidal aquatic beds, estuarine waters, intertidal flats, intertidal marshes and intertidal forested wetlands. The wetlands are also important habitat for animal taxa at vulnerable stages in their life cycles, provide a refuge during adverse conditions, and are of outstanding historical or cultural significance (*Directory of Important Wetlands of Australia* 1996).

This site is considered to be a good example of estuarine wetlands on the north coast and includes large areas of mangroves and saltmarsh in a healthy condition (West *et al.* 1985). Large riverine estuaries such as the Macleay are a characteristic feature of the northern half of the bioregion and should be represented within the reserve system.

The wetlands include 520 ha of mangroves, 191 ha of seagrasses and 365 ha of saltmarsh (West *et al.* 1985). Mangrove species within the estuary include Grey Mangrove (*Avicennia marina*), River Mangrove (*Aegiceras corniculatum*) and Milky Mangrove (*Excoecaria agallocha*). The saltmarsh community includes species such as Couch (*Sporobolus virginicus*), Sedge (*Cyperus polystachyos*), Sea Rush (*Juncus kraussii*), the sedge *Fimbristylis ferruginea*, Seaberry Saltbush (*Rhagodia candolleana* sp. *candolleana*) and Ruby Saltbush (*Enchylaena tomentosa*). Freshwater swamp forest also occurs along the estuary and includes species such as Paperbark (*Melaleuca quinquenervia*), Willow Bottlebrush (*Callistemon salignus*) and Swamp Oak (*Casuarina glauca*).

The area is potentially an important habitat for many species of migratory waders. The Osprey (*Pandion haliaetus*) and Magpie Goose (*Anseranas semipalmata*), considered vulnerable at a state level, have been recorded within the Clybucca Estuary. The White-bellied Sea-eagle (*Haliaeetus leucogaster*) listed under CAMBA, has been recorded within the estuary. The Whimbrel (*Numenius phaeopus*), Common Sandpiper (*Actitus hypoleucos*) and the Marsh Sandpiper (*Tringa stagnatilis*) occur within the estuary and are listed under JAMBA and CAMBA (NPWS 1998b).

Other bird species recorded within the estuary include the Australian White Ibis (*Threskiornis molucca*), Straw-necked Ibis (*Threskiornis spinicollis*), Pied Oystercatcher (*Haematopus longirostris*), Pelican (*Pelecanus conspicillatus*), Whimbrel (*Numenius phaeopus*), Pied Cormorant (*Phalacrocorax varius*), Little Pied Cormorant (*Phalacrocorax melanoleucos*), Welcome Swallow (*Hirundo neoxena*) and Azure Kingfisher (*Alcedo azurea*). As with other areas of estuarine wetland, Clybucca Creek Estuary is an important habitat for many commercial fish species.

2.13 Warrell Creek – Nambucca River

Warrell Creek may represent the single largest area of wetland and dune complex vegetation remaining in the Nambucca River estuary (LandSat7 imagery 2000). It contains extensive areas of protected SEPP 14 wetlands and includes examples of freshwater wetlands including Swamp Oak forests, Swamp Mahogany forests, Broad Leaved Paperbark forests and open freshwater wetlands dominated by sedges and reeds, as well as examples of SEPP 26 rainforest and moist coastal vegetation (i.e. Scribbly Gum dominated forests and areas of Wet Heath) (Graham in prep.).

Wetlands of the Nambucca River provide habitat for a number of threatened species including the Osprey, Jabiru, Pied Oystercatcher, Sanderling, Little Tern, Loggerhead Turtle, Beach Stone-curlew, Black Bittern and Terek Sandpiper. Threatened plant species in the Nambucca River wetlands include Grove's Melaleuca and the endangered ecological community 'Lowland rainforests on floodplain in the NSW North Coast Bioregion' (*Threatened Species Conservation Act*) (Graham in prep.).

2.14 Manning River (Harrington) and Manning River South Channel (Farquhar Inlet)

Much of the Manning River delta area has been cleared for agriculture (LandSat7 imagery 2000) although remnant vegetation still remains around the mouth of the Farquhar Inlet and the Manning River channel. Both the north and south channel have moderately built-up urban areas near their mouths (i.e. Harrington and Old Bar). Important values of both sites include the presence of estuarine vegetation along edge of the river channel, significant littoral rainforest communities and the presence of significant Little Tern breeding sites. No terrestrial reserves currently occur near either mouth.

2.15 Intertidal rocky shores and inshore reefs

NSW Fisheries (Otway and Morrison in prep.) is currently analysing species composition data for rocky intertidal shores in the Manning Shelf Bioregion. Initial surveys have mapped 52 shores and scored the number of 'community types' (platform, boulder, cobble, pool, crevice) present on each shore. Twenty-one shores included all five community types, 15 shores included four community types and 15 shores included three community types.

The National Trust Headland and Rock Platform survey in 1982 identified only one rock platform, Bald Head, for protection in the Manning Shelf Bioregion. The survey carried out by the Total Environment Centre in 1995 identified 19 rock platforms in the Manning Shelf Bioregion for protection. Until detailed surveys and recommendations for aquatic reserves are complete this study defers from making any more specific conclusions until this information is available.

2.16 Offshore reefs, islands, and aggregations of Grey Nurse Sharks

Significant offshore reefs, islands, and aggregations of Grey Nurse Sharks occur at:

- Fish Rock and Green Island near South West Rocks
- the Cod Grounds near Laurieton
- the Pinnacle near Cape Hawke and Forster
- Big Seal and Little Seal rocks near Sugarloaf Point
- Broughton Island near Port Stephens.

These sites represent offshore islands, rocks or pinnacles in deep water (30–40 m), often influenced by the East Australian Current and renowned for their diverse and abundant fish and invertebrate fauna. They include the largest aggregations of threatened Grey Nurse Sharks (*Carcharias taurus*) sighted in Eastern Australia and have together accounted for over 50% of all recent Grey Nurse sightings in New South Wales.

Reports of threatened and protected species have been made from Fish Rock, including Grey Nurse Shark, Black Cod, Queensland Groper and Loggerhead Turtles. Reefs offshore of South West Rocks support some of the southern-most sub-tropical coral communities in Australia (Harriott *et al.* 1999).

These areas are among the most popular offshore dive and fishing sites in New South Wales and current and future human activities have the potential to impact on the conservation values and the sustainable use of these areas. Otway and Parker (2000) and Otway *et al.* (2003) have recommended that these sites be considered for declaration as aquatic reserves for the long term conservation of Grey Nurse Sharks. Critical habitat areas for these species were declared at these sites in December 2002.

Extensive areas of subtidal reef were also mapped offshore of:

- the coast between Crowdy Head and Diamond Head
- the coast between the Hallidays Point, Khappinghat Creek and the Manning River

For large areas of less prominent reef and intervening sediment there was little broad-scale survey information on habitats and associated biodiversity. While variation in depth provides approximate indicators of offshore biodiversity, more work is required to collate and analyse data available in individual geological reports and establish baseline biological surveys for these important areas.

▪ Appendix 3.

▪ Options for MPAs in the Hawkesbury Shelf Marine Bioregion

3.1 Option A. Hunter River to Avoca Lake

The main features of the estuaries, coast and ocean between the Hunter River and Avoca Lake are as follows:

- Option A includes two of the four estuarine ecosystem types that occur in the Hawkesbury Shelf bioregion: wave dominated barrier estuaries (Hunter River, Lake Macquarie and Tuggerah Lakes) and intermittent estuaries (Wamberal, Terrigal and Avoca Lagoons).
- Together with existing MPAs, this option would help represent almost 80% of the area of wave dominated barrier estuaries and 30% of intermittent estuaries. It would not add to the 7% of tide dominated drowned rivers in the bioregion already represented in North Sydney Harbour Aquatic Reserve, Shiprock Aquatic Reserve and the national parks and nature reserves in the Hawkesbury River and Port Hacking. Nor would it add to the 26% of ocean embayment already represented in Towra Point Aquatic Reserve and Towra Point Nature Reserve (**Error! Reference source not found.**).
- Option A includes sites at Fullerton Cove, Lake Macquarie and Wamberal Lagoon, previously listed as candidates in a NSW Fisheries[2] assessment of estuarine aquatic reserves (Frances 2000). The sites in the Hunter River and Lake Macquarie were, however, excluded after community consultation at that time.
- This option would contribute large areas of ocean ecosystems between 0-20 m (38% of this zone within NSW coastal waters) and 20-60 m (38% of this zone within NSW coastal waters). However, deeper areas in the 60-200 m zone for this option, all lie outside the 3 nm limit to State waters.
- Option A includes Lake Macquarie and Tuggerah Lakes which include the two largest areas of seagrass habitat in the bioregion. Together with existing MPAs, this option would help include 60% of the bioregion’s seagrass habitat within MPAs.
- Option A includes the estuary with the largest area of mangrove habitat in the bioregion, the Hunter River. Together with existing MPAs, this option would include 55% of the bioregion’s mangrove habitat in, or directly adjacent to MPAs.
- The largest areas of saltmarsh habitat also occur in the Hunter River. Together with existing MPAs, this option would include a total of 61% of this habitat in, or directly adjacent to some form of MPA.

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[2] now within the NSW Department of Primary Industry

- Option A would contribute large areas of exposed intertidal beach (54% by area for all MPAs combined), exposed intertidal rocky shore (41%), inshore shallow reef (40%), inshore sand (45%) and islands (16%) to a system of MPAs in the bioregion.
- This option includes Towoon Point (south of The Entrance), selected in the NSW Fisheries[2] assessment to identify aquatic reserves for rocky intertidal shores and Nobby's Head (south of the Hunter River) and Yumool Point (south of Bateau Bay) originally short listed for investigation by an advisory panel of stakeholders and community representatives (Otway 1999).
- Nine rock platforms in this option were recommended for protection in an assessment by Short (1995).
- Summed irreplaceability scores for representation of 20% of estuarine habitats and ecosystems for the Hunter River, Lake Macquarie and Tuggerah Lakes are the highest in the bioregion and scores for the Hunter-Lake Macquarie and Munmorah-Tuggerah sections of ocean and coast are exceeded only by the Stanwell Park-Shellharbour sections of the bioregion.
- Option A for a large, multiple-use marine park could contribute towards representing a total of approximately 750 km^2 of marine habitat in some form of MPA in the Hawkesbury Shelf bioregion. This would represent 37% of estuarine and coastal waters under NSW jurisdiction (within 3nm) in the bioregion.
- This option includes no aquatic reserves but does include the marine components of Kooragang Island Nature Reserve (Fullerton Cove), Hexham Swamp Nature Reserve and Wamberal Lagoon Nature Reserve.
- Option A includes sightings of threatened and protected fish species including Black Cod, Grey Nurse Shark, Bleeker's Devil Fish and Weedy Sea dragon.
- Moon Island and Caves Beach Reef off Swansea, Wybung Head Reef, Hargraves Reef and Three Mile Reef off Norah Head, and Foggy's Cave and East Bombora off Terrigal are all sites where threatened Grey Nurse Shark have been observed in the past or recorded in recent surveys.
- The Hunter River, Lake Macquarie and Tuggerah Lakes all have a relatively diverse and productive commercial fish catch.
- The option includes previous nesting sites of the Little Tern at the Hunter River, Redhead, Swansea, Budgewoi and The Entrance.
- Option A includes areas with the highest diversity and abundance of threatened bird species in the bioregion.
- Kooragang Island and Fullerton Cove include the largest areas of mangrove and saltmarsh habitat in the Hawkesbury Shelf bioregion. This area is recognised as a nationally and internationally important wetland by the Directory of Important Wetlands, RAMSAR and

the Register of National Estate. It provides habitat for many species of migratory waders (ANCA 1996) and endangered bird species including the Little Tern (*Sterna albifrons*).

Large areas of tidal mudflats in Fullerton Cove are visited by up to 10,000 waders each summer including the vulnerable Freckled Duck (*Stictonetta naevosa*), Pied Oystercatcher (*Haematopus longirostris*), Mongolian Plover (*Charadrius mongolus*), Large Sandplover (*Charadrius leschenaultii*), Black-tailed Godwit (*Limosa limosa*), Terek Sandpiper (*Xenus cinereus*), Great Knot (*Calidris tenuirostris*) and Broad-billed Sandpiper (*Limicola falcinellus*).

The estuarine herb *Zannechellia palustris*, considered endangered at a state level and found in NSW only in the Newcastle/Lake Macquarie area, has been recorded immediately adjacent to the western end of the Reserve (ANCA1996).

After Myall Lakes, Kooragang Nature Reserve is the second largest MPA in NSW managed by the National Parks and Wildlife Service[1] but the area has no direct protection for fish and aquatic invertebrates from fishing.

- Hexham Swamp, located on the Hunter River at Ironbark Creek, is listed in the Directory of Important Wetlands. Before the construction of floodgates in 1971, approximately one third of the swamp was estuarine wetland. Existing vegetation includes mangrove forests with Grey (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*), saltmarsh including Samphire (*Sarcocornia quinqueflora*) and Marine Couch (*Sporobolus virginicus*), Water Buttons (*Cotula coronopifolia*), Sea Rush (*Juncus krausii*), Water Couch (*Paspalum distichum*), Common Reed (*Phragmites australis*), Broad-leaved Cumbungi (*Typha orientalis*) and Swamp Oak (*Casuarina glauca*).

  The estuarine wetlands were used as feeding habitat by migratory waders and many other birds. The endangered Black-necked Stork (*Ephippiorhynchus asiaticus*) and Green and Golden Bell Frog (*Litoria aurea*) and the vulnerable Magpie Goose (*Anseranas semipalmata*), Freckled Duck (*Stictonetta naevosa*), Australasian Bittern (*Botaurus poiciloptilus*), Painted Snipe (*Rostratula bengalensis*) and Comb-crested Jacana (*Irediparra gallinacea*) have been recorded from the swamp. Hexham swamp is the most important habitat in the Hunter region for the migratory Latham's Snipe (*Gallinago hardwickii*) listed under JAMBA and CAMBA. Prior to the floodgates the estuarine wetland also provided habitat for other species listed under JAMBA and CAMBA, including the Red-necked Stint (*Calidris ruficollis*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Whimbrel (*Numenius phaeopus*), Grey-tailed Tattler (*Tringa brevipes*), and Greenshank (*Tringa nebularia*). These and other migratory waders would be expected to return to Hexham Swamp if the estuarine habitats were re-established (ANCA 1996).

[1] now within the NSW Department of Environment and Conservation

Historical records indicate that the waters of Hexham Swamp were also an important fisheries habitat prior to construction of the floodgates.

