# 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 |

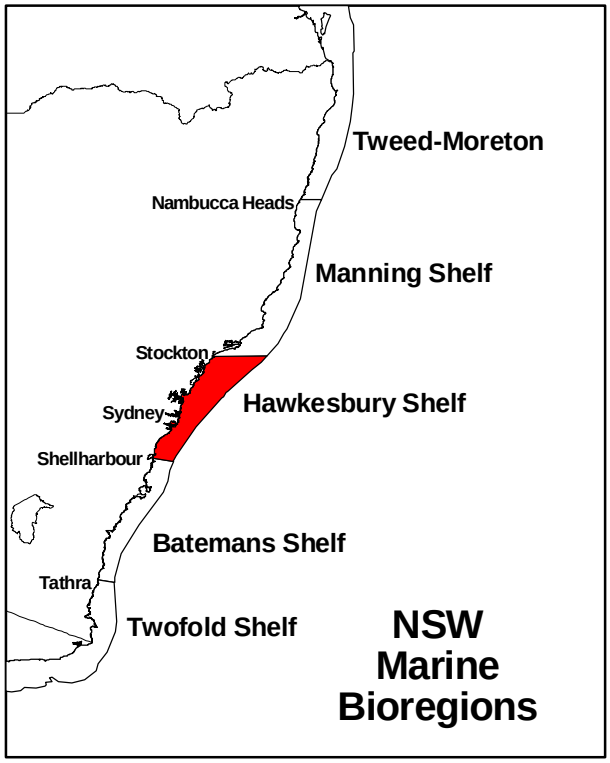



Figure 7.1. Hawkesbury Shelf marine bioregion (IMCRA 1998).

## 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. | | |

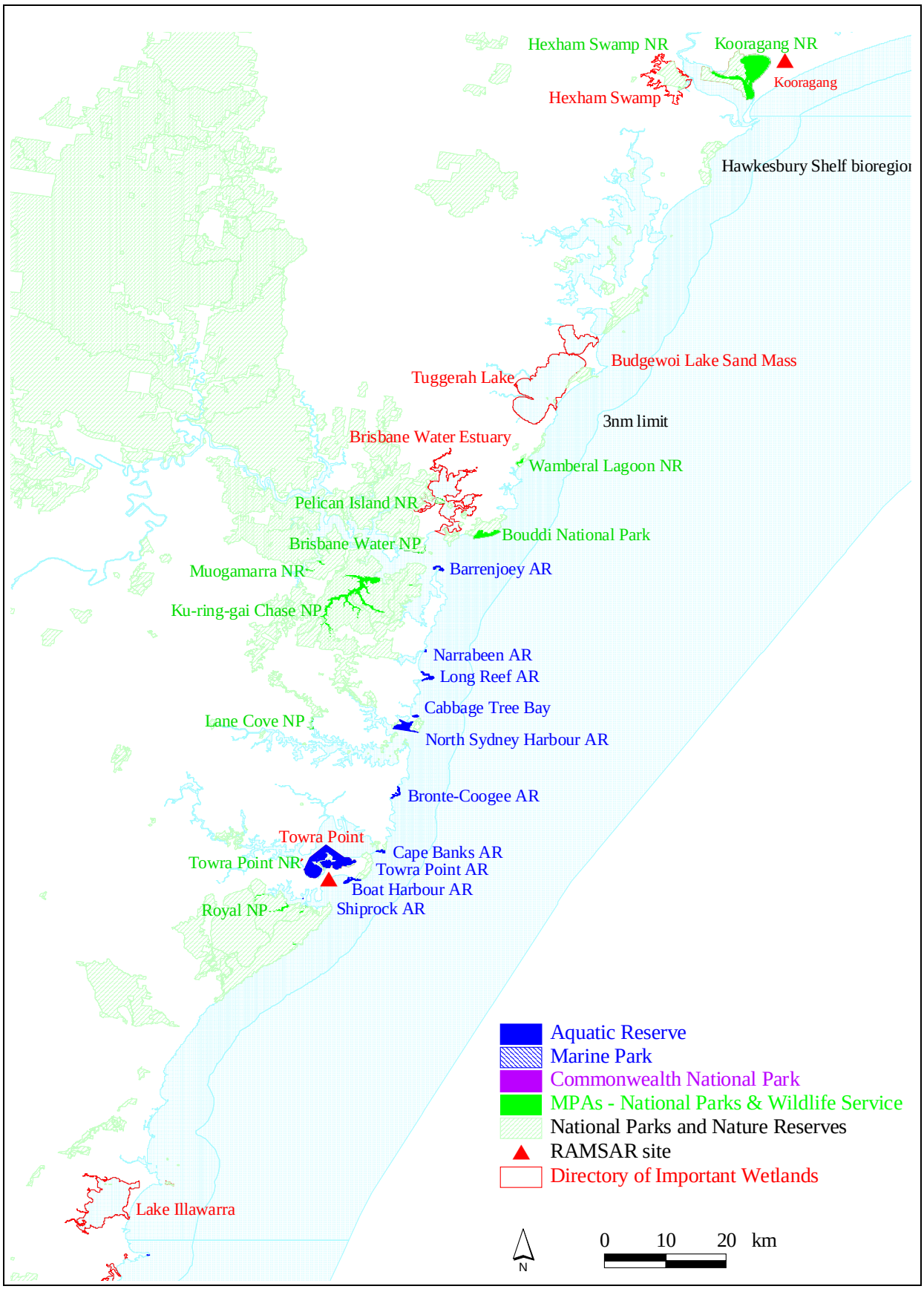



Figure 7.2. Marine protected areas (aquatic reserves and marine components of national parks and nature reserves), RAMSAR sites and important wetlands in the Hawkesbury Shelf bioregion. Data from D. Breen and Danielle Morrison, Fisheries, Department of Primary Industry (DPI) and Rodney James, National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

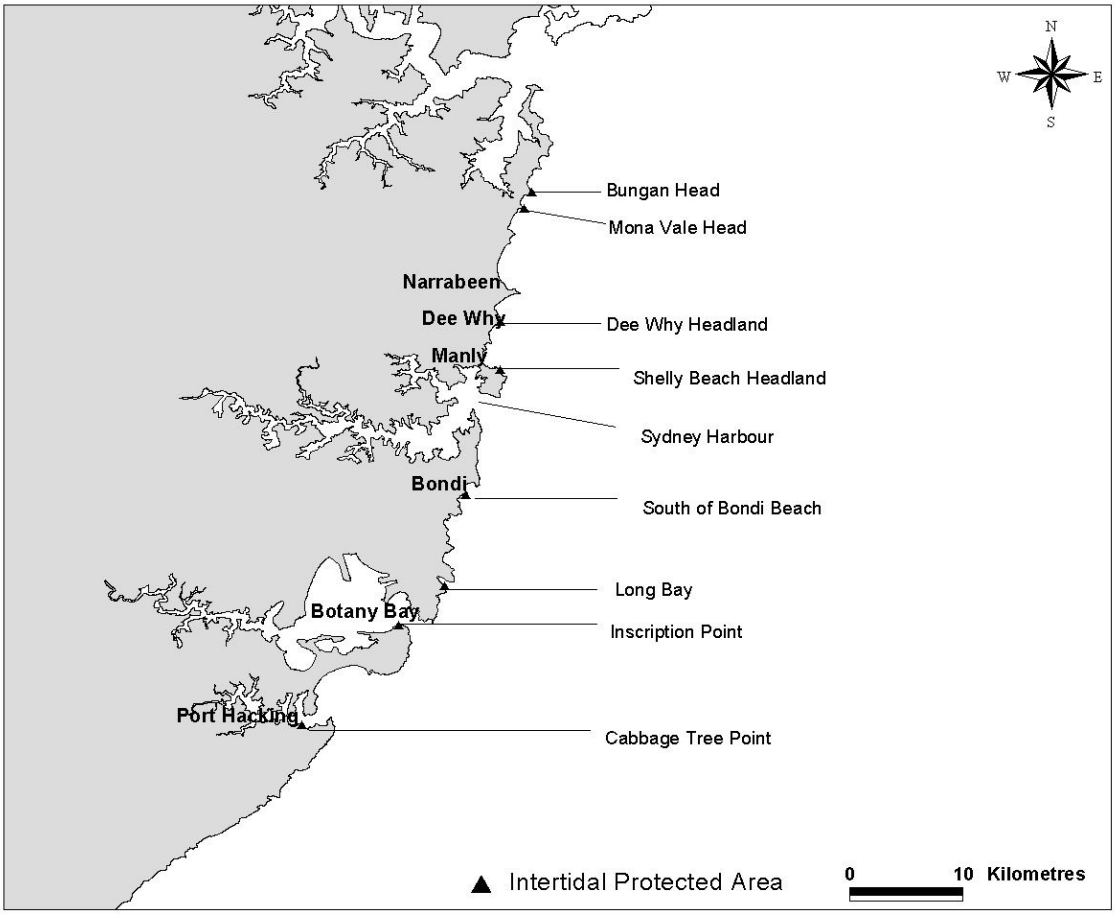



Figure 7.3. Intertidal protected areas in the Sydney region. Map by Danielle Morrison, Fisheries, NSW Department of Primary Industry.

## 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.

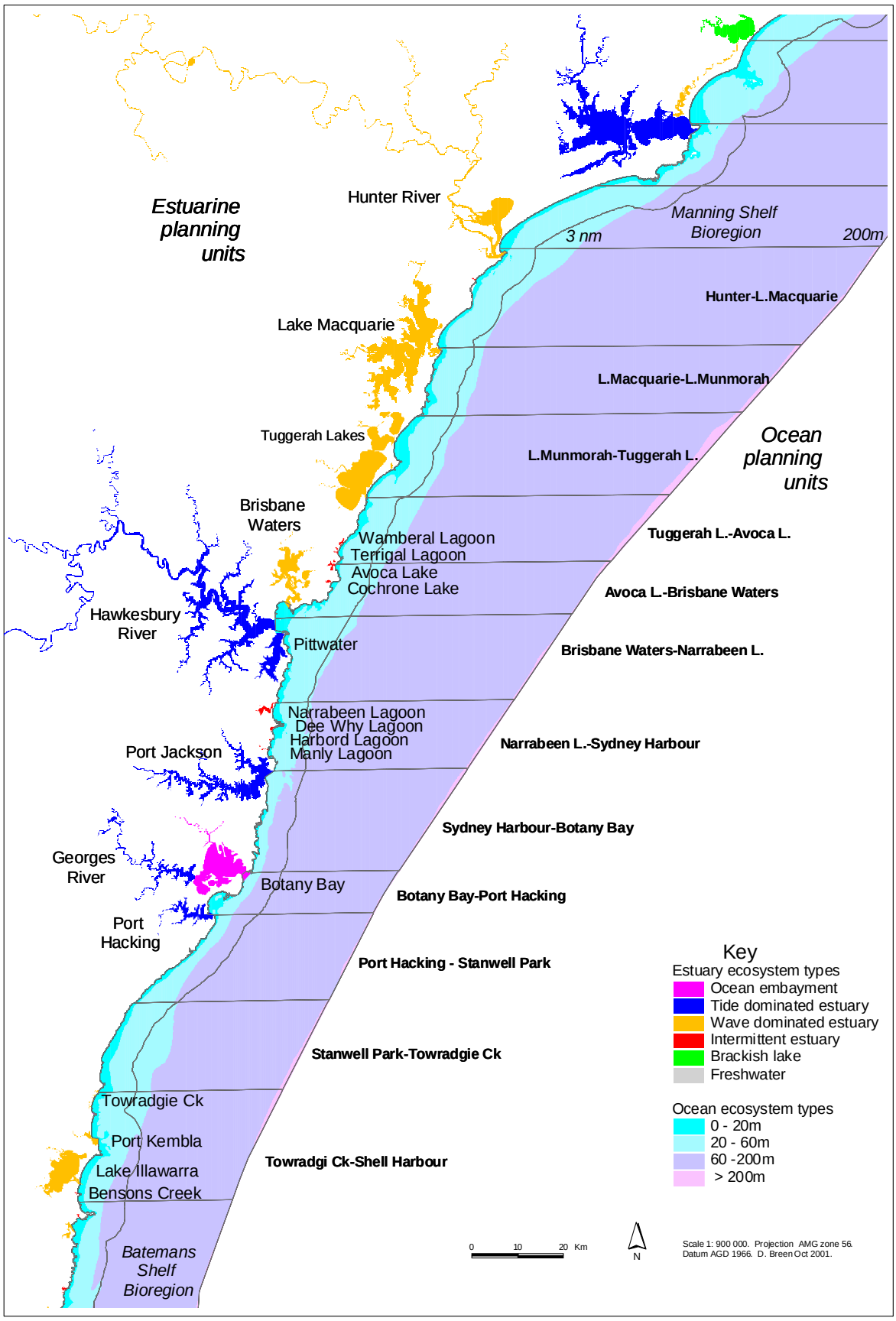



Figure 7.4. Large scale planning units of whole estuaries and sections of exposed coast with mapped estuarine and ocean ecosystem types.

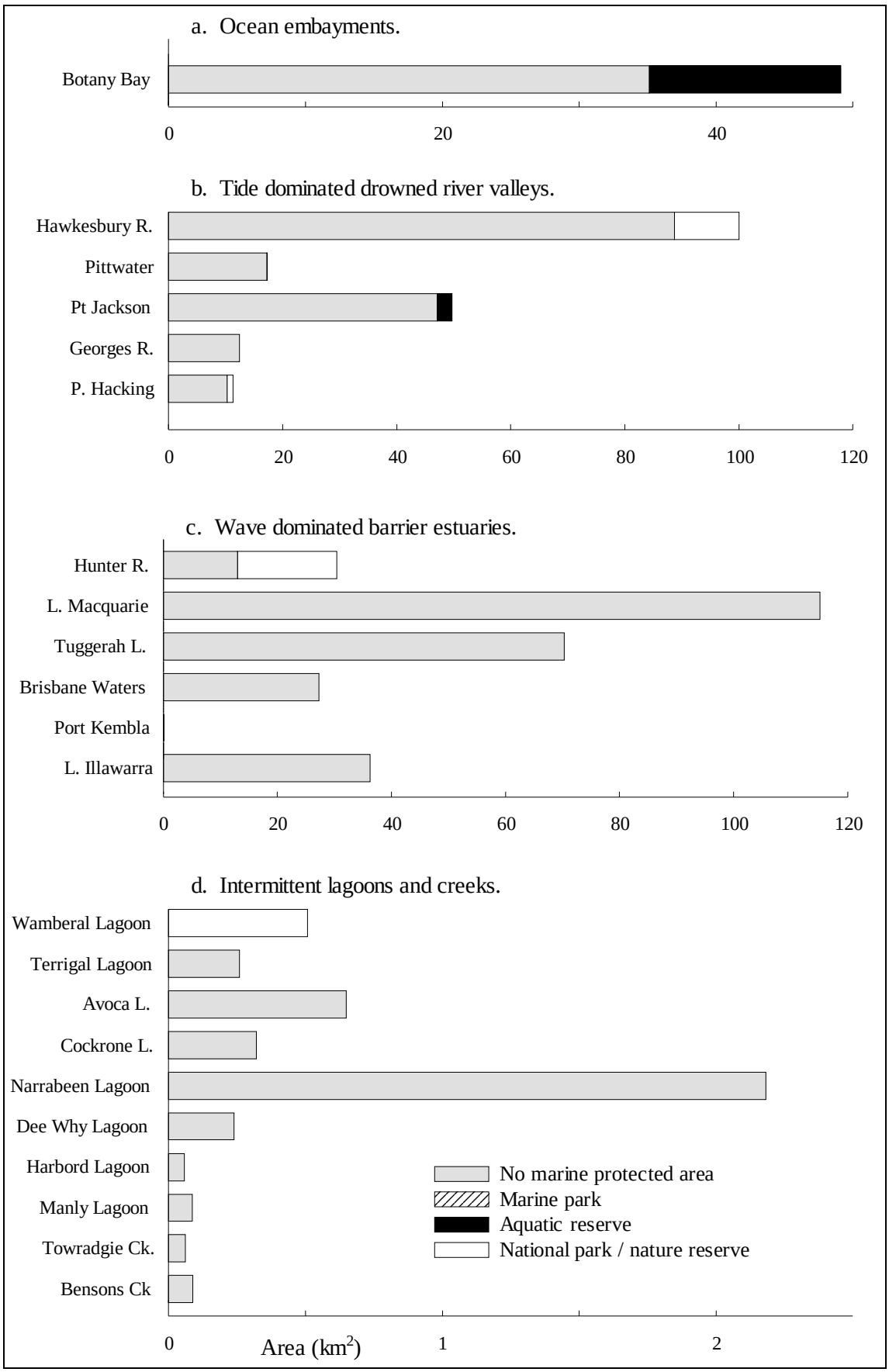



Figure 7.5a-d. Area ($km^2$) of open water for different estuarine ecosystem types in the Hawkesbury Shelf bioregion within marine protected areas. Data from West *et al.* (1985), estuaries classified according to Roy *et al.* (2001).

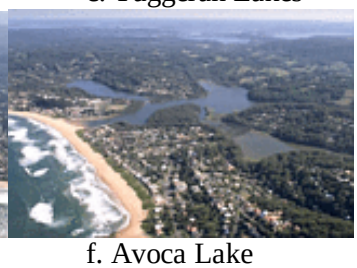

a. Hunter River


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.

