Dinsdale, Elizabeth (2004) *Coral reef health indicators: integrating ecological and perceptual assessments of anchor damage.* PhD thesis, James Cook University.

CHAPTER 1

GENERAL INTRODUCTION: EXPLORING THE ECOSYSTEM HEALTH CONCEPT

1.1 Introduction

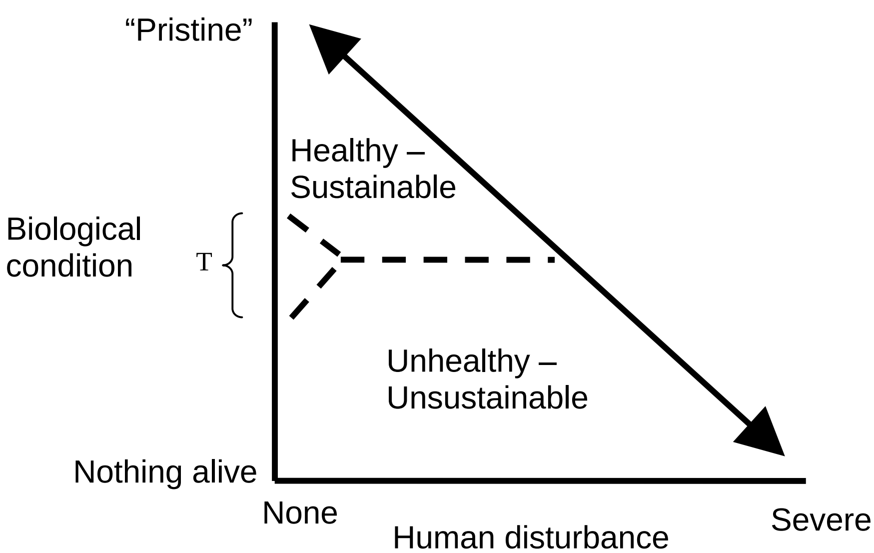
The foundations of the ecosystem health concept began in the 1940s with writings by Leopold (1949) who described the need for a land ethic, where land is seen as a community to which people[1] belong. The ethic suggested that development is conducted with consideration for the needs of the environment, thus ensuring that the land and therefore people are healthy. Ecosystem health, which at its root refers to the capacity of a system (whether biological, social or mechanical) to preform normal function, is being integrated into environmental management policy (Costanza *et al.* 1992; Rapport *et al.* 1998a). Ecosystem health was expressed as an objective in the Rio Convention on the sustainable development of the environment and has been adopted in some, but not all public domains (Rapport 2003). Importantly, ecosystem health builds a broad consensus of what is a healthy environment and brings together an extensive range of people, such as landowners, farmers, tourist operators, environmental management agencies, non-government organisations and conservationists into environmental management. However, there is contention about the concept and the extent to which it should be used to inform environmental management policy.

The ecosystem health concept relies on a description of the environment along a gradient determined by biological condition and human disturbance (Karr 2000) (Figure 1.1). The state of the environment is described as healthy or not. A healthy environment is deemed sustainable, able to supply requirements for both human and non-human communities. Conversely, an unhealthy environment is unsustainable and requires a change in activities conducted by people to improve its condition and re-establish the function of the environment (Karr 1999). Conceptually, ecosystem health is logical; however

[1] People in this thesis are members of contemporary society, which work and reside in a region adjacent to a natural resource and could be involved or provided with incentives to participate in environmental management. These people may or may not have expert and / or local knowledge of the environment.

implementing the concept has proved difficult. The greatest problems in implementing the concept and the focus of my research are the identification of indicators that could be used to describe the environment along the health gradient and the combination of social and ecological data to describe when an environment changes from healthy to unhealthy.

Figure 1.1 The ecosystem health concept describes the condition of the environment using two dimensions, biological condition and human disturbance (from Karr 2000). Describing the change in condition of the environment along the health gradient (arrowed line) and identifying the point (somewhere in the vicinity of T) at which the environment changes from healthy to unhealthy (dashed line) are the major problems encountered in using the ecosystem health concept.



Examining the “ecosystem health” concept further reveals that both words are difficult to define and require subjective judgements. Callicott *et al.* (1999 page 27) described ecosystems as “devilishly complex and wonderfully idiosyncratic.” Ecosystems have no obvious spatial boundary, but are portions of the landscape that researchers arbitrarily label (Fitzsimmons 2003). Defining ecosystems is particularly difficult in a marine environment, where juveniles and adults of some species, which are the components of the ecosystem, move regularly between systems, so that at any one time different components may be present within each ecosystem. Ecosystems are not organised in the same manner as organisms and therefore, the health concept is suggested to be inappropriate when applied to them (Rapport 2003). Individual organisms within an ecosystem are not striving for the survival of the entire system, but with their own survival (Callicott 1995; Harwell *et al*. 1999; Wilkins 1999). Ecosystems are in flux because of natural disturbances, therefore the components and processes within an ecosystem are changing over time, which makes a description of health status difficult (Ehrenfeld 1992). However, organisms within an ecosystem are interconnected and energy flows through the system, when these processes and functions are within the relevant hierarchies of organisation and cycles of change that control system behaviour, then ecosystems are said to be healthy (Campbell 2000).

The term ‘health’ is criticised as being value-laden and difficult to measure. The definitions of health are socially constructed and its subjectivity could cause variations in the definition of a healthy environment between different groups of people (Callicott 1995; Fitzsimmons 2003). The subjectivity of the term healthy means that it could be manipulated by parties for their own benefit. To reduce the subjectivity of the term ecosystem health, Rapport *et al.* (1998c) suggested that ecologists determine the objective parameters of healthy ecosystems and within those parameters, people could determine how the ecosystem should be altered to achieve various social goals. For example, to identify the success of a watershed rehabilitation process, stakeholders agreed that the quality of the water, certain landscape elements and the availability of ecosystem services, such as recreational use, would be required to describe whether the areas could be defined as healthy or not (Hilden 2000).

The ecosystem health concept is contentious (Suter 1993; Wicklum & Davies 1995; Lancaster 2000; Fitzsimmons 2003; Lackey 2003) because it links scientific ideas and value judgements. The proponents of ecosystem health describe the concept as one that would encourage people to be involved in natural resource management, thus achieving positive outcomes for both people and the environment (Orr 2002). Policy goals that protect health, whether landscape, rivers or children are likely to engage the publics interest and gain support (Karr 2000). Those opposed to the concept describe it as a system for managing the environment using emotive value judgements, not independent scientific reality (Suter 1993). The ecosystem health concept views the environment in a holistic manner and promotes collaboration between people and management agencies. In contrast, Westernised natural resource management often focuses on managing the natural resource using centralised top-down control that often excludes people from the decision making process (Bryant & Wilson 1998). The top-down control policies have solved some of the conspicuous environmental problems, such as pollution emissions, but have failed to solve the others. The major reason that top-down approaches do not work is because people are not involved in the decision making, the policies are inflexible and seen by the community as excessive. The ecosystem health concept has been explored in this thesis because it is being adopted in many environmental policies and is seen as a way to involve people in environmental management decisions (Rapport 2003).

Ecosystem health motivates action by using a metaphor, and like all metaphors its use causes discomfort or tension (Ross *et al*. 1997). Metaphors are ordinary language used in an extraordinary way, however, it is the tension or discomfort that gives the metaphor its power (Eisenberg 1992; Ross *et al*. 1997). Metaphors are used to attract attention and transmit information efficiently. The term, "ecosystem health", causes tension because it links a scientific concept, ecosystems, with the human value, health. This attracts attention, but also evokes action because most of us can relate to a state of well-being in our own bodies (Ross *et al*. 1997) and therefore, the concept transfers directly to a healthy environment.

Although, the ecosystem health concept is contentious, a holistic view for managing the environment is widely promoted (Grumbine 1994; Christensen 1996; Jasanoff *et al.* 1997; Slocombe 1998). A holistic view is required because of weaknesses in management models that consider ecological, social or economic strategies separately. The state of the environment, however, is a consequence of interactions between all three systems. Ecological relationships between plants and animals, for example, affect resource condition, but so do cultural values and beliefs of the local community and economic importance of the resource on the global market. As stated by Abel and Blaikie (1986 page

736) it is necessary to combine both ecological and social data because “exclusion of the first leaves the analysis incapable of ecological explanation, while neglect of the second leaves the explanation in the realm of academic ecological relations where the effects of the people and their institutions are unexplained and which assumes the problem is one based in nature”.

Several models that integrate social and ecological data are currently being used to inform environmental policy decisions including, 1) ecosystem management, 2) sustainable development and 3) ecosystem health. The three models foster a more holistic approach to environmental management. A holistic approach to environmental management recognises people as a fundamental part of the environment. These models also identify that complex linkages occur across spatial and temporal scales and that an adaptive approach to environmental management is required (Walters & Holling 1990). These models share many attributes and are often used interchangeably. Ecosystem management focuses on maintaining the natural environment (Grumbine 1994; Christensen 1996), often with a goal of conserving environments to pre-industrial condition. The integration of people in decision making was initially limited (Machlis 1992; Endter-Wada *et al.* 1998; Song & M'Gonigle 2001; Mascia *et al.* 2003), but has increased in recent years. Sustainable development focuses on development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED 1987). The guidelines are not very specific, but have been adopted by many governments. The concept provides no direction for management and no readily identifiable means for achieving the desired end results (Lorenz 1999). Sustainable development, considers the environment, but has a focus on social and economic goals, such as skill acquisition, employment and maintenance and operation of industries and societies (Lyons *et al.* 2001; Walters & Samways 2001; O'Regan *et al.* 2002). Reporting for sustainable development now requires a triple bottom line where environment, social and financial measures are recorded.

Ecosystem health, the last of the three models, encourages people to be involved in management and care for the environment as part of their everyday activity because it uses familiar terms and invokes a societal value. The effects people have on the environment are widespread requiring an environmental ethic in all areas of life. The ecosystem health concept focuses on building a bond between people and the environment. The ecosystem health concept is highly integrated, recognising that people affect the health of the environment and that the health of the environment affects the health and well-being of people (McMichael *et al.* 1999; Kusel & Alder 2003). Furthermore, when people view themselves a part of the environment they are more likely to increase their environmental concern and act accordingly (Schultz 2000). While these management strategies are similar ecosystem health was chosen because the terminology is people friendly and may more readily encourage involvement of the broader community.

Importantly, ecosystem health can be described by disciplines with the social sciences, such as anthropology, environmental psychology, economics, population health and others, rather than being the sole responsibility of natural sciences, broadening our understanding of environmental condition and increasing flexibility and innovation in management decisions (Ross *et al.* 1997; Slocombe 1998; Ura 2003). The integration of these fields is an important step in overcoming institutional barriers in implementing integrated approaches to natural resource management (Heberlein 1988). People who have a long association with the environment usually develop effective community-based management (Atran *et al*. 1996; Berkes & Folke 2000), which has been eroded by colonialism and globalisation (Machlis 1992; MacKinson 2001; Song & M'Gonigle 2001). Western science, which is the basis of many natural resource management policies, however, is based on the separation of nature and culture which rejects local knowledge (Robertson *et al.* 2000; Song & M'Gonigle 2001) as it does not follow scientific norms. Local knowledge is not grounded in empirical methods and peer review or even presented in a written context, but it is experiential with knowledge accumulated over generations (Machlis 1992; MacKinson 2001; Song & M'Gonigle 2001). These differences, plus institutional separation makes local and scientific knowledge difficult to integrate into environmental management. Additionally, there is concern from natural scientists that if control of natural resources is dominated by local communities and natural science is but one opinion in many, conservation goals may not be met and the environment could be manipulated for private gains (Callicott 1995). Recent studies however suggest that combining local and scientific knowledge in the management process benefits both the environment and community involved (Kusel & Alder 2003; Rapport *et al*. 2003).

The ecosystem health concept hinges on using common language, local involvement and sharing of knowledge to motivate people to act in a manner that maintains environmental health. For the ecosystem health concept to be effective, a link between people's belief and their behaviour is required. Theodori & Luloff (2002) identified that people who were sympathetic or pro-environment in their beliefs where more likely to engage in pro-environmental behaviours, than those people who were neutral in their belief towards the environment. People's beliefs are influenced by demographic variables such as literacy, income, social status and power (Stern & Dietz 1994; Kaplan 2000; Stern 2000) and therefore the ecosystem health concept focuses on influencing these demographic variables. Involving people in environmental management is empowering because a person's knowledge is incorporated into the management decisions, people within the community are given new roles improving their social status.

The three integrative models are being used to manage natural resources in systems where technical top-down styles of management have failed. Modern agricultural methods for example, focused on technical solutions to produce high yields that required high inputs of chemical and nutrients but has caused major land degradation problems (Altieri & Nicholls 2003). In Australia for example, farming practices have cleared native vegetation from the land causing loss in biodiversity, soil water logging and dryland salinity (Curtis & Lockwood 2000; Carr 2002). The farming areas have become non-productive and high in costs to maintain, reducing profits from agriculture products and land values (Bell *et al.* 2001). Changes in farming practices, such as Landcare, that have focused on restoring the health of the land, increasing biodiversity, involvement, employment and profitability, have provided promising results (Curtis & Lockwood 2000; Bell *et al.* 2001; Carr 2002). In Californian grasslands, communication and project developments between graziers, conservationists and tourist operators have developed strategies that have increased biodiversity and maintained grazing and tourism opportunities (Hamilton 2003; Reiner 2003). Agricultural properties in the United Kingdom and Europe manage to promote environmentally focused agriculture have improved the biodiversity and been economically profitable compared with the countryside as a whole (Peach *et al.* 2001; Carey *et al.* 2002).