- Option A includes Moon Island, Bird Island Nature Reserve and Wamberal Lagoon Nature Reserve, all of which are on the Register of the National Estate.
- Moon Island, a 1 ha island located 1 km north-east of Swansea, is a breeding site for the Wedge-tailed Shearwater (*Puffinus pacificus*), Little Penguins (*Eudyptula minor*), Black Backed Gull (*Larus dominicus*), Sooty Oystercatcher (*Haematopus fuliginosus*) and the Crested Tern (*Sterna bergii*).
- Bird Island is a 7 ha, island approximately 60 m high and 1.6 km offshore of Lake Munmorah. Twelve species of seabird listed under JAMBA and CAMBA have been recorded from the island including the threatened Sooty Oystercatcher (*Haematopus fuliginosus*), the Wedge-tailed Shearwater (*Puffinus pacificus*), Short-tailed Shearwater (*P. tenuirostris*), Ruddy Turnstone (*Arenaria interpres*), Eastern Curlew (*Numenius madagascariensis*), Whimbrel (*Numenius phaeopus*), Bar-tailed Godwit (*Limosa lapponica*), Red-necked Stint (*Calidris ruficollis*), Arctic Jaegar (*Stercorarius pomarinus*), Caspian Tern (*Sterna caspia*), Common Tern (*Sterna hirundo*), White-fronted Tern (*Sterna striata*) and the endangered Little Tern (*Sterna albifrons*) (Commonwealth of Australia 2003).
- Lake Macquarie includes the largest area of seagrass habitat in the bioregion, and includes important habitat for fish (Miskiewicz 1987) and invertebrates (Gibbs 1987). The area between Swansea Heads, Wangi Wangi, Belmont and Crangan Bay was identified by an expert panel in a NSW Fisheries[2] assessment as a first priority candidate for an estuarine aquatic reserve (Frances 2000, NSW Fisheries 2001). The site was, however, excluded during subsequent community consultation.
- Tuggerah Lake is listed in the Directory of Important Wetlands and is important for its swamps of Paperbark (*Melaleuca quinquenervia*), Casuarina (*Casuarina glauca*), Swamp Oak, extensive beds of seagrasses (*Zostera capricorni*, *Halophila ovalis* and *Ruppia megacarpa*), and saltmarshes including Samphire (*Sarcocornia quinqueflora*), Saltwater Couch (*Paspalum vaginatum*) and Rushes (*Juncus sp.*) (ANCA 1996).

  The area is a priority wetland for waders with up to 2500 migratory birds present in late spring and summer and up to 2000 Black Swans (*Cygnus atratus*), Chestnut Teal (*Anas castanea*) and Grey Teal (*Anas rhynchotis*) which feed on the exposed seagrass beds. The lake shores in summer are used by migrant waders listed under JAMBA or CAMBA including Bar-tailed Godwits (*Limosa lapponica*), Curlew Sandpiper (*Calidris ferruginea*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red-necked Stint (*Calidris ruficollis*) and Red

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Knot (*Calidris canutus*). White-breasted Sea-Eagles (*Haliaeetus leucogaster*) and Whistling Kites (*Haliastur sphenurus*) nest around the lake (ANCA 1996).

- Budgewoi Lake Sand Mass on the eastern side of Budgewoi Lake is listed in the Directory of Important Wetlands and is the most important area of waterbird feeding habitat in the Tuggerah Lakes. It is a broad sand flat occupying about 30% of the lake floor in depths less than a metre. Seagrasses (*Zostera capricorni, Halophila ovalis* and *Ruppia megacarpa*) border the western side of the sand flat and adjacent habitat includes Samphire (*Sarcocornia quinqueflora*), Saltwater Couch (*Paspalum vaginatum*), Sea Rush (*Juncus kraussii*), Common Reeds (*Phragmites australis*), Swamp Oak (*Casuarina glauca*), Broad-leaved Paperbark (*Melaleuca quinquenervia*) and scattered Cabbage Tree Palms (*Livistona australis*) (ANCA 1996).

  Large numbers of Black Swans (*Cygnus atratus*) feed on the seagrasses and many Grey Teal (*Anas gracilis*), Chestnut Teal (*Anas castanea*) and Shoveller (*Anas rhynchotis*) have been observed at this site. Caspian Tern (*Sterna caspia*), Little Tern (*Sterna albifrons*) and Gull-billed Terns (*Sterna nilotica*) feed in the shallows during summer and waders listed under JAMBA and CAMBA, such as Bar-tailed Godwits (*Limosa lapponica*), Red Knots (*Calidris canutus*) and Curlew Sandpiper (*Calidris ferruginea*) are present each summer on the mud and sand flats. Less common waders like Grey Plover (*Pluvialis squatarola*), Double-banded Plover (*Charadrius bicinctus*) and Greenshank (*Tringa nebularia*) also occur (ANCA 1996).

- Colongra Swamp, listed in the Directory of Important Wetlands, is located on the west side of Lake Munmorah. It is a small, shallow freshwater wetland with Broad-leafed Paperbark (*Melaleuca quinquenervia*) and reedbeds of Cumbungi (*Typha augustifolia*) and Sea Rush (*Juncus kraussii*) (ANCA 1996).
- Up to 200 breeding pairs of Great Cormorant (*Phalacrocorax carbo*), Pied Cormorant (*Phalacrocorax varius*), Little Pied Cormorant (*Phalacrocorax melanoleucos*) and Little Black Cormorants (*Phalacrocorax sulcirostris*) occur here with smaller numbers of Darters (*Anhinga melanogaster*), Royal Spoonbill (*Platalea regia*) and White Ibis (*Threskiornis molucca*) also nesting. White-bellied Sea-Eagles (*Haliaeetus leucogaster*) and Whistling Kites (*Haliastur sphenurus*) nest in the swamp, and Black Swans (*Cygnus atratus*) nest in the reedbeds. Hoary-headed Grebes (*Poliocephalus poliocephalus*) occur in winter. Species listed under JAMBA or CAMBA include the White-bellied Sea-Eagle (*Haliaeetus leucogaster*) and Crested Tern (*Sterna bergii*) (ANCA 1996).
- Wamberal Lagoon Nature Reserve includes reed beds, sedgeland and important habitat for fish, molluscs, crustaceans and a range of migratory waders.
- All of the waters and 16% of the lands surrounding Wamberal Lagoon are included in nature reserve. However with the exception of Fullerton Cove in the Hunter River, less than 5% of the lands around other estuaries in this option are protected in terrestrial reserves.

Sections of ocean coast in this option all include less than 20% of adjacent lands in national park or nature reserve.

- With the exception of the Hunter River, most estuaries in this option had 20-50% of adjacent lands in urban development. The ocean coast between the Hunter River and Tuggerah Lakes had less than 20% of adjacent lands in urban development, and the Tuggerah-Avoca section had greater than 50% of the coast built on.
- The estuaries and coast in this option tended to have a relatively high percentage of adjacent land with disturbed or high risk acid sulphate soils.
- Mean river and catchment disturbance indices were low to moderate for most estuaries and sections of coast.
- Much wetland habitat has been lost in the Hunter River catchment and many estuarine and floodplain wetlands have been alienated from the river and substantially degraded. The diversity of estuarine habitat has declined due to losses in shoreline length, saltmarsh area and open water and at least 18 of the 33 species of migratory wading birds using the estuary have declined in numbers. The estimated mean number of birds fell by nearly 50% between the 1970s and 1990s (Healthy Rivers Commission 2002b).
- Kooragang Island originally consisted of several smaller islands and bars, but attempts to control siltation has aggregated these areas into larger units by filling channels, constructing training walls, building levee banks and draining wetland areas for agriculture. Past filling has destroyed up to 10 km^2 of estuarine wetlands, but the remaining wetlands remain in a healthy condition (ANCA1996).
- Industries on the Hunter River (previous steelworks, associated industry and port), Lake Macquarie (two power stations and a smelter) and Tuggerah Lakes (power station) have had at least localised impacts on marine habitats in these estuaries.
- The Healthy Rivers Commission Independent Inquiry into Coastal Lakes rates the catchment condition of Lake Macquarie and Tuggerah Lakes as modified, the condition of Lake Macquarie as severely affected and the condition of Tuggerah Lakes as moderately affected. Both estuaries were rated as having a high conservation value but were “targeted for repair”.
- As with many coastal areas in the Hawkesbury Shelf bioregion some of the most valuable areas for conservation of biodiversity and sustainable use of marine resources are threatened by increasing urban development and industrialisation.

3.2 Option B. Lake Munmorah (Wybung Point) to Narrabeen Lakes

The main features of the estuaries, coast and ocean between Lake Munmorah (Wybung Point) and Narrabeen Lakes are as follows:

- Option B includes three of the four estuarine ecosystem types that occur in the Hawkesbury Shelf bioregion including tide dominated river valleys (Hawkesbury River and Pittwater), barrier estuaries (Brisbane Water and Tuggerah) and intermittent estuaries (Wamberal and Terrigal Lagoons and Avoca, Cockrone and Narrabeen Lakes).

- Together with existing MPAs, this option would account for a total of 64% of the area of tide dominated drowned estuaries, 41% of wave dominated barrier estuaries and 81% of the area of intermittent estuaries. However, this option would not add to the 26% of ocean embayment already represented in Towra Point Aquatic Reserve and Nature Reserve.

- Option B would add large areas of the ocean ecosystems between 0-20 m (38% of this zone within NSW coastal waters) and 20-60 m (38% of this zone within NSW coastal waters). However, it would not represent deeper areas in the 60-200 m zone, which lie outside the 3 nm limit to State waters.

- Option B includes estuaries with the second (Tuggerah Lakes) and fourth (Brisbane Water) largest areas of seagrass habitat in the bioregion as well as significant areas of seagrass in Pittwater, the Hawkesbury River and several of the intermittent lagoons. If adopted, it would help contribute to a total of 48% of the bioregions seagrass habitat protected within MPAs.

- Option B includes the Hawkesbury River, with the second largest area of mangrove habitat in the bioregion and other significant mangrove habitats in Brisbane Water and Pittwater. If adopted, it would help contribute to a total of 53% of the bioregion’s mangrove being included in, or directly adjacent to MPAs.

- This option includes the third and fourth largest areas of saltmarsh habitat in the bioregion in the Hawkesbury River and Brisbane Water and would contribute to a total of 23% of this habitat included in, or directly adjacent to some form of MPA.

- Together with existing MPAs, Option B could include large areas of exposed intertidal beach (36%), exposed intertidal rocky shore (34%), inshore shallow reef (39%), inshore sand (32%) and islands (11%) within a system of MPAs in this bioregion.

- Towoon Point (south of The Entrance) and Tudibaring Head (north of Cochrone Lake) were both selected as candidate sites for aquatic reserves in an assessment of intertidal rocky shores by NSW Fisheries[2]. Yumool Point (south of Bateau Bay) was originally short listed for investigation by an advisory panel of community and stakeholders (Otway 1999).

- Nine rock platforms in this option were recommended for protection by Short (1995).
- Summed irreplaceability scores for representation of 20% of all estuarine habitats and ecosystems were high for Tuggerah Lakes, the Hawkesbury River and Brisbane Water and for the Munmorah-Tuggerah and Tuggerah-Avoca sections of ocean and coast.
- Option B for a large marine park covers approximately 710 km^2 representing 35% of NSW waters in the Hawkesbury Shelf bioregion.
- This area includes existing aquatic reserves at Barrenjoey and Narrabeen Heads, Intertidal Protected Areas at Bungan and Mona Vale Heads, and the marine components of Wamberal Lagoon, Muogamarra, Pelican and Riley's Island Nature Reserves and Ku-ring-gai Chase, Brisbane Water and Bouddi National Parks.
- Option B includes sightings of threatened and protected fish species including Black Cod, Grey Nurse Shark, Bleeker's Devil Fish and Weedy Sea dragon.
- Wybung Head Reef, Hargraves Reef and Three Mile Reef off Norah Head, Foggy's Cave and East Bombora off Terrigal, South Palm Beach Reef and Hole in the Wall are all sites where threatened Grey Nurse Shark have been sighted in the past or recorded in recent surveys.
- The Hawkesbury River and Tuggerah Lakes have a relatively diverse and productive commercial fish catch.
- Option B includes previous nesting sites of the Little Tern at Budgewoi and The Entrance.
- This option includes the greatest diversity of threatened bird species, most sightings of threatened birds and the largest area of significant shore bird habitat.
- Lion Island, Long Island, Riley's Island, Pelican Island, Spectacle Island and Muogamarra Nature Reserves in the Hawkesbury River, Wamberal Lagoon Nature Reserve, and the Long Reef to Barrenjoey Coastal Rocks are all on the Register of the National Estate.
- Lion Island provides breeding habitat for Wedge-tailed Shearwater (*Puffinus pacificus*), Sooty Shearwater (*Puffinus griseus*) and the Little Penguin (*Eudyptyla minor*).
- Wamberal Lagoon Nature Reserve includes almost all of Wamberal Lagoon and reed beds, sedgeland and important habitat for fish, molluscs, crustaceans and a range of migratory waders.

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- Bird Island Nature Reserve (east of Lake Munmorah) is listed on the Register of National Estate as an important nesting site for seabirds and described in detail in Option A.
- Tuggerah Lake, Budgewoi Lake Sand Mass and Colongra Swamp are listed in the Directory of Important Wetlands and these areas are described in detail in Option A.
- Brisbane Water is listed in the Directory of Important Wetlands, includes large areas of Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) and extensive seagrass beds. Swans feed on the seagrass beds in spring and summer and the area is an important nursery and spawning ground for fish and crustaceans.

  Riley's Island and Pelican Island Nature Reserves provide critical feeding and breeding areas for a range of migratory wader species, twelve of which are listed in JAMBA or CAMBA. The site is also important for the Bush Stone-Curlew (*Burhinus grallarius*), Pied Oystercatcher (*Haematopus longirostris*), Eastern Curlew (*Numenius madagascariensis*) and a pelican rookery.