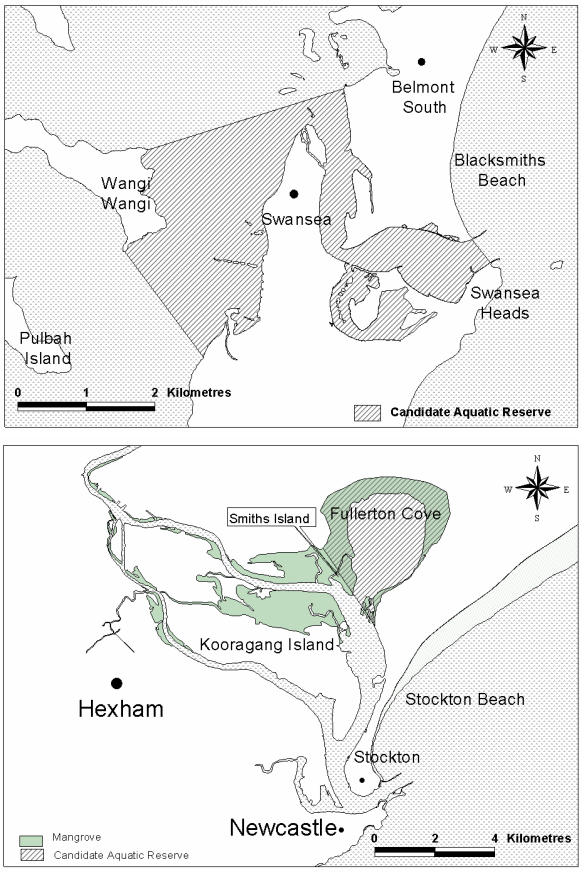
#### Assessment

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.

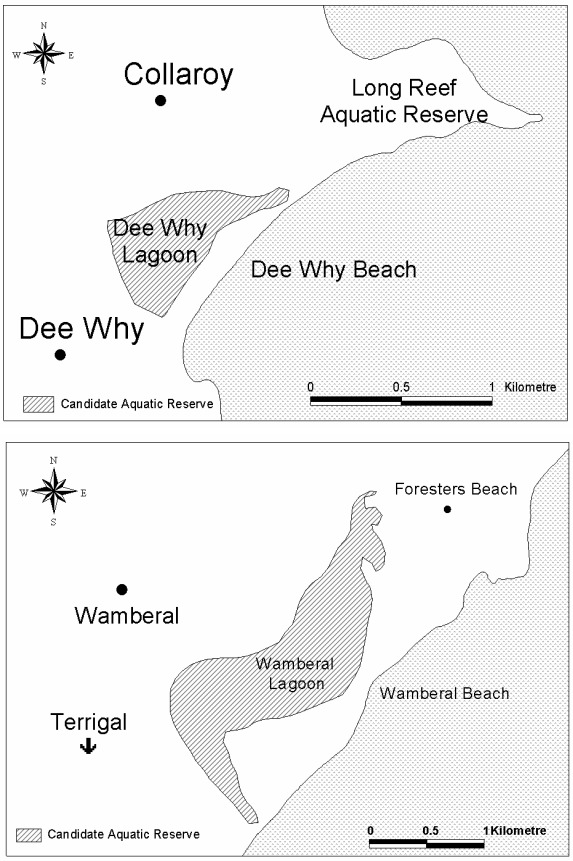
| Type | Estuary | Ecological importance | Uniqueness | Naturalness | Vulnerability | Priority |
|---|---|---|---|---|---|---|
| Youthful Wave dominated | L. Macquarie | High | No data | Medium | High | 1 |
| | Brisbane W. | High | High | Medium | Medium | 2 |
| | L. Illawarra | High | No data | Low | 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 | |




a.

b.

Figure 7.7. Priority candidate aquatic reserves at a. Lake Macquarie b. Fullerton Cove on the Hunter River (NSW Fisheries Office of Conservation 2001).




a.

b.

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).

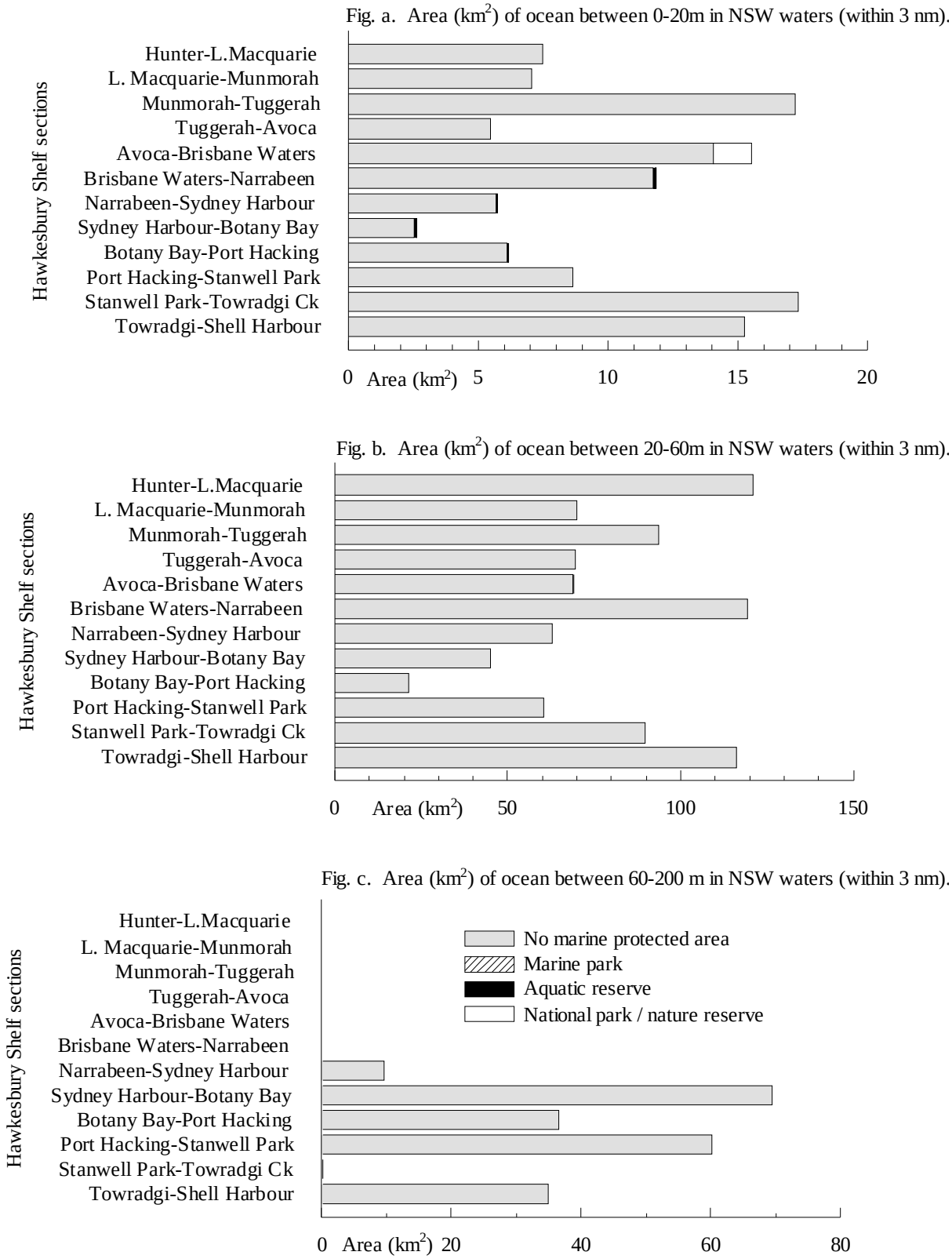



Figure 7.9a-c. Area (km$^2$) of ocean depth zones in marine protected areas within sections of ocean coast in NSW waters (within 3 nm) of the Hawkesbury Shelf bioregion.

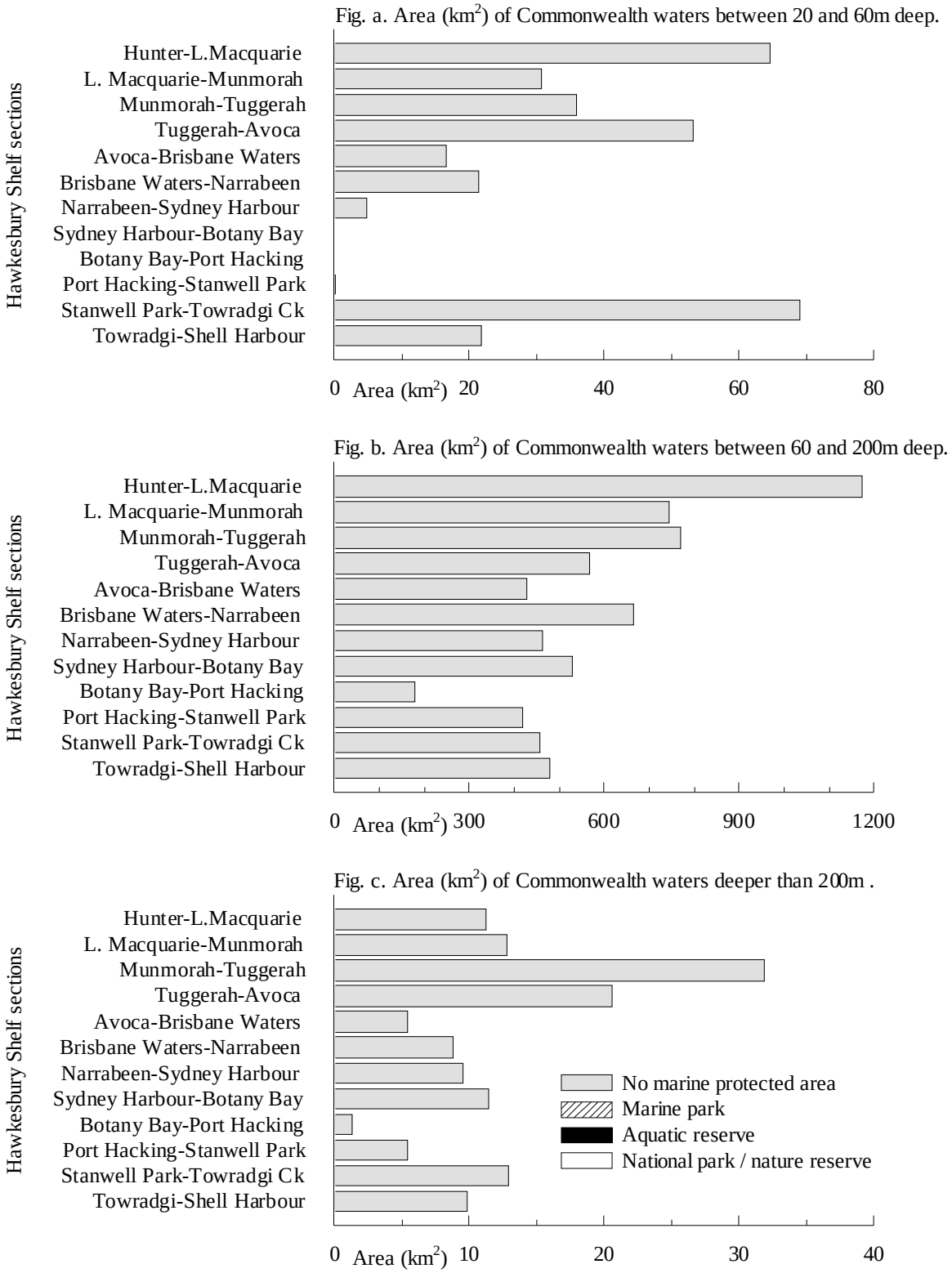



Figure 7.10a-c. Area ($km^2$) of ocean depth zones in marine protected areas for Commonwealth waters (outside of 3 nm) of the Hawkesbury Shelf bioregion.

### 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

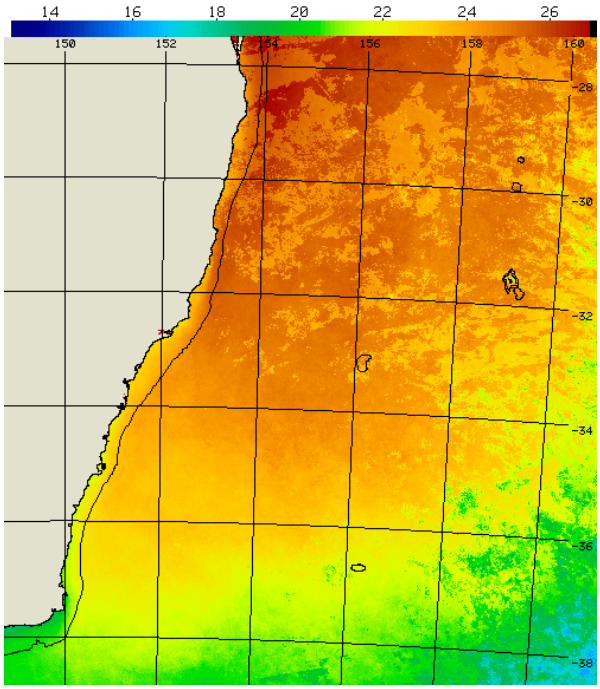
The East Australian Current (EAC) runs south along the East Coast of Australia from the Coral Sea into the Tasman Sea bringing warm tropical and sub tropical water into the cooler temperate waters of NSW (Figure 7.11 and Figure 7.12). It has a significant influence on the marine biodiversity of coastal 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.

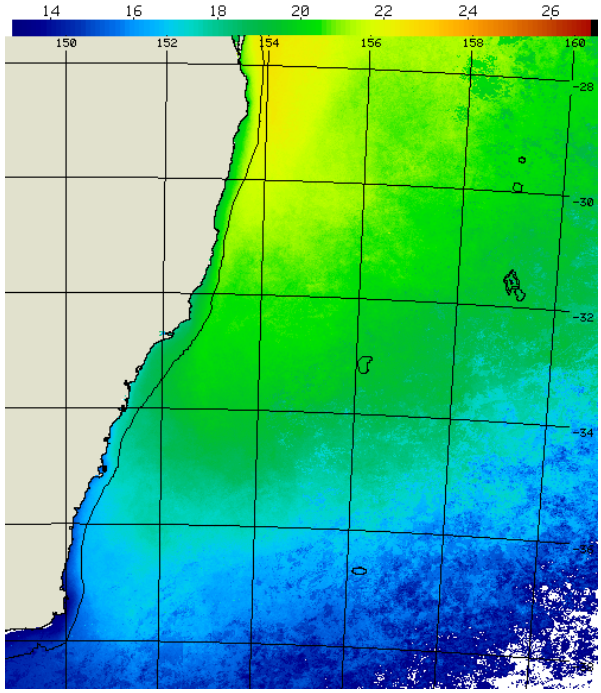
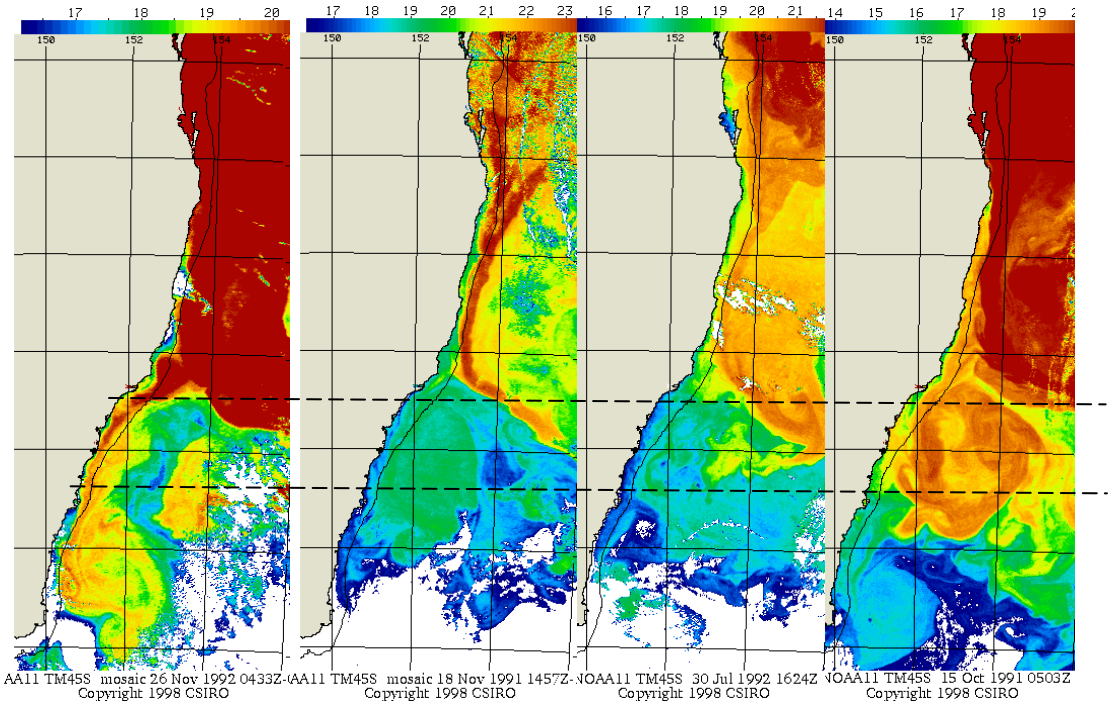



Figure 7.11. Mean sea surface temperature off NSW coast averaged for summer (January-March) and b. winter (July-September) (Cresswell 1998). Colour scale for temperature in degrees Celsius across the top of each map.