This thesis explores the usefulness of the ecosystem health concept and addresses the tensions between scientific and local knowledge by using a case study of coral reefs that are associated with different levels of boating use and as a consequence, various levels of anchor damage. Coral reefs are important marine communities that support a high biodiversity, similar to that of rainforests, are highly productive and support major fisheries and tourism operations. The coral reef structures also play an important role in protection of coastline from storm damage. Anchor damage clearly links a direct human impact with the condition of the environment and allows for a gradient of environmental condition, similar to the continuum described in the ecosystem health concept (Figure 1.1), to be assessed.

1.2 General aims and significance

The ecosystem health concept is important in environmental management; however defining the term and finding ways to measure the health of an ecosystem is problematic. The false dichotomy of nature and culture, which is the basis of much natural resource management and science, has led to this problem. Natural sciences are conducted following a hypothetico-deductive approach of testing hypothesis under the umbrella of established theory using objective quantification. The definition of health, on the other hand, is not a measurable environmental condition, but requires a culturally-based value judgement. Combining these two knowledge systems into one concept is difficult. The benefit of the ecosystem health concept, which encourages people to be involved in environmental management and provide a value judgement, is the very thing that causes problems. To understand the relationship between these knowledge systems, the ecosystem health concept is explored by assessing the condition of coral reefs associated with different intensities of anchoring from both an ecological and social perspective. Specifically, the research aims to: 1) identify environmental indicators to evaluate management strategies; 2) identify perceptual meanings ascribed to coral reefs, 3) evaluate the relationship of perceptual meanings, health judgements and environmental indicators; and 4) use the ecosystem health indicators developed to assess a coral reef management strategy.

1.3 Thesis Outline

People view coral reefs in various ways. Chapter 2 explores the importance of community involvement in natural resource management and outlines information about the condition of coral reefs provided by various members of society. An overview of research techniques to identify indicators using both ecological and perceptual assessments is provided.

Natural environments include a vast array of biota, biological interactions and physical processes, thus eliminating the possibility of measuring every variable during an evaluation. Therefore, a few essential variables or indicators need to be selected to measure whether the objectives of management strategies have been achieved. Chapter 3 develops a framework for selecting environmental indicators using a coral reef habitat as a case study.

Incorporating people's values and beliefs during environmental management increases collaboration between stakeholders and produces innovative and flexible strategies. In Chapter 4, participants with a range of experience of coral reefs were asked to describe photographs of coral reefs associated with different intensities of anchoring, to elicit perceptual meanings ascribed to coral reefs.

Disciplinary separation of the natural and social sciences has hampered understanding of the relationships between people and nature, making the description of a healthy environment difficult to define. Chapter 5 combines the ecological and perceptual assessments of coral reefs associated with different levels of anchor damage to identify which elements of the environment are consistent within a description of a healthy coral reef.

Managing an environment to meet ecosystem health goals will only be successful if the environment is measured and managers and community informed about the success or otherwise of the strategy. In Chapter 6, the ecosystem health indicators, developed in this thesis, are used to evaluate a management strategy implemented in the Whitsunday region to protect coral reefs from the cumulative effects of anchoring.

The final chapter reviews the appropriateness of ecosystem health concept, when applied to the coral reef environment. The appropriateness is assessed by reviewing the relationship between people's perceptual meanings and health judgements and by looking at the effectiveness of the Reef Protection Program.

CHAPTER 2

INDICATORS TO ASSESS CORAL REEF CONDITION: INTEGRATING VIEWS OF SOCIETY[2]

2.1 Introduction

This chapter explores the importance of community involvement in environmental management and outlines information about the condition of coral reefs provided by various members of society. This chapter discusses some of the difficulties in identifying indicators that could be used to measure the environment, particularly with respect to coral reefs and anchor damage. The methods used in this thesis are also broadly outlined.

Indicators that measure environmental condition are required to conduct evaluations of management strategies (Dudley *et al.* 1999b; Hockings & Phillips 1999). Evaluating the state of the environment facilitates adaptive management and maintains enthusiasm for protected areas. To conduct evaluations, indicators that measure important attributes of the environment are needed. The choice of indicators is critical to how people construct and solve environmental problems (Machlis 1992). Indicators are needed to measure the environment to evaluate whether the objectives of management have been met and to provide information to local communities that encourages conservation and adherence to the management plan (Hockings *et al*. 2000). It is unlikely that one indicator could be useful for both purposes. For raising awareness of environmental problems, it is important to choose an indicator that is valued by people. In terrestrial environments the use of charismatic species such as pandas and elephants, as indicators, is an effective awareness-raising strategy. In comparison, the use of insects might provide early warning of environmental change, but are not of particular interest to most people (Machlis 1992). Similarly, there may be elements of coral reefs that are important to local communities,

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although not to scientists, that could be useful indicators of changes occurring to the environment in response to the management plan.

Encouraging community participation in conservation, both within and outside protected areas, benefits natural environments and the communities involved. Communities initiate and manage some marine protected areas (MPAs) (Katon *et al*. 1999; Chuenpagdee *et al*. 2002; Hodgson & Liebeler 2002). In the Philippines, rapid population growth increased destructive fishing practices, including the use of cyanide, blast fishing and small-mesh nets (Katon *et al*. 1999). The increased fishing effort devastated coral and fish populations. Shared community and government fisheries management schemes have since established MPAs. The local community conducts the day-to-day running of the protected areas, which has led to a decline in illegal fishing practices. People reported benefits from the joint management arrangements, including increased knowledge, better information exchange, faster conflict resolution and more fisheries resources. The cover of coral and abundance of fish have increased within the MPAs (Katon *et al*. 1999). Similar increases in fishing pressure in San Felipe, Mexico, led to the establishment of an MPA by fishing co-operative and groups of local fishers, without the support of state or federal governments. Fishers' knowledge was used to ensure that important nursery grounds for lobster, grouper and octopus were included in the protected area (Chuenpagdee *et al*. 2002). Although levels of illegal fishing have declined, resource condition since closure has not been evaluated.

Monitoring environmental condition by local community groups is an effective way to involve people in conservation. Monitoring techniques are generally developed by scientists and modified to suit the skill and financial level of the community. Reef Check, for instance, mobilised 5 000 volunteers to measure coral reefs around the world. Scientists trained the volunteers, and supervised monitoring and data collation. Volunteers were also taught about the ecology and value of coral reefs. Involvement in Reef Check has led to the initiation of new coral reef management activities and established a measurably successful marine park (Hodgson & Liebeler 2002). Using media coverage, Reef Check additionally raised awareness of coral reef degradation with people not directly involved with monitoring.

Often questions are raised about the rigor of data collected by community groups and whether the data can provide useful information for management decisions. However, programs such as Water Watch in Australia have shown that their techniques are consistent, and their data have been incorporated into government databases and management decisions (Carr 2002).

Monitoring by community volunteers can extend the spatial and temporal replication of data beyond those collected by professionals alone. In addition, selection of indicators with greater local meaning than the standard scientific measurements could increase community awareness and motivate action. For instance, indigenous cultures use indicators within the environment to rate the stocks of hunted species or quality of pastures prior to exploiting the resource (Berkes & Folke 2000). Gasteyer & Flora (2000) found that community action was stimulated when the problem of water turbidity was expressed as the depth at which one could no longer see a pair of white tennis shoes. Expressing the problem in familiar terms led to greater efforts to reduce effluent and soil erosion. Use of community-based terms to describe coral reef condition could increase conservation efforts.

This chapter explores the tension between objective and subjective knowledge systems with relation to descriptions of coral reefs. I describe how indicators that measure changes to coral reef condition associated with different levels of anchoring could be identified using ecological measurements and people's perceptions. The indicators developed by these techniques may extend people's involvement in conservation of coral reefs in three ways. First, the indicators identified by ecological techniques (Chapter 3) can be used to monitor coral reefs according to the classical community monitoring design. Second, showing people underwater scenes of coral reefs (Chapter 4) may increase awareness of environmental change. Finally, exploring people's perceptions of coral reefs may identify elements of the reef that are important to people (Chapter 5), but not necessarily scientists. If coral reef condition is described using indicators that have high perceived value, people might be motivated to initiate or intensify conservation efforts.

2.2 Ecological indicators for coral reefs

Natural scientists measure many different components of coral reefs and there is conjecture about which element would best describe changes to coral reef condition associated with different levels of boating use. Measuring damage to corals may provide the most useful indicator. However, physical damage occurs as a result of both human and natural impacts, and identifying the cause of the damage is difficult. Dustan and Halas (1987) found significant amounts of fragmentation of *Acropora palmata* at heavily used areas of Carysfort Reef (Florida Keys). These fragmented areas also contained high numbers of broken propellers, lines, personal effects and other debris. Researchers used the presence of "human debris" and lack of damage in adjacent low-use areas to suggest that recreational use caused the recorded damage. Jameson *et al*. (1999) did not identify the cause of damage, but compared the amount of broken corals and percent cover of rubble at high-use sites with rates of natural damage recorded in the literature. High numbers of overturned, gouged and fragmented colonies were found on reefs associated with high levels of anchor use on the Great Barrier Reef (Malcolm 1998). Measuring one or all of these types of coral damage may provide a useful indicator of change in coral reef condition associated with anchoring.

Percent cover of benthic categories is widely used for monitoring reefs throughout the world and is particularly useful in observing gross changes to coral communities over large areas. Mortality of corals and increase in algal cover is a sign of coral reef degradation (Done 1992b; Hughes 1994). However, there are some problems in interpreting these indicators for coral reef condition, because there is a need for earlier baseline data, which are often not available (Bak and Meesters 1998). Often, a change in coral cover is reflecting a change in one or possibly two major taxa, for example, the status of tabular *Acropora* drove many changes in coral cover on the Great Barrier Reef (Sweatman 1999). How the growth and death of a fast-growing coral affects long-term coral reef health is debated (Sweatman 1999).

Number of species affects diversity and structural complexity of coral reefs. Coral reefs generally have high numbers of species and structural diversity, although corals can also form mono-specific stands. Disturbance can influence the relative occurrence of coral species on a reef. For example, high use by boats might deplete fragile species. Species that are associated with, or missing from, coral reefs may affect how people perceive them and make useful indicators.

The health of individual corals is important in determining the overall health of a coral reef. Coral diseases are present in low prevalence on the Great Barrier Reef (Dinsdale 2002; Willis *et al.* 2004), and are an important cause of mortality of coral reefs in the Caribbean (Aronson & Precht 2001). Coral bleaching, where individual colonies lose their symbiotic zooxanthellae, is a sign of stress and is highly visible on affected reefs. Another major cause of mortality of corals that affects the health of coral reefs on the Great Barrier Reef is outbreaks of *Acanthaster planci*, a coral eating starfish. Whether signs of coral stress are greater on reefs with higher levels of visitation requires investigation.

Large coral colonies are important in populations for their increased reproductive output and structural complexity. Large corals have high aesthetic value. To maintain coral communities and visitor satisfaction, these colonies need to be protected (Done 1995; De Vantier *et al*. 1998). Hawkins & Roberts (1993) found smaller colonies in trampled areas, attributable to higher rates of fragmentation and lower growth rates. Size structure of coral communities supplies information on the time between disturbances (Bak and Meesters 1998). Therefore, size structure could be a useful indicator of the condition of coral reefs influenced by different levels of boating activity.

To identify the most useful ecological indicators, surveys were conducted at three coral reef sites with high levels of anchoring and three coral reef sites with low levels of anchoring (Dinsdale & Harriott 2004). At each site the following ecological variables were measured, the amount of damage, disease, coral cover, species diversity and size frequency of selected species and evaluated against a set of selection criteria (Chapter 3). My research also identified the useful indicators from a subjective community approach, outlined in 2.3 and Chapter 4.

2.3 Community indicators of coral reefs

Coral reefs are popular tourist destinations; therefore research has been conducted on the links between coral reef condition and visitor satisfaction. Visitors rate experiencing nature or seeing natural beauty as the most important influence to their satisfaction (Shafer & Inglis 2000). People are therefore highly aware of their surroundings. Corals and fish have a positive influence on enjoyment of coral reefs (Shafer *et al*. 1993); in general, visitors rated highly the condition of corals and fish on trips to the Great Barrier Reef. However, condition of corals and fish was rated higher by snorkellers than by non-snorkellers. Return visitors rated coral condition lower than did first-time visitors (Shafer *et al*. 1993). Therefore, experiences influenced the judgements of environmental condition. However the condition of the coral reef visited by the people surveyed by Shafer *et al* (1993) was not measured.