- In an assessment of estuaries by NSW Fisheries[2], Brisbane Water was identified by an expert panel as a second priority candidate (after Lake Macquarie) for an aquatic reserve (Frances 2000, NSW Fisheries 2001). The estuary includes a rare combination of fish species (D. Hoese, pers. comm. in Frances 2000) and it remains the only barrier estuary in the bioregion with an entrance not kept open by artificial breakwalls.
- Narrabeen Lakes and Wamberal Lagoon were identified by an expert panel in the NSW Fisheries[2] assessment as first and second priority candidates for estuarine aquatic reserves (Frances 2000). Narrabeen Lakes include unique and ecologically important habitats and 42 species of benthic infauna have been recorded from the area (Patterson Britton and Partners 1995). Wamberal Lagoon has recorded the most diverse and abundant fish assemblages of those lagoons between the Hawkesbury River and Tuggerah Lakes (Frances 2000).
- Option B includes the marine extension to Bouddi National Park within which fishing is currently prohibited through a temporary (five year) fisheries closure. The vulnerable Sooty Oystercatcher, endangered Little Tern, and Osprey are found in the marine section of the national park and several species of migratory waders use the Brisbane Water section of the Park (NPWS 1999).
- Much of the catchment and shoreline of Option B is included in national park or nature reserve and much is inaccessible except by boat or on foot. The Hawkesbury River (with 42% of land within 1 km included in national park or reserve), Pittwater (45%), Brisbane Water (15%) and Wamberal Lagoon (all waters and 16% of land within 1 km) all have significant proportions of adjacent lands included in national park or nature reserve.

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- The Avoca-Brisbane Water section of ocean and coast in Option B has 42% of adjoining land included in national parks and nature reserves while other sections in this option have approximately 12% of adjacent land in terrestrial reserve.
- The Hawkesbury River has the least proportion of urban development (0.6%) within 1 km of its shores in the bioregion, but sections of ocean coast, particularly Tuggerah-Avoca (60%) and Brisbane Water–Narrabeen (58%) have a relatively high degree of urban development.
- The Hawkesbury River has a relatively low percentage of disturbed or high risk acid sulphate soils on adjacent lands, while Brisbane Water and Tuggerah Lakes have a moderate proportion of acid sulphate soils on adjacent land.
- Mean river and catchment disturbance indices were low to moderate for most estuaries and sections of coast in this option.
- The "Independent Inquiry into Coastal Lakes" carried out by the Healthy Rivers Commission rates the catchment condition of Tuggerah Lakes as modified and the lake condition as moderately affected with a high conservation value and a management recommendation of "targeted for repair". A power station on Lake Munmorah discharges heated water into the upper part of the Tuggerah Lakes estuary.
- Many parts of the Hawkesbury and Nepean River are in relatively good condition due to the protection of catchment and shoreline in national park or nature reserve. However smaller urbanised sections of the catchment have poor water quality, particularly near centres like Goulbourn, Lithgow, Penrith, Hornsby and between Windsor and Sackville. Water quality is generally better in the lower reaches of the Hawkesbury estuary but there is concern over the potential for blue-green algae blooms and the presence of toxic dinoflagellate cysts in sediments (Healthy Rivers Commission 1998).
- Of the four scenarios described in this report, Option B is probably one of the least affected by heavy industry but may be affected by sewage input into the upper Hawkesbury River and urban development along the central coast and far northern beaches of Sydney.

3.3 Option C. Avoca Lake to Port Hacking

The main features of the estuaries, coast and ocean between Avoca Lake and Port Hacking are as follows:

- Option C would represent all four estuarine ecosystem types that occur in the Hawkesbury Shelf bioregion including tide dominated river valleys (Hawkesbury River, Pittwater, Parramatta River, Georges River and Port Hacking), barrier estuaries (Brisbane Water), intermittent estuaries (Avoca, Cockrone, Narrabeen, Dee Why, Harbord and Manly Lagoons) and ocean embayments (Botany Bay).
- Together with existing MPAs this option would account for a total of 100% of the area of tide dominated drowned rivers, 15% of wave dominated barrier estuaries, 92% of the area of intermittent estuaries and 100% of ocean embayments.
- It would add large areas of ocean ecosystems between 0-20 m (32% of this zone within NSW coastal waters) and between 20-60 m (34% of this zone within NSW coastal waters), and a significant proportion (55%) of those areas of the 60-200 m zone that lie within the 3 nm limit to State waters.
- Option C includes Brisbane Water which has the fourth largest area of seagrass habitat in the bioregion, as well as significant areas of seagrass in Pittwater, the Hawkesbury River, Parramatta River, Botany Bay, Port Hacking and several intermittent lagoons. Adopting this option could help protect 32% of the bioregions seagrass habitat within MPAs.
- Option C includes the Hawkesbury River, which has the second largest area of mangrove habitat in the bioregion, as well as significant mangrove habitats in Brisbane Water, Pittwater, Port Jackson, Botany Bay and the Georges River. If adopted, it would contribute toward a total of 67% of mangrove habitat in the bioregion in, or adjacent to MPAs.
- Option C includes estuaries with the second (Botany Bay), third (Hawkesbury River) and fourth (Brisbane Water) largest areas of saltmarsh habitat in the bioregion and could contribute to a system of MPAs with 40% of this habitat in, or adjacent to some form of MPA.
- Option C would contribute to representation of large areas of exposed intertidal beach (24%), exposed intertidal rocky shore (35%), inshore shallow reef (34%), inshore sand (30%) and islands (12%) within MPAs.
- Eleven rock platforms in this option were recommended for protection by Short (1995).
- Summed irreplaceability scores for representation of 20% of all habitats and ecosystems were moderately high for most estuaries and sections of ocean and coast in this option.

- Option C for a large marine park covers approximately 840 km^2 representing 42% of NSW waters in the Hawkesbury Shelf bioregion.
- This area includes existing aquatic reserves at Barrenjoey Head, Narrabeen Head, Long Reef, Cabbage Tree Bay, North Sydney Harbour, Bronte-Coogee, Cape Banks, Towra Point, Boat Harbour and Ship Rock.
- It includes Intertidal Protected Areas at Bungan Head, Mona Vale Head, Dee Why Head, Shelly Beach Head, Sydney Harbour, Bondi, Long Bay, Inscription Point and Cabbage Tree Point.
- It includes the marine components of the Wamberal Lagoon, Muogamarra, Pelican Island, and Rileys Island Nature Reserves and Brisbane Water, Ku-ring-gai Chase, Bouddi, Lane Cove and the Royal National Parks.
- Option C includes sightings of threatened and protected fish species including Black Cod, Great White Shark, Grey Nurse Shark, Bleeker's Devil Fish, Elegant Wrasse, Estuary Cod, Queensland Grouper and Weedy Sea Dragon.
- South Palm Beach Reef, Hole in the Wall and Long Reef are all sites where threatened Grey Nurse Shark have been sighted in the past and Magic Point at South Maroubra is an important aggregation site included within critical habitat for this endangered species.
- The Hawkesbury River and other estuaries in the area have yielded relatively diverse and productive commercial fish catches.
- The area includes previous nesting sites of the Little Tern at Dee Why Lagoon, Homebush Bay, Maroubra, and Boat Harbour and a significant current nesting site at Towra Spit, Botany Bay.
- The Parramatta River has the second highest diversity and summed irreplaceability for threatened bird species.
- Lion Island, Long Island, Rileys Island, Pelican Island, Spectacle Island and Muogamarra Nature Reserves in the Hawkesbury River, the Long Reef to Barrenjoey Coastal Rocks, Dee Why Lagoon Reserve, North Head, Sydney Harbour National Park, Parramatta River wetlands, North Bondi Cliffline, Cape Banks, Kurnell and Towra Point and Voyager Point, are all on the Register of the National Estate (Commonwealth of Australia 2003).
- Important conservation values for Lion Island, Long Island, Rileys Island, Pelican Island, Spectacle Island and Muogamarra Nature Reserves are described in Option B.
- Brisbane Water is listed in the Directory of Important Wetlands as described in Option B.
- Dee Why Lagoon Reserve is listed on the Register of the National Estate. It is considered one of the best examples, in the Sydney Region, of an estuarine lagoon (Commonwealth of

Australia 2003) and one of the few in the region remaining in good condition. The saltmarsh around the lagoon is a relatively diverse and uncommon remnant, formerly more widespread in the Sydney Region. Other aquatic vegetation includes *Zostera capricorni*, saltmarsh (*Suaeda australis*) and rushes (*Juncus kraussi, J. acutus*). The lagoon supports several species of waders and cryptic species such as the Tailor Cisticola (*Cisticola exilis*) and the Tawny Grassbird (*Megalurus timoriensis*). It provides habitat for fish species including pilchard (*Sardinops neopilchardus*), sand whiting (*Silago cilliata*), silver biddy (*Gerres ovatus*) and sand mullet (*Myxus elongatus*).

Dee Why Lagoon was identified by an expert panel in a NSW Fisheries[2] assessment as a first priority candidate for an estuarine aquatic reserve. It has the most diverse fish community of any mature intermittent estuary in the Hawkesbury Shelf bioregion (D. Hoese pers. comm. in Frances 2000).

- Nine significant wetland remnants on the upper Parramatta River (Ermington Bay, Meadowbank Park, Yarralla Bay, Majors Bay, Mason Park, Homebush Bay, Silverwater Saltmarsh, Lower Duck River and Haslem's Creek) are listed on the register of the National Estate. Newington Wetlands is listed in the Directory Of Important Wetlands and includes mangrove and saltmarsh habitats bordering four brackish ponds. These areas were once part of extensive mangrove and saltmarsh wetlands on the Parramatta River. The saltmarsh communities are in good health and display a species composition uncommon in the Sydney area and include Samphire (*Sarcocornia quinqueflora*), Seablite (*Suaeda australis*), Sand Couch Grass (*Sporobolus virginicus*), the restricted saltmarsh species, *Lampranthus tegens* (small pig face), an important stand of native rush (*Juncus kraussi*), the Chenopod *Halosarcia pergranulata* and one of the largest remaining populations of the uncommon *Wilsonia backhousei*, which is at its northern limit in Sydney (ANCA 1996, Commonwealth of Australia 2003).

  The wetlands support seventy-five bird species, of which thirty-seven species occur regularly, and the area provides breeding habitat for seventeen species. The wetlands have been ranked sixth in importance for waders in New South Wales and they provide habitat for twenty species listed under JAMBA and 19 species listed under CAMBA, including Pacific Golden Plover (*Pluvialis fulva*), Latham's Snipe (*Gallinago hardwickii*), Bar-tailed Godwit (*Limosa lapponica baueri*), Sharp-tailed Sandpiper (*Calidris acuminata*), Curlew Sandpiper (*Calidris ferruginea*) and Greenshank (*Tringa nebularia*).

  Two endangered species, the Little Tern (*Sterna albifrons*) and the Black Tailed Godwit (*Limosa limosa*), are found here and the wetland also supports one of the two Sydney colonies of the White Fronted Chat (*Epthianura albifrons*); one of the largest populations of

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Chestnut Teal (*Anas castanea*) in NSW; a regionally significant population (200-400 individuals) of the Black-winged Stilt (*Himantopus himantopus*); and more than one percent of the Australian population of the Lesser Golden Plover (*Pluvialis dominica*). The endangered Green and Golden Bell Frog (*Litoria aurea*) has also been recorded from the area (Commonwealth of Australia 2003).

- Towra Point Nature Reserve, Aquatic Reserve and Taren Point in Botany Bay are included in the Directory of Important Wetlands and include a variety of estuarine habitats including spits, bars, mudflats, dunes and beaches. The extensive tidal wetlands, include approximately 600 ha of seagrasses including *Posidonia australis*, *Zostera capricorni*, and *Halophila ovalis* and *H. decipiens*. There are 400 ha of mangroves including the Grey (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) and 161 ha of saltmarshes, representing one of the few large remnant systems near Sydney (ANCA 1996).

  NSW Fisheries[2] has described over 230 species of fish and invertebrates in the Towra Point Aquatic Reserve and the area supports commercial and recreational fish stocks in the coastal Sydney region.

  Towra Point is an important bird feeding, roosting and nesting site for migratory waders and waterfowl and is listed under the Ramsar Convention. Approximately 200 bird species have been recorded from the Towra Point area including 31 of the 66 species listed under JAMBA (References in ANCA 1996). Towra Point has a regular occurrence of 2% of the Australian population of the Eastern Curlew (*Numenius madagascariensis*), 6% of the Lesser Golden Plover (*Pluvialis dominica*) and 1% of the Ruddy Turnstone (*Arenaria interpres*) (References in ANCA 1996). The sand spit area is also breeding habitat for threatened species like the Little Tern (*Sterna albifrons*), Pied Oystercatcher (*Haematopus longirostris*) and the Terek Sandpiper (*Xenus cinereus*) (ANCA 1996). The Taren Point Shorebird Community is listed as an endangered ecological community.

  There are significant threats to this location from heavy industry and port facilities around the shores of the bay, including pollution, dredging, changes in wave action by revetment walls, and shoreline instability and erosion. The sand flats and beach at the eastern end of Towra Point and the western end of Towra Spit are being damaged by coastal erosion with the spit extending in a south-westerly direction.

- Eve Street Marsh, on the Cooks River near Arncliffe is listed in the Directory of Important Wetlands and includes diverse saltmarsh habitat including Sea Rush (*Juncus kraussi*), Seablite (*Suaeda australis*), Samphire (*Sarcocornia quinqueflora*) and the uncommon Creeping Monkey-flower (*Mimulus repens*) (References in ANCA 1996). The marsh

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provides habitat for six JAMBA / CAMBA species including the Great Egret (*Ardea alba*), Greenshank (*Tringa nebularia*), Curlew Sandpiper (*Calidris ferruginea*), Red-necked Stint (*Calidris ruficollis*), Sharp-tailed Sandpiper (*Calidris acuminata*) and Bar-tailed Godwit (*Limosa lapponica*).

- Voyager Point Wetlands at the junction of the Georges River and Williams Creek are listed on the Register of the National Estate (Commonwealth of Australia 2003). The area includes wetlands characteristic of the Georges River including mangroves and *Casuarina glauca*. Saltmarsh species here include *Samolus repens*, *Suaeda australis*, *Sarcocornia quinqueflora, Sporobolus virginicus* and *Cotula coronopifolia* and a pure stand of the uncommon species *Wilsonia backhousei*. Estuarine sedgeland here includes *Juncus kraussi*, *Baumea juncea* and *Phragmites australis.* The freshwater wetlands are characterised by paperbark swamps and emergent and submerged aquatic vegetation including *Eleocharis sphacelata*, *Triglochin procera typha orientalis* and species of *Myriophyllum, Utricularia, Nymphoides* and *Persicaria*. Threats to the area include changes in water quality, wash from speedboats and drainage from nearby housing developments.