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

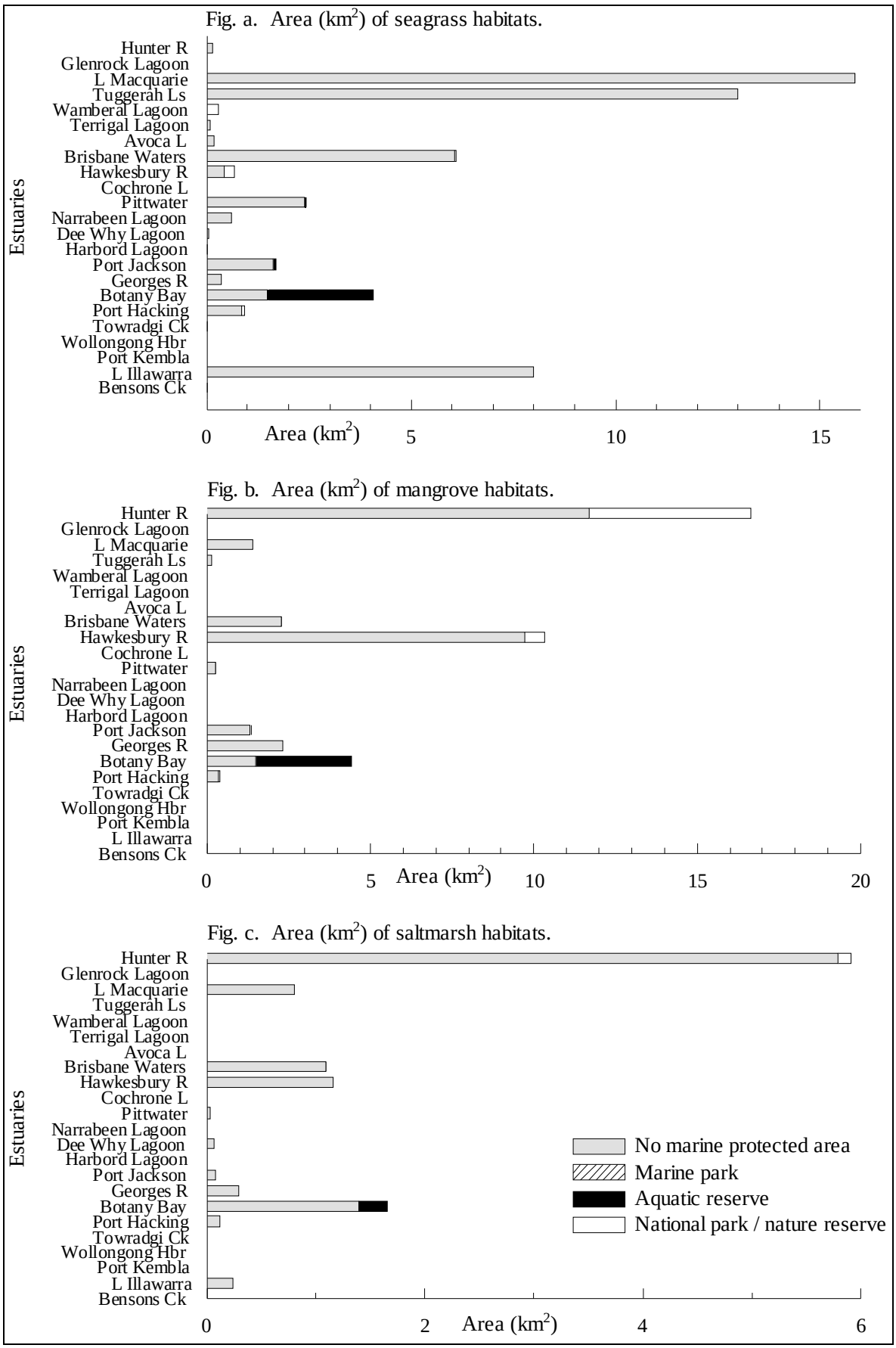



Figure 7.13a-c. Area (km$^2$) of seagrass, mangrove and saltmarsh habitat in marine protected areas of the Hawkesbury Shelf bioregion.

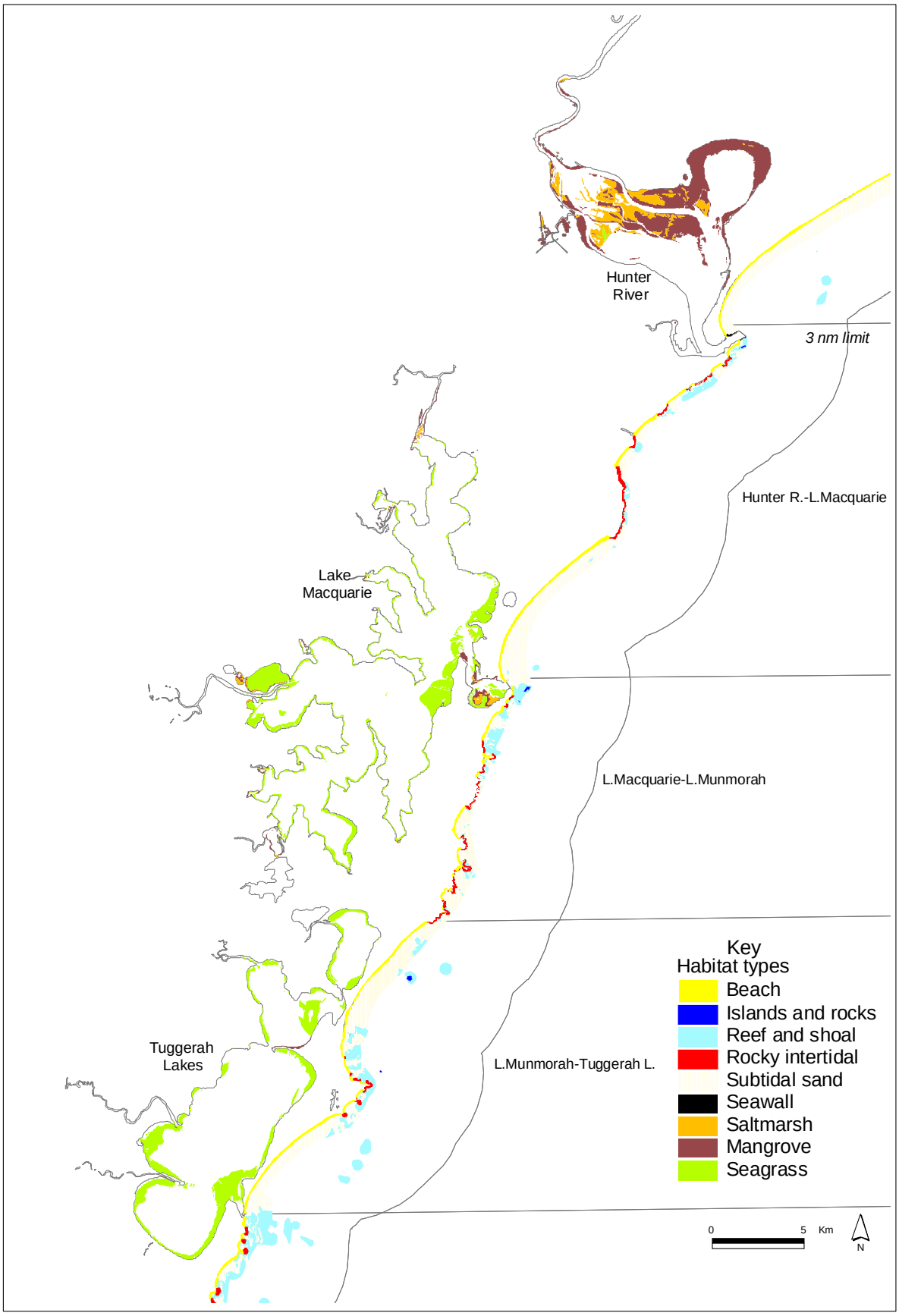



Figure 7.14. Mapped habitat types between the Hunter River and Tuggerah Lakes.

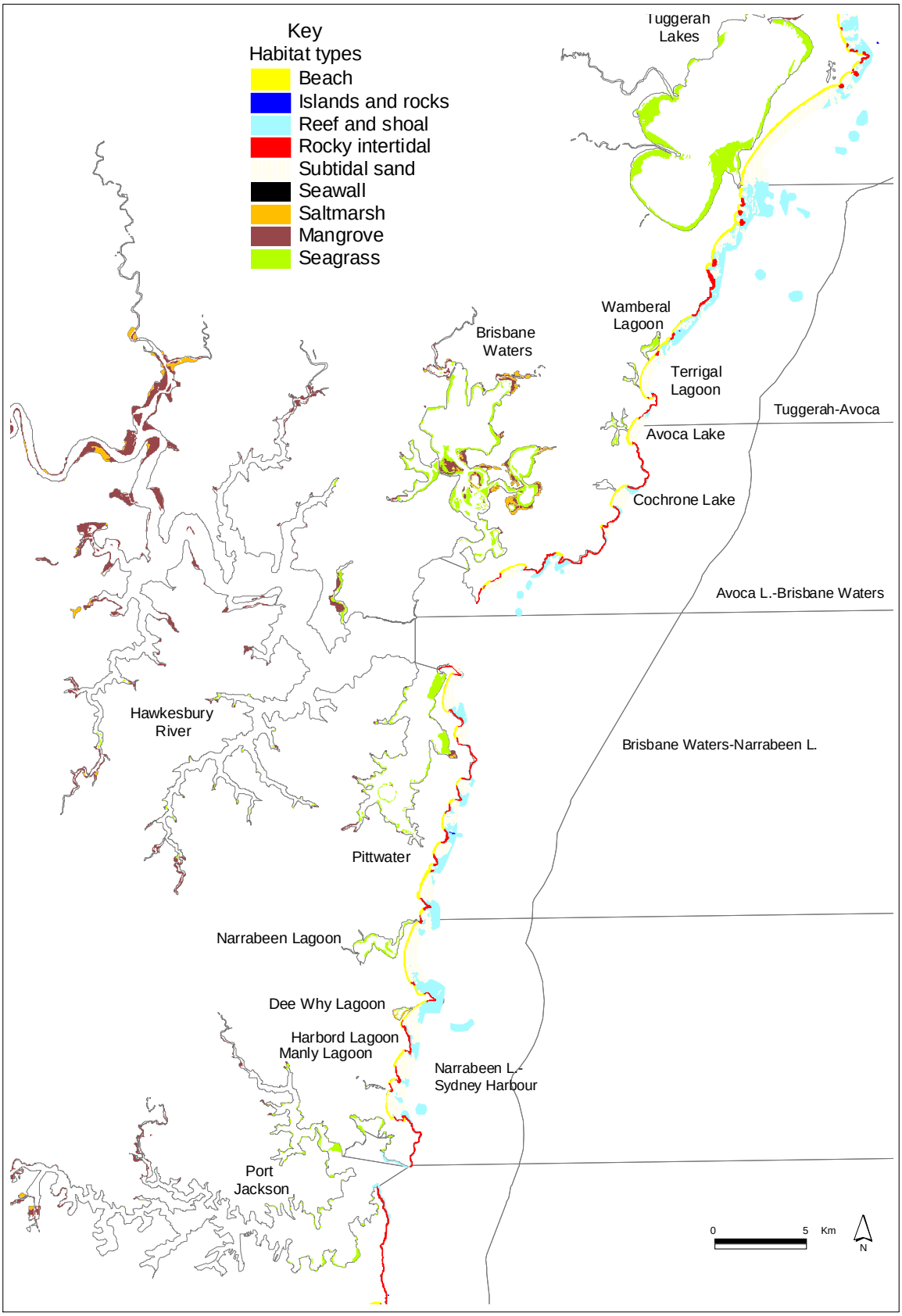



Figure 7.15. Mapped habitat types between Tuggerah Lakes and Sydney Harbour.

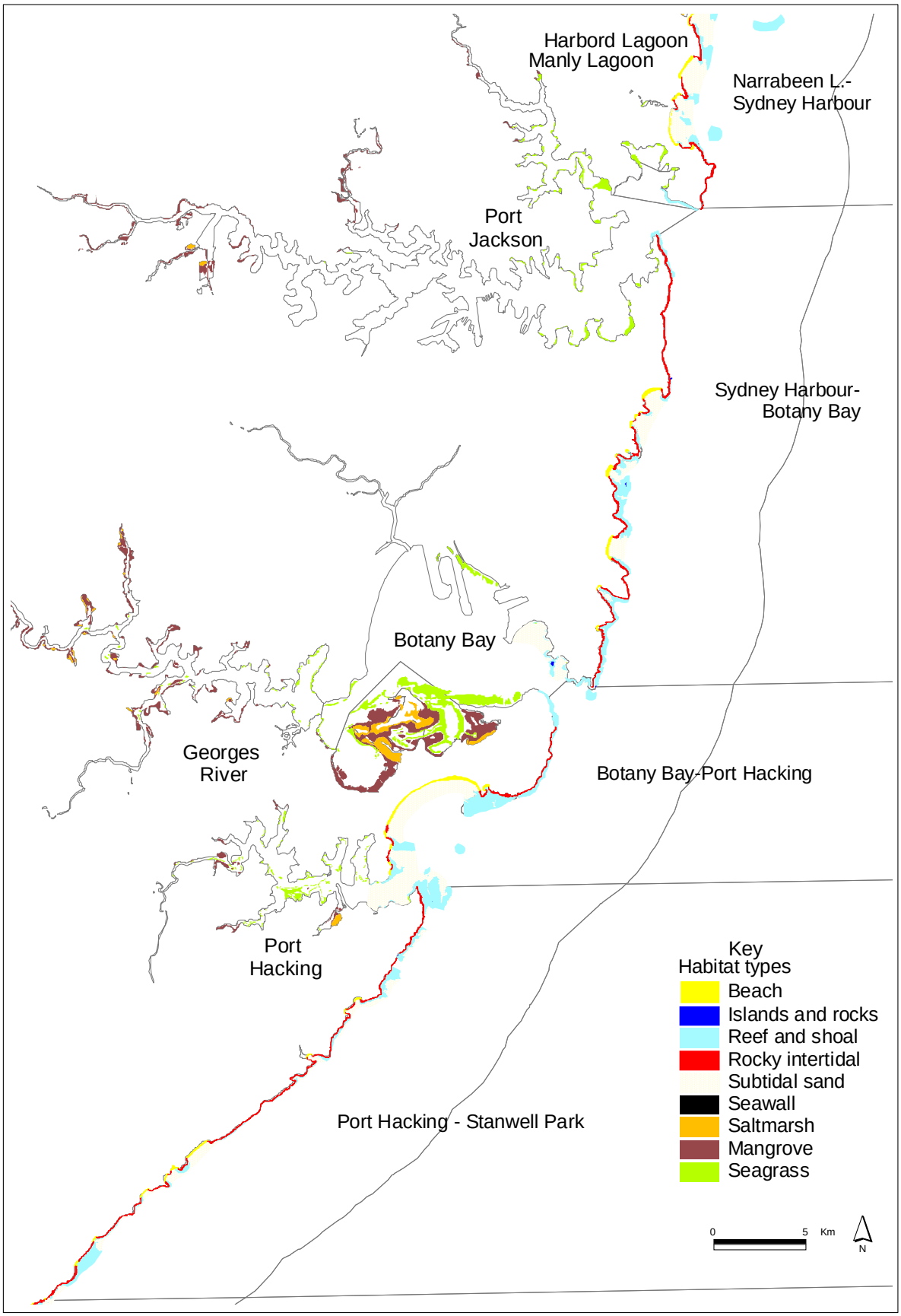



Figure 7.16. Mapped habitat types between Sydney Harbour and Port Hacking.

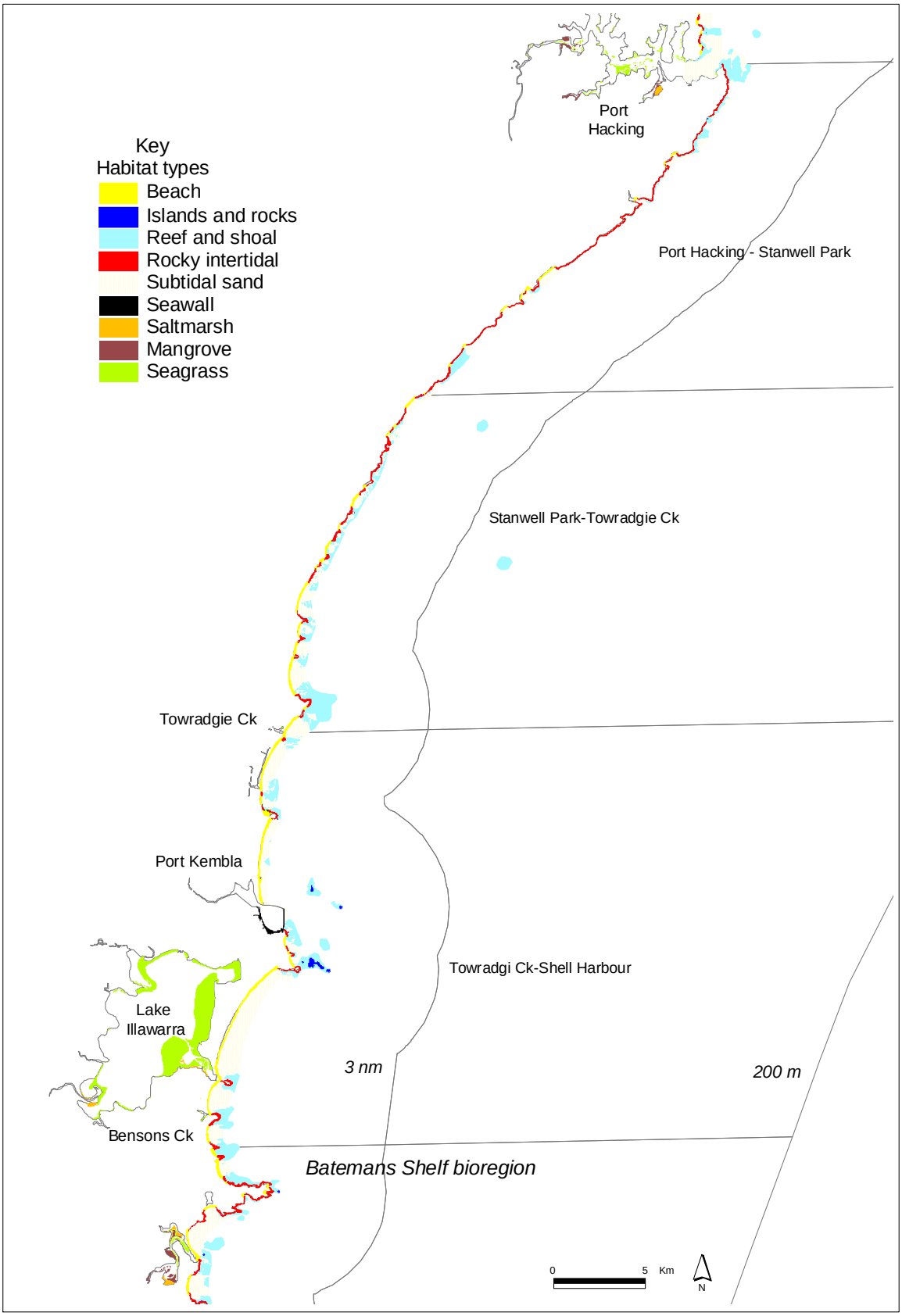



Figure 7.17. Mapped habitat types between Port Hacking and Shellharbour.