Similar to the coral reef examples, people with different levels of experience vary in their views of other ecosystems (Purcell 1992; Tahvanainen *et al.* 2001; Tahvanainen *et al.* 2002). Brunson & Reiter (1996) found that experience changed how participants, who were provided with information about ecosystem management, viewed photographs of forested areas that were manipulated with different types of forest management strategies. Participants with greater experience interpreted the ecological information provided and described the forests managed with an ecosystem management goal as more acceptable than younger participants with little experience (Brunson & Reiter 1996).

Divers who return often to the same sites detect change to environmental condition. Long-term divers at Julian Rocks perceived a decline in marine environmental condition coinciding with increases in numbers of recreational divers (Davis *et al*. 1995). Divers surveyed in Bonaire remarked that the under-water visibility had deteriorated over a five-year period (Dixon *et al*. 1993). Experienced divers at Bonaire noted a decline in coral cover, but not an increase in sand, suggesting that there were more dead corals than previously seen at the site. Ecological surveys identified a decline in coral cover and an increase in dead corals around the dive site, confirming the divers' observations (Dixon *et* *al*. 1993). These surveys suggest that divers, particularly those with experience, are observing the changes in environmental conditions that are detected by scientists.

People with and without reef experience were asked to rate coral reef scenes with respect to ideal image and perceived health (Fenton *et al*. 1998). Both groups of people gave remarkably similar judgements. Typical images of coral reefs from the Great Barrier Reef were rated lower for health than the perceived ideal image. Low ratings were given to coral reef scenes showing damage from *Acanthaster planci*, a coral eating starfish, and cyclones (Fenton *et al*. 1998). The photographs used in the survey were not measured ecologically; therefore, it is not known whether particular types of coral, fish, or change in coral cover or condition influenced perceptions.

People detect changes in the condition of coral reefs, but there appears to be a relationship between the amount of experience a person has and their judgement. To explore which elements of the coral reef environment influence observer judgements, my research is novel by conducting ecological and perceptual studies simultaneously. Perceptual studies are frequently used to identify how different groups of people view the environment and what characteristics of either the environment or the participant causes variation in those perceptions (Kaplan & Kaplan 1982; Nasar 1988).

Preferences for different types of environments are a combination of biophysical, psychological and phenomenological elements (Fenton & Reser 1988). Therefore, evaluations of the three elements are required for an understanding of perceptions. The initial focus of a perceptual study was to relate people's preferences with biophysical elements within the scene. The researcher quantifies the biophysical elements, including measurement of the area and perimeter of each biological element present and estimations of the slope and relief. The scenes are presented to people to ascertain their preference. Preferences for terrestrial landscape scenes are related to the areas of vegetation and water (Bell *et al*. 1996), but it is not known what biophysical elements of underwater coral reef scenes are preferred.

The variation between preferences can not, however, be attributed solely to biophysical elements within the scene. Furthermore, the predictors do not always make intuitive or theoretical sense (Bell *et al*. 1996). Therefore, the second stage of the photographic study relates preferences to psychological or cognitive processes rather than to biophysical elements. Kaplan and Kaplan (1989) suggested that preferences for a scene were related to predictors such as complexity, mystery, coherence and legibility. However, these predictors were not constant between scenes; for example, complexity could predict preference for one scene and mystery for another. Different types of predictors could be important in underwater scenes, for example, turbidity, colour and light.

Preference for a scene relates not only to the presence of certain biophysical elements, or psychological predictors, but to experiences and beliefs. Therefore, the last stage of the study follows the phenomenological approach, which identifies preferences based on subjective descriptions related to experience. Preference for a scene varies according to familiarity, knowledge and experience (Purcell 1992). For example, people who had spent time in a wetland setting preferred that scenery to alpine scenery that is usually preferred (Mugica & Vicente de Lucio 1996). Perceptual studies use photographs taken from the environment of interest and present them to a range of participants to gain an understanding of the relationship between their indicators. Photographic surveys have been found to provide a useful representation of the environment (Shuttleworth 1980). In comparison, written surveys may restrict focus and pre-empt answers, since the researcher may provide the environmental cues. Management strategies and environmental changes are also perceived more negatively when presented as written descriptions than as photographs (Tahvanainen *et al*. 2001).

In this thesis, to explore the relationship between experience and descriptions of coral reefs, managers, scientists and people from the local community were asked to participate in a perceptual study that focused on the phenomenological approach (Chapter 4). People were asked to describe differences and to judge the health of the coral reefs presented photographically. The coral reef photographs presented to people were from the same location as the ecological study outlined in section 2.3 and described in Chapter 3. Seventysix participants with a range of coral reef experience provided their perceptions of the coral reef scenes depicted in the photographs. The views of people and the ecological measurements were compared to identify the components of coral reefs that are important for people's perceptions (Chapter 5). Therefore, the research is unique in identifying the most useful indicators to describe changes in coral condition associated with anchor damage from two perspectives: the objective science and subjective community approach.

2.4 Application of the indicators

Since management strategies have multiple objectives, my research identifies indicators of coral reefs from different perspectives. Therefore, the condition of coral reefs under different management schemes could be described in terms with which either scientists or non-scientists are familiar. Managers could use the indicators to evaluate the effectiveness of their strategies and the local people could use the indicators to see how a change in their activity has benefited the condition of the environment. My research explores the relationships between descriptions of coral reefs provided by ecological measures, perceptual meanings and judgements of health, thus identifying how to describe the coral condition to a wide audience.

CHAPTER 3

ASSESSING ANCHOR DAMAGE ON CORAL REEFS: A CASE STUDY IN SELECTION OF ENVIRONMENTAL INDICATORS[3]

3.1 Introduction

This chapter starts the process of identifying ecosystem health indicators by taking a positivist science approach to measuring coral condition associated with different levels of anchoring intensity. The chapter is structured to develop a framework to identify environmental indicators that can be used to evaluate the effectiveness of management strategies.

Historically, selection and management of protected areas has been based on a belief that management strategies benefit the target species or habitats. At times when resource management for conservation is expensive, and there are many competing demands for limited resources, there has been increased emphasis on demonstrating the success of management strategies. Implementation of protected areas can impinge upon people's recreation and livelihood. To maintain support for the management strategies, it is imperative that indicators measure and communicate positive achievements for conservation. In addition, evaluating the success or otherwise of environmental management improves conservation of natural resources by allowing for adaptive planning, raising awareness of success and identifying areas of concern (Dudley *et al.* 1999a).

Evaluations describe and record changes, if any, to the resource that are linked to management strategies. Until very recently, evaluations of protected areas have reviewed the implementation and management processes, but have not measured their effectiveness in maintaining or improving environmental condition (Alder 1996; Attwood *et al.* 1997). A lack of available data and tools to measure the environment has restricted these evaluations

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to superficial levels (Dudley *et al.* 1999b; Hershman *et al.* 1999; Hockings *et al.* 2000). This also applies to protected areas on coral reefs, which lack long-term data that would allow analysis of the effectiveness of management strategies (McClanahan 1999; Wells 1999).

Natural environments include a vast array of biota, biological interactions and physical processes, thus eliminating the possibility of measuring every variable during an evaluation. A few essential variables or indicators that describe environmental condition need to be identified. An indicator is used to measure whether the objectives of a management strategy have been achieved, i.e. has the indicator "improved" in the area where management has been implemented. Since management plans have ecological, social, and economic objectives, indicators could communicate trends in any of these processes. Thus, an indicator is defined as any variable that measures changes to the environment associated with human activities, both protective and extractive, and can provide information about the system beyond its face value (see (Waltner-Toews 1996; Griffith 1998; Margoluis & Salafsky 1998).

While lists of potential indicators have been produced (Dahl 2000), identifying the right indicator for each management strategy has proved difficult. Many indicators measure broad-scale processes that are not appropriate for specific human activities or management strategies. For example, measuring the extent of coral reefs as an indicator of the amount of coral reef habitat within Australian waters (Ward 2000), would only detect change after catastrophic events and would not be suitable to identify the localised effects of anchoring.

Often multiple variables are suggested to measure environmental change without considering correlations between variables, leading to redundancy in data collection. Yu *et al* (1998) compared the amount of information gained from fourteen different indicators. Four indicators explained 62% of the variation, suggesting that little information is gained for the additional effort of measuring the extra ten variables. Allegations of bias are another problem encountered during the selection of indicators. To avoid these allegations, indicators need to be selected against a set of criteria that is open to public scrutiny (Crabtree & Bayfield 1998; Dale & Beyeler 2001).

Some indicators have proven of little value in separating areas affected by human activities from areas unaffected. Four variables, including measurements of epiphytes, nominated as important to perceptions of seagrass health were found not to differ significantly between healthy and perceived degraded sites (Wood & Lavery 2000). In this study, a combination of the variables, shoot density, canopy cover, shoot height, above ground biomass, productivity and leaf area index, were found to be useful indicators of seagrass health (Wood & Lavery 2000). Similar problems have been encountered during the selection of indicators to assess the effects of human activities on coral reefs. Edinger *et al* (2000) expected a reduction in coral growth rates with increased input of nutrients and sediments related to human activity. However, corals were able to compensate for lack of light in more turbid conditions with increased consumption of particulate matter, so coral growth rates were maintained. Therefore, coral growth was not a useful indicator of water quality changes.

Variables that measure social changes may provide useful indicators of environmental condition. Pollnac *et al* (2000) expected a correlation between high human pressure and poor coral reef condition. However, the opposite occurred because people moved from low condition reefs and set up business on reefs that could provide a high quality product. Therefore, a one-off measure of the number of people using a resource is not a useful indicator of its condition.

To address the problems in indicator selection, a framework is required to filter through the large number of potential variables and identify those that are appropriate to measure changes to the environment associated with a specific human activity. Several frameworks have been suggested to increase transparency and effectiveness of indicator selection. Belnap (1998) measured all possible variables at terrestrial sites traversed by people on their way to view scenic areas. Two sites were selected to measure of a range of variables, one site with high use and one site with low use. However, the lack of replication means that indicators identified may have differed because of natural variability, rather than as a result of human activities. Lorenz (1999) used available data as a starting point for indicator selection, but noted that such a restriction on variables may cause other simple and cost effective variables to be overlooked. Similarly, Hockings (1998) identified indicators for evaluating management programs by reviewing the literature and holding discussions with managers and experts, but did not conduct field tests. The lack of field-testing will make it difficult to identify the best indicators.

To select indicators, the framework developed here integrates three major phases, (i) information gathering, (ii) on-site measurement and (iii) evaluation of variable usefulness (Figure 3.1).

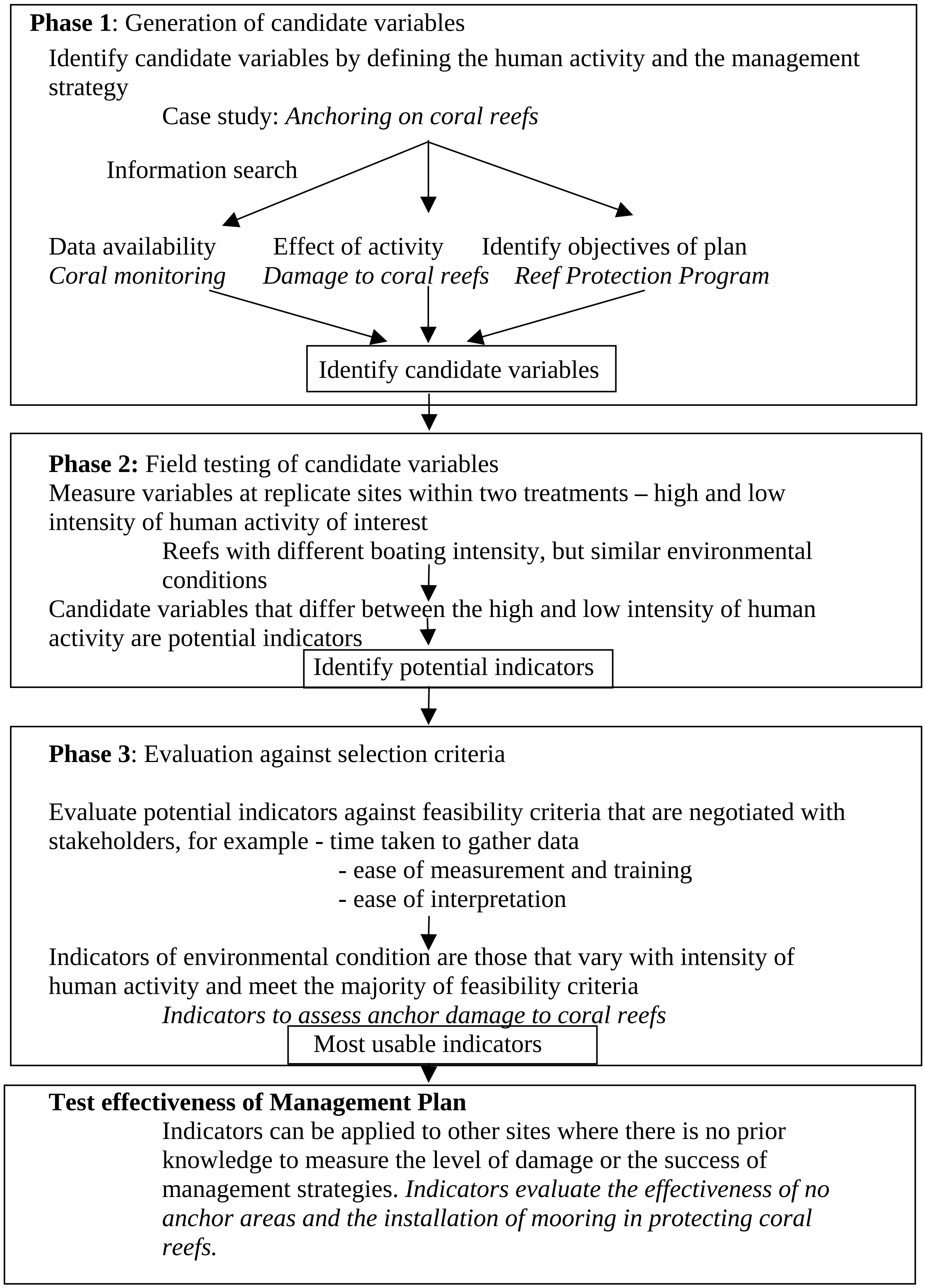
(i) The information-gathering phase identifies how the human activity affects the resource, the objectives of management strategies, and the availability of baseline data. Information from managers and stakeholders identifies their vision for the state of the resource after implementation of the management strategy. Information gathering generates a list of candidate variables that may make useful indicators.