- Option C includes within its boundaries, the majority of coastal and estuarine marine habitats in the Sydney Metropolitan area. It includes areas ranging from the most impacted locations to relatively unaffected areas in the Hawkesbury River and Port Hacking. The Hacking River (with 64% of adjacent land in national park), Hawkesbury River (42%), Pittwater (45%), Brisbane Water (15%) and Wamberal Lagoon (all waters and 16% of adjacent land in reserve) all have significant proportions of adjacent lands included in national parks or nature reserves. However Botany Bay, the Parramatta River and Georges River all have less than 10% of their shores in terrestrial reserves.

  The Avoca-Brisbane Waters (42% of land within 1 km of the coast) and Botany-Port Hacking (26%) have moderate proportions of adjacent lands in national parks and nature reserves but other sections of coast in this option have less than 12% of adjacent land in terrestrial reserves.

- Option C includes the most extensive urban and industrial areas in NSW. While the Hawkesbury River has a relatively low level of urban development (0.6%) within 1 km of its shores, estuaries between Dee Why and the Georges River all had over 50% of their shores built on. Over 50% of the ocean coast between Barrenjoey and Cape Banks is adjacent to urban areas.

- Mean river and catchment disturbance indices for this option were generally the highest in the State with the exceptions of Port Hacking and the Hawkesbury River. Inputs from sewage and stormwater outlets throughout the Sydney area are also likely to be higher than elsewhere in the bioregion and there is evidence of contamination of estuarine sediments with heavy metals and PCBs in sections of the Parramatta River, Botany Bay and the Georges River (Birch 1995).

- The Healthy Rivers Commission "Independent Inquiry into Coastal Lakes" rates the catchment condition of Dee Why, Curl Curl and Manly Lagoons as severely modified and the lake conditions as severely affected with recommended management as "targeted for repair".
- Many shores in the Sydney Metropolitan area have been substantially modified or replaced with walls, wharves or marinas, particularly in Sydney Harbour. However a number of studies have shown that these may support very diverse assemblages of marine species and that despite an extremely high level of urban development, marine biodiversity may be very high (Chapman and Bulleri 2003). It can also be argued that irreplaceable areas at risk should be given priority over remote locations, which may be in better condition, but may require less immediate protection.

3.4 Option D. Cape Banks to Shellharbour

The main features of the estuaries, coast and ocean between Cape Banks and Shellharbour are as follows:

- Option D includes three of the four estuarine ecosystem types that occur in the Hawkesbury Shelf bioregion including a tide dominated river valley (Port Hacking), barrier estuaries (Lake Illawarra and Port Kembla) and intermittent estuaries (Towradgi and Benson Creeks).
- Together with existing MPAs, this option would account for a total of 12% of the area of tide dominated drowned rivers in the bioregion, 18% of wave dominated barrier estuaries and 11% of the area of intermittent estuaries. However, this option would not add to the 26% of ocean embayment already represented in Towra Point Aquatic Reserve and Nature Reserve. [1]
- Option D would add large areas of ocean ecosystems between 0-20 m (39% of this zone within NSW coastal waters) and between 20-60 m (31% of this zone within NSW coastal waters), and a significant proportion of those deeper areas in the 60-200 m zone (63%) that lie within the 3 nm limit to State waters.
- Option D includes Lake Illawarra which has the fourth largest area of seagrass habitat in the bioregion. There are also significant areas of seagrass in Port Hacking. Together with existing MPAs this option would help protect 22% of the bioregion's seagrass habitat in MPAs.
- Port Hacking includes small areas of mangrove habitat adding slightly to existing habitats already protected in MPAs for a total of 23% of the bioregion's mangrove habitats included in, or adjacent to MPAs.
- Port Hacking and Lake Illawarra include small areas of saltmarsh adding slightly to a total of 6% of this habitat included in, or adjacent to some form of MPA.
- Option D would add large areas of exposed intertidal beach (29%), exposed intertidal rocky shore (40%), inshore shallow reef (41%), and inshore sand (34%) to the total area of these habitats protected in MPAs.
- The majority of the area of inshore and offshore islands in the Hawkesbury Shelf are found in this option. Together with existing MPAs, this marine park option would help contribute towards protecting 73% of the area of islands in the bioregion within MPAs.
- Six rock platforms in this option were recommended for protection by Short (1995).

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[2] now within the NSW Department of Primary Industry

[1] Although a variation on this option might also include Botany Bay and the Georges River, thereby representing all estuarine ecosystem types within one large multiple-use marine park.

- This option also includes Brickyard Point (north of Wollongong), selected as a candidate site for a marine protected area in the NSW Fisheries[2] assessment to identify aquatic reserves for rocky intertidal shores (Otway 1999).
- Summed irreplaceability scores for representation of 20% of habitats and ecosystems were low for Port Hacking but relatively high for Lake Illawarra and the highest in the bioregion for the Towradgi-Shellharbour section of coast and ocean. The latter score strongly reflects the presence of offshore islands in this area.
- Option D for a large marine park covers approximately 570 km^2 representing 28% of NSW waters in the Hawkesbury Shelf bioregion.
- This area includes existing aquatic reserves at Boat Harbour and Ship Rock, Intertidal Protected Areas at Inscription Point (Kurnell) and Cabbage Tree Point in Port Hacking, and the marine components of the Royal National Park in Cabbage Tree Basin, South West Arm, the Hacking River and Wattamolla Lagoon.
- The area includes sightings of threatened and protected fish species including Black Cod, Grey Nurse Shark, Bleeker's Devil Fish, Elegant Wrasse and Weedy Sea dragon.
- Jibbon Bombora, Marley Point, Toothbrush Island and Windang Island are all sites where threatened Grey Nurse Shark have been sighted in the past or recorded in surveys.
- Port Hacking has a relatively small commercial catch and diversity of species, while Lake Illawarra has a somewhat larger catch and greater diversity of species in catches.
- The area includes previous nesting sites of Little Tern at Boat Harbour, Bellambi Point, Towradgi Beach, South Wollongong Beach, Port Kembla Harbour, Port Kembla Beach, Lake Illawarra and Shellharbour.
- A high number of threatened bird species, sightings, and a moderate summed irreplaceability are recorded for Lake Illawarra and a moderate number of species and sightings reported for the Towradgi-Shellharbour section.
- Coomaditchy Lagoon, a small coastal dunal lake at the original entrance to Lake Illawarra, is listed in the Directory of Important Wetlands (ANCA 1996). The lagoon is only slightly brackish, probably sourcing some sea water through diffusion. It provides habitat for a variety of birds, reptiles, frogs and fish and contains a reed swamp and sedge swamp on the southern and western shores used as breeding sites for waterbirds. The area includes remnant hind dune and littoral rainforest vegetation, a population of endangered Green and Golden Bell Frog (*Litoria aurea*) and is the only area in the Illawarra region to record Wandering Whistling Duck (*Dendrocygna arcuata*). JAMBA or CAMBA species observed include the Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*),

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Latham's Snipe (*Gallinago hardwickii*), and Sharp-tailed Sandpiper (*Calidris acuminata*) (references in ANCA 1996).

- Five Islands Nature Reserve is listed in the Directory of Important Wetlands, is an important area for seabird breeding and provides habitat for many migratory birds. The islands are important for the vulnerable Sooty Oystercatcher (*Haematopus fuliginosus*) with 30% of the NSW population breeding on the islands and relying on the intertidal zone around the islands for foraging. The vulnerable Black-browed Albatross (*Diomedea melanophrys*) has also been recorded here and JAMBA/ CAMBA species observed include the Wedge-tailed Shearwater (*Puffinus pacificus*), Lesser Frigatebird (*Fregata ariel*), Eastern Reef Egret (*Egretta sacra*), and Crested Tern (*Sterna bergii*) (references in ANCA 1996).

- Lake Illawarra is listed in the Directory of Important Wetlands (ANCA 1996). Berkeley Nature Reserve, which includes Gooseberry and Hooka Islands in Lake Illawarra, is on the Register of the National Estate. Seagrasses such as *Zostera* sp. and *Ruppia* sp. provide food for waterfowl on the Lake. A total of 24 species of waterbirds are recorded from here, including Grey Teal (*Anas gibberifrons*), Chestnut Teal (*Anas castanea*), Black Swan (*Cygnus atratus*) and Australasian Little Grebe (*Podiceps novaehollandiae*). Foreshore vegetation includes saltmarsh with Samphire (*Sarcocornia quinqueflora*), Shore Rush (*Juncus kraussii*), Common Reed (*Phragmites australis*), Swamp Oak (*Casuarina glauca*), and Creeping Saltbush (*Atriplex australasica*) (ANCA 1996).

  Endangered species recorded within Lake Illawarra include the Little Tern (*Sterna albifrons*) and the Hooded Plover (*Thinornis rubricollis*). Vulnerable species include the Freckled Duck (*Stictonetta naevosa*), Australasian Bittern (*Botaurus poiciloptilus*), Black Bittern (*Ixobrychus flavicollis*), Sanderling (*Calidris alba*), Great Knot (*Calidris tenuirostris*), Black-tailed Godwit (*Limosa limosa*), Terek Sandpiper (*Xenus cinereus*), Pied Oystercatcher (*Haematopus longirostris*), Greater Sand Plover (*Charadrius leschenaultii*) and the White Tern (*Gygis alba*) (ANCA 1996).

  Species listed under JAMBA or CAMBA recorded near Lake Illawarra include the Sooty Shearwater (*Puffinus griseus*), Brown Booby (*Sula leucogaster*), Great Egret (*Ardea alba*), Cattle Egret (*Ardea ibis*), Eastern Reef Egret (*Egretta sacra*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Common Sandpiper (*Actitis hypoleucos*), Ruddy Turnstone (*Arenaria interpres*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red Knot (*Calidris canutus*), Curlew Sandpiper (*Calidris ferruginea*), Pectoral Sandpiper (*Calidris melanotos*), Red-necked Stint (*Calidris ruficollis*), Latham's Snipe (*Gallinago hardwickii*), Grey-tailed Tattler (*Heteroscelus brevipes*), Wandering Tattler (*Heteroscelus incanus*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Common Greenshank (*Tringa nebularia*), Marsh Sandpiper (*Tringa stagnatilis*), Lesser Golden

Plover (*Pluvialis dominica*), Grey Plover (*Pluvialis squatarola*), White-winged Black Tern (*Chlidonias leucopterus*), Crested Tern (*Sterna bergii*), Caspian Tern (*Sterna caspia*), Common Tern (*Sterna hirundo*), and Fork-tailed Swift (*Apus pacificus*) (ANCA 1996).

Macquarie Rivulet in Lake Illawarra was identified by an expert panel in a NSW Fisheries[2] assessment as a third priority candidate (after Lake Macquarie and Brisbane Water) for an estuarine aquatic reserve (Frances 2000, NSW Fisheries 2001). The estuary has a distinctive fish assemblage (R. West, pers. comm. in Frances 2000) and Macquarie Rivulet has, in the past, provided important habitat for the Australian Grayling (*Prototroctes maraena*) (Farragher, in press cited in Frances 2000). Threats to this area include pollution and loss of habitat from urban development and industry (ANCA 1996).

- When compared to all other areas in the bioregion, Port Hacking had the highest proportion of adjacent land in national parks and nature reserve (64% of land within 1 km) and the Port Hacking-Stanwell Park section had most adjacent coast in terrestrial reserves (92%).
- Port Hacking (31%) and Lake Illawarra (42%) had a moderate proportion of adjacent lands in urban areas while much of the area adjacent to Port Kembla (88%) and Towradgi Creek (72%) was heavily developed or industrialised. The Port Hacking-Stanwell Park section (1.2%) had the least proportion of coast within built-up areas.
- Port Hacking had the lowest percentage of disturbed or high risk acid sulphate soils in adjacent lands in the bioregion, while Port Kembla had the highest.
- Mean river and catchment disturbance indices were lowest in the bioregion for Port Hacking and the Port Hacking-Stanwell Park section. Disturbance indices were generally low to moderate for other estuaries and sections of coast in this option but high for the Towradgi-Shellharbour coast.
- The Healthy Rivers Commission “Independent Inquiry into Coastal Lakes” rates the catchment condition of Lake Illawarra as modified and the lake condition as severely affected but with a high conservation value and recommended management as “targeted for repair”.
- A large proportion of Option D is likely to be relatively unaffected by urban development, industry or agriculture. This is largely due to the presence of the Royal National Park which borders the southern shores of Port Hacking and the coast between Port Hacking and Stanwell Park.
- South of the national park, there are increasing levels of urban settlement on the narrow coastal strip beneath the Illawarra Escarpment, and heavy industry around the shipping port at Port Kembla. As for other locations in the Hawkesbury Shelf bioregion, these developed areas often adjoin some of the most important and vulnerable sites for marine conservation.

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[2] now within the NSW Department of Primary Industry

Appendix 4.

Options in the Batemans and Twofold Shelf Bioregions

4.1 Option A. Shellharbour to Jervis Bay Marine Park (Batemans Shelf)

The main ecological features that Option A could include are as follows:

- All estuarine ecosystem types, except tide dominated drowned river valley and extensive examples of estuarine habitats partially represented in Jervis Bay Marine Park.
- All ocean ecosystem depth zones occurring in NSW waters and all ocean habitats.
- Jervis Bay, the largest ocean embayment with the largest area of seagrass in the bioregion. The Bay, its associated wetlands and the Jervis Bay Sea Cliffs are listed in the Directory of Important Wetlands and the Register of the National Estate. The area includes a very wide diversity of habitats including tidal, intertidal and estuarine wetlands, freshwater lagoons, swamp, saltmarsh, sedgeland, sheltered and exposed rocky shores, beaches, reef, subtidal sediments and non-tidal forested wetlands (ANCA 1996).

  The bay has extensive beds of *Posidonia*, *Zostera* and *Halophila* seagrasses and the largest beds of *Posidonia australis* in NSW. Jervis Bay also includes areas of the seagrasses *Heterozostera tasmanica* and *Zostera muelleri*, both uncommon in NSW. Mangrove species include River (*Avicennia marina*) and Grey Mangrove (*Aegiceras corniculatum*). Saltmarsh species include *Sarcocornia quinqueflora*, *Wilsonia backhousei*, and *Sporobolus virginicus*. The saltmarsh on the cliff tops of Bowen Island is unique in that it receives its moisture from sea spray (ANCA 1996).

  Bowen Island supports a colony of Little Penguins, three shearwater species and sea eagles. The rare Pied Oystercatcher (*Haematopus longirostris*) nests near the bay and 27 wader species, 17 of which are listed under JAMBA or CAMBA use the area. The Green and Golden Bell frog (*Litoria aurea*) is found on Bowen Island and in the northern part of the Jervis Bay area (ANCA 1996).