### 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.

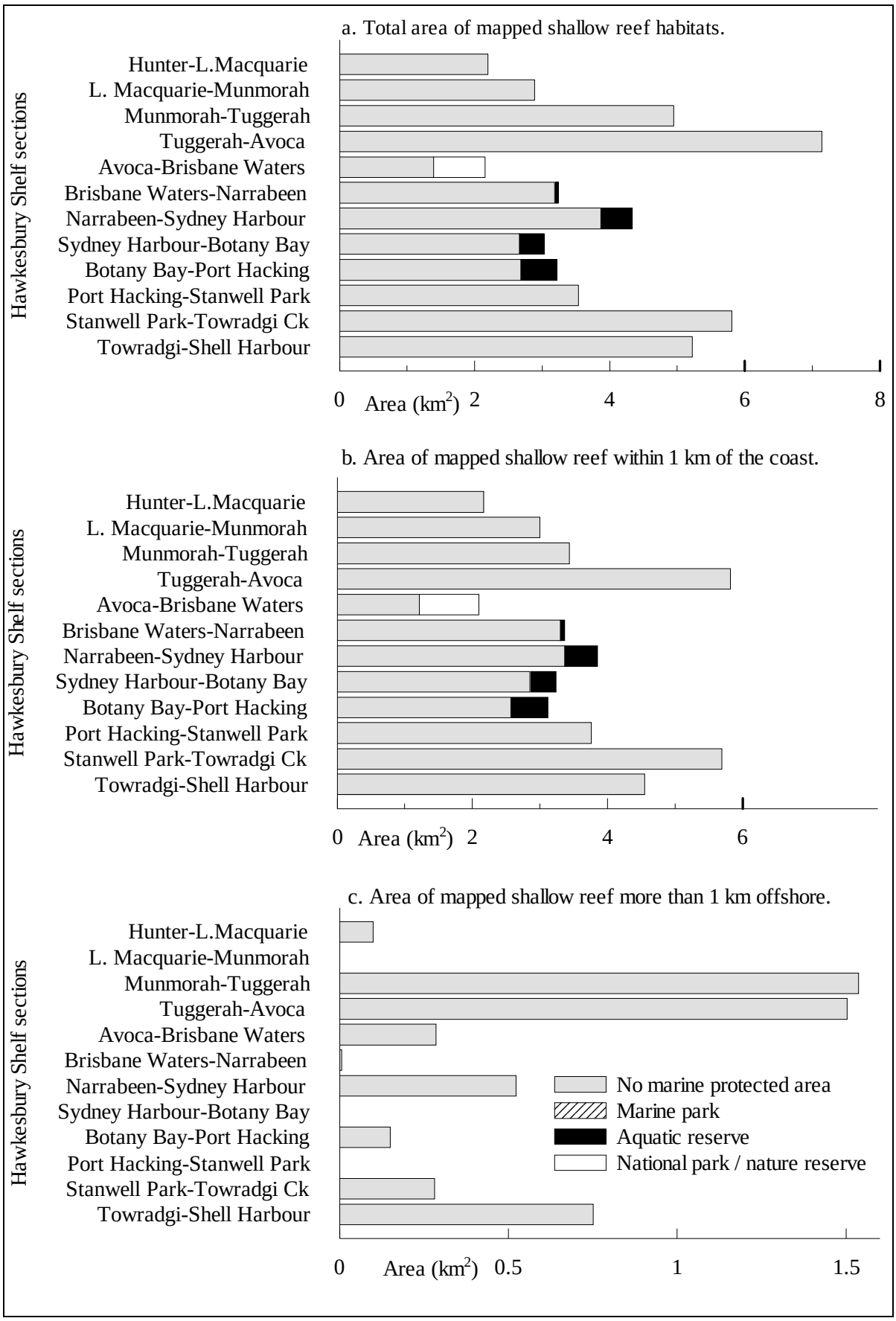



Figure 7.18. Area of mapped shallow reef for sections of ocean coast.

### 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.

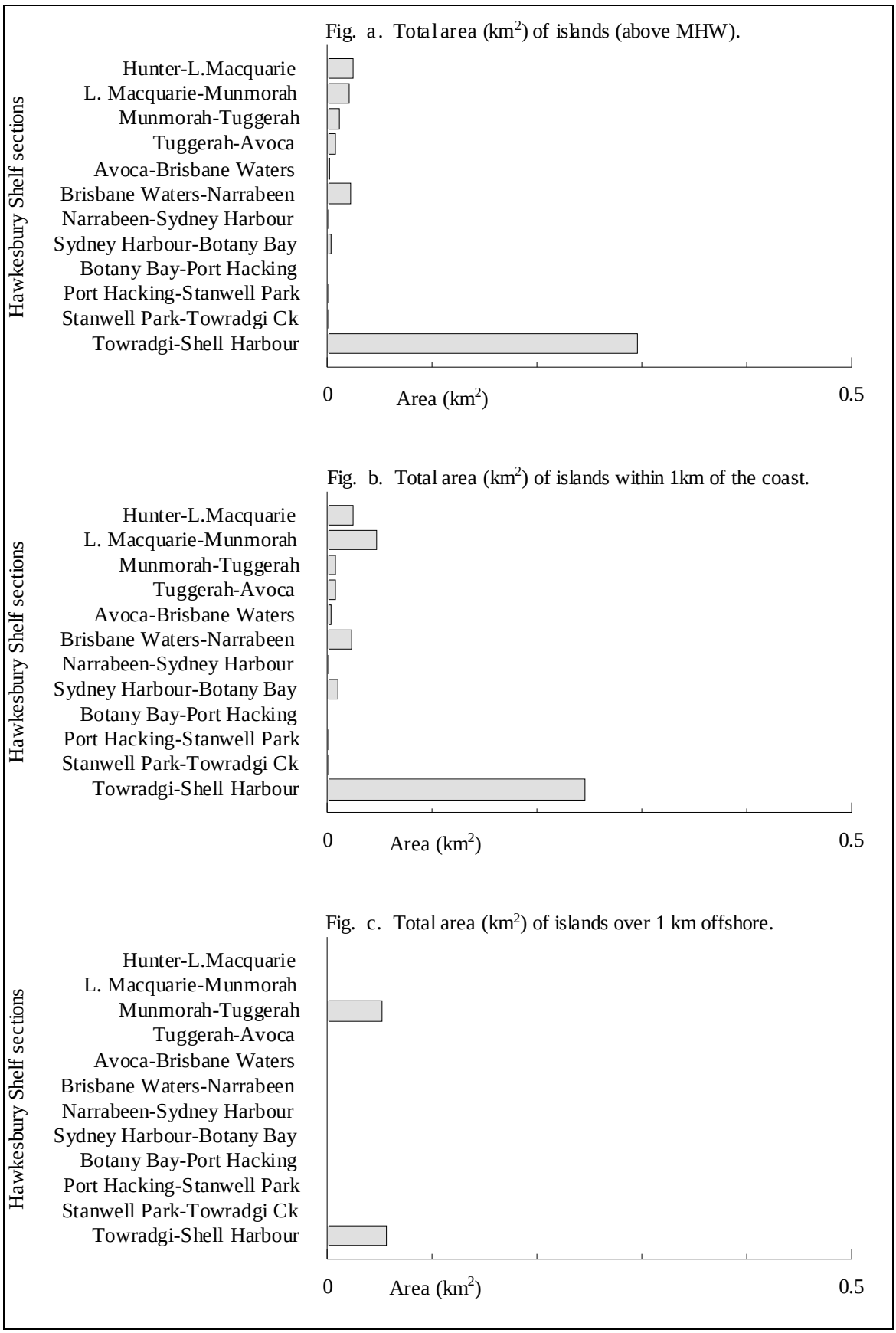



Figure 7.19a-c. Area ($km^2$) of total, inshore and offshore islands (above mean high water) for coastal sections (NSW waters within 3nm) of the Hawkesbury Shelf bioregions.

### 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.

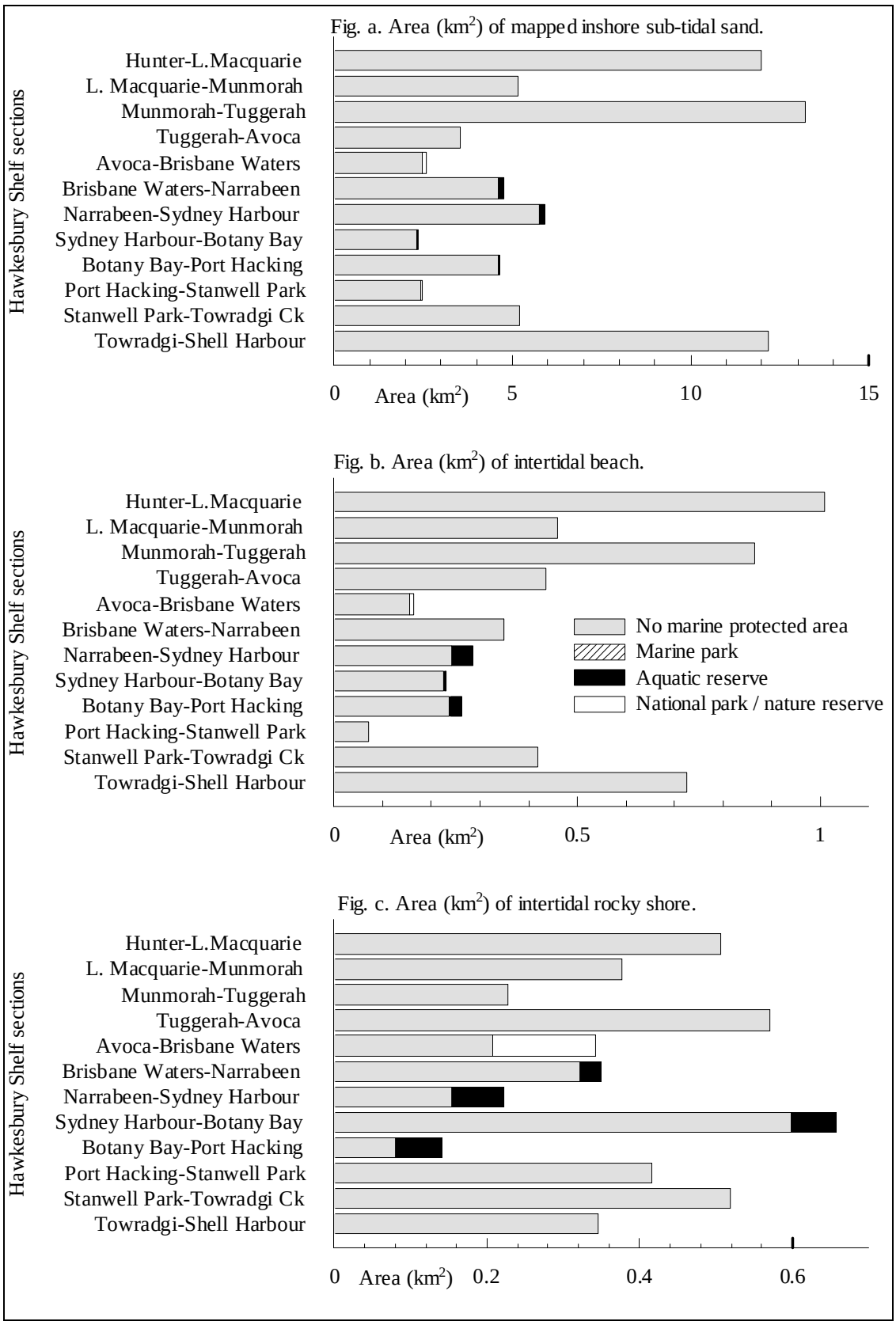



Figure 7.20a-c. Area ($km^2$) of mapped (inshore) subtidal sand, intertidal beach, and intertidal rocky shore habitat in marine protected areas within coastal sections (NSW waters within 3nm) of the Hawkesbury Shelf bioregion.

### 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

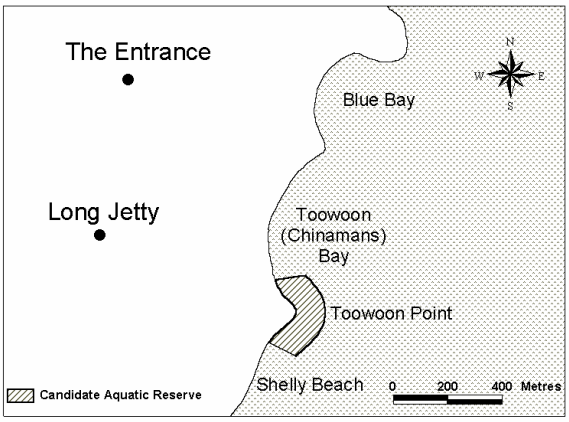



Figure 7.21. Towoon Bay candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

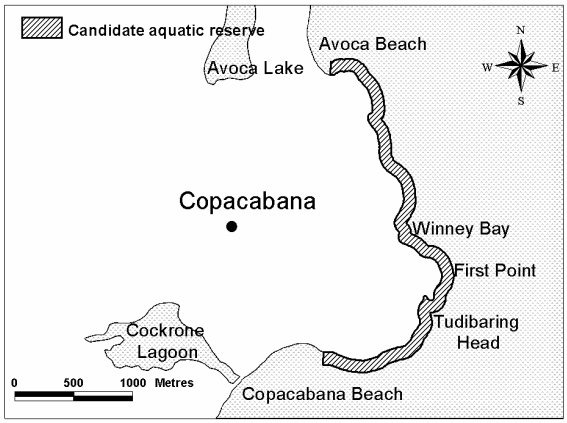



Figure 7.22. Tudibaring Head candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

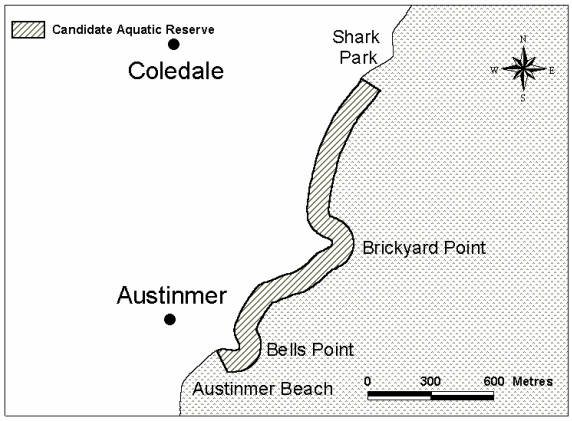



Figure 7.23. Brickyard Point candidate rocky intertidal aquatic reserve (NSW Fisheries Office of Conservation 2001).

### 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.

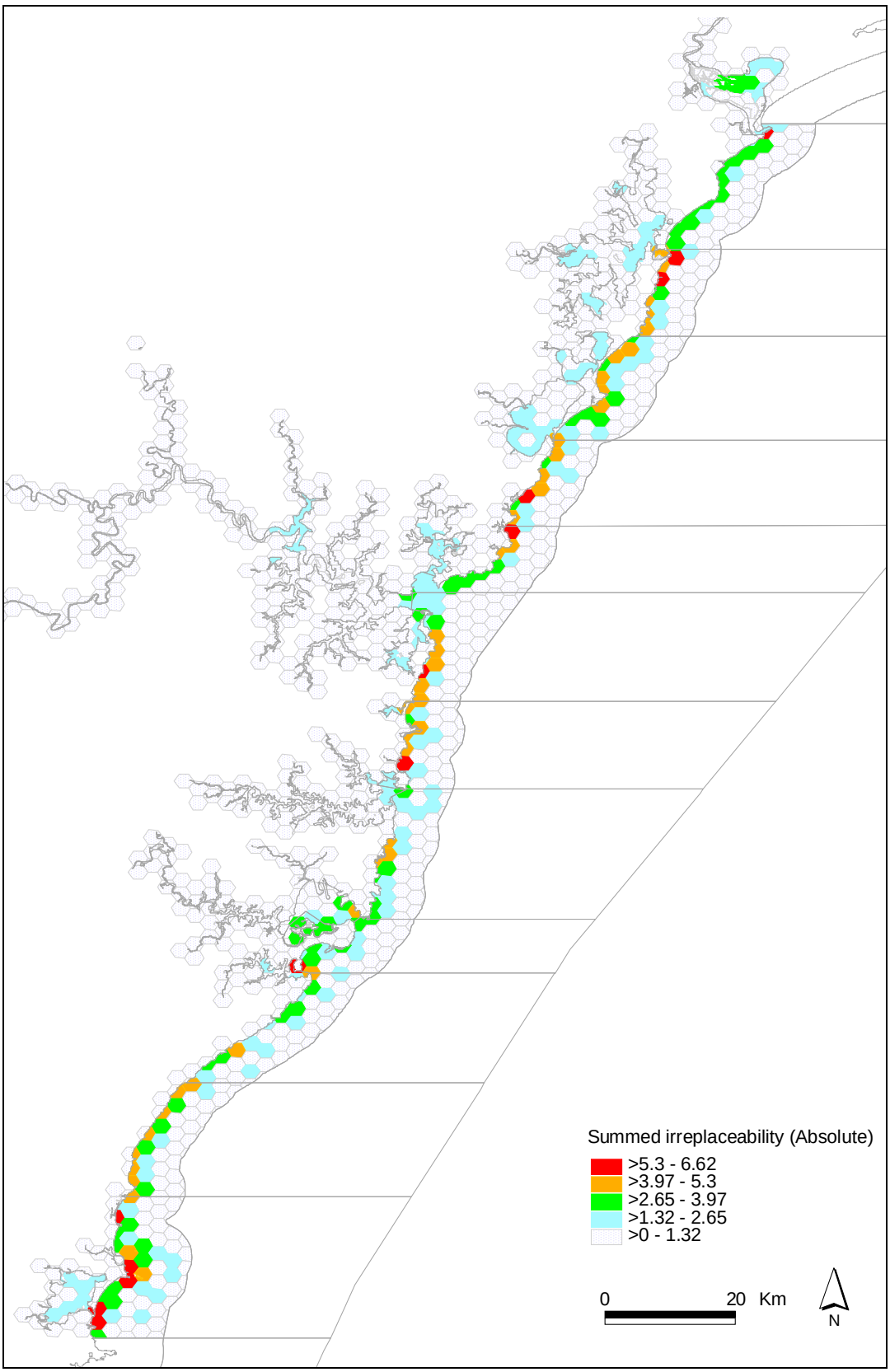



Figure 7.24. Summed irreplaceability of fine scale (4 km$^2$) planning units for ecosystem and habitat types in the NSW waters (within 3 nm) of the Hawkesbury Shelf bioregion. Values indicate the degree to which a unit can contribute to meeting a hypothetical 20% goal for a number of different estuarine 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