(ii) Candidate variables are then measured at sites that vary in the intensity of the human activity of interest. Replicate sites selected must be similar in ambient condition, thereby reducing confounding results.

(iii) The potential indicators are evaluated against a set of selection criteria for their usefulness to managers and client groups.

Here, I focus on identification of indicators of coral condition that are useful in assessing the benefits of a program to protect coral reefs from anchor damage in the Whitsunday Islands, Great Barrier Reef (GBR). The framework developed could be modified for application in other management contexts.

Figure 3.1. Framework for selecting indicators. Steps for choosing indicators are described in plain text and examples particular to the case study are in italics.



Management of anchoring - a case study from the Great Barrier Reef

Many factors, both natural and anthropogenic, cause damage to coral reefs. Natural changes include storm damage, extreme temperature events, predation, competition and disease. Anthropogenic factors include pollution, sedimentation, fishing, mining, trampling, anchoring, and diver damage (review by (Brown & Howard 1985). The intensity of natural disturbance in marine environments often masks the effects of anthropogenic disturbance (Short & Wyllie-Echeverria 1996; Keough & Quinn 1998), so selecting indicators that detect changes associated with anthropogenic activities is difficult.

Anchors cause damage to coral reefs during setting, retrieval and while at anchor. Corals are broken, fragmented or overturned as the anchor drops to the substratum. Once set, further damage occurs by the chain dragging across the substratum or wrapping around reef structures. If the anchor lodges under a coral colony, overturning occurs during the retrieval process, particularly if an electronic winch is used. Coral reefs that experience high intensities of boating activities have higher levels of broken corals. Higher numbers of fragmented coral were found at Carysfort Reef (Florida Keys), which has high intensities of boating, compared to nearby reefs with less boating activity (Dustan & Halas 1987). These fragmented areas also contained high numbers of broken propellers, lines, personal effects and other debris, further reducing the condition of the coral reef. Four high use coral reefs in the Egyptian Red Sea had higher levels of broken coral and rubble compared with rates of natural damage recorded in the literature (Jameson *et al.* 1999).

Anchor damage has been identified as a management problem on the GBR at sites that receive high levels of boating activity. The Whitsunday Islands is one region with high levels of both recreational small boat usage and commercial charter of small yachts. The management response of the Great Barrier Reef Management Park Authority (GBRMPA) and community organisations to perceived anchor damage has been to develop a “Reef Protection Program”. The ecological objectives of the program are “to protect fringing reefs in popular bays and anchorages from the cumulative impacts of anchoring so that natural coral communities in the area are maintained" (page 2 GBRMPA 1999). The program has two components; reef markers and moorings. Reef protection markers are placed on the surface at strategic positions around the bay, denoting where the cover of coral reef organisms is low and the substratum is comprised of sand. Boat operators line up two markers and drop their anchor seaward (only) of the imaginary line between markers. Therefore, reefs shoreward of the markers are placed within a no anchor area. Moorings were installed to ensure that people have access to the bays while protecting the corals.

The process described below is intended to identify a suite of indicators that can be effectively used to measure the success of the Reef Protection Program. The selected indicators can be used to determine the success of the management strategy to reduce anchor damage. After a period of time, if the strategy is successful, the indicators in the managed area should resemble that for an area with low human use. As a first step to identify outcome indicators, appropriate variables must be identified, field tested then evaluated using a set of transparent selection criteria. The selected indicators will be used to examine the effectiveness of the specific management program in the future.

The indicators identified in this study focus on the outcomes of management, answering the question "has the management strategy improved the condition of the resource?" Other indicators that measure the success of management inputs and processes are also required during the evaluation (Hockings 1998). However, these indicators are outside the scope of this thesis.

3.2 Methods

Phase 1: Generation of candidate variables

A review of the literature and discussion with coral reef managers allowed the identification of a suite of candidate variables, which might be used to measure changes to coral reefs condition associated with anchoring. These candidate variables were broadly grouped into five categories: injury types; coral cover; substratum cover; community processes and coral colony size.

Injury types: Corals injured by anchors show many different symptoms of damage, including abrasion of surface tissue and skeletons, death to portions of the coral colony, fragmentation and removal of the coral colony from the substratum. Furthermore, coral colonies with different morphologies are likely to vary in injury type. Branching species are more likely to fragment, while massive species suffer injuries to surface tissue and skeleton (Marshall 2000). Measuring injury types seems likely to provide useful indicators of anchor damage on a coral reef.

Coral cover: Percent cover of benthic biota is the most widely measured and reported variable for monitoring reefs across the world (Sweatman *et al.* 2000; Wilkinson 2000). A direct symptom of coral reef degradation is decline in coral cover and increase in algae (Hughes 1994). However, coral cover has high natural variability, so detecting changes in coral cover may only be possible after catastrophic events. Hawkins and Roberts (1993) compared relative abundance of corals on trampled and non-trampled reefs and found no significant differences. No difference to coral cover was found on coral reefs in Kenya that experienced different numbers of visitors (Muthiga & McClanahan 1997). While total coral cover may not vary, the cover of some species or family groups may show a difference with anchoring intensity and requires investigation.

Substratum cover: In extreme conditions on a physically damaged reef, coral reef biota may be replaced by dead rubble or limestone pavement from which corals have been removed. A change from high cover of reef biota to other substratum type would indicate severe reef damage. Furthermore, if physical damage continues, the pavement or reef structure itself could also decline to produce more rubble or sand.

Community processes: Coral species differ in their ability to resist damage (Marshall 2000), so it is possible that susceptible species may be lost from coral reefs with high intensities of boating activity. In a study identifying the effects of trampling on reef flat coral colonies, massive species were more resistant to physical damage than robust branching species, whilst delicate branching species were highly susceptible (Liddle & Kay 1987). Therefore, changes in numbers or types of coral species present may be a useful indicator. Changes in species composition could lead to a change in diversity and evenness measures and these should be considered during indicator selection.

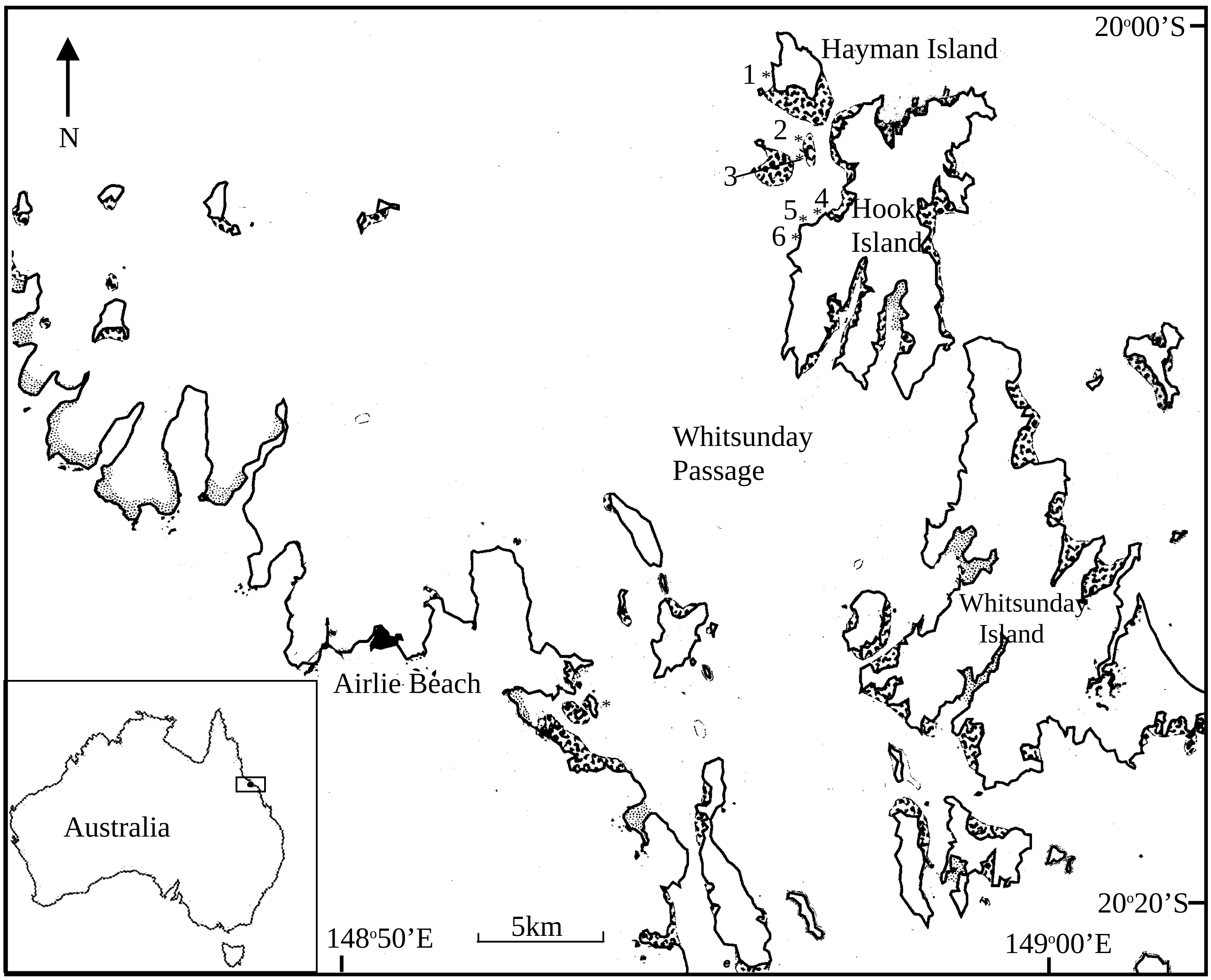
Colony size: The sizes of coral colonies may change with different frequency of disturbance (Bak & Meesters 1998). Reduction in coral size has occurred with intensive boating activity, because corals are broken into smaller pieces and energy is spent on repair rather than growth (Hawkins & Roberts 1993). To maintain coral communities and provide quality visitor experiences, large corals need to be conserved (Done 1995). Therefore, measuring the size structure of the coral community is potentially a useful indicator of changes associated with boating activity.

Phase 2: Field testing of candidate variables

The Whitsunday Islands (148 ^{o} E, 20^{o} S, Figure 3.2) consist of approximately 74 individual islands surrounded by fringing coral reefs. The Whitsunday Islands were chosen for the study for two reasons: first there are multiple reefs that are exposed to similar environmental conditions, such as current and wave regimes. Second, the islands are ideal for boating activities because they are close to the mainland, protected from prevailing winds and provide spectacular scenery. Therefore, the region contains replicate coral reefs that were exposed to similar environmental conditions and influenced by different anchoring intensities. All sites used in the study were westerly facing and protected from prevailing south-easterly winds by prominent headlands. The sites have high turbidity associated with a large (3-4m) tidal range and are located approximately 24 km from the mainland (Figure 3.2).

Field testing of candidate variables took place in July/August 2000 and February 2001. Coral reefs that received high and low intensities of boating activity were selected using information from GBRMPA, the community and on-site observations. Anchoring levels ranged from 0.09 to 4.0 boats anchoring per day, the equivalent range of 36 to 1460 anchors per year. These coral reefs were typically visited by yachts, which use large sand-wedge anchors and electronic winches. The boats were either skippered by commercial operators or hired by people with minimal experience. There appeared to be no preference for any coral reef site by different types of operators. The six sites were divided into two treatments, high anchoring activity (mean of 3.3 anchors dropped per day) and low anchoring activity (mean of 0.37 anchors dropped per day). At each site, two depths were surveyed: the lower slope (8-11m) and the crest (1-3m). Large anchors and chain primarily affect the lower slope. The crest is affected by small reef anchors and associated chain or rope. At each of the six sites, 24 candidate variables in the five broad categories identified in phase 1 were measured as described below.