  The sea cliffs on the Beecroft and Bherwerre Peninsulas are some of the tallest on the NSW coast and include incised inlets such as Eves Ravine and Devils Inlet, islets like the Drum and Drum Sticks and marine caves, overhangs, tunnels and crevices.
- The Shoalhaven River, the second largest wave dominated barrier estuary in the bioregion with the largest area of mangrove habitat, the second largest area of saltmarsh in the bioregion and the highest summed irreplaceability score for estuarine ecosystems and habitats.

The river includes important habitat for Australian Bass and the Australian Grayling and was identified as a third priority candidate aquatic reserve in a previous NSW Fisheries[2] assessment for estuarine MPAs.

The lower estuary is listed in the Directory of Important Wetlands. Wetland plants include River Mangrove (*Aegiceras corniculatum*), Sea Rush (*Juncus kraussii*), *Juncus polyanthemus*, Common Reed (*Phragmites australis*), Swamp Oak (*Casuarina glauca*), Samphire (*Sarcocornia quinqueflora*), *Sporobolus virginicus*, Seablite (*Suaeda australis*), Goosefoot (*Chenopodium glaucum*) and New Zealand Spinach (*Tetragonia tetragonioides*). The largest remaining area of littoral rainforest on the south coast occurs on the south- western side of Comerong Island (ANCA 1996).

This estuary is one of five coastal wetlands considered to be the second most important for shorebirds on the NSW coast. It supports the endangered Little Tern (*Sterna albifrons*), Beach Thick-knee (*Esacus neglectus*) and Hooded Plover (*Thinornis rubricollis*), and vulnerable species including the Mongolian Plover (*Charadrius mongolus*), Large Sand Plover (*Charadrius leschenaultii*), Sooty Oystercatcher (*Haematopus fuliginosus*), Pied Oystercatcher (*Haematopus longirostris*), Terek Sandpiper (*Xenus cinereus*), Broad-billed Sandpiper (*Limicola falcinellus*), Great Knot (*Calidris tenuirostris*), the Black-tailed Godwit (*Limosa limosa*) and Osprey (Pandion haliaetus).

Species found here and listed under JAMBA or CAMBA include the Wedge-tailed Shearwater (*Puffinus pacificus*), Short-tailed Shearwater (*Puffinus tenuirostris*), Cattle Egret (*Ardeola ibis*), Great Egret (*Egretta alba*), Grey Plover (*Pluvialis squatarola*), Lesser Golden Plover (*Pluvialis dominica*), Ruddy Turnstone (*Arenareia interpres*), Eastern Curlew (*Numenius madagascariensis*), Whimbrel (*Numenius phaeopus*), Grey-tailed Tattler (*Tringa brevipes*), Common Sandpiper (*Tringa hypoleucos*), Greenshank (*Tringa nebularia*), Marsh Sandpiper (*Tringa stagnatilis*), Latham’s Snipe (*Gallinago hardwickii*), Asian Dowitcher (*Limnodromus semipalmatus*), Bar-tailed Godwit (*Limosa lapponica*), Red Knot (*Calidris canutus*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red-necked Stint (*Calidris ruficollis*), Long-toed Stint (*Calidris subminuta*), Curlew Sandpiper (*Calidris ferruginea*), Sanderling (*Calidris alba*), White-winged Tern (*Chlidonias leucoptera*), Caspian Tern (*Sterna caspia*), Common Tern (*Sterna hirundo*) and Crested Tern (*Sterna bergii*). The endangered Green and Golden Bell Frog (*Litoria aurea*) has also been found here (ANCA 1996).

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[2] now within the NSW Department of Primary Industry

- Lake Wollumboola, the largest intermittent estuary in the bioregion and a first priority candidate in a NSW Fisheries[2] assessment for estuarine aquatic reserves. The lake is now included within Jervis Bay National Park. It is the fourth largest and second most successful nesting area for the endangered Little Tern in NSW. It supports 11 threatened bird species, at least 24 JAMBA/CAMBA species and is listed in the Directory of Important Wetlands.

  The lake includes beds of seagrass and the surrounding wetlands include Casuarina forest, teatree, saltmarsh, sedgelands and species including Common Reed (*Phragmites australis*), Salt Rush (*Juncus kraussii*), Sedge, *Baumea juncea, Wilsonia rotundifolia*, Samphire (*Sarcocornia quinqueflora*), Paperbark (*Melaleuca* sp.) and Swamp She-oak (*Casuarina glauca*) (ANCA 1996).

  The lake is important as feeding habitat for Black Swans and Chestnut Teal and supports vulnerable bird species including the Little Shearwater (*Puffinus assimilus*), Broad-billed Sandpiper (*Limicola falcinellus*) and Lesser Sand Plover (*Charadrius mongolus*) (ANCA 1996).

  Species listed under JAMBA or CAMBA include the Bar-tailed Godwit (*Limosa lapponica*), Great Egret (*Ardea alba*), Cattle Egret (*Ardea ibis*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Latham's Snipe (*Gallinago hardwickii*), Common Greenshank (*Tringa nebularia*), Grey Plover (*Pluvialis squatarola*), White-winged Black Tern (*Chlidonias leucopterus*), Crested Tern (*Sterna bergii*) and Caspian Tern (*Sterna caspia*) (ANCA 1996). Pollard (references in ANCA 1996) recorded 41 fish species from the lake of which 26 were of commercial importance.

- Killalea Lagoon, listed in the Directory of Important Wetlands, and breeding habitat for large numbers of Black Swans and vulnerable species including Pied Oystercatcher (*Haematopus longirostris*), Comb-crested Jacana (*Irediparra gallinacea*), Blue-billed Duck (*Oxyura australis*) and Australasian Bittern (*Botaurus poiciloptilus*) (References in the ANCA 1996).

  Species listed under JAMBA or CAMBA found here include The Great Egret (*Ardea alba*), Cattle Egret (*Ardea ibis*), Glossy Ibis (*Plegadis falcinellus*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red-necked Stint (*Calidris ruficollis*), Latham's Snipe (*Gallinago hardwickii*), Bar-tailed Godwit (*Limosa lapponica*), Common Greenshank (*Tringa nebularia*), Marsh Sandpiper (*Tringa stagnatilis*), Wood Sandpiper (*Tringa glareola*), Common Sandpiper (*Actitis hypoleucos*), Curlew Sandpiper (*Calidris ferruginea*), Crested Tern (*Sterna bergii*) and the Caspian

[2] now within the NSW Department of Primary Industry

Tern (*Sterna caspia*). Other waterbird species include Pied Cormorant (*Phalacrocorax varius*), Little Black Cormorant (*Phalacrocorax sulcirostris*), Pelicans and Black Duck (*Anas superciliousa*) (References in the ANCA 1996). The area also provides habitat for the endangered Green and Golden Bell Frog (*Litoria aurea*) (References in the ANCA 1996).

- The Minnamurra River, an important wetland with significant mangrove and saltmarsh communities supporting vulnerable bird species and 7 JAMBA/CAMBA species. The river has Grey Mangrove (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) with saltmarsh, *Casuarina* and rushes in tidal areas. Saltmarsh species include Samphire (*Sarcocornia quinqueflora*), Salt Couch (*Sporobolus virginicus*) and pigface. The floodplain area is crossed by a number of creeks which support fringes of mangroves. Species present also include Swamp She-oak (*Casuarina glauca*), Northern Boobialla (*Myoporum acuminatum*), Salt Rush (*Juncus kraussii*), Club Rush (*Isolepis nodosa*), Seablite (*Suaeda australis*), Salt Couch (*Sporobolus virginicus*), Salt Rush (*Juncus kraussii*), Streaked Arrowgrass (*Triglochin striata*) and Creeping Brookweed (*Samolus repens*) (ANCA 1996).

  Bird species listed as threatened include the Australasian Bittern (*Botaurus poiciloptilus*), Comb-crested Jacana (*Irediparra gallinacea*), Sooty Oystercatcher (*Haematopus fuliginosus*) and the Black Bittern (*Ixobrychus flavicollis*) (ANCA 1996).

  Birds listed under JAMBA or CAMBA include the Great Egret (*Ardea alba*), Cattle Egret (*Ardea ibis*), Glossy Ibis (*Plegadis falcinellus*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Whimbrel (*Numenius phaeopus*), Crested Tern (*Sterna bergii*) and the Caspian Tern (*Sterna caspia*) (ANCA 1996).

- Bass Point, an aggregation site and declared critical habitat for the endangered Grey Nurse Shark. The site was previously proposed as a candidate for an Aquatic Reserve and is listed on the Register of the National Estate.

  The area includes relatively undisturbed examples of high diversity, fringing reef, intertidal pool and boulder field communities with soft corals, gorgonian sea fans, sponge gardens and many crustacean, mollusc and cnidarian species not commonly found in the Illawarra region (Commonwealth of Australia 2003).

  The protected Bleeker's Devilfish (*Paraplesiops bleekeri*), Black Rock Cod (*Epinephelus daemelii*) and Elegant Wrasse (*Anampses elegans*) and 151 other fish species have been recorded from this area, a higher number than found at similar sites (Commonwealth of Australia 2003). At least seventeen rare or uncommon fish species occur in the area, as well as a rare zoanthid, two rare coral species, a rare sea pen, eight rare or uncommon molluscs, four rare crustaceans, two rare sea spiders, four rare echinoderms and two rare or uncommon ascidians. The broach shell (*Trigonia strangeii*) and the sand dollar (*Clypeaster tumidus*) are also thought to occur here (Commonwealth of Australia 2003).

- Bushrangers Bay, an aquatic reserve listed on the Register of the National Estate. This small, rocky, semi-enclosed oceanic bay includes boulder, reef and sand habitats, an area of *Posidonia australis*, and a diverse fish and invertebrate fauna including cuttlefish, sea dragons, nudibranchs, leather jackets, bream, yellowtail, bullseyes, stingrays, squid, octopus, morwongs, blue groper, starfish, feather stars, hawkfish, catfish, moray eels and nudibranchs. Beyond the entrance there are also sponge gardens and soft corals (Commonwealth of Australia 2003).
- Bombo Head, previously proposed as an aquatic reserve by NSW Fisheries[2] and listed on the Register of the National Estate for its geological significance. Penguin Head at Culburra, Black Head at Gerroa, and the Kiama Blowhole and Little Blowhole are geological sites also listed on the Register of the National Estate.
- Jervis Bay, the Shoalhaven River and the coast between Shellharbour and Lake Wollumboola score highly in summed irreplaceability analyses as they include habitats and ecosystems not readily found elsewhere in the bioregion.
- Jervis Bay Marine Park already includes some of the most important areas in the Batemans Shelf bioregion for marine biodiversity. This option adds large areas of barrier estuary, intermittent lagoon, deeper ocean ecosystems and mangrove and saltmarsh habitats not well represented in the existing marine park. Option A, however, does not include tide dominated, drowned river valley ecosystems.
- Many parts of the Shoalhaven River are in relatively good condition. However Tallowa Dam obstructs 80% of the catchment and there are many other obstructions to fish passage. Inappropriate land use and increasing urban development in the lower parts of the river have also caused oxidation of acid sulphate soils, bank erosion and loss of wetlands (Healthy Rivers Commission 1999).
- Areas of coast and estuary in the south of Option A are protected in Comerong Island Nature Reserve and Jervis Bay and Seven Mile Beach National Parks. However, the aquatic components of these reserves do not have direct protection for fish or aquatic invertebrates from fishing. The areas in the northern part of Option A are vulnerable to urban and industrial development.

[2] now within the NSW Department of Primary Industry

4.2 Option B. Termeil Lake to the Moruya River (Batemans Shelf)

The main ecological features that Option B could include are as follows:

- All estuarine ecosystem types found in the bioregion and substantial areas of estuarine habitats partially represented in Jervis Bay Marine Park.
- All ocean ecosystem depth zones within NSW waters and significant examples of all mapped ocean habitats.
- Termeil, Meroo and Durras Lakes, intermittent estuaries with near pristine catchments protected in national parks. These lakes were recommended for comprehensive protection by the Coastal Lakes Inquiry.
- Durras Lake, the fifth largest intermittent estuary in the bioregion. The lake was previously proposed as a candidate for an estuarine aquatic reserve and is now included within Jervis Bay National Park. It is listed in the Directory of Important Wetlands and the adjoining swamp and forest is listed in the Register of the National Estate. The lake has extensive seagrass beds of *Zostera capricorni*, with Swamp Oak forest (*Casuarina glauca*), sedge, Sea Rush (*Juncus krausii*), Bare Twig-rush (*Baumea juncea*) and Spotted Gum (*Eucalyptus maculata*) forest surrounding most of the lake.

  Species listed here as endangered include the Hooded Plover (*Thinornis rubricollis*) and vulnerable species include the Little Shearwater (*Puffinus assimilus*), Flesh-footed Shearwater (*Puffinus carneipes*), Shy Albatross (*Diomedea cauta*), Black-browed Albatross (*Diomedea chlororhynchos*), Osprey (*Pandion haliaetus*), Sooty Oystercatcher (*Haematopus fuliginosus*), Pied Oystercatcher (*Haematopus longirostris*), Greater Sand Plover (*Charadrius leschenaultii*), Sooty Tern (*Sterna fusca*) and Black Bittern (*Ixobrychus flavicollis*) (ANCA 1996).

  Species listed under JAMBA or CAMBA include the Short-tailed Shearwater (*Puffinus tenuirostris*), Great Egret (*Ardea alba*), Eastern Reef Egret (*Egretta sacra*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red Knot (*Calidris canutus*), Red-necked Stint (*Calidris ruficollis*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Crested Tern (*Sterna bergii*), Caspian Tern (*Sterna caspia*) and Common Tern (*Sterna hirundo*) (ANCA 1996).
- The Clyde River, the only tide dominated, drowned river valley in the bioregion. The estuary includes the second largest area of mangrove habitat in the bioregion, large areas of saltmarsh, and has the second highest summed irreplaceability score for estuarine ecosystems and habitats (after the Shoalhaven). Much of the river’s catchment and shores

are within State Forest and it is listed in the Directory of Important Wetlands and the Register of the National Estate.

The Clyde River is "important in the evolution of Australia's fauna and flora as a complete ecosystem relatively untouched by human habitation". Approximately 95% of the catchment of the Clyde River is uncleared and it may be the "only river left on the NSW coast that flows uninterrupted from its source to the sea" (Commonwealth of Australia 2003).