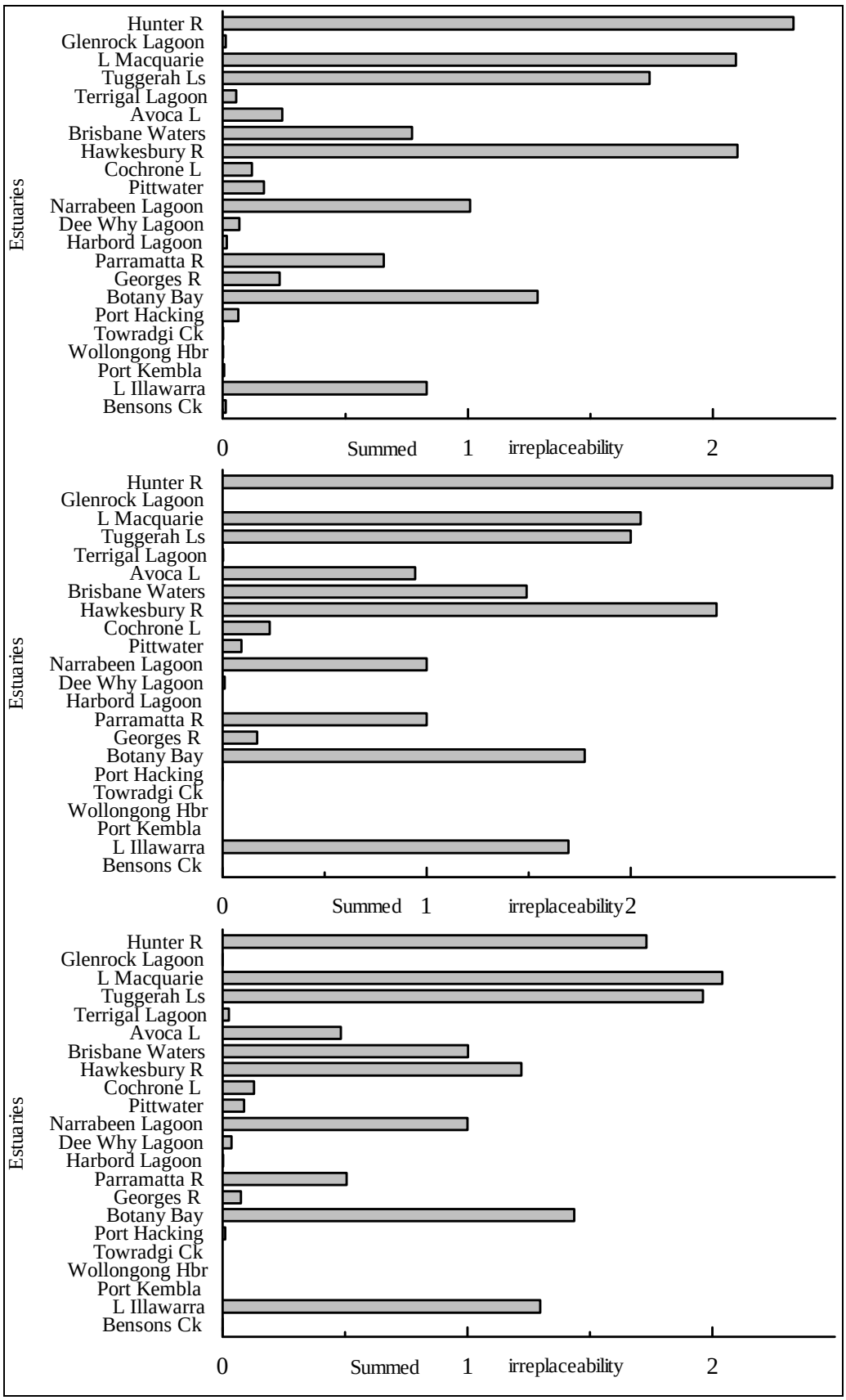



Figure 7.25. Summed irreplaceability scores for estuaries a. assuming there are no existing MPAs; b. allowing for areas in marine parks and aquatic reserves. c. allowing for areas included in marine parks, aquatic reserves, national parks and nature reserves. Values estimated using C-Plan reserve selection software (NPWS 2001).

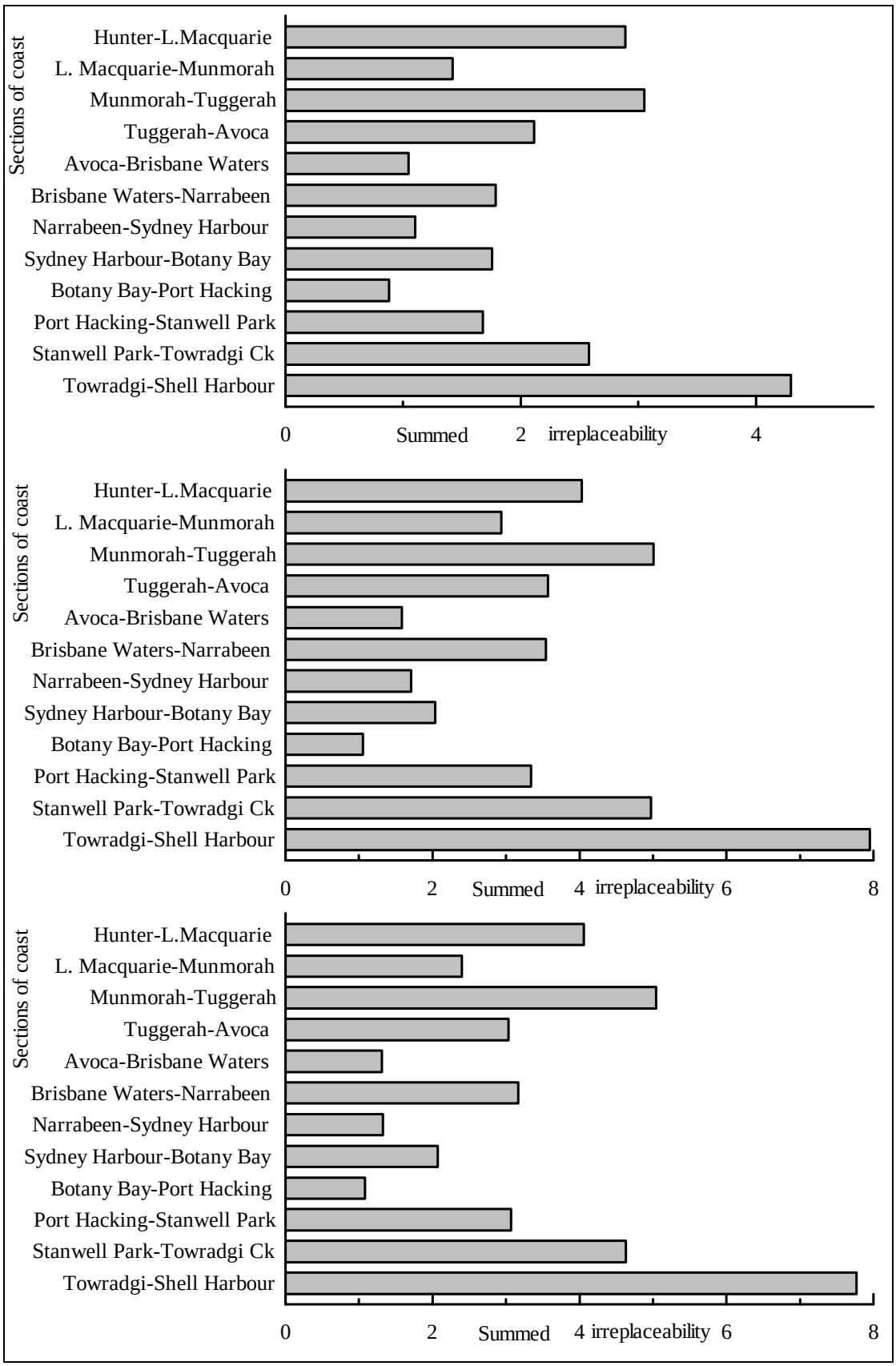



Figure 7.26. Summed irreplaceability scores for sections of coast a. assuming no existing MPAs; b. allowing for areas included in marine parks and aquatic reserves. c. allowing for areas included in marine parks, aquatic reserves, national parks and nature reserves. Values estimated using C-Plan reserve 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

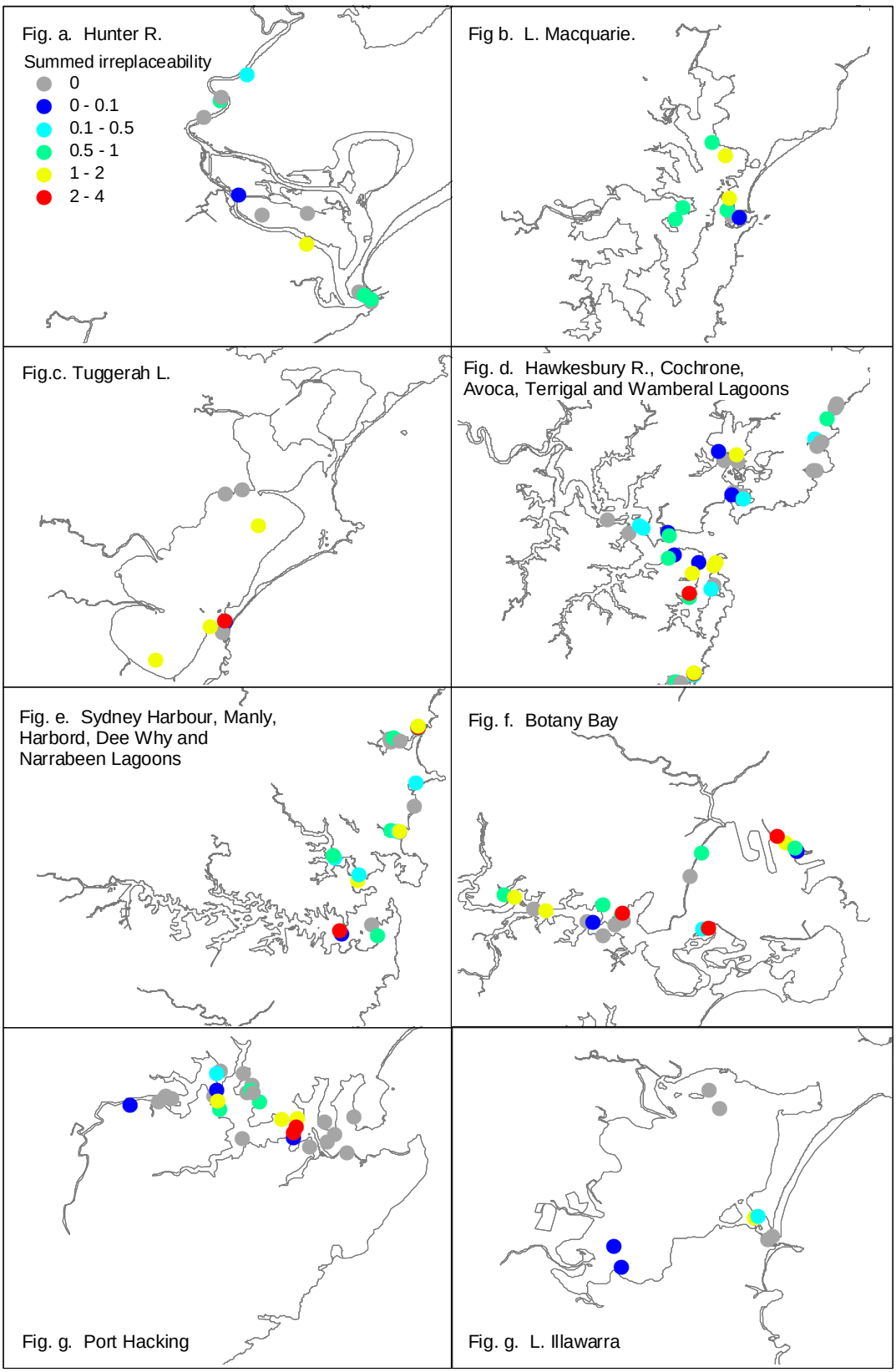



Figure 7.27 a-h. Summed irreplaceability (values from C-Plan, NPWS 2001) for representation of at least one of each species of juvenile fish and invertebrate sampled by seine net (n=5 hauls) along estuary shores in the Hawkesbury Shelf bioregion. Data from Natural Heritage Trust funded, NSW Fisheries[2], 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).

[2] now within the NSW Department of Primary Industry

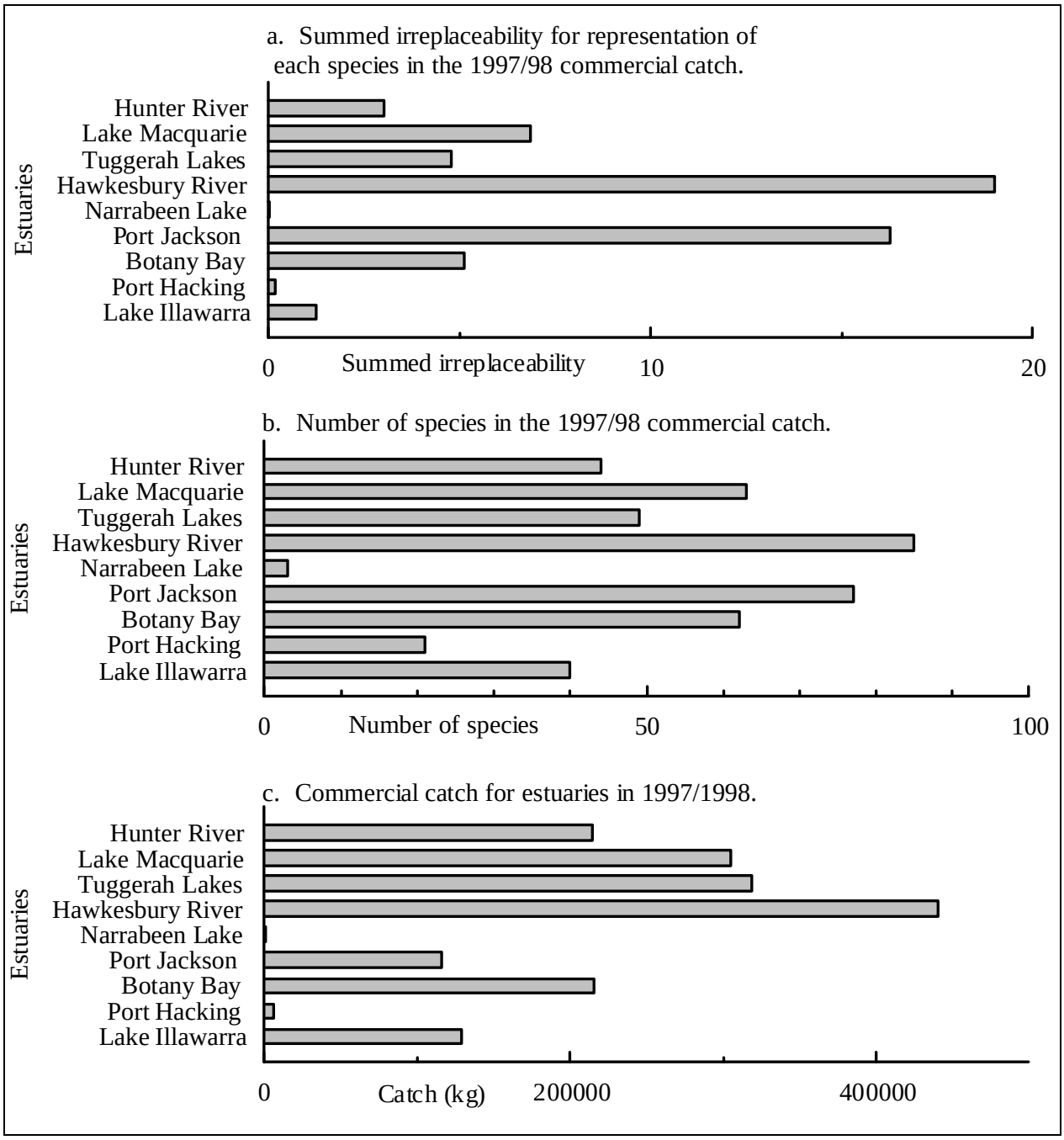



Figure 7.28. Summed irreplaceability (values from C-Plan (NPWS 2001), number of species and weight of commercial catch for estuaries in the Hawkesbury Shelf bioregion in 1997/98. Data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[2] now within the NSW Department of Primary Industry

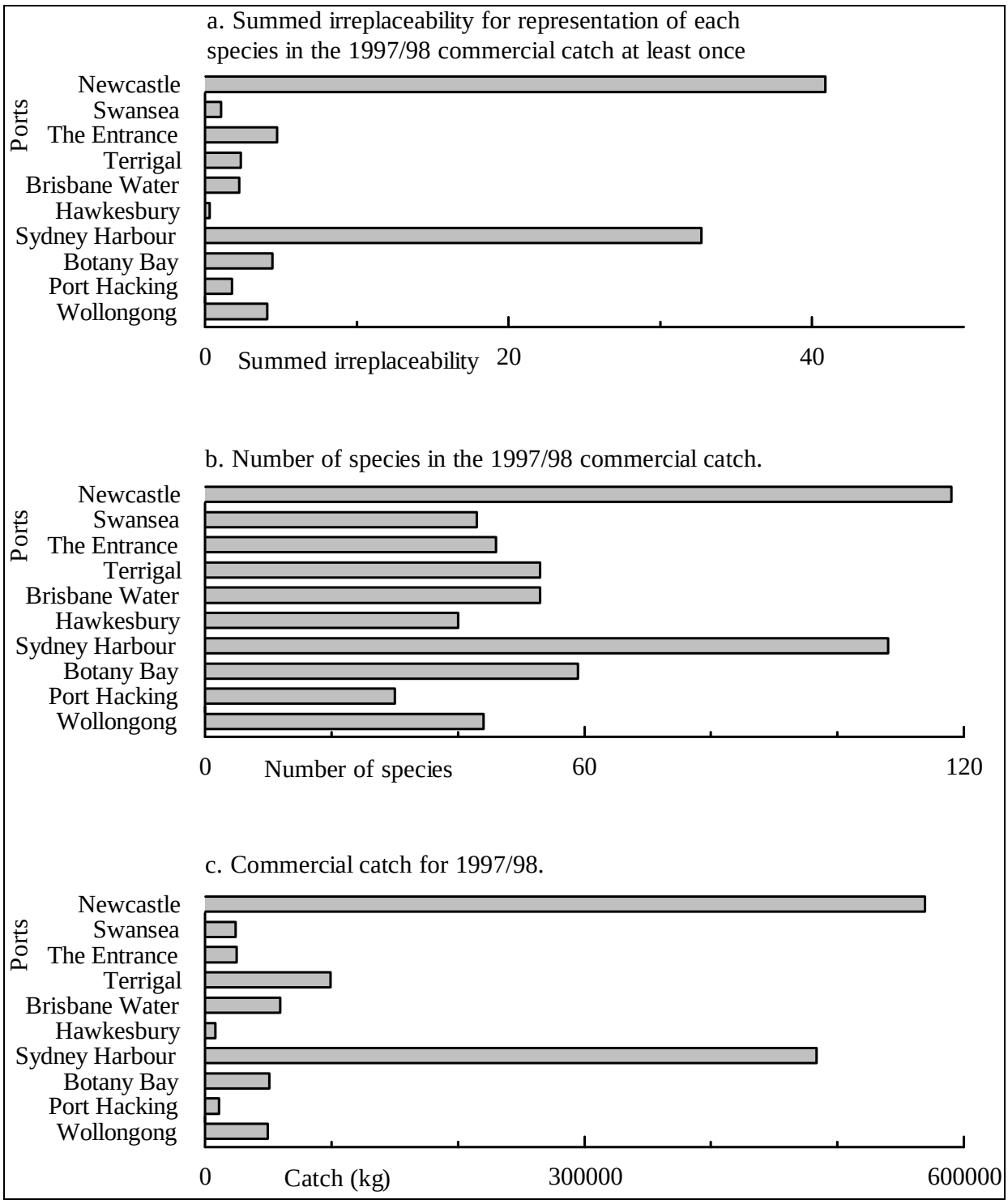



Figure 7.29. Summed irreplaceability (values from C-Plan, NPWS 2001), number of species and weight of commercial catch for ocean ports in the Hawkesbury Shelf bioregion in 1997/98. Data from NSW Fisheries[2] (pers. comm. Geoff Liggins and Marnie Tanner).