Figure 3.2 . Location of survey sites (*) on the Whitsunday Islands. Low levels of anchoring occurred at sites 1 - 3 and high levels of anchoring occurred at sites 4 - 6. Note the similarities of the six sites with respect to distance from shore and protection from southeast prevailing winds. Coral reefs are the darkly stippled areas and mangrove areas are lightly stippled.



Injury types

Six types of coral injuries were sampled within ten, 10*1m belt transects laid haphazardly at the two depths within the six sites. Within each transect, the number of fragments, overturned colonies, breaks, gouges, pieces of rubble and diseased individuals were counted. Fragments are defined as the “live portions of a coral colony that has become physically separated, due to breakages of the skeleton, from the rest of the colony” (Highsmith 1982), and remained unattached from the substratum. Overturned colonies are corals that are dislodged from the substratum and move when touched. They may have living tissue or be dead.

Breaks are the loss of individual branches on branching colonies and appear as bright white round circles on the tops of branches. More than one break per colony is possible. Pieces of rubble are dead fragments larger than 10 cm lying on the substratum. Gouges are large pieces of missing tissue and skeleton, often with crushing damage evident (Hawkins & Roberts 1993). Colonies displaying signs of white band or spot disease (Green & Bruckner 2000), black band disease (Dinsdale 2002) or pink spot (Aeby 1998) were counted.

Coral cover

While the belt transect was in position, the percent cover of benthic components were measured using the line intercept method (English *et al.* 1997). The percent cover of benthos was measured in seven categories. The percent cover of four scleractinian coral families including Acroporidae, Poritidae, Faviidae, Pocilloporidae, and a combined group consisting of rarer hard corals (Mussidae, Dendrophylliidae, Fungiidae, Caryophylliidae) was recorded. The percent covers of two more benthic categories were measured 1) the hydrozoans in the family Milleporidae and 2) soft corals. Included in the soft coral category were sponges and zooanthids, however these components contributed minimal cover.

Substratum cover

Substratum cover was measured using the line intercept method. The substratum type was classified as; reef biota, rubble, sand or pavement. Rubble was selected as an important category because it is generated by damage to corals. Sand, for the purpose of this study, included all fine grain material. Consolidated reef matrix with no benthic organisms (except turfing algae) was classified as pavement.

Community processes

Shannon -Weaver Index, and Evenness measures were used to calculate diversity using the percent cover data divided into 16 categories adapted from Hughes *et al* (2000). Two dives were devoted to identifying the Scleractinian coral species present at each site. Field classification is inherently difficult, therefore, underestimation of the numbers of species in the genus *Montipora* and family Poritidae was possible.

Coral Size

To compare the average size of coral colonies, the largest diameter (length) and perpendicular diameter (width) of fifty colonies in four taxa were measured to the nearest centimetre. Surface area was calculated for each colony using the formula for an ellipse. Species measured were *Acropora loripes*, *Seriatopora hystrix*, *Pocillopora damicornis* and branching *Millepora* sp. These species were selected because they were relatively abundant and have different growth morphologies, which suggest they may vary in susceptibility to physical damage. Colonies were measured between a 6-10m depth and the first 50 colonies of each species encountered during a fifty-metre swim were measured.

Statistical Analysis

Variables were tested using multiple analyses of variances (MANOVA) with anchoring treatment (high and low) and sites as fixed factors. Sites were nested within the anchoring treatments. A useful indicator variable shows a significant difference with the intensity of the human activity. Therefore significance levels were evaluated for differences between the anchoring treatments. Interaction terms were not tested because the sampling design is not fully orthogonal. The metrics for candidate variables differed, for example injuries were count data and coral cover was measured using percentages. Therefore, MANOVAs were conducted to test the significance of candidate variables grouped into their broad categories, as described above. Depth as a factor was tested separately for two reasons. First, corals show a distinct zonation patterns with depth and second, the intensity of human activity varied with depth. To achieve normality of the data, numeric data were log (x+1) transformed and percentage data were arc-sin square root transformed (Underwood 1997).

Canonical discriminant analyses (CDA) illustrate multivariate data in a reduced set of dimensions. CDA were used to determine the contributions of different “injury” and “cover” variables in describing the differences in coral condition associated with anchoring. The first CDA used the five injury types and the second CDA used percent cover of the eight coral cover groups. The relationship between sites or groups of sites was displayed on canonical axes (Tabachnick and Fidell 2001). The influence of each candidate variables was identified using a bivariate combination plot (bi-plots).

Consecutive CDAs were used to test the ability of different combinations of candidate variables to describe the changes in coral condition associated with different levels of anchoring. Four CDAs were performed, including combinations of; 1) injury types and coral cover, 2) overturned corals and coral cover, 3) overturned corals, cover of Acroporidae and soft corals and 4) a stepwise CDA. Cross validation was used to identify the combination of candidate variables that correctly classified the most replicates (Tabachnick & Fidell 2001). The data is divided into 12 categories (six sites by two depths) of equal numbers, therefore, the number of replicates correctly classified by chance alone is 8.3%. The percent correct classification has to be substantially larger than 8.3% for the classifying variables to be useful.

Phase 3: Evaluation against selection criteria

The candidate variables that showed a difference between coral reef sites with different intensity of anchoring (potential indicators) were evaluated against a set of feasibility criteria. Potential indicators were ranked 1-5 depending on the number of criteria they met, where 1 was the most useful and 5 was the least useful. The criteria were selected to identify indicators that measure the condition of the coral reef and are simple enough to be effectively and efficiently monitored and modelled. Building upon discussions by Belnap (1998), Dale and Beyeler (2001), Lorenz (1999) and local stakeholders, each potential indicator was evaluated against the following feasibility criteria:

Reliable repeatable measure; indicators that are readily identifiable regardless of ambient conditions.

Relevance; indicators that can be linked causally with a specific human activity.

Respond to management; indicators that have a predictable and rapid response to the implementation of management strategies would be most useful.

Ease of measurement and lack of ambiguity; allowing for measurements to be conducted by volunteers.

Robustness; indicators should be unambiguous and low in variation.

Persistence of variables in the environment; variables that persist in the environment allow for impacts to be detected for a longer time period following the impact.

Time required for data collection; indicators that are quick to measure reduce the cost of data collection.

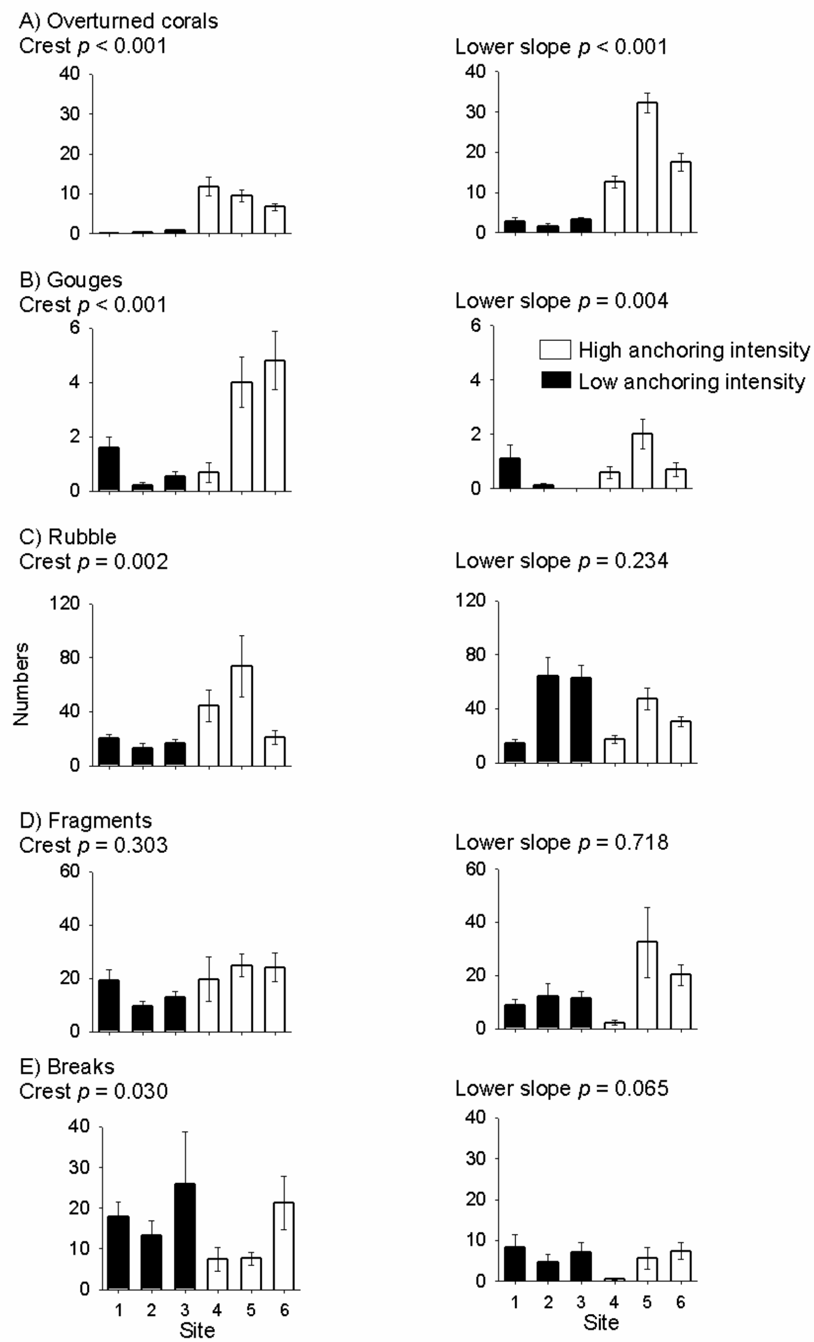
Availability of baseline data; knowing the history of a coral reef gives better understanding of its present condition.

Non-destructive measuring techniques; ensures monitoring does not cause further damage to protected sites.

3.3 Results

Multivariate analysis revealed that significant differences in coral condition occurred between coral reefs associated with different anchoring intensities. Of the five types of injuries to corals, overturned colonies and gouges were significantly higher at the three sites with high intensities of anchoring for both depths (Figure 3.3A and 3.3B). The amount of rubble was higher with greater anchoring intensities on the crest, but not on the lower slope (Figure 3.3C). Fragments generated showed no trend with anchoring intensity (Figure 3.3D). Breaks differed between anchoring intensities on the crest, however there were higher numbers of breaks on the low anchoring intensity sites compared with high anchoring intensity sites, so this was not a useful indicator. Breaks did not vary on the lower slope (Figure 3.3E). Disease incidence was extremely low and did not vary with anchoring intensity.

Figure 3.3. Mean number (+ 1 standard error) of injuries to corals on the crest and lower slope of coral reefs influenced by high (clear bars) and low (shaded bars) intensities of anchoring. Results of MANOVA are presented, degrees of freedom are 1:4:53. Note the different scales on the y-axes.



Percent cover of some coral family groups varied with anchoring intensity. Soft coral cover was lower on both the crest and lower slope of intensely anchored sites (Figure 3.4A). Acroporidae and Milleporidae had lower cover on the crest of intensely anchored sites, but not the lower slope (Figure 3.4B and 3.4C). The cover of Pocilloporidae was not significantly different on the crest, but was lower at the deeper site with intensive anchoring (Figure 3.4D). Cover of Faviidae and Poritidae were higher on the crest of the intensely anchored sites, but did not vary on the lower slope (Figure 3.4E and 3.4F). The cover of rarer hard corals did not vary with anchoring intensity (Figure 3.4G). Variation between coral family groups suggests that anchoring affect some family groups more than others.

At both depths, cover of total reef biota was lower on intensely anchored sites (Figure 3.5A). Cover of rubble and sand was higher on the crest of intensely anchored sites, but there was no difference on the lower slope (Figure 3.5B and 3.5C). Cover of pavement was similar on sites with different anchoring intensities (Figure 3.5D).

Between 96 and 108 scleractinian coral species were found at the six sites, and species richness showed no trend with anchoring intensity. It appears that no species were lost as a result of anchor damage. Neither diversity nor evenness varied with respect to anchoring intensity (Diversity: crest $F = 9.467*10-3$, $df = 1:4:54$, $p = 0.785$, lower slope; $F = 1.361$, $df = 1:4:54$, $p = 0.248$, Evenness: crest $F = 4.648*10-3$, $df = 1:4:54$, $p = 0.572$, lower slope; $F = 0.011$, $df = 1:4:54$, $p = 0.327$).

Mean colony size of the four coral species was highly variable (Figure 3.6). One of the four coral species examined, *Millepora* sp., displayed different colony size between anchoring intensities (Figure 3.6A).

Figure 3.4. Mean percent coral cover (+ 1 standard error) on the crest and lower slope of coral reefs influenced by high (clear bars) and low (shaded bars) intensities of anchoring. Results of MANOVA are presented, degrees of freedom are 1:4:54. Note the different scale on the y-axes.