Native fish species found in the river include gudgeons (*Hypseleotris*), Australian Smelt (*Retropinna semoni*), eels, bullrouts, Australian Bass (*Macquarie novemaculeata*) and Australian Grayling (*Prototroctes maraena*). Three endangered fish species have been recorded from the river. The river also provides potential habitat for migratory waders, but is poorly studied. Vulnerable waterbird species found in the estuary include the Sooty Oystercatcher (*Haematopus fuliginosus*).

Cullendulla Creek Embayment, a drowned creek gully on the Clyde River, is listed in the Directory of Important Wetlands and the Register of the National Estate. The beach chenier here is uncommon in NSW and provides a record of shoreline trends during the Holocene (from 10 000 years ago). The embayment is a good example of a low energy beach ridge and mud flats in an enclosed bay (ANCA 1996). *Limonium australe* occurs in the saltmarsh and is probably the largest population in NSW. The White-bellied Sea-Eagle (*Haliaeetus leucogaster*) listed under CAMBA also occurs here.

- Batemans Bay, the second largest ocean embayment in the bioregion after Jervis Bay. The bay includes offshore island and reef habitats and an important aggregation site declared as critical habitat for the endangered Grey Nurse Shark (*Carcharias taurus*). At the Tollgate Islands, sharks have been observed during 90% of surveys in numbers representing 8.9% of the observed NSW population and 15.4% of the observed female population. This site is the most important known aggregation site for females, and it is thought that females may be gestating at this site during summer and autumn.
- The Moruya River is an example of a wave dominated barrier estuary with significant areas of saltmarsh listed in the Directory of Important Wetlands and the Register of the National Estate. The estuary includes a "number of extensive, modified salt and brackish marshes…all of conservation significance, and due to their variability, of considerable floristic interest (Adam 1992 cited in ANCA 1996).

  These diverse saltmarshes include Samphire (*Sarcocornia quinqueflora*), Seablite (*Suaeda australis*), Sea Rush (*Juncus krausii*), Streaked Arrowgrass (*Triglochin striata*), Native Sea Lavender (*Limonium australe*), Creeping Monkey-flower (*Mimulus repens*), scattered Chaffy Saw-sedge (*Gahnia filum*) and Saltbush (*Atriplex australasica*). The upper marsh includes species such as *Selliera radicans*, New Zealand Spinach (*Tetragonia tetragonioides*), *Leptinella longipes,* Sea Celery (*Apium prostratum*), Creeping Brookweed (*Samolus repens*) and Swamp Oak (*Casuarina glauca*). Grey (*Avicennia marina*) and River Mangrove (*Aegiceras corniculatum*) grow on the channels draining the saltmarsh (ANCA 1996).

The endangered Wandering Albatross (*Diomedea exulans*) and Hooded Plover (*Thinornis rubricollis*), and the vulnerable Shy Albatross (*Diomedea cauta*), Black-browed Albatross (*Diomedea melanophrys*), Square-tailed Kite (*Lophoictinia isura*), Sanderling (*Calidris alba*), Great Knot (*Calidris tenuirostris*), Black-tailed Godwit (*Limosa limosa*) and Pied Oystercatcher (*Haematopus longirostris*) are recorded from the estuary. Species listed under JAMBA or CAMBA from the estuary include the Ruddy Turnstone (*Arenaria interpres*), Red Knot (*Calidris canutus*), Latham's Snipe (*Gallinago hardwickii*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Whimbrel (*Numenius phaeopus*) and Grey Plover (*Pluvialis squatarola*).

- The Willinga-Durras section of ocean coast has some of the largest areas of inshore reef and island habitat, includes significant offshore habitats and had the second highest summed irreplaceability score for ocean ecosystems and habitats.
- Option B includes the most seabird breeding islands and the greatest diversity and abundance of breeding seabirds in the bioregion. Belowla and Brush Islands are listed on the Register of the National Estate and Brush Island, in particular, provides important nesting habitat for Little Penguins, Wedge Tailed Shearwaters, Short Tailed shearwaters and the Sooty Oyster Catcher.
- The Clyde and Moruya Rivers and the coast between Willinga Lake and Durras Lake score very highly in summed irreplaceability analyses as they include ecosystems and habitats not readily found in other parts of the bioregion.
- Between 40 and 75% of the ocean coast and most islands in the sections of coast between Termeil Lake and Durras Lake are within national parks and this option includes some of the most pristine waterways and catchments in the Batemans Shelf Bioregion.
- Areas of Termeil and Meroo Lakes are already protected in national parks but have no direct protection for fish or aquatic invertebrates.

4.3 Option C. Durras Lake to Wallaga Lake (Batemans Shelf)

The main ecological features that Option C could include are as follows:

- All ocean depth zones within NSW waters and the most extensive examples of mapped ocean habitats in the bioregion.
- All estuary ecosystem types and substantial areas of estuarine habitats partially represented in Jervis Bay Marine Park.
- Durras Lake (described in 5.2), the fifth largest intermittent estuary in the bioregion. The lake was proposed as a candidate for an estuarine aquatic reserve and was recently included within Jervis Bay National Park. It provides important habitat for threatened birds and migratory waders protected under JAMBA and CAMBA agreements and is listed in the Directory of Important Wetlands and the adjoining swamp and forest is listed in the Register of the National Estate.
- The Clyde River (described in 5.2), the only tide dominated, drowned river valley in the bioregion. The river includes the second largest area of mangrove habitat in the bioregion and large areas of saltmarsh. It has the second highest summed irreplaceability score (after the Shoalhaven) for estuarine ecosystems and habitats. Much of its catchment and shores are within State Forest and the Clyde River is listed in the Directory of Important Wetlands.
- Batemans Bay (described in 5.2), the second largest ocean embayment in the bioregion after Jervis Bay with important sheltered rocky shores, beaches and offshore island and reef habitats.
- Montague Island, the largest offshore island in NSW with the exception of Lord Howe Island. Montague Island has been classified by the National Trust as a Landscape Conservation Area for its scenic, scientific and historical values. The island is the most northerly and only remaining haul out site in NSW for Australian fur seals. It is one of the most important sea bird breeding islands in NSW and the second largest breeding area in Australia for Little Penguins. The threatened sooty oystercatcher (*Haematopus fuliginosus*) breeds here and the wandering albatross (*Diomedea exulans*) and fleshy-footed shearwater (*Puffinus carneipes*) have been recorded on the island or in adjacent waters (NPWS 1995). Montague Island is also important for the high diversity and biogeographic significance of its marine algae (Alan Millar pers. comm., National Herbarium of New South Wales).

- Montague Island and the Tollgate Islands are two important aggregation sites and areas of critical habitat for the Grey Nurse Shark (*Carcharias taurus*). At the Tollgate Islands, sharks have been observed during 90% of surveys in numbers representing 8.9% of the observed population and 15.4% of the observed female population.

  At Montague Island, sharks aggregate mainly at the northern tip of the island but also at three sites on the western side of the island. Sharks were observed during 20% of surveys in numbers representing 1.3% of the total observed NSW population. Most sharks surveyed here were females and a number of these may have been pregnant.

- Tuross Lake, Wallaga Lake, Wagonga Inlet and the Moruya River (described in Section 14.2), the largest wave dominated barrier estuaries in the bioregion after the Shoalhaven River and St. Georges Basin.

- Coila Lake, the largest intermittent estuary in the bioregion and Durras, Brunderee, Tarourga, Brou, and Nargal Lakes, intermittent estuaries with near pristine catchments that have been recommended for comprehensive protection by the Coastal Lakes Inquiry.

- Coila Creek Delta is listed in the Directory of Important Wetlands and has important areas of saltmarsh in good condition and includes Samphire (*Sarcocornia quinqueflora*), *Wilsonia rotundifolia*, Sea Rush (*Juncus krausii*), *Selliera radicans,* Creeping Monkey-flower (*Mimulus repens*) and Swamp Oak (*Casuarina glauca*) forest. The large, healthy population of *Wilsonia rotundifolia* is near its northern extent and has high conservation significance (Adam 1992 in ANCA 1996). Algae, Seagrass (*Zostera* sp.), Sea Tassel (*Ruppia* sp.) and Sea Wrack (*Halophila* sp.) are also present adjoining the saltmarsh (ANCA 1996). The vulnerable Pied Oystercatcher (*Haematopus longirostris*) has been recorded within the lake and species listed under JAMBA or CAMBA include the Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*) and the Crested Tern (*Sterna bergii*) (ANCA 1996).

- The Tuross River Estuary delta is listed in the Directory of Important Wetlands and provides a diversity of habitats along its extensive shoreline. The delta islands support a variety of plant and animal communities including mangroves (*Avicennia marina*), saltmarsh (*Sarcocornia quinqueflora*), *Casuarina* swamp, littoral rainforest, *Zostera*, *Halophila* and sand and mud flats.

  The endangered Little Tern (*Sterna albifrons*) and Hooded Plover (*Thiornis rubricollis*) and the vulnerable Black-tailed Godwit (*Limosa limosa*), Pied Oystercatcher (*Haematopus longirostris*) and Lesser Sandplover (*Charadrius mongolus*) have been recorded from the estuary.

Species listed under JAMBA or CAMBA include the Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Common Sandpiper (*Actitis hypoleucos*), Ruddy Turnstone (*Arenaria interpres*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red Knot (*Calidris canutus*), Curlew Sandpiper (*Calidris ferruginea*), Red-necked Stint (*Calidris ruficollis*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Whimbrel (*Numenius phaeopus*), Marsh Sandpiper (*Tringa stagnatilis*), White-winged Black Tern (*Chlidonias leucopterus*) and Crested Tern (*Sterna bergii*). Cormorant rookeries are also found in upper parts of the area (ANCA 1996).

- Wallaga Lake was proposed as an estuarine aquatic reserve in a previous assessment by NSW Fisheries[2] and is listed in the Directory of Important Wetlands. The lake has large areas of sand flat exposed at low tide near the entrance, a number of inflowing tributaries and open forest, with Swamp Oak (*Casuarina glauca*) and Swamp Paperbark (*Melaleuca ericifolia*) along much of the shoreline and islands within the lake. The upper tributaries have saltmarsh habitats with mangroves and seagrasses (*Zostera* and *Halophila*). The sand flats provide habitat for foraging and resting waterbirds and seabirds.

The endangered Little Tern (*Sterna albifrons*) nests on the fore dunes of the beach and fledglings and adults feed in the estuary. The endangered Hooded Plover (*Thiornis rubricollis*) and vulnerable Pied Oystercatcher (*Haematopus longirostris*) and Osprey (*Pandion haliaetus*) occur in the estuary.

Species listed under JAMBA or CAMBA recorded at Wallaga Lake include the Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Sharp-tailed Sandpiper (*Calidris acuminata*), Curlew Sandpiper (*Calidris ferruginea*), Red-necked Stint (*Calidris ruficollis*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Lesser Golden Plover (*Pluvialis dominica*), Crested Tern (*Sterna bergii*), Caspian Tern (*Sterna caspia*) and Common Tern (*Sterna hirundo*) (ANCA 1996).

- Nargal Lake is listed in the Directory of Important Wetlands and is one of the few dune-swale freshwater lakes in the region (along with Bondi Lake). The shoreline includes small areas of Swamp Oak (*Casuarina glauca*) forest and sedgelands of Spike-rush (*Eleocharis sp.*) which provide shelter for waterbirds including Musk Duck (*Biziura lobata*) and breeding areas for Black Swan (*Cygnus atratus*). A herbfield of *Selliera radicans* and other species occurs on the eastern shoreline. The White-bellied Sea-Eagle (*Haliaeetus leucogaster*) listed under CAMBA has been recorded here (ANCA 1996).

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[2] now within the NSW Department of Primary Industry

- The Wagonga-Wallaga section of ocean coast, includes the largest area of rocky intertidal shore and offshore islands in the bioregion, and the second largest area of offshore reef in the bioregion. Wagonga Head was proposed as an aquatic reserve in a previous assessment of intertidal rocky shores by NSW Fisheries[2]. The shore is also a significant fossil site listed in the Register of the National Estate.
- The Clyde, Moruya and Tuross Rivers and the coast and ocean between Wagonga and Wallaga Lakes score very highly in summed irreplaceability analyses as they include ecosystems and habitats not readily found in other parts of the bioregion.
- Approximately 75% of the ocean coast between Durras Lake and Batemans Bay and 30% of the coast between Tuross Lake and Wagonga are included in national park, but there is less national park bordering other sections of the coast in this option. As with Option B, this option includes some of the most pristine waterways and catchments in the Batemans Shelf bioregion but there has been significant development at a number of urban centres.
- Parts of Congo Creek, Meringo Creek, Lake Brunderee, Lake Tarouga, Lake Brou and Mummuga Lake and sections of ocean beach and rocky shore are already included in Eurobodalla National Park but have no direct protection for fish or aquatic invertebrates from fishing.

[2] now within the NSW Department of Primary Industry.

4.4 Option D. Middle Lagoon to Twofold Bay (Batemans / Twofold Shelf)

The main ecological features that Option D could include are as follows:

- All ocean ecosystem depth zones within NSW waters of the Twofold Shelf bioregion and representative examples of mapped ocean habitats from the NSW section of the bioregion.
- All estuary ecosystem types found in the NSW section of the Twofold Shelf bioregion and the most substantial areas of estuarine habitat from the NSW section of the bioregion. These estuarine habitats and ecosystems may not be represented in MPAs in the Victorian or Tasmanian sections of the Twofold Shelf bioregion.
- Pambula Lake, the largest wave dominated barrier estuary in the NSW section of the Twofold Shelf bioregion. The lake has the second largest area of seagrass, the largest area of mangrove and the third largest area of saltmarsh in the NSW section of the bioregion. This estuary type occurs in the Victorian section of the bioregion but is not represented in MPAs. Areas upstream of the lake include channels, sand flats, mangroves, saltmarsh, and brackish and freshwater assemblages listed in the Directory of Important Wetlands.
- Merimbula Lake, the second largest barrier estuary in the NSW section of the bioregion. The lake includes the largest area of seagrass habitat, the second largest area of mangrove and the largest area of saltmarsh in the NSW section of the bioregion. The lake is at the southern limit for River Mangrove (*Aegiceras corniculatum*) and includes a significant population of the Saltbush *Sclerostegia arbuscula* (P. Adam in ANCA 1996). The area provides habitat for endangered and vulnerable bird species and waders protected under JAMBA and CAMBA and is listed in the Directory of Important Wetlands.