[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.

[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.

[2] now within the NSW Department of Primary Industry

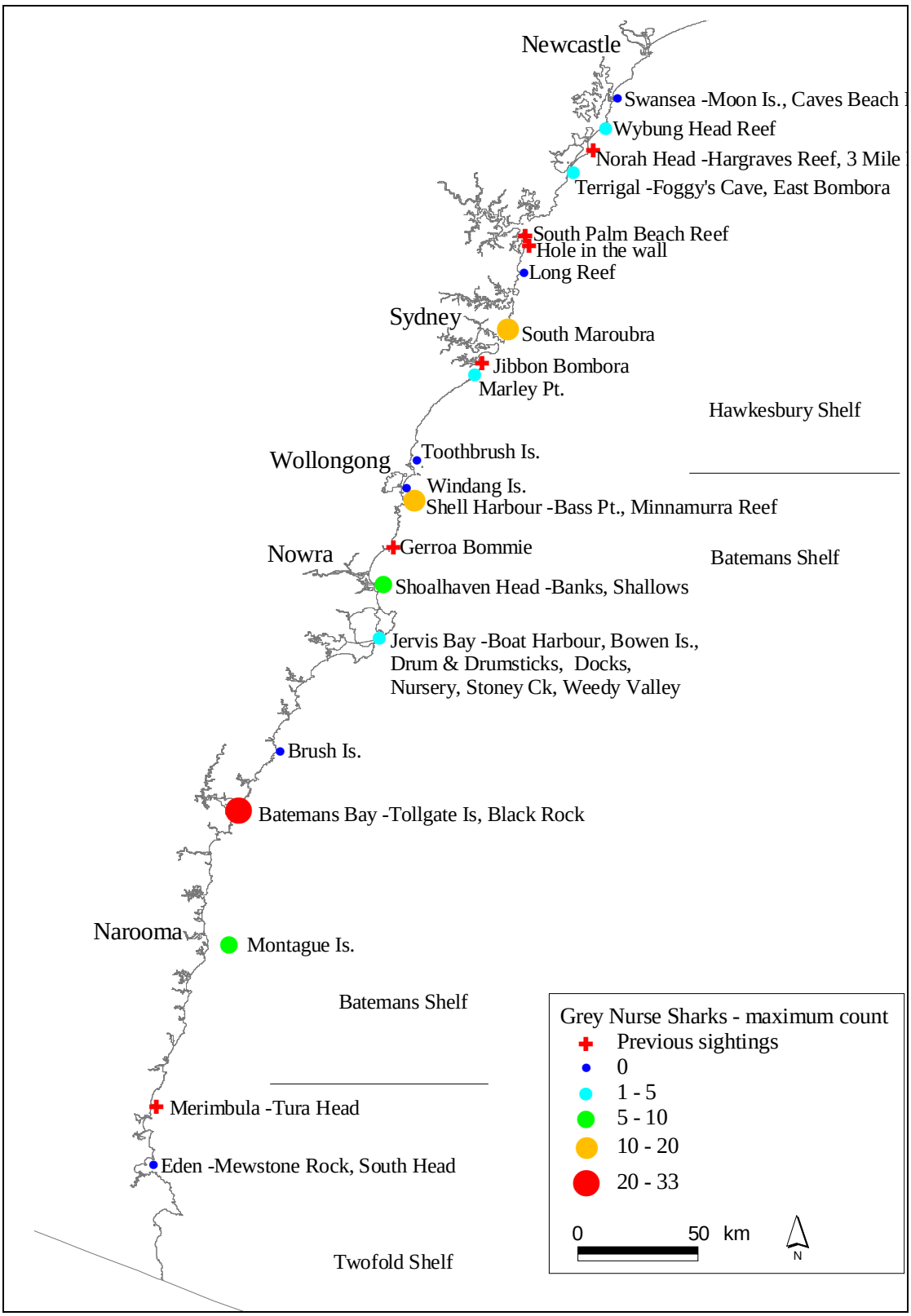



Figure 7.30. Maximum numbers of Grey Nurse Shark (*Carcharias taurus*) observed at dive sites in the Hawkesbury Shelf bioregion during eight survey seasons in 1998 and 2000 and additional previous historical sightings (data from Otway and Parker (2000) and Otway *et al.* (2003)).

### 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).

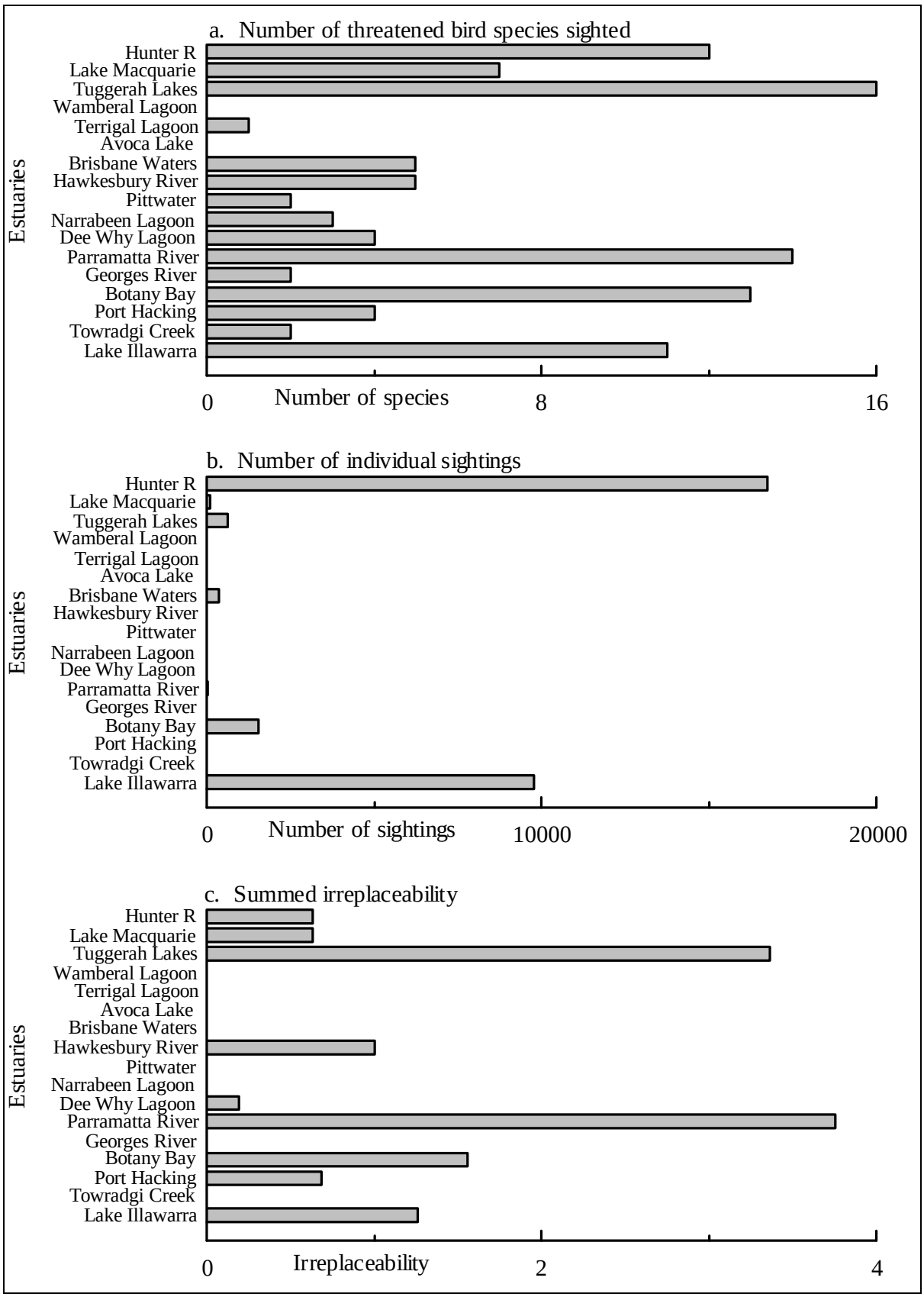


Figure 7.32. Number of threatened bird species sighted, number of sightings and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for estuaries in the Hawkesbury Shelf bioregion (Data from NPWS Wildlife Atlas).

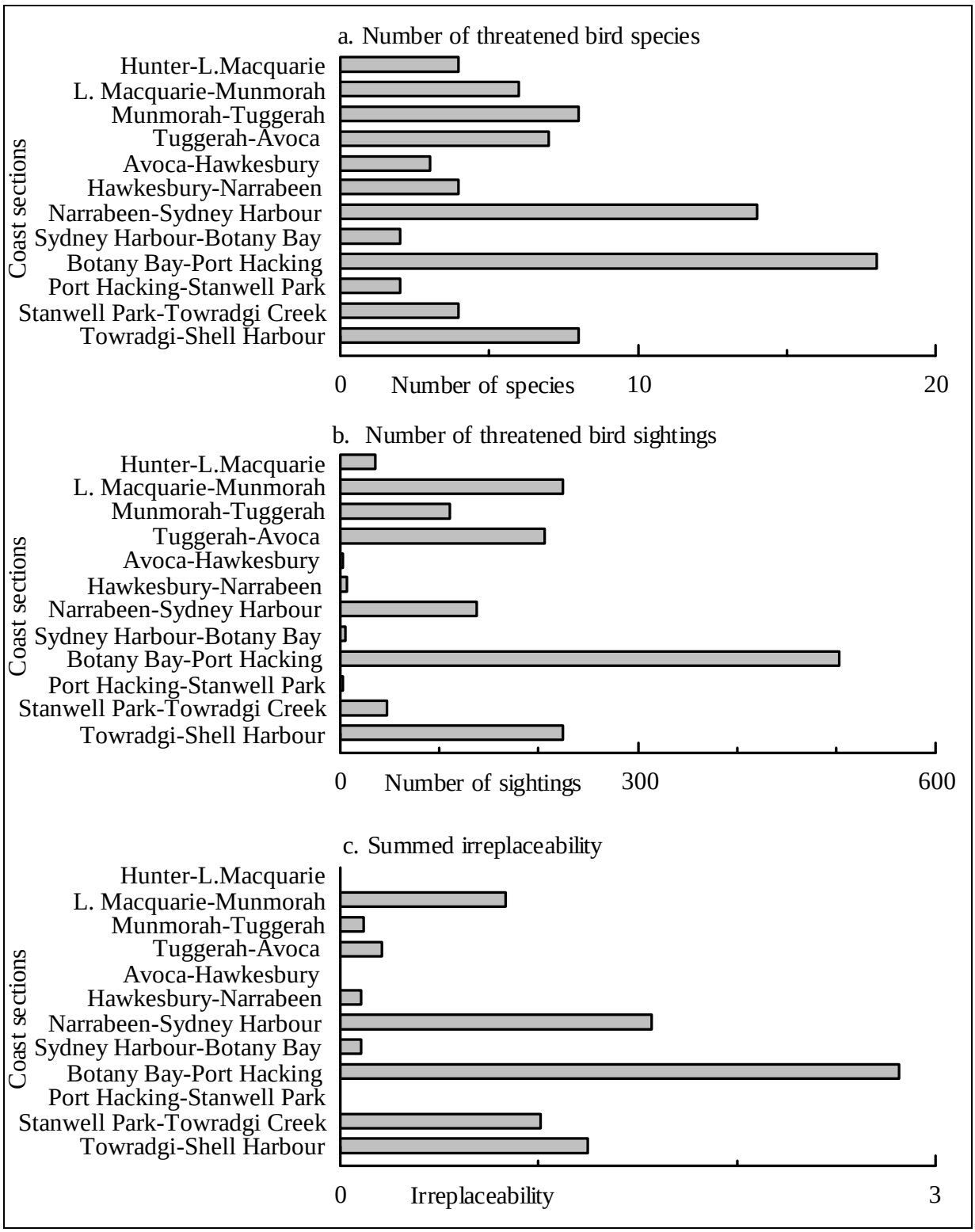


Figure 7.33. Number of threatened bird species sighted, number of sightings and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for sections of ocean and coast in the Hawkesbury Shelf bioregion (Data from NPWS Wildlife Atlas).

### 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).

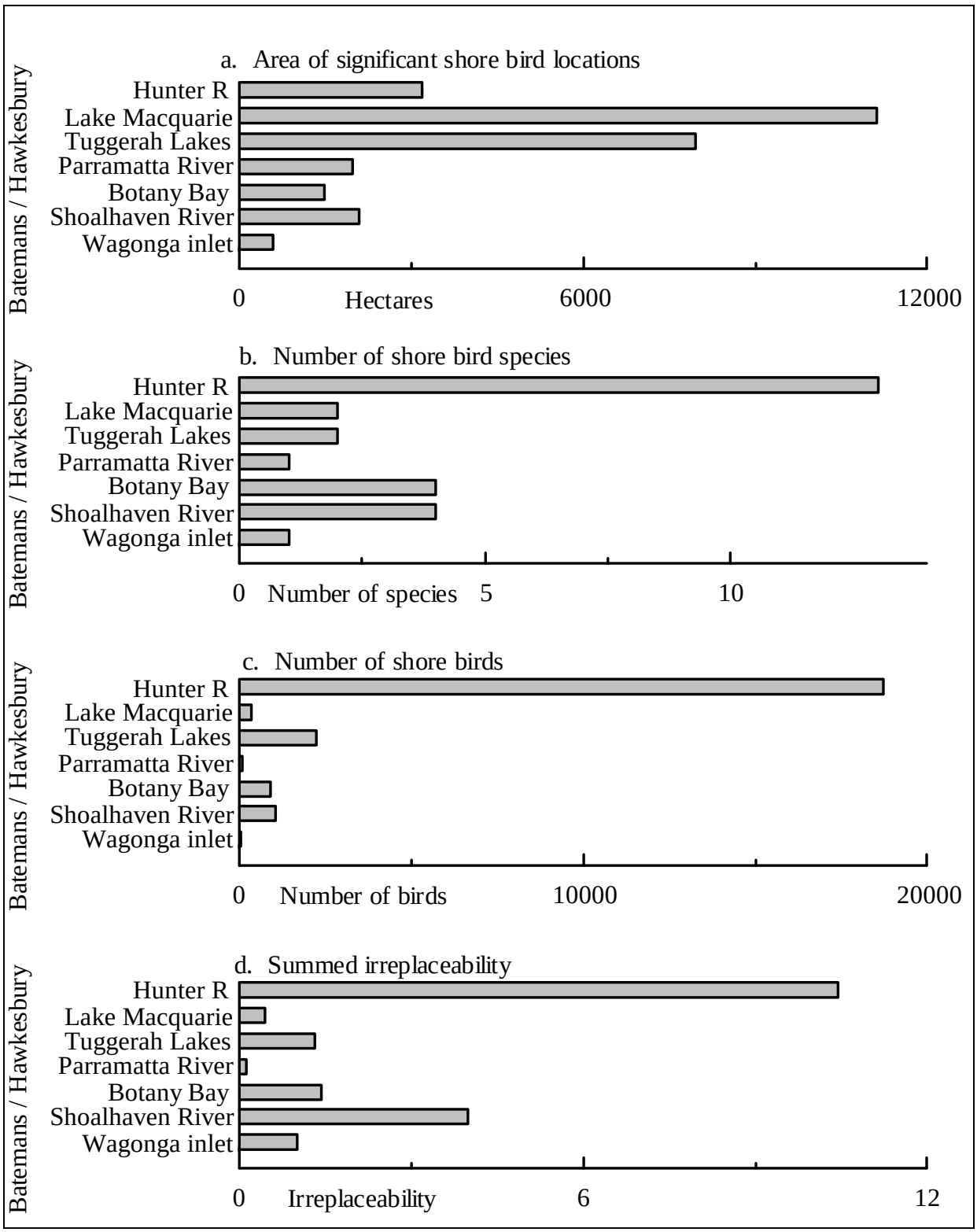


Figure 7.34. Area, number of species, number of birds and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for significant shore bird locations in the Hawkesbury and Batemans Shelf bioregions (data from the Department of Environment and Heritage).