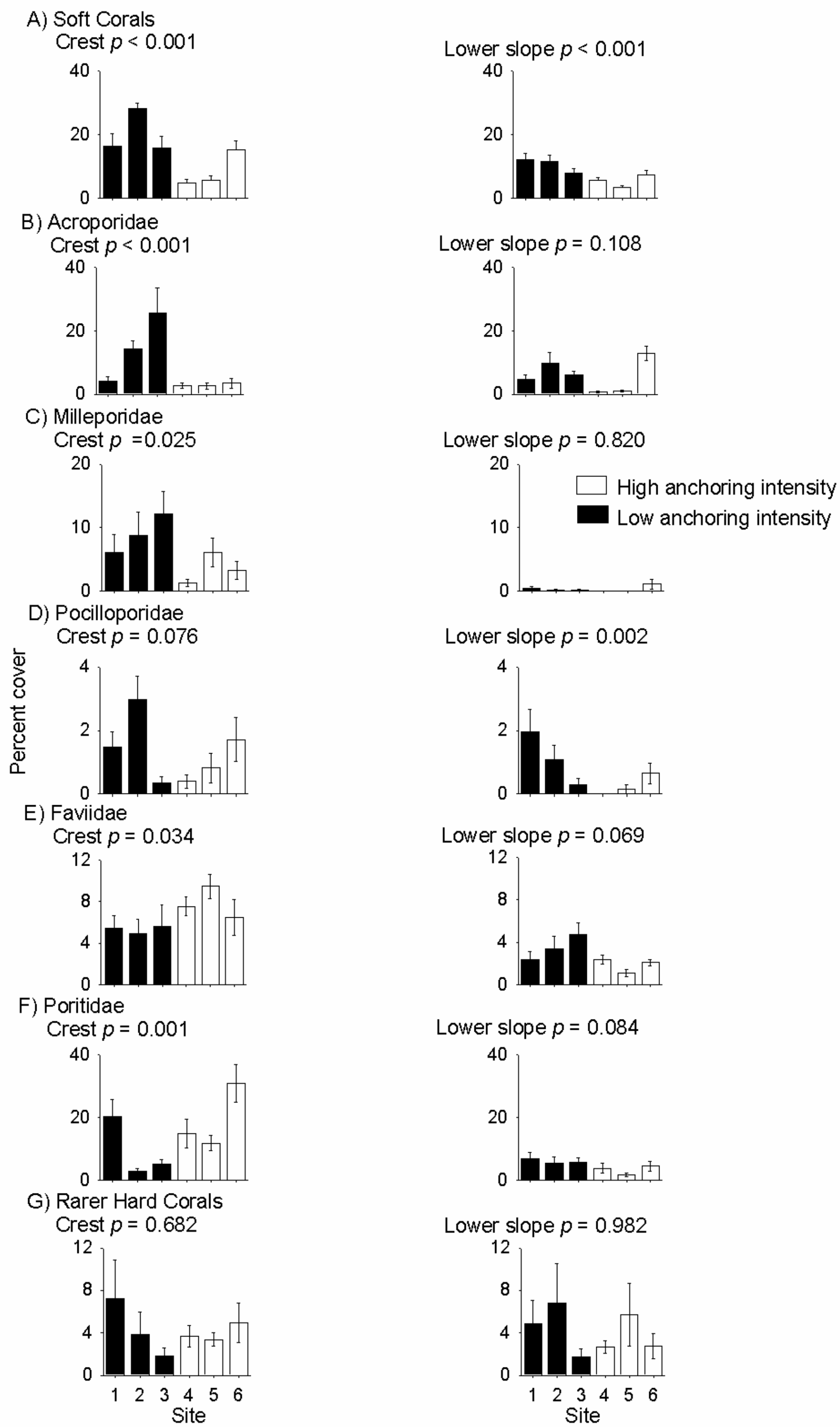


Figure 3.5. Mean percent cover of substrate type including total reef biota (+ 1 standard error) on the crest and lower slope of coral reefs influenced by high (clear bars) and low (shaded bars) intensities of anchoring. Results of MANOVA are presented, degrees of freedom are 1:4:54. Note the different scales on the y-axes.

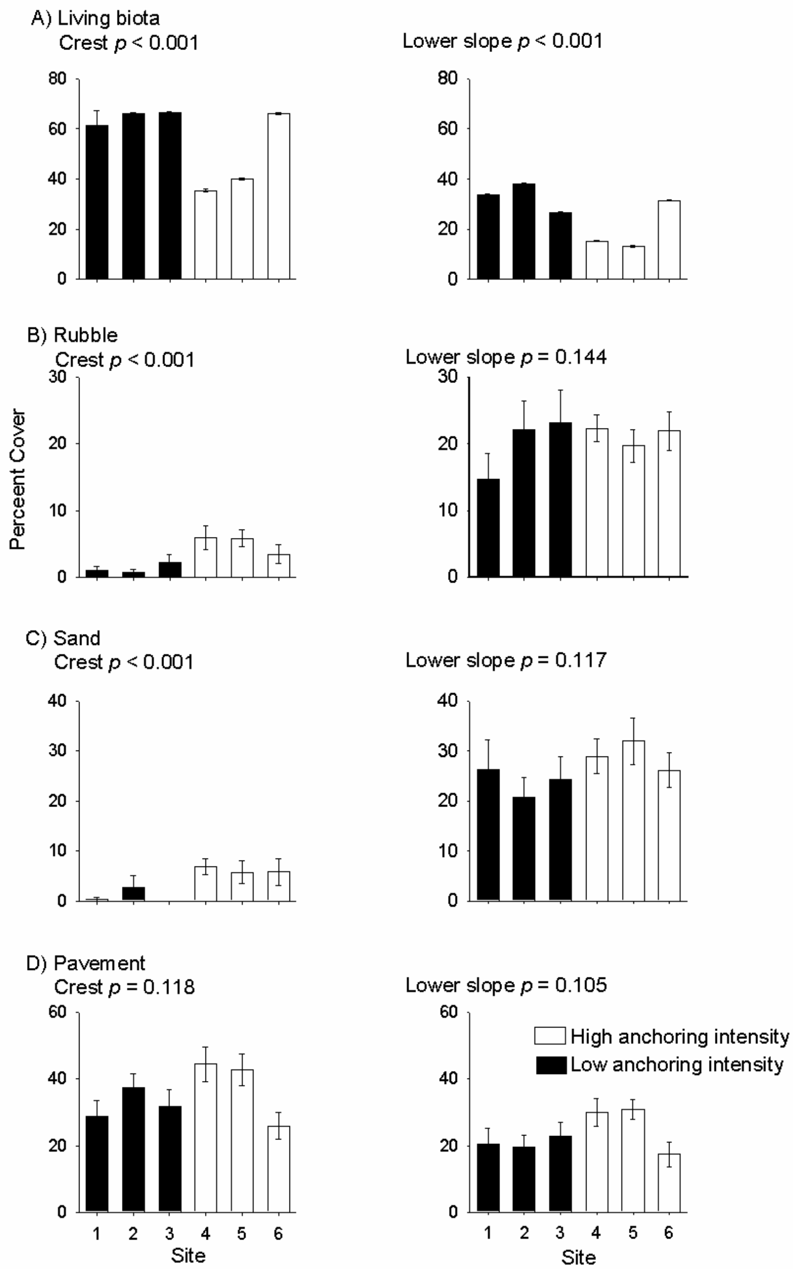
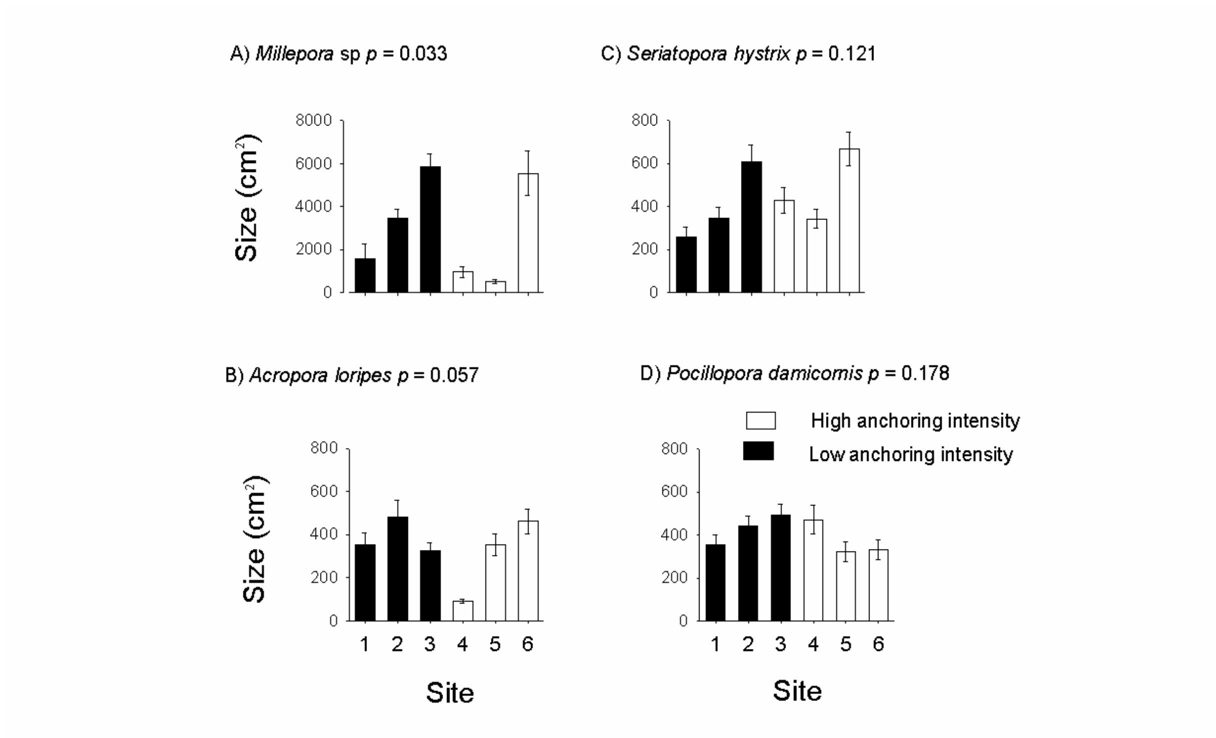


Figure 3.6. Mean colony area (± 1 standard error) for four coral species on reefs influenced by high (clear bars) and low (shaded bars) intensities of anchoring. Results of MANOVA are presented, degrees of freedom are 1:4:280 and alpha levels were set at $p = 0.05$. Note the different scales on the y-axes.



CDA analysis

Complete spatial separation of sites influenced by different anchoring intensities was achieved by describing the condition of coral reefs using five injury types (Figure 3.7). Sites influenced by higher anchoring intensities were grouped to the right and sites influenced by low anchoring intensities were grouped to the left. The relative abundance of each type of injury determined the position of each site in multidimensional space. Sites influenced by higher intensity of anchoring had relatively more overturned corals compared to the sites with lower anchoring intensities. Fragments, rubble and breaks had less influence on the position of the sites compared with overturned corals and gouges (Figure

3.7). Describing the condition of coral reefs using injury type explained 87.9 % of the variation and correctly classified 49.6 % of the replicates, substantially more than the 8.3% expected by chance (Table 3.1).

In comparison, CDA performed on coral cover variables did not successfully separate coral reef sites influenced by different intensities of anchoring (Figure 3.8). Describing the condition of coral reefs using coral cover explained less of the variation (77.3%) and correctly classified fewer replicates (34.2%) compared with measuring injury types (Table 3.1). The variable that had most influence on the separation of sites was the amount of substratum (Figure 3.8).

The CDA conducted using both injury and coral cover variables best described changes in coral condition associated with anchoring and correctly classified the highest number of replicates. However, collecting data on all these variables was time consuming (Table 3.1). A stepwise CDA identified 8 variables (overturned corals, gouges, rubble, cover of soft corals, Acroporidae, Faviidae, Poritidae and Milleporidae), as the most useful variables to describe the condition of coral reefs influenced by anchoring. The stepwise CDA correctly classified 61.3 % of replicates, but collecting data on each of these variables was also time consuming (Table 3.1). However, a combination of the number of overturned corals and coral cover correctly classified 52.1% of replicates and was time efficient. Further reduction in data collection time with minimal loss of correct classification was achieved by measuring overturned corals plus the cover of soft corals and Acroporidae (Table 3.1).

Figure 3.7. Results of CDA using five injury variables on reef sites influenced by low (dark grey) and high (white) intensities of anchoring. The length of the bi-plot line reflects the relative influence of each variable on the positioning of the sites. The number in each circle denotes the group centroid and is equivalent to the site number from Figure 3.2. Crest sites (C), lower slope (S). The diameter of the circle is equivalent to one standard error.