  The endangered Hooded Plover (*Thinornis rubricollis*) and vulnerable Australasian Bittern (*Botaurus poiciloptilus*), Sooty Oystercatcher (*Haematopus fuliginosus*) and Pied Oystercatcher (*Haematopus longirostris*) have been recorded from the lake (ANCA 1996).

  Species listed under JAMBA or CAMBA include the Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Latham's Snipe (*Gallinago hardwickii*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*) and Whimbrel (*Numenius phaeopus*) (ANCA 1996).

- Nelson Lagoon, proposed in a previous NSW Fisheries[2] assessment as an estuarine aquatic reserve and Bondi and Bournda Lagoons, all intermittent estuaries with near pristine catchments and slightly affected to pristine waters. All are recommended in the Coastal Lakes Inquiry for comprehensive protection. Nelson Lagoon is listed in the Directory of Important Wetlands and the area around the lagoon includes saltmarshes of significant conservation value (Adam 1992 in ANCA 1996).

- Bondi Lake is listed in the Directory of Important Wetlands. Although it is generally fresh, the lake appears to become more saline as its volume diminishes. The 200 ha catchment is wholly within Bournda National Park. Species listed under JAMBA or CAMBA include the White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Sharp-tailed Sandpiper (*Calidris acuminata*), Curlew Sandpiper (*Calidris ferruginea*), Red-necked Stint (*Calidris ruficollis*) and Common Greenshank (*Tringa nebularia*) (references in ANCA 1996).

- Wallagoot Lake, the largest intermittent lagoon in this option, occurs at the border of the Twofold and Batemans Shelf bioregions. The lake is listed in the Directory of Important Wetlands and has extensive sand spits and sandy islets at the east end of the lagoon and extensive seagrass beds (including *Posidonia*), rushes, sedges, Saltmarsh (*Sarcocornia quinqueflora*), Streaked Arrow-grass (*Triglochin striata*), Saw-sedge (*Gahnia* sp.) and Common Reed (*Phragmites australis*).

  Endangered species sighted here include the Little Tern (*Sterna albifrons*) and the Hooded Plover (*Thinornis rubricollis*). Vulnerable species sighted here include Pied Oystercatcher (*Haematopus longirostris*), Australasian Bittern (*Botaurus poiciloptilus*) and Sanderling (*Calidris alba*).

  Species listed under JAMBA or CAMBA include the Short-tailed Shearwater (*Puffinus tenuirostris*), Great Egret (*Ardea alba*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*), Ruddy Turnstone (*Arenaria interpres*), Sharp-tailed Sandpiper (*Calidris acuminata*), Curlew Sandpiper (*Calidris ferruginea*), Red-necked Stint (*Calidris ruficollis*), Bar-tailed Godwit (*Limosa lapponica*), Eastern Curlew (*Numenius madagascariensis*), Common Greenshank (*Tringa nebularia*), Common Redshank (*Tringa totanus*), Lesser Golden Plover (*Pluvialis dominica*), Grey Plover (*Pluvialis squatarola*), Crested Tern (*Sterna bergii*), Caspian Tern (*Sterna caspia*), Common Tern (*Sterna hirundo*) and the White-throated Needletail (*Hirundapus caudacutus*) (ANCA 1996).

[2] now within the NSW Department of Primary Industry

- Twofold Bay, the only ocean embayment in the Twofold Shelf bioregion within NSW or Victoria. The bay and the four intermittent and barrier estuaries that flow into it are listed in the Directory of Important Wetlands. The sheltered rocky shores, beaches, reefs, deep water areas, sand flats and wetlands around the bay provide important habitat for marine life, cetaceans and threatened and migratory birds (ANCA 1996).

  The endangered Hooded Plover (*Thiornis rubricollis*) and the vulnerable Shy Albatross (*Diomedea cauta*), Black-browed Albatross (*Diomedea melanophrys*), Sooty Albatross (*Phoebetria fusca*) and Pied Oystercatcher (*Haematopus longirostris*) have been recorded from Twofold Bay.

  Humpback Whales (*Megaptera novaeangliae*) are regularly sighted here when migrating north and south. Southern Right Whales (*Eubalaena australis*) and the Blue Whale (*Balaenoptera musculus*) also visit the bay occasionally as well as other cetaceans including dolphins and Pilot Whales. The bay is a known resting locality for cetacean migrants (ANCA 1996).

  Species listed under JAMBA or CAMBA include the Short-tailed Shearwater (*Puffinus tenuirostris*), Australian Reef Egret (*Egretta sacra*), White-bellied Sea-Eagle (*Haliaeetus leucogaster*) and Grey Plover (*Pluvialis squatarola*) (ANCA 1996).

- The Middle-Wallagoot section of ocean coast includes the largest area of islands between Bega and Victoria. The rocky shores and subtidal reef south of Tathra are important for the high diversity and biogeographic significance of the marine algae found there (Alan Millar pers. comm., National Herbarium of New South Wales). Tathra Head was short listed as an aquatic reserve candidate by a community advisory panel in a previous assessment of intertidal areas by NSW Fisheries[2].

- Bondi Lake and Bournda Lagoon are surrounded by national park, and most of Nelson and Middle Lagoon, and approximately 40% of Pambula and Wallagoot Lakes are surrounded by national park.

- Over 60% of the ocean coast between Middle and Wallagoot Lakes, 30% of the coast between Wallagoot and Pambula and 95% of the coast between Pambula and Twofold Bay is within national park.

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[2] now within the NSW Department of Primary Industry.

4.5 Option E. Twofold Bay to Nadgee

Twofold Shelf

The main ecological features that Option E could include are as follows:

- All ocean ecosystem depth zones within NSW waters of the Twofold Shelf bioregion and representative examples of mapped ocean habitats from the NSW section of the bioregion.
- All estuary ecosystem types found in the NSW section of the Twofold Shelf bioregion and relatively small areas of estuarine habitat from the NSW section of the bioregion. These estuarine habitats and ecosystems may not be represented in MPAs in the Victorian or Tasmanian sections of the Twofold Shelf bioregion.
- Twofold Bay (described in Section 14.4), the only ocean embayment in the Twofold Shelf bioregion within NSW or Victoria.
- Towamba and Wonboyn Rivers, representative barrier estuaries in a largely unmodified condition and Wonboyne Lake, recommended by the Coastal Lakes Inquiry for significant protection.
- Saltwater, Woodburn and Bittangabee Creeks, which are entirely surrounded by Ben Boyd National Park.
- Wirra Birra, Table and Little Creeks, Merrica River, Nadgee River and Nadgee Lake, which are entirely included in the Nadgee Nature Reserve and Wilderness area.
- The ocean coast between Twofold Bay and Wonboyn River which includes the largest area of mapped inshore reef in NSW south of Tuross Heads. The section includes small areas of inshore islands and rocks and the largest area of intertidal rocky shore of all sections in the Batemans Shelf bioregion or the NSW section of the Twofold Shelf bioregion.
- Almost all the ocean coast between Twofold Bay and the Victorian border is included in national park or nature reserve and much of it is in the declared Wilderness area. These areas are likely to be among the least disturbed coastal areas in NSW.
- Nadgee Lake and River, Table and Little Creek, Merrica River, and Saltwater and Woodburn Creeks are protected in national park but have no direct protection for fish or aquatic invertebrates from fishing.
- This option would adjoin the Cape Howe Marine National Park in Victoria, which lies immediately south of the NSW border.

Appendix 5. Steering and expert committee members for the Great Barrier Reef Representative Areas Project

Scientific Steering Committee

Mr Richard Kenchington (former Executive Director, GBRMPA)

Dr Bruce Mapstone (James Cook University/CRC Reef)

Dr Rob Coles (QDPI) Dr Peter Doherty (AIMS)

Dr Dave Williams (AIMS/CRC Reef)

Dr Terry Done (AIMS)

Prof Helene Marsh (JCU)

Dr Ian Poiner (CSIRO, Marine Division)

Dr Trevor Ward (University of Western Australia)

Dr Glenn De'ath (CRC Reef).

Reef Panel:

Dr Tony Ayling (Consultant, Sea Research)

Dr Terry Done (AIMS)

Dr Katharina Fabricius (AIMS & CRC Reef)

Dr Laurence McCook (AIMS & CRC Reef)

Lyle Squires (Consultant, Cairns Marine Aquarium Fish)

Dr David Williams (AIMS & CRC Reef).

Non-reef Panel:

Dr Rob Coles (QDPI)

Dr Miles Furnas (AIMS)

Dr Chris Jenkins (Ocean Sciences Institute University of Sydney)

Dr John Hooper (Queensland Museum)

Dr Patricia Hutchings **(**Australian Museum)

Mr Warren Lee Long (QDPI)

Dr Roland Pitcher (CSIRO)

Dr David Williams (AIMS & CRC Reef).

Appendix 6. Survey of scientists for the GBRMPA Representative Areas Program

Survey of reserve habitat requirements for adequate representation and protection of biological diversity in the Great Barrier Reef Region

As part of the Representative Areas Program, we are surveying a select group of experts researching different groups of organisms in the Great Barrier Reef Region.

Our aims are to describe:

-the prime habitat requirements of different groups of organisms,

-the main causes and patterns of diversity for those groups,

-appropriate reserve designs for these organisms

-additional sources of data and expertise

-any areas of special importance for the maintenance of marine ecosystem diversity and function.

While we realise that information may be incomplete, we urge you to use your expert opinion and judgement in answering this survey as best you can. If you would like to qualify your response or are unable to complete the survey please give reasons in the spaces below or on the spare sheets provided.

Please consider the following questions in the context of choosing representative areas of habitat to be protected by Marine Park zoning. This relates particularly to the scale of information you provide. For practical reasons protected areas are likely to range in size from a few km to 100s of km's. For example zoning decisions are more likely to be influenced by environmental variation among different reefs than variation within a single reef.

You may wish to fill out the electronic version of this form by typing responses in the shaded yellow boxes and drawing lines and labels on the maps with the drawing tools provided, or you may wish to print out this form and write and draw on the paper copies.

More detailed maps of each section of the Marine Park are attached to this e-mail if you require them.

1. Your name?
2. Your position?
3. Your organisation?

4. Which groups (eg. populations, taxa, or communities) of organisms are you most familiar with (eg. southern Dugong, butterfly fishes, soft bottom infauna) in the GBR region?

Group 1

Group 2

Group 3

Group 4

Group 5

For **one of these groups** please attempt to answer the following questions. (Feel free to provide information for **additional groups** on separate copies of this survey.)

5. Organism group (eg. algae)

6. What environmental **factors** (or even approximate surrogate variables) and **categories** would best define the most distinct **spatial patterns in diversity and abundance** for this group?

		Categories				
	Factor	**1**	**2**	**3**	**4**	**5**
Example 1	*salinity*	*0-5 o/oo*	*5-20 o/oo*	*20-30 o/oo*	*>30 o/oo*	
Example 2	*slope*	*flat*	*moderate*	*steep*		
Factor 1						
Factor 2						
Factor 3						
Factor 4						
Factor 5						
Factor 6						

Please answer the following questions with regard to maintaining representative diversity in the organism group described, while allowing for reasonable use.

(To allow for uncertainty feel free to provide a range of values eg. "between 20-30%")

7. Is any particular shape, orientation or configuration of reserve of value in preserving the organism group?

8. Is any particular shape, orientation or configuration of reserve to be avoided?

9. If several reserves are used, what distance apart should they be to maintain connectivity among organisms?

10. Are there any environmental boundaries that need to be considered when siting protected areas?

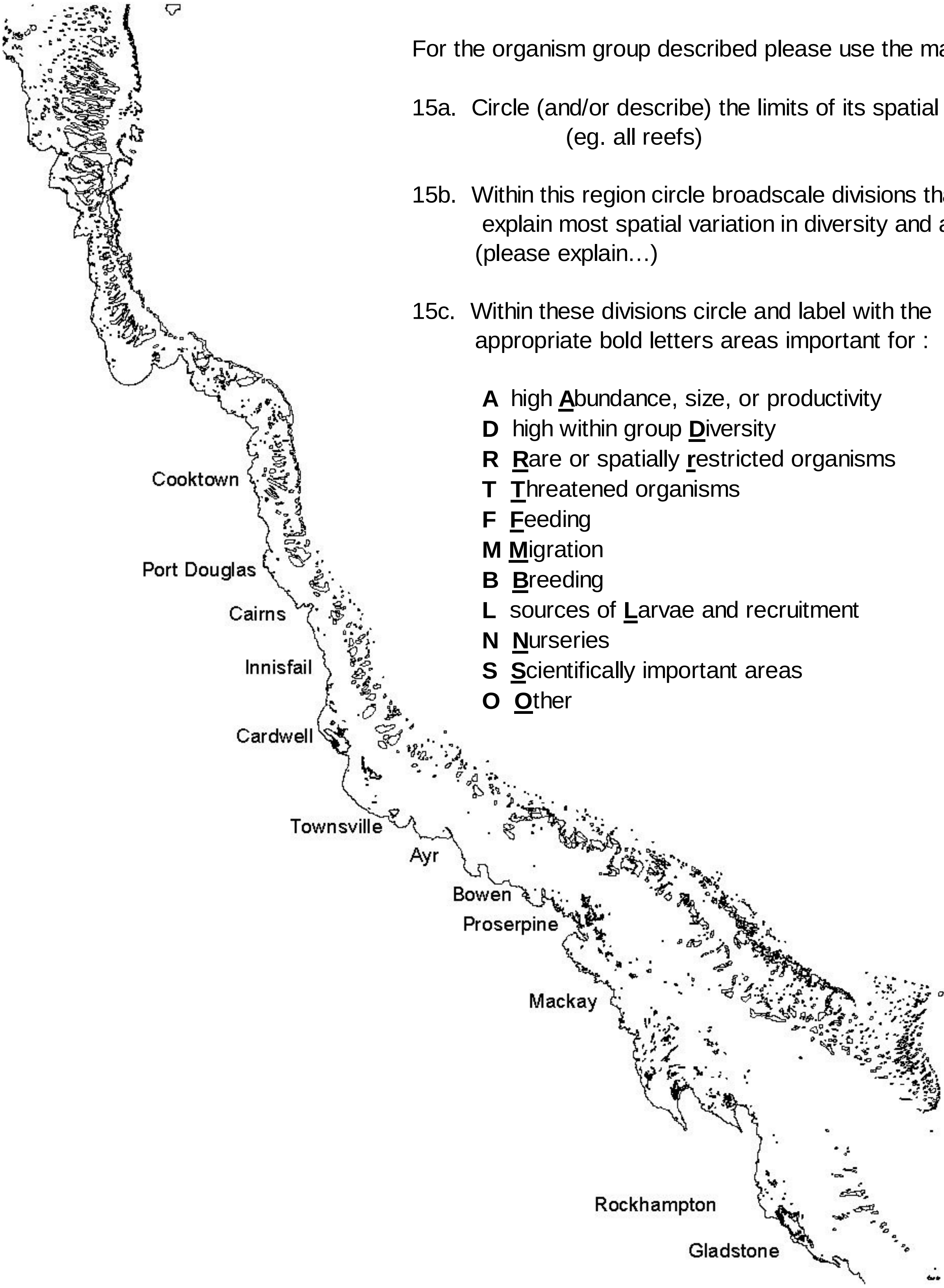
11. What major threats need to be considered for the conservation of this group of organisms?