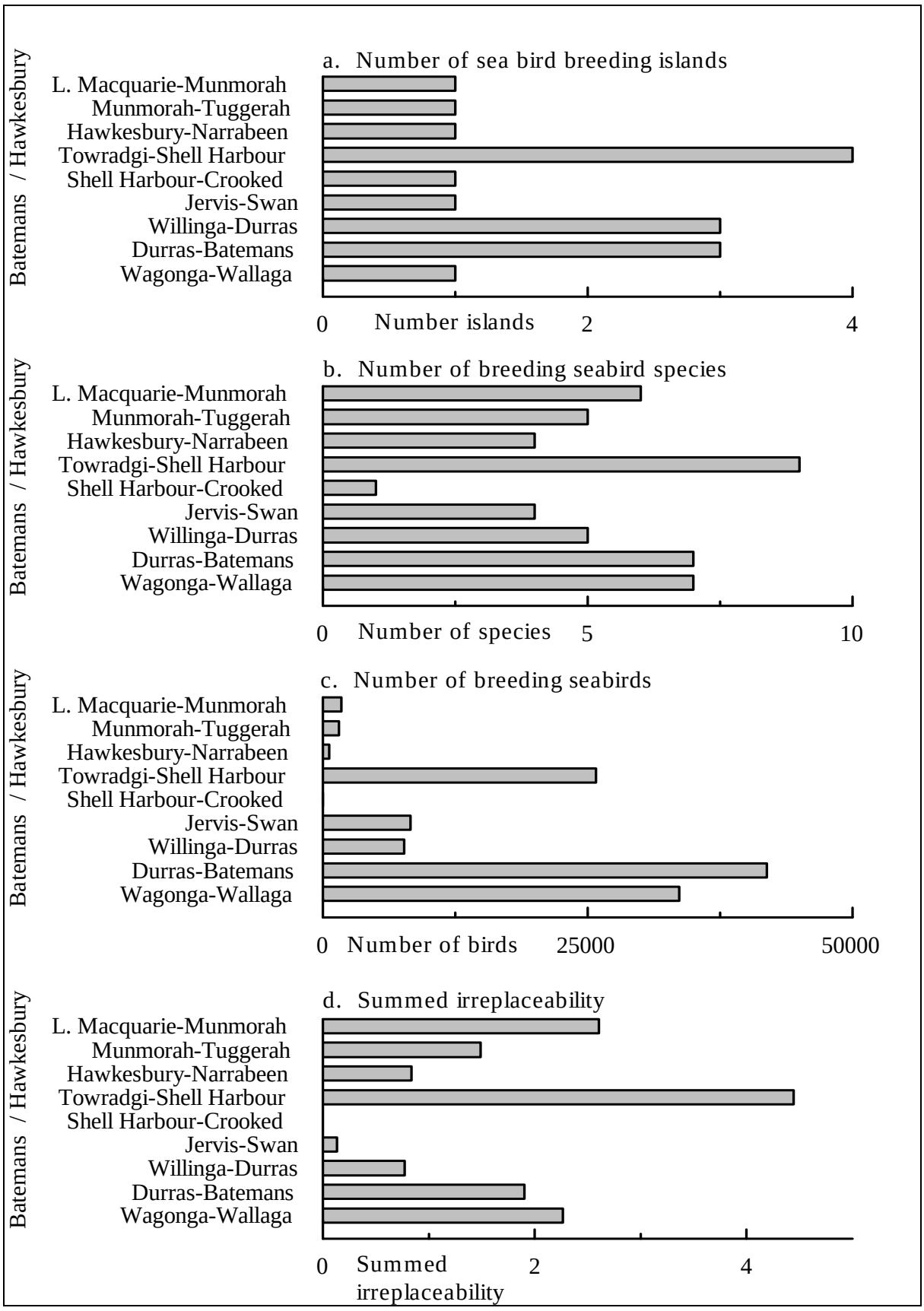


Figure 7.35. Area, number of species, number of birds and summed irreplaceability (values from C-Plan, NPWS 2001) for representation of each species at least once for sea bird breeding islands in the Hawkesbury and Batemans Shelf bioregions (data from the Department of Environment and Heritage).

### 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 20$^{th}$ 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).

[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.

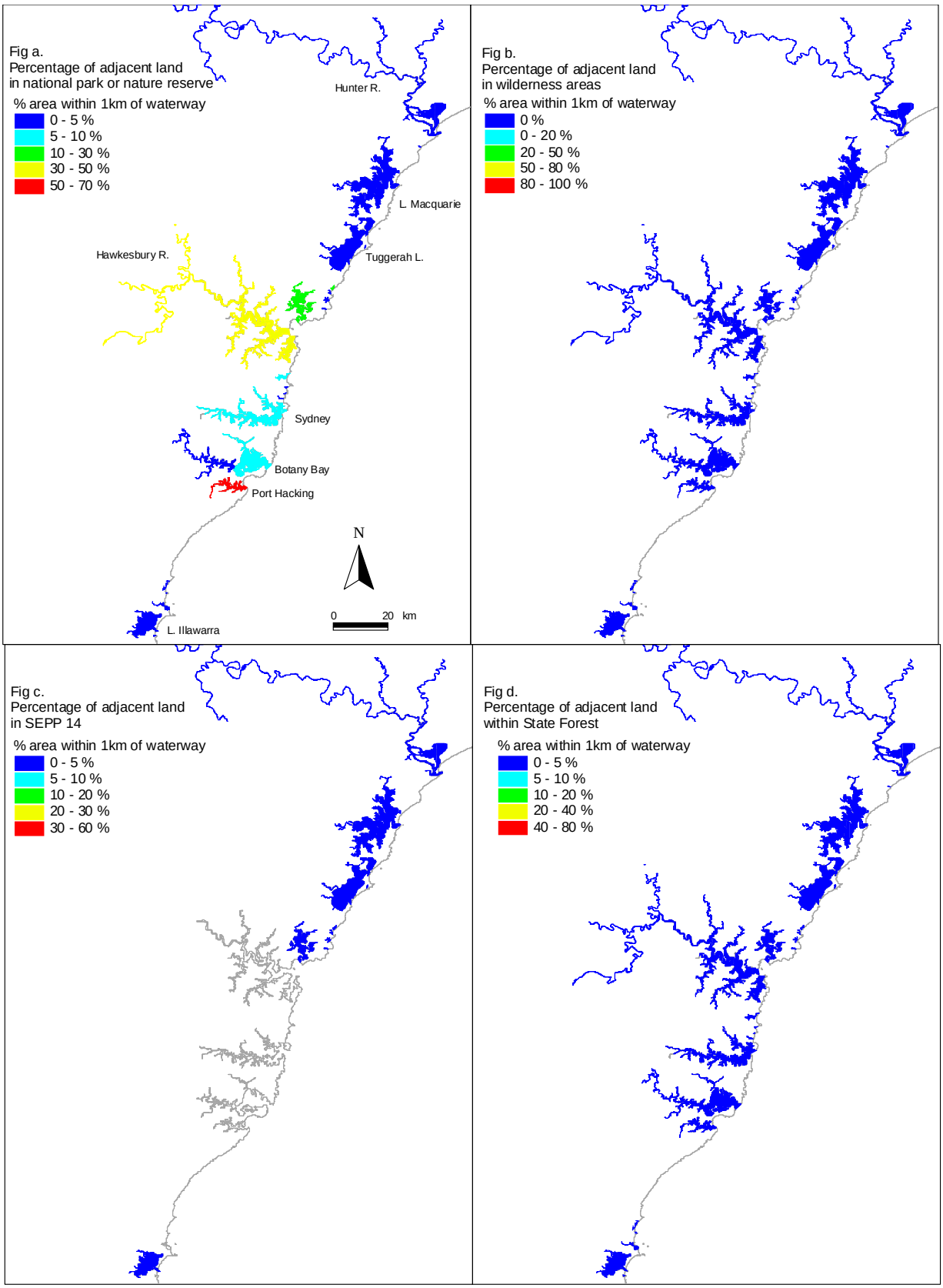


Figure 7.36. Percentage area of lands within 1 km of estuaries within national parks or nature reserves, wilderness areas, State Environmental Planning Policy 14 (wetland) areas and State Forest in the Hawkesbury Shelf bioregion.

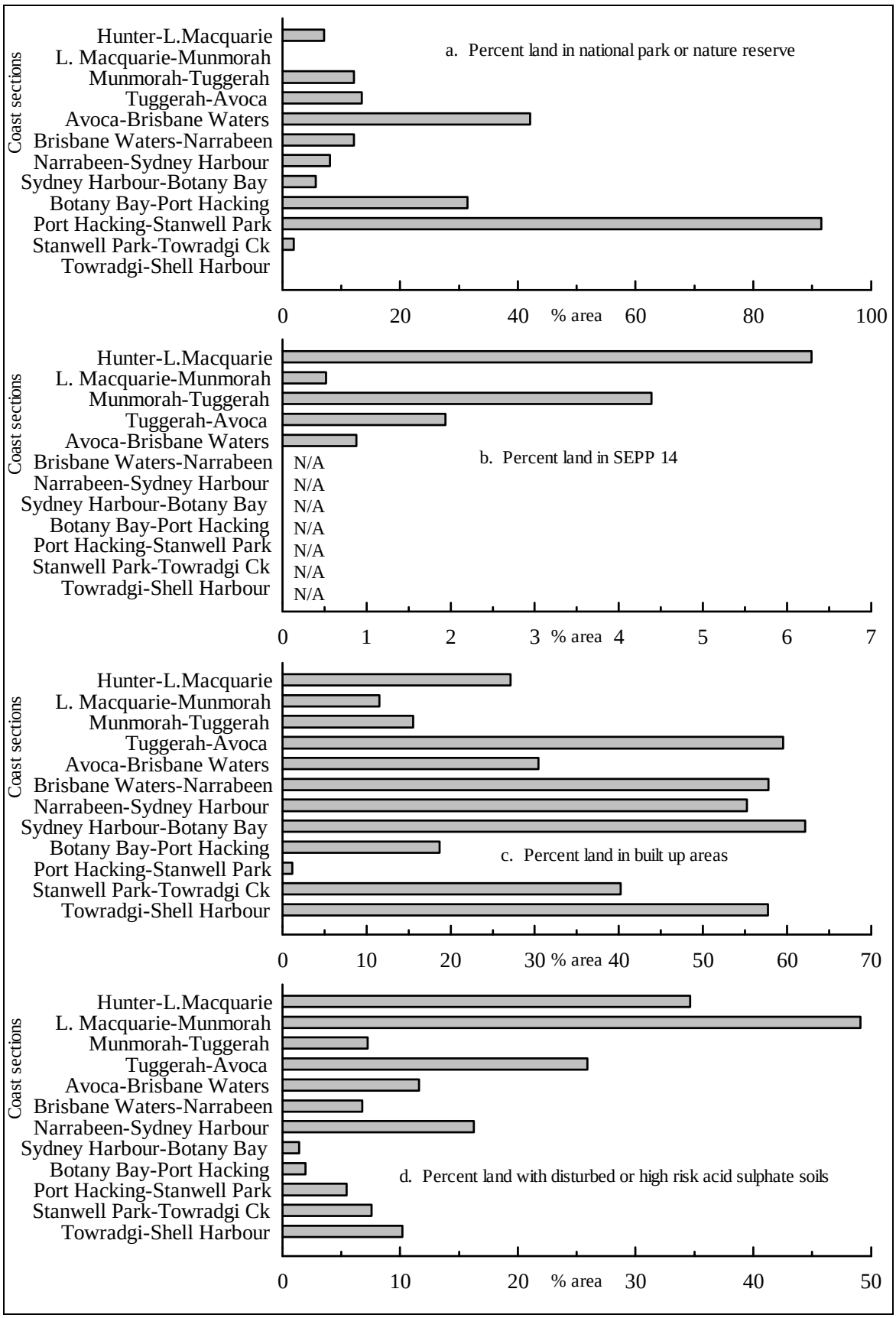


Figure 7.37. Percentage area of land within 1 km of coast in national park or nature reserve, SEPP 14 areas (not available for Sydney Metropolitan Area), built up areas and disturbed or high risk acid sulphate soil areas in the Hawkesbury Shelf bioregion.

### 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).

[3] now the Department of Infrastructure, Planning and Natural Resources

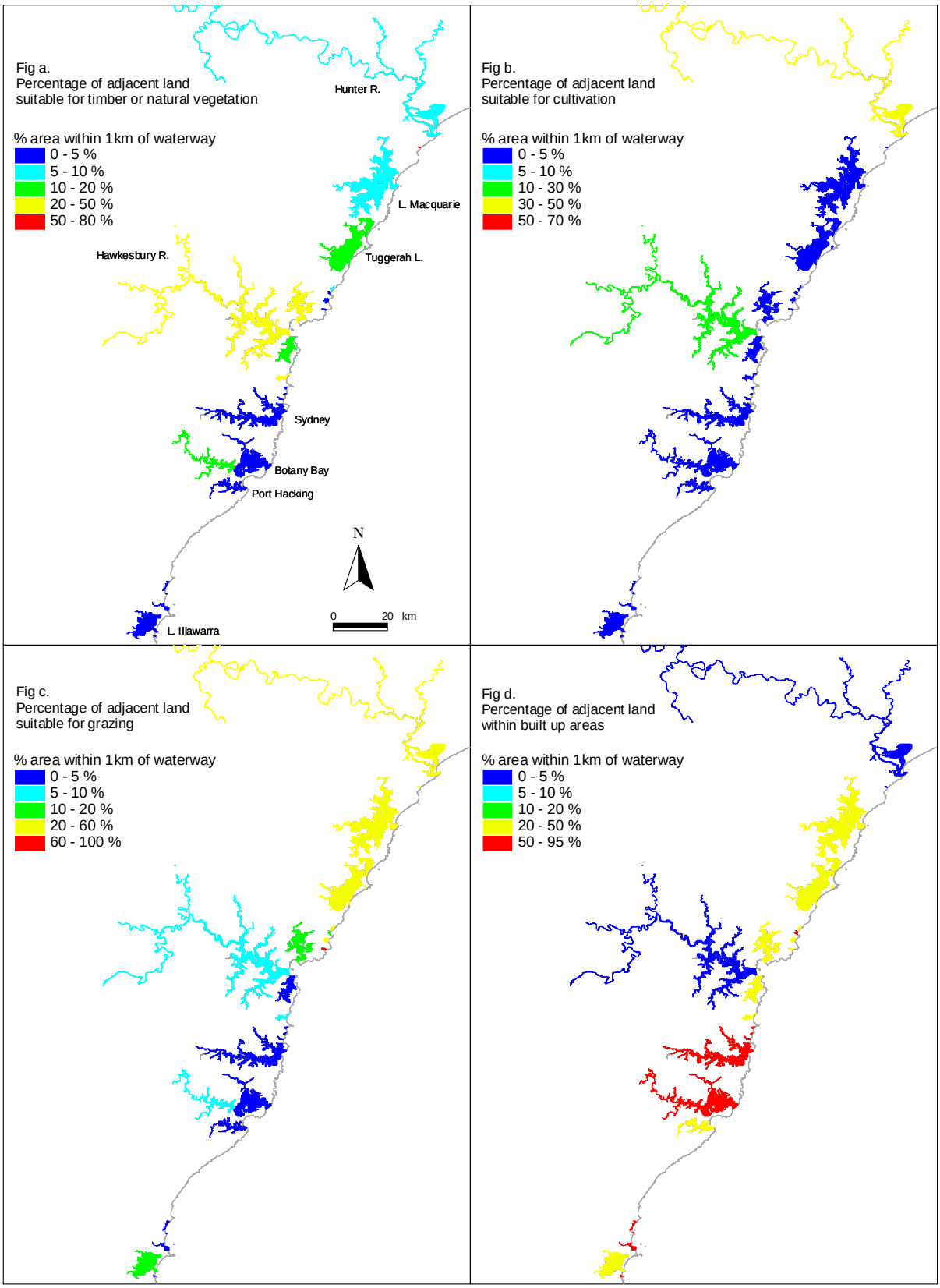


Figure 7.38. Percentage area of lands within 1 km of estuaries suited to different land uses and within built up areas in the Hawkesbury Shelf bioregion.