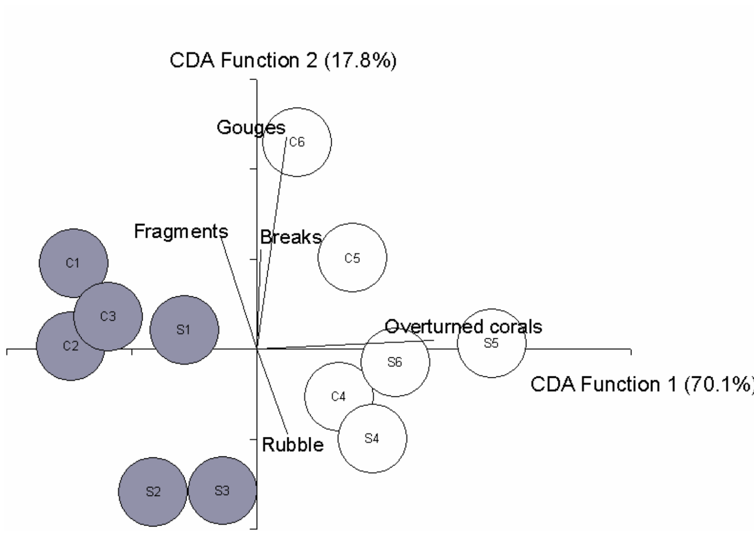


Figure 3.8. Results of CDA using eight coral cover variables on reef sites influenced by low (dark grey) and high (white) intensities of anchoring. The length of the bi-plot line reflects the relative influence of each variable on the positioning of the sites. The number in each circle denotes the group centroid and is equivalent to the site number from Figure 3.2. Crest sites (C), lower slope (S). The diameter of the circle is equals one standard error.

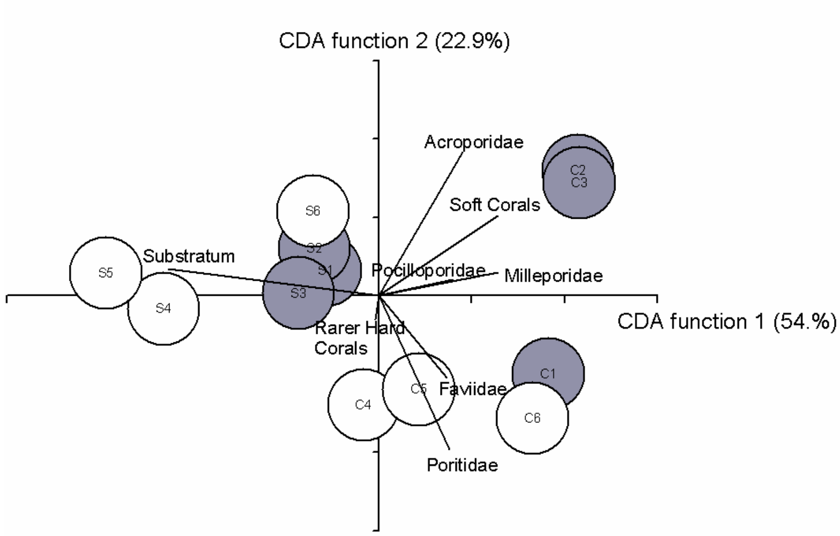


Table 3.1. Comparison of ability and time required for combinations of variables to describe the changes in coral reef condition associated with different intensities of anchoring. Measuring overturned corals plus cover of soft coral and Acroporidae provided efficient classification. Variables selected in the stepwise analysis where overturned corals, gouges, rubble, cover of soft corals, Acroporidae, Faviidae, Poritidae and Milleporidae.

Variables	Percent variation explained	Cross validation	Collection Time minutes/transect
Injury types	87.9	49.6	14
Coral cover	77.3	34.2	6
Injuries and coral cover	74.5	63.0	20
Stepwise	77.2	61.3	16
Overturned + cover	84.2	52.1	9
Overturned + soft corals + Acroporidae	96.3	45.4	Not measured, but estimated as < 9

Evaluation of Potential Indicators against Feasibility Criteria

Eleven candidate variables of the initial 24 differed significantly between anchoring treatment and are considered potential indicators. A matrix was constructed to evaluate the 11 potential indicators against the feasibility criteria (Table 3.2). Overturned colonies met seven out of nine feasibility criteria and were efficient in separating sites with high and low anchoring intensity, ranking it the most useful indicator. There were two drawbacks to using overturned corals to evaluate management action. First, overturned colonies persist for a long time, so may be slow to respond to protective strategies introduced by managers. Second, there is little baseline data available on the number of overturned colonies on coral reefs on a local scale.

Gouges were present in relatively low numbers, but showed a significant difference between anchoring intensities. Gouges were quickly covered in sediment making their identification less reliable, increasing training requirements. Therefore, gouges are considered less suitable than some other measures. Counting pieces of rubble was difficult and unreliable. Furthermore, rubble would take a long time to respond to management strategies, reducing its usefulness as an indicator.

Coral cover variables were not as efficient in distinguishing sites with different anchoring intensities as variables that measured injuries to corals (Figure 3.7 and 3.8). However, they relate directly to management objectives of maintaining coral communities and are important to measure. Soft corals and corals in the family Acroporidae were identified in both the stepwise CDA and MANOVA as varying with anchoring intensity at both depths for soft corals and on the crest for Acroporidae. These coral groups are easily identified and could be monitored by volunteers. For rapid assessment of coral reefs, measuring these two coral groups plus overturned colonies described changes occurring to coral reef condition associated with anchoring (Table 3.1 and 3.2).

Collecting information at coral family level takes longer and requires more training compared with collecting data on substratum categories (Table 3.2). However, the increased costs associated with collecting data at a higher resolution may be worthwhile, as it communicates the effects of anchoring at an earlier stage. Recognising the effects of anchoring earlier allows management strategies to be implemented before degradation has proceeded to a stage where recovery times are long.

The average colony size of selected species was variable and only *Millepora* sp. varied significantly with anchoring intensity. The high variability and extensive measurement times, suggests that measuring sizes of coral colonies is not a usable indicator (Table 3.2).

Table 3.2. The potential indicators were evaluated against nine feasibility criteria. The potential indicators were ranked from 1-5 for their usefulness as indicators, where 1 was most useful and five least.

Potential Indicators	Reliable repeatable measures	Relevance	Time to response to management	Ease of measure	Natural variability (se)	Sampling window	Ease of training	Baseline data	Time to measure minutes/ transect	Rank (1-5)
Damage										
Overturned	High	Yes	Slow	Easy	0.77	Long	Easy	Regional	3.1	1
Gouges	Low	Yes	Medium	Difficult	0.07	Short	Medium	Regional	2.2	3
Rubble	Low	Yes	Fast	Difficult	2.3	Long	Easy	None	5.4	4
Coral Cover										
Soft corals	Yes	Yes	Not predictable	Easy	1.9 %	Long	Medium	Local	6.1	1
Acroporidae	Yes	Yes	Not predictable	Easy	2.0 %	Long	Medium	Local		1
Milleporidae	Yes	Yes	Not predictable	Medium	1.3 %	Long	Medium	Local		3
Pocilloporidae	Yes	Yes	Not predictable	Medium	0.4 %	Long	Medium	Local		3
Substratum cover										
Reef biota	Yes	No	Not predictable	Easy	3.7 %	Long	Easy	Local	3.2	3
Rubble	Yes	No	Slow	Easy	2.3 %	Long	Easy	Local		3
Sand	Yes	No	Slow	Easy	3.0 %	Long	Easy	Local		3
Colony size										
Millepora sp.	Yes	Yes	Slow	Medium	186.3cm^2	Long	Medium	None	32.3	5

3.4 Discussion

Anchor damage is a common disturbance to coral reefs (Jameson *et al.* 1999; Rogers & Beets 2001). Indicators that measure the effects of anchoring on coral reef condition can be used to evaluate management strategies implemented to protect coral reefs from such damage. Selecting useful indicators to measure changes in the condition of coral reefs, as with other natural resources, has proven difficult. To meet the requirements of managers, indicators need to respond to the human activity in question, be cost effective, and relate to management objectives. Therefore, I have developed a framework that evaluates a range of candidate variables to identify the most useful indicator(s). Following the indicator selection framework, 24 variables of coral reef condition were evaluated and three were identified as being of the most use as indicators.

Increases in the number of injured coral colonies occurred on the intensely anchored sites, similar to results reported from coral reefs that are associated with high levels of human activities elsewhere (Davis 1977; Hawkins & Roberts 1992; Allison 1996; Muthiga & McClanahan 1997; Jameson *et al.* 1999; Schleyer & Tomalin 2000). In this study, measuring the number of overturned colonies was the most useful indicator in separating sites that were influenced by different intensities of anchoring. Coral colonies are overturned in cyclonic or storm conditions (Done 1992a), but not during typical weather patterns, so overturned coral are usually present on coral reefs in only low numbers. The number of overturned corals is a usable indicator because they are easily identified underwater, therefore data collection is quick and could be conducted by volunteers, further reducing costs.

Hawkins and Roberts (1992) measured the number of fragmented corals and breaks to describe changes to coral reef condition associated with human activities. Fragments did not vary with anchoring intensity in the Whitsunday case study. A possible explanation for the lack of variation is that fragments are regularly generated on the Great Barrier Reef (Wallace 1985; Rouphael & Inglis 1997; Smith & Hughes 1999). Therefore, the difference between the numbers of fragments generated with and without the influence of anchoring needs to be high to detect a difference. The numbers of breaks was not related to anchoring intensities either, but appeared to be related to the abundance of branching corals, such as Acroporidae and Milleporidae. Rouphael and Inglis (1997) reported an increase of the number of breaks caused by divers on coral reefs with high cover of branching corals.

Measuring injuries to corals was more efficient than the more traditional measures of coral cover in describing the condition of coral reefs influenced by anchoring. Since changes may be detected earlier using other indicators, relying on coral cover may result in a delay in identifying damage or recovery of coral communities. Comparing levels of injuries to coral rather than coral cover identified a decline in condition of coral reefs associated with high levels of human activities in Kenya (Muthiga & McClanahan 1997).

Since coral cover relates directly to the management objectives and provides beneficial information for comparative studies, it was explored further by comparing how anchoring intensity influenced the abundance of different coral families. Coral family groups responded differently to anchoring, primarily because they have different types of growth patterns. Soft corals lack a hard skeleton, are highly susceptible to physical damage and therefore were highly responsive to anchoring. The cover of Acroporidae and Milleporidae on the crest and Pocilloporidae on the lower slope was reduced with anchoring intensity. These corals have a branching morphology that is susceptible to physical damage (Hall 1998; Marshall 2000) such as that caused by anchors. Corals in the family Poritidae and Faviidae have a massive morphology, which is more resistant to physical damage (Marshall 2000) and the cover of these corals varied little with anchoring intensity.

The process followed in the Whitsunday case study identified that measuring a combination of injury variables and the most responsive coral cover variables would be the most useful indicators to describe changes to coral reef condition associated with different anchoring intensities. The indicators identified were overturned corals plus the cover of soft corals and corals in the family Acroporidae. The three indicators could be used to evaluate the effectiveness of the Reef Protection Program implemented in the Whitsunday Region at a relatively low effort for data collection. If the management program is effective, indicators for heavily used reefs where the program is implemented should change over time to resemble values for reefs with historically low anchoring rates.

Selecting appropriate indicators to evaluate management is difficult (Crabtree & Bayfield 1998). The indicator selection framework developed has addressed difficulties in identifying indicators by evaluating a range of variables at sites with high and low intensity of the human activity of interest. The framework is transparent and could easily be adapted to other natural resource management strategies. Where indicators are easy to measure, volunteer organisations can collect data, reducing cost and increasing stakeholder collaboration. The framework developed, using anchoring on coral reefs in the Whitsunday Islands as a case study, identifies indicators to measure and communicate the achievements of management strategies. For these indicators to be useful in evaluating similar management strategies implemented in other coral reef locations, some adaptations may be required. The type of indicator selected will vary depending on the dominant taxa in the local community. Nevertheless, the framework developed here for selection of indicators can be applied to other coral reefs, or even terrestrial situations.

In this chapter, ecological measures of the environment were explored within the context of developing performance indicators to evaluate the effectiveness of management strategies. The framework identified three indicators that were most useful in describing changes in coral condition associated with anchoring intensity. In the next chapter, the same coral reefs are reviewed by people to see how they describe the coral reef environment. The perceptual meanings provided by the participants represent the second stage in exploring the ecosystem health concept.

CHAPTER 4

ASSESSING CORAL REEF CONDITION: ELICITING COMMUNITY MEANINGS[4]

4.1 Introduction

Chapter 4 is the second stage of developing ecosystem health indicators and is conducted from a phenomenological approach. The phenomenological approach is where the descriptions of the environment are identified using participant's descriptions, which relate to their past experiences and beliefs. The chapter is set in the context of identifying perceptual meaning ascribed to the coral reef environment by participants with a range of experience of the coral reef environment.

Collaborative resource management has achieved successful conservation outcomes and benefits for the well-being of the participating community (Russ & Alcala 1999; Carey *et al.* 2002; Carr 2002; Chuenpagdee *et al.* 2002; Hodgson & Liebeler 2002; Pretty 2003a). Where centralised management of natural resources often tends to polarise the public and raise strong opposition, collaboration allows for open discussions of disparate environmental opinions, the sharing of information from different knowledge systems to build knowledge partnerships (Huntington 2000; Lackey 2003) and negotiated solutions to environmental problems. In the Philippines, for example, co-managed marine protected areas have lead to a decline in illegal fishing, improved resource condition, and cooperation and communication between community members (Katon *et al.* 1999). In Australia, local community groups have driven the process to establish fish habitat protection areas (Chalmers 2003) and local knowledge from commercial fishers has been integrated into designing systems of marine protected areas (Williams & Bax 2003).