12. Assuming zoning is effective what other strategies are required to protect these organisms?

13. Can you provide any other relevant data, information or references to other sources? (see attached contact list)

14. Would you like to provide additional information during the selection of Representative Protected Areas and the subsequent rezoning process?

Please turn over to the map below or if required use the more detailed section maps in the attached .exe files.



For the organism group described please use the map to:

15a. Circle (and/or describe) the limits of its spatial distribution (eg. all reefs)

15b. Within this region circle broadscale divisions that explain most spatial variation in diversity and abundance. (please explain…)

15c. Within these divisions circle and label with the appropriate bold letters areas important for :

A high **A**bundance, size, or productivity
D high within group **D**iversity
R **R**are or spatially **r**estricted organisms
T **T**hreatened organisms
F **F**eeding
M **M**igration
B **B**reeding
L sources of **L**arvae and recruitment
N **N**urseries
S **S**cientifically important areas
O **O**ther

Thank you for your help, if you have any inquiries please call Dan Breen at GBRMPA at (07) 4750 0700.

Appendix 7.
Protected Area Management Categories from "Guidelines for Protected Area Management Categories" IUCN (1994).

CATEGORY I Strict Nature Reserve/Wilderness Area
: protected area managed mainly for science or wilderness protection

CATEGORY la Strict Nature Reserve: protected area managed mainly for science

Definition
Area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

Objectives of Management
- to preserve habitats, ecosystems and species in as undisturbed a state as possible;
- to maintain genetic resources in a dynamic and evolutionary state;
- to maintain established ecological processes;
- to safeguard structural landscape features or rock exposures;
- to secure examples of the natural environment for scientific studies, environmental monitoring and education, including baseline areas from which all avoidable access is excluded;
- to minimise disturbance by careful planning and execution of research and other approved activities; and
- to limit public access.

Guidance for Selection
The area should be large enough to ensure the integrity of its ecosystems and to accomplish the management objectives for which it is protected. The area should be significantly free of direct human intervention and capable of remaining so. The conservation of the area's biodiversity should be achievable through protection and not require substantial active management or habitat manipulation (c.f. Category IV).

Organizational Responsibility
Ownership and control should be by the national or other level of government, acting through a professionallyqualified agency, or by a private foundation, university or institution which has an established research or conservation function, or by owners working in cooperation with any of the foregoing government or private institutions. Adequate safeguard and controls relating to long-term protection should be secured before designation. International agreements over areas subject to disputed national sovereignty can provide exceptions (e.g. Antarctica).

Equivalent Category in 1978 System
Scientific Reserve / Strict Nature Reserve

CATEGORY Ib Wilderness Area:
protected area managed mainly for wilderness protection

Definition
Large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.

Objectives of Management

- to ensure that future generations have the opportunity to experience understanding and enjoyment of areas that have been largely undisturbed by human action over a long period of time;
- to maintain the essential natural attributes and qualities of the environment over the long term;
- to provide for public access at levels and of a type which will serve best the physical and spiritual wellbeing of visitors and maintain the wilderness qualities of the area for present and future generations; and
- to enable indigenous human communities living at low density and in balance with the available resources to maintain their life style.

Guidance for Selection
The area should possess high natural quality, be governed primarily by the forces of nature, with human disturbance substantially absent and be likely to continue to display those attributes if managed as proposed. The area should contain significant ecological, geological, physiogeographic, or other features of scientific, educational, scenic or historic value. The area should offer outstanding opportunities for solitude, enjoyed once the area has been reached, by simple, quiet, non-polluting and non-intrusive means of travel (i.e. non-motorised). The area should be of sufficient size to make practical such preservation and use.

Organizational Responsibility
As for Sub-Category Ia.

Equivalent Category in 1978 System
This sub-category did not appear in the 1978 system, but has been introduced following the IUCN General
Assembly Resolution (16/34) on Protection of Wilderness Resources and Values, adopted at the 1984 General
Assembly in Madrid, Spain.

CATEGORY II National Park:
protected area managed mainly for ecosystem protection and recreation

Definition
Natural area of land and/or sea, designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

Objectives of Management
- to protect natural and scenic areas of national and international significance for spiritual, scientific, educational, recreational or tourist purposes;
- to perpetuate, in as natural a state as possible, representative examples of physiographic regions, biotic communities, genetic resources, and species, to provide ecological stability and diversity;
- to manage visitor use for inspirational, educational, cultural and recreational purposes at a level which will maintain the area in a natural or near natural state;
- to eliminate and thereafter prevent exploitation or occupation inimical to the purposes of designation;
- to maintain respect for the ecological, geomorphologic, sacred or aesthetic attributes which warranted designation; and
- to take into account the needs of indigenous people, including subsistence resource use, in so far as these will not adversely affect the other objectives of management.

Guidance for Selection
The area should contain a representative sample of major natural regions, features or scenery, where plant and animal species, habitats and geomorphological sites are of special spiritual, scientific, educational, recreational and tourist significance. The area should be large enough to contain one or more entire ecosystems not materially altered by current human occupation or exploitation.

Organizational Responsibility
Ownership and management should normally be by the highest competent authority of the nation having jurisdiction over it. However, they may also be vested in another level of government, council of indigenous people, foundation or other legally established body which has dedicated the area to long-term conservation.

Equivalent Category in 1978 System
National Park

CATEGORY Ill Natural Monument:
protected area managed mainly for conservation of specific natural features

Definition
Area containing one, or more, specific natural or natural/cultural feature which is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities or cultural significance.

Objectives of Management

- to protect or preserve in perpetuity specific outstanding natural features because of their natural significance, unique or representational quality, and/or spiritual connotations;
- to an extent consistent with the foregoing objective, to provide opportunities for research, education, interpretation and public appreciation;
- to eliminate and thereafter prevent exploitation or occupation inimical to the purpose of designation; and
- to deliver to any resident population such benefits as are consistent with the other objectives of management.

Guidance for Selection
The area should contain one or more features of outstanding significance (appropriate natural features include spectacular waterfalls, caves, craters, fossil beds, sand dunes and marine features, along with unique or representative fauna and flora; associated cultural features might include cave dwellings, clifftop forts, archaeological sites, or natural sites which have heritage significance to indigenous peoples). The area should be large enough to protect the integrity of the feature and its immediately related surroundings.

Organizational Responsibility
Ownership and management should be by the national government or, with appropriate safeguards and controls, by another level of .government, council of indigenous people, non-profit trust, corporation or, exceptionally, by a private body, provided the long-term protection of the inherent character of the area is assured before
designation.

Equivalent Category in 1978 System
Natural Monument / Natural Landmark

CATEGORY IV Habitat/Species Management Area:
protected area managed mainly for conservation through management intervention

Definition
Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance
of habitats and/or to meet the requirements of specific species.

Objectives of Management

- to secure and maintain the habitat conditions necessary to protect significant species, groups of species, biotic communities or physical features of the environment where these require specific human manipulation for optimum management;
- to facilitate scientific research and environmental monitoring as primary activities associated with sustainable resource management;
- to develop limited areas for public education and appreciation of the characteristics of the habitats concerned and of the work of wildlife management;
- to eliminate and thereafter prevent exploitation or occupation inimical to the purposes of designation;
- and to deliver such benefits to people living within the designated area as are consistent with the other objectives of management.

Guidance for Selection
The area should play an important role in the protection of nature and the survival of species, (incorporating, as appropriate, breeding areas, wetlands, coral reefs, estuaries, grasslands, forests or spawning areas, including marine feeding beds). The area should be one where the protection of the habitat is essential to the well-being of nationally or locally-important flora, or to resident or migratory fauna. Conservation of these habitats and species should depend upon active intervention by the management authority, if necessary through habitat manipulation (c.f. Category Ia). The size of the area should depend on the habitat requirements of the species to be protected and may range from relatively small to very extensive.

Organizational Responsibility
Ownership and management should be by the national government or, with appropriate safeguards and controls, by another level of government, non-profit trust, corporation, private group or individual.

Equivalent Category in 1978 System
Nature Conservation Reserve / Managed Nature Reserve / Wildlife Sanctuary

CATEGORY V Protected Landscape/Seascape:
protected area managed mainly for landscape/seascape conservation and recreation

Definition
Area of land, with coast and sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

Objectives of Management
- to maintain the harmonious interaction of nature and culture through the protection of landscape and/or seascape and the continuation of traditional land uses, building practices and social and cultural manifestations;
- to support lifestyles and economic activities which are in harmony with nature and the preservation of the social and cultural fabric of the communities concerned;
- to maintain the diversity of landscape and habitat, and of associated species and ecosystems; to eliminate where necessary, and thereafter prevent, land uses and activities which are inappropriate in scale and/or character;
- to provide opportunities for public enjoyment through recreation and tourism appropriate in type and scale to the essential qualities of the areas;
- to encourage scientific and educational activities which will contribute to the long term well-being of resident populations and to the development of public support for the environmental protection of such areas; and
- to bring benefits to, and to contribute to the welfare of, the local community through the provision of natural products (such as forest and fisheries products) and services (such as clean water or income derived from sustainable forms of tourism).

Guidance for Selection
The area should possess a landscape and/or coastal and island seascape of high scenic quality, with diverse associated habitats, flora and fauna along with manifestations of unique or traditional land-use patterns and social organisations as evidenced in human settlements and local customs, livelihoods, and beliefs. The area should provide opportunities for public enjoyment through recreation and tourism within its normal lifestyle and economic activities.

Organizational Responsibility
The area may be owned by a public authority, but is more likely to comprise a mosaic of private and public ownerships operating a variety of management regimes. These regimes should be subject to a degree of planning or other control and supported, where appropriate, by public funding and other incentives, to ensure that the quality of the landscape/seascape and the relevant local customs and beliefs arc maintained in the long term.

Equivalent Category in 1978 System
Protected Landscape

CATEGORY VI Managed Resource Protected Area:
protected area managed mainly for the sustainable use of natural ecosystems

Definition
Area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

Objectives of Management

- to protect and maintain the biological diversity and other natural values of the area in the long term;
- to promote sound management practices for sustainable production purposes;
- to protect the natural resource base from being alienated for other land-use purposes that would be
- detrimental to the area's biological diversity; and
- to contribute to regional and national development.

Guidance for Selection
The area should be at least two-thirds in a natural condition, although it may also contain limited areas of modified ecosystems; large commercial plantations would *not* be appropriate for inclusion. The area should be large enough to absorb sustainable resource uses without detriment to its overall longterm natural values.

Organizational Responsibility
Management should be undertaken by public bodies with a unambiguous remit for conservation, and carried out in partnership with the local community; or management may be provided through local custom supported and advised by governmental or non-governmental agencies. Ownership may be by the national or other level of government, the community, private individuals, or a combination of these.

Equivalent Category in 1978 System
This category does not correspond directly with any of those in the 1978 system, although it is likely to include some areas previously classified as “Resource Reserves”, “Natural Biotic Areas/Anthropological Reserves” and “Multiple Use Management Areas / Managed Resource Areas”.

Appendix 8.
Electronic copy of thesis and data files.

Glossary

Adequacy	The maintenance of the ecological viability and integrity of populations, species and communities (ANZECC 1999).
Biodiversity	The variety of life forms: the different plants, animals and micro-organisms, the genes they contain, and the ecosystems they form (NSW National Parks 1999).
Bioregion	An area defined by a combination of biological, social and geographic criteria, rather than by geopolitical considerations. Generally, a system of related, interconnected ecosystems (ANZECC 1999).
Comprehensiveness	Includes the full range of ecosystems recognised at an appropriate scale within and across each bioregion (ANZECC 1999).
Ecologically sustainable use	Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained and the total quality of life, now and in the future can be increased.
Ecosystem	All of the organisms in a community in a given area in interaction with their abiotic (non-living) environment and each other.
Endemism	Originating in a given area and confined to that area (NSW National Parks 1999).
Habitat	The living space of a species or community, providing a particular set of environmental conditions (NSW National Parks 1999).
Irreplaceability	Irreplaceability is a measure designed to estimate the likelihood of a site being required to meet a conservation target or the extent to which conservation options are reduced if that site is unavailable. *Summed* irreplaceability is calculated by adding the individual feature irreplaceabilities for all the features at a site.
Naturalness	The extent to which an area is free from human induced change.
NSW waters	Waters within 3 nautical miles of the NSW coast and islands, under the jurisdiction of the State of NSW.
Representativeness	Those marine areas that are selected for inclusion in reserves should reasonably reflect the biotic diversity of the marine ecosystems from which they derive (ANZECC 1999).

Abbreviations

AHO	Australian Hydrographic Office
AMBIS	Australian Marine Boundary Information System
ARCCD	Australian River and Catchment Condition Database
ANZECC	Australian and New Zealand Environment and Conservation Council
CAR	Comprehensive, adequate and representative
DEC	NSW Department of Environment and Conservation
DIPNR	NSW Department of Infrastructure, Planning and Natural Resources
DPI	NSW Department of Primary Industries
EEZ	Exclusive economic zone
EPA	NSW Environmental Protection Authority
FMA	*Fisheries Management Act 1994*
IMCRA	Interim Marine and Coastal Regionalisation for Australia
IUCN	World Conservation Union (formerly known as International Union for the Conservation of Nature and Natural Resources)
MPA	Marine protected area (includes marine and estuary areas)
MPAC	Marine Park Advisory Council
NPWS	National Parks and Wildlife Service
NPWAC	National Parks and Wildlife Advisory Council
NRSMPA	National Representative System of Marine Protected Areas
NSWMPA	NSW Marine Parks Authority
NSWSMPA	NSW System of Marine Protected Areas
SEPP	State Environmental Planning Policy