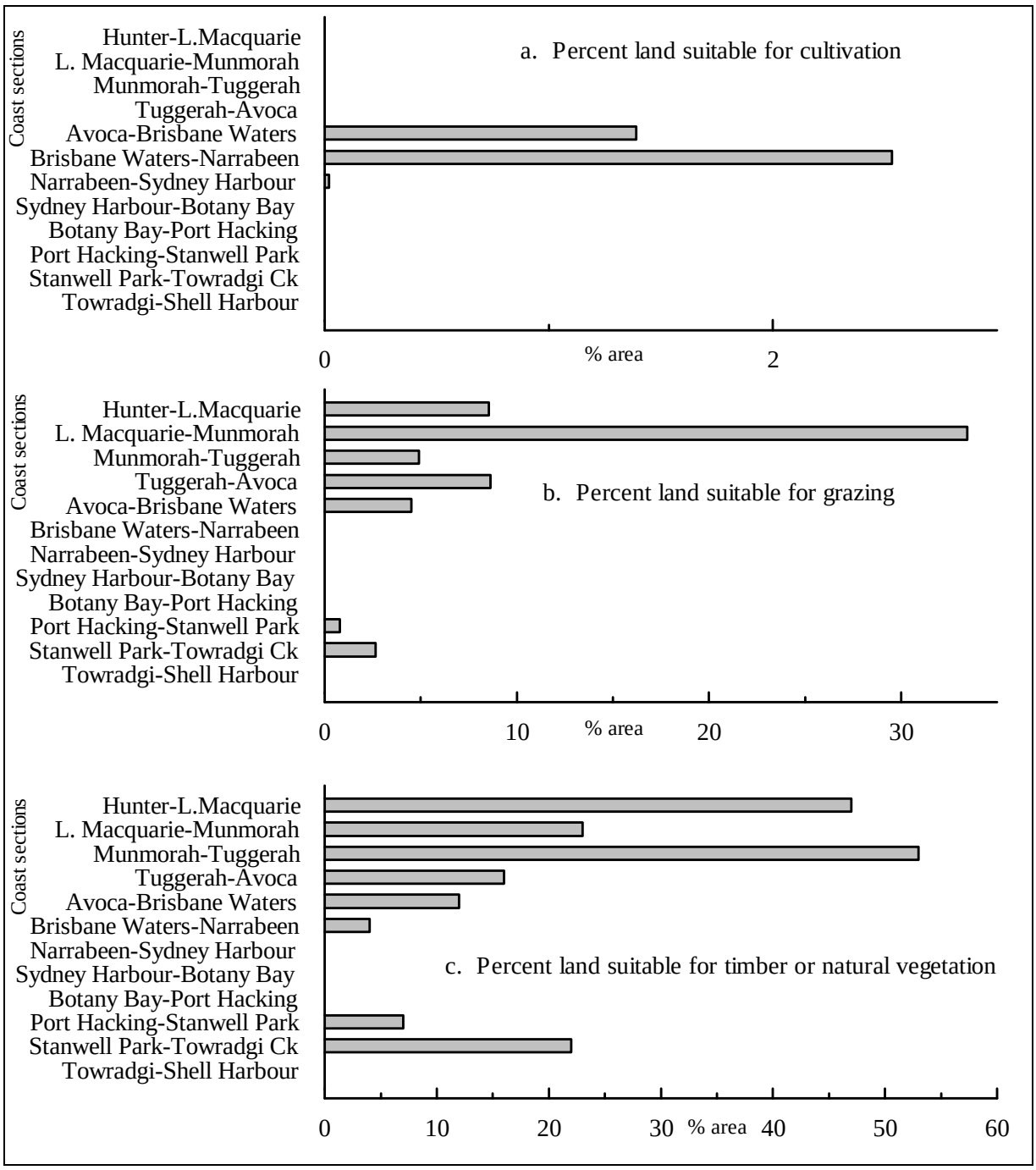


Figure 7.39. Percentage area of land within 1 km of coast in areas suitable for cultivation, grazing and timber or natural vegetation for the Hawkesbury Shelf bioregion.

### 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).

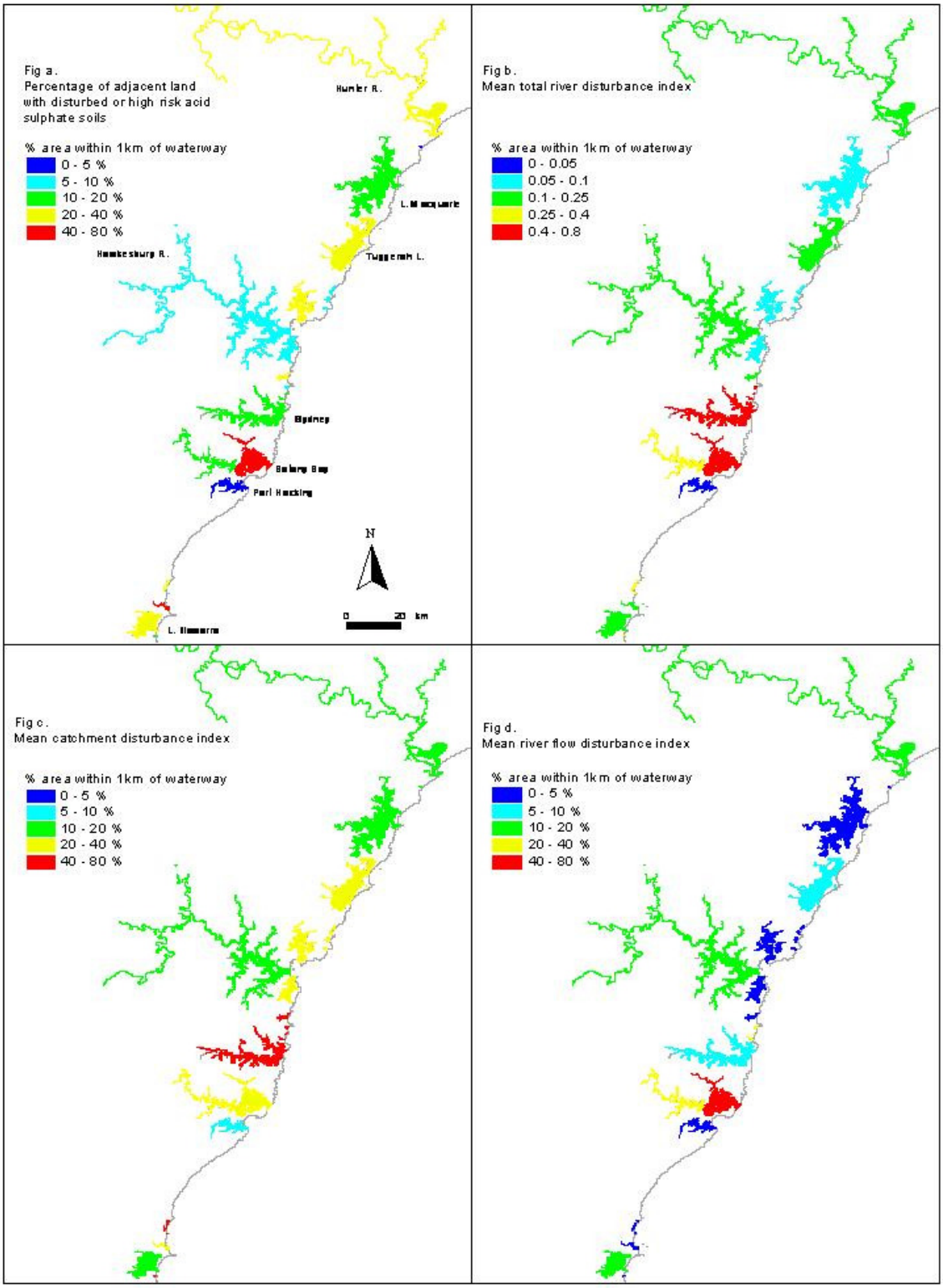


Figure 7.40. Percentage area of lands within 1 km of estuaries with disturbed or high risk acid sulphate soils and mean Australian river and catchment condition indices for estuaries in the Hawkesbury Shelf bioregion.

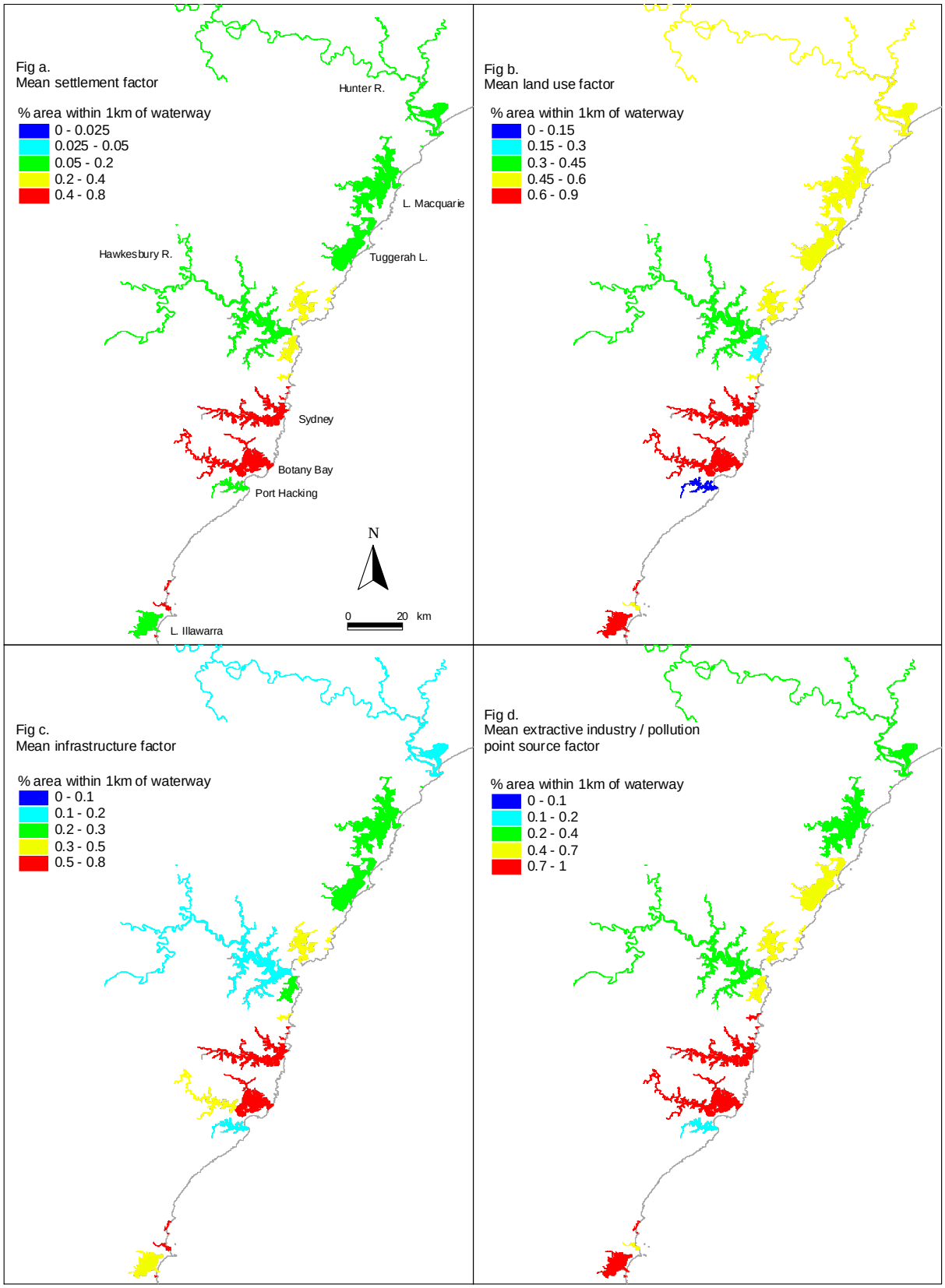


Figure 7.41. Mean Australian river and catchment condition indices (continued) for estuaries in the Hawkesbury Shelf bioregion.

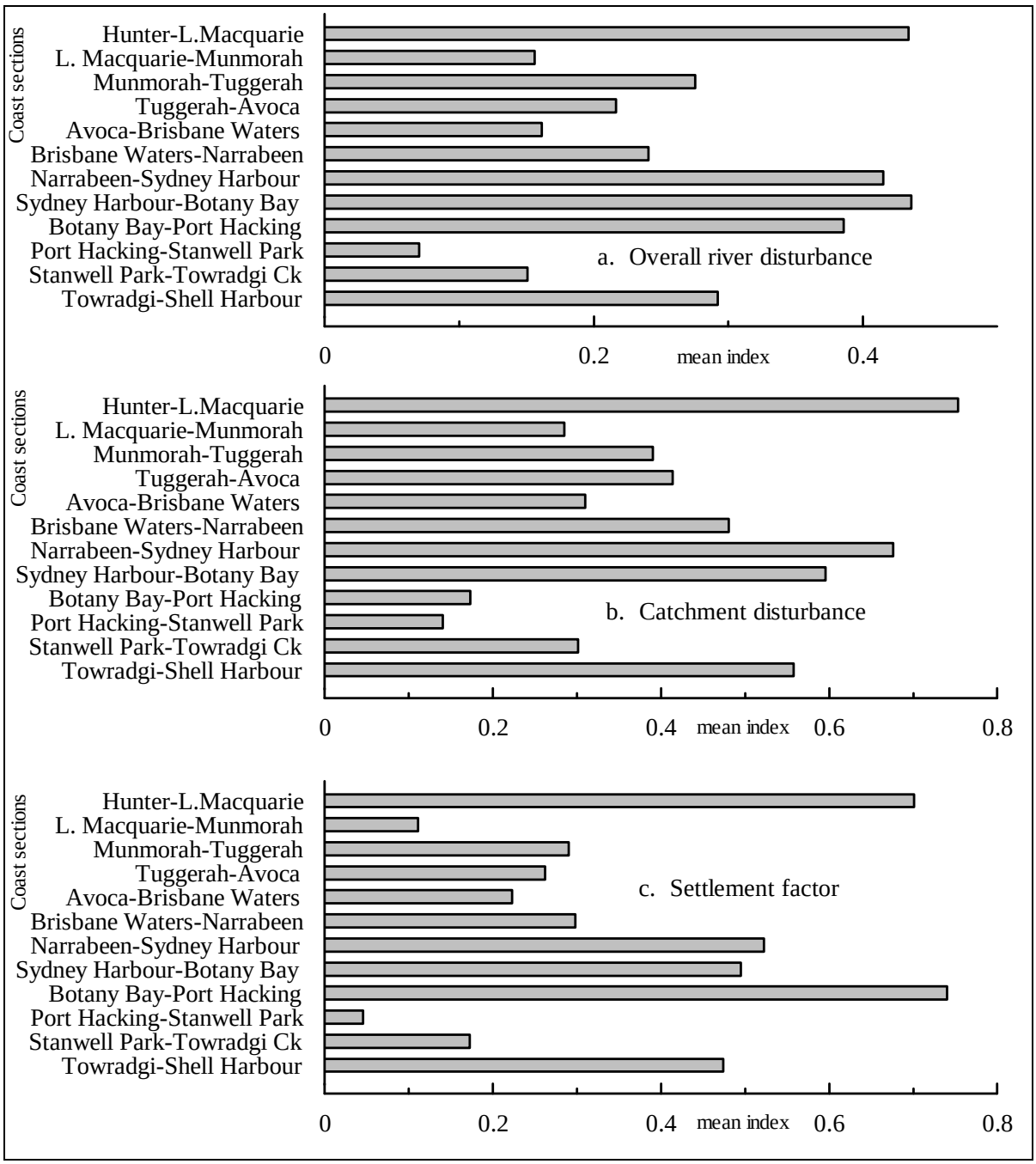


Figure 7.42. Mean Australian river and catchment condition indices within 5 km of coast for overall river disturbance, catchment disturbance and settlement for the Hawkesbury Shelf bioregion.

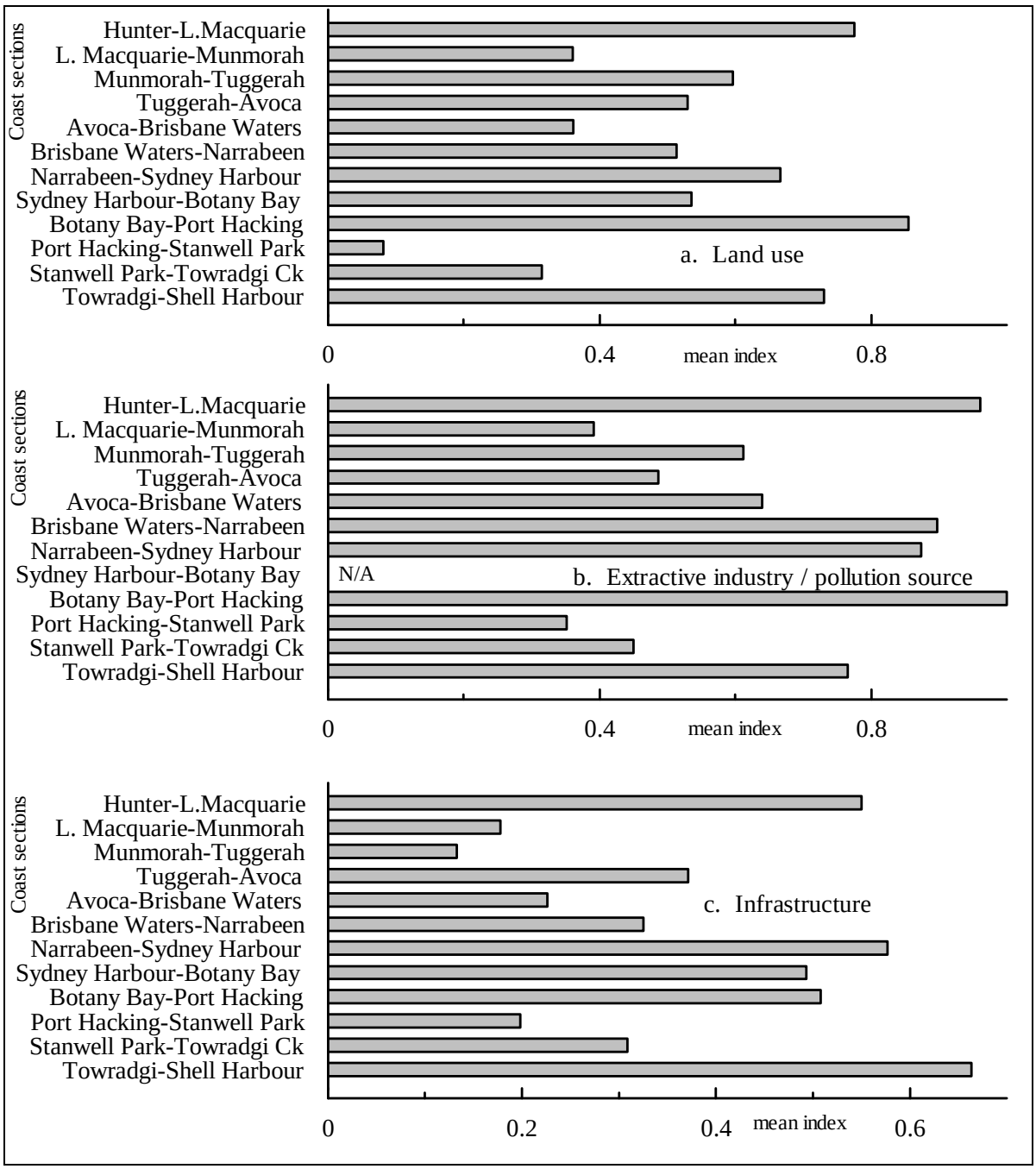


Figure 7.43. Mean Australian river and catchment condition indices within 5 km of coast for land use, extractive industries and pollution, and infrastructure for the Hawkesbury Shelf bioregion.

## 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.