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To fully develop the co-management of natural resources and attain associated benefits, some barriers need to be overcome. One barrier is to legitimise the use of environmental information provided by people with different backgrounds and experiences, rather than relying on knowledge provided by natural scientists collected using methods of objective quantification (Maxwell 1984; Meffe & Viederman 1995). Centralised resource management, the dominant model of environmental management in Western cultures (Bright & Manfredo 1997; Lachapelle *et al.* 2003), is based on information provided by scientists and often rejects knowledge provided by local people without specialist training (Song & M'Gonigle 2001). Under the centralised management model, scientists present their knowledge and describe the decision process to the community; thus educating the community and obtaining consensus for the management plans (Endter-Wada *et al.* 1998; Patterson & Williams 1998; Robertson & Hull 2001; Capitini *et al.* 2004; Chuenpagdee *et al.* 2004). People who are affected by the management decisions are not given a forum to provide their understanding of the situation and scientists often express doubt concerning the readiness or competency of the community to have direct and equitable involvement in management (Chuenpagdee *et al.* 2004). The community, on the other hand, are concerned about the willingness of managers and scientists to part with authority and embrace the concept of power sharing, which is the cornerstone of co-management (Zanetell & Knuth 2002; Capitini *et al.* 2004; Chuenpagdee *et al.* 2004).

Integration of scientific and local knowledge is important in the management context because while scientists can provide information about the condition of the environment, they generally have a narrow perspective on what the desirable conditions is. Since the desirability of environmental condition is a normative decision, judgements provided by a wider spectrum of the community are required (Lachapelle *et al.* 2003). Combining information provided by lay people and scientists provides a holistic view of the environment (Robertson *et al.* 2000; Huntington *et al.* 2002; Robertson & McGee 2003). Under the present management and research structures, ecological and perceptual studies are conducted separately. Preference studies generally provide a range of environments for people to judge, but rarely do they provide an ecologically measured gradient of environmental condition to be judged. Consequently, there remains a lack of understanding of the relationship between meanings people ascribe to the environment and changes in environmental conditions (Nassauer 1995; Gobster 2001).

Research into people's environmental preferences has identified that there is remarkable consistency in human preference for natural landscapes, particularly those scenes that include canopy trees or water features and which allow a view or vista of the landscape (Kaplan & Kaplan 1982; Nassauer 1995). People's preference for these landscapes is explained using numerous theories, including biological theories that stress the evolutionary advantages of views that simultaneously afford prospect (a wide open view that allows observation of approaching predators) and refuge (protected settings that prevent the viewer from being seen) (Appleton 1988). In addition, information - processing theories have also been developed, which acknowledge a biological explanation, but also suggest that visual preferences are influenced by the amount of meaning within the landscape or landscapes that afford desirable experiences (Gibson 1979). Kaplan and Kaplan (1989) described specific organisational attributes such as complexity, mystery, coherence and legibility that related to preferences. Finally explanations of visual environmental preferences for natural environments have also been developed using a phenomenological approach, which identifies preferences based on subjective descriptions related to people's past experiences and beliefs (Fenton & Reser 1988).

To examine the utility of perceptual information my research uses personal constructs to identify how people perceive a key environment, that of a coral reef. Coral reefs are valued for their diversity, production of food, protection of coastlines and importance to the economy particularly as a tourist destination. To determine whether perceptual information would provide useful information for management, photographs depicting a gradient of coral condition associated with anchoring were used. Furthermore, people with a range of backgrounds, including people whose occupation has a level of interaction with the coral reef environment and those that have no such interaction, participated in the study, enabling some understanding of the variation amongst participants to be assessed. The participants in this study were from a contemporary society rather than a more traditional society that are often the focus of ecological knowledge research. I review personal construct theory and the effects of anchoring and boating use on coral reefs is briefly mentioned (see also Chapter 3) prior to describing the study.

Personal construct theory

Personal construct theory is concerned with how people make sense of the world (Kelly 1955). The theory was developed in the field of psychology to examine the role that different people played in interpersonal relationships (Kelly 1955), but has been adapted to understand how people ascribe meanings to their environment (Fenton 1988; Fenton & Syme 1989; Walmsley & Jenkins 1993; Pike 2003). The theory states that people have an individual view of the people and events that are part of their life (Kelly 1955; Lester 1995). People are constantly examining the people and places around them to generate expectations about what those people and places are like (Walmsley & Jenkins 1993).

The theory states that people have a transparent pattern or template which they create about the world and with each experience they re-mould or recreate their template to explain the world (Kelly 1955). The template is called a construct and each person constructs their own view of the world or events. Constructs are the means by which an individual views the world and aids a person in predicting and controlling the outcome of events. A construct is essentially a bipolar discrimination made by a person and represents a fundamental way of viewing the world (Fransella & Bannister 1977). Constructs are bipolar because by stating what something is, a person is also stating what it is not (Fransella & Bannister 1977; Lester 1995). Accordingly, eliciting these constructs allows the researcher to understand how a person views and values the environment. Each person uses a different construct system however there must be some commonality if people are to communicate to one another about the world around them.

Constructs are elicited using a repertory grid method (Fransella & Bannister 1977). The grid method provides elements or stimuli for participants to discriminate. The participants provide a description and rating of the elements to reveal the underlying way they view the elements. The elements are the objects under study and can be people's names, places or photographs. Using a triad method, participants are generally asked to describe how two of the elements are similar but different from a third element. The elements are ranked or rated in relation to each construct. Repertory grids are used in eliciting meanings from a single participant or from groups of participants (Fransella & Bannister 1977; Fenton & Syme 1989; Young 1995).

Damage to coral reefs associated with anchoring and boat use

Many factors, both natural and anthropogenic, cause damage to coral reefs. Natural changes include storm damage, extreme temperature events, predation, competition and disease. Anthropogenic factors include pollution, sedimentation, fishing, mining, trampling, anchoring, and diver damage (Brown & Howard 1985). Anchors cause damage to coral reefs during setting, retrieval and while at anchor. Corals are broken, fragmented or overturned as the anchor drops to the substratum. Once set, further damage often occurs by the chain dragging across the substratum or wrapping around reef structures. If the anchor lodges under a coral colony, overturning occurs during the retrieval process, particularly if an electronic winch is used. Coral reefs associated with higher intensities of anchoring on the Great Barrier Reef had higher levels of overturned corals and lower cover of soft corals and corals in the family Acroporidae, in comparison with coral reefs associated with lower levels of anchoring (Dinsdale & Harriott 2004). On coral reefs in Florida, higher numbers of fragmented coral were found at reefs which have high intensities of boating, compared to nearby reefs with less boating activity (Dustan & Halas 1987). Four high use coral reefs in the Egyptian Red Sea had higher levels of broken coral and rubble compared with rates of natural damage recorded in the literature (Jameson *et al.* 1999).

The underwater environment is unfamiliar to most people, but several studies suggest that people do perceive changes in the condition of the underwater environment. Long-term divers at Julian Rocks, for example, perceived a decline in marine environmental condition (Davis et al. 1995). Similarly, experienced divers in Bonaire noted a decline in underwater visibility and coral cover and an increase in dead corals over a five year period (Dixon *et al.* 1993). In addition, people with and without reef experience rated coral reef scenes associated with cyclone damage and outbreaks of *Acanthaster planci* (a coral eating starfish) as lower in health and non-ideal in comparison to coral reefs not associated with these damaging influences (Fenton *et al.* 1998).

4.2 Methods

Underwater photography

Obtaining people's judgements of environments presented photographically are comparable with environmental judgements made in the field (Shuttleworth 1980; Shelby & Harris 1985). Therefore, when field trips are logistically impractical photographic surveys provide a comparable alternative. Photographs were obtained from six coral reef sites situated in the Whitsundays region of the Great Barrier Reef. Anchoring activity was calculated using GBRMPA data and by observing boating activity during the field research. Of the six coral reef sites surveyed, three were associated with high levels of anchoring and three were associated with lower anchoring activity (a mean of 3.3 anchor drops per day for the high-use sites and a mean of 0.37 anchor drops per day for the low-use sites). At each site, two depths, the crest (1-3 m) and the lower slope (9-11 m), were surveyed to provide a wide range of coral conditions for participants to judge. Full site description is provided in Chapter 3.

The photographs of the coral reef sites were taken in a non-biased manner by taking one photograph approximately every 1.5 meters along a 50 m transect line laid at each site (Fenton 1981). The transect line was used as a guide for the photograph position, but was not present in the photograph. A side view of the coral reef was taken, because it gave a more familiar appearance to the reef, compared with a photograph taken looking down at the reef structure. The quality of underwater photographs is affected by the weather, tide and time of day; therefore photographs were taken during comparable environmental conditions between March and May 2002.

Selection of photographs and questionnaire construction

A representative set of photographs was selected using four stages; 1) removal of unusable photographs and random selection of six photographs from the 36 photographs taken at each site-depth combination (i.e. 72 photographs selected from the 432 taken), 2) measurement of important coral community characteristics using a grid point survey, 3) a principal component analysis to select photographs with the widest range of variation in coral community characteristics and 4) arrangement of photographs for the perceptual study. Steps 2 - 4 are described in more detail below.

The grid point survey (Fenton 1981) was conducted on the six randomly selected photographs from each site-depth combination, 72 photographs in all, to select the photographs for the study. First, the number of points associated with three broad categories; water, background and foreground were measured to ensure the photographs had a standardised layout. The category “water” is self-evident. The category “background” was the portion of the coral reef that could not be identified because of the integrity of the photograph, for example, shaded by other components, or too distant. The “foreground” comprised coral reef components that were readily identified. The three categories were similar for photographs from each site-depth combination. Photographs comprised on average 65.3 ± 3.6% foreground, 14.4 ± 3.2% background and 20.3 ± 4.4% water, suggesting a standardised layout of the components in the photographs (Figure 4.1). Second, the foreground area was further surveyed (using the grid point technique) to quantify the percent cover of seven coral types, five coral damage types and numbers of fish. These ecological measurements were taken to ensure a gradient of coral condition was provided for the participants to judge and to establish that the photographs were representative of the condition measured in the field (Chapter 3).

Figure 4.1. An example of a typical coral reef photograph used in the perceptual study, showing extent of foreground, background and water.

A principal component analysis (PCA) was conducted on the ecological measurement to select a reduced set of photographs, but maintain the variation across photographs. Photographs from the two depths were analysed separately. Five principal components with eigenvalues exceeding one were identified on the crest and four on the lower slope. Each principal component value was sorted and the photographs with the highest, median and lowest values were selected. The median photograph on the fifth component of the crest was not used because an even number of photographs were required. Any duplicates were discarded and the next slide in the relevant series selected. The selection technique produced 14 photographs from the crest and 12 photographs from the lower slope, providing a total of 26 coral reef photographs from the 72 ecologically measured photographs to be used in the perceptual study.

In a repertory grid methodology a triad of photographs are used to elicit constructs (Fransella & Bannister 1977). However, the underwater scenes were deemed too complex for participants to describe the similarities in two photographs compared with the differences in a third. Therefore, the coral reef photographs were arranged into pairs. Pairs mixing the lower slope and crest were not used. The pairings were randomly distributed between the sites that experienced high and low intensities of anchoring. Therefore, pairings included photographs of sites with high-high, low-low and high-low intensity of anchoring. Pairings were not all high-low anchoring intensity as that may have created a disturbed / non-disturbed pattern that would influence the judgments of participants.

Study procedure

To understand how people describe coral reefs, I elicited meanings that were important to the participants based on the range and organisation of their experience. The meanings ascribed to the coral reef environment were obtained using a modification of Kelly's repertory grid technique (Kelly 1955). The modified repertory grid used photographs of coral reefs as the **elements**, to which people responded. The responses used in discriminating amongst elements are referred to as **constructs.** Constructs are essentially a bipolar discrimination that represents the fundamental way a person views the world. Each construct has an **emergent pole**, which is the first description provided by the participant and an opposite or **implicit pole,** which is the second description provided by the participant for each of the paired elements (Lester 1995). The constructs relate to each other to build a picture or view of how a person perceives his / her surroundings. Eliciting construct systems provides a description of the meanings ascribed to the elements.

The researcher introduced the study to each participant and explained the process for completing the repertory grid. Participants were told that the research was interested in how people described coral reefs, but further information about the purpose of the study or the location of the photographs was not provided (a copy of the repertory grid is presented in Appendix 1.). The participants completed the assessment individually and not as a group.

The study was undertaken in three phases. The first phase asked participants to specify some important way in which pairs of coral reef photographs differ; thus identifying the emergent and implicit pole of each construct. For instance, the participants were asked to "describe one thing that differed between the pairs of photographs". The study was constructed so the participants filled in blanks for the question "Photograph 1 is (or has)

…..? While photograph 2 is (or has) ……?" The verbal description given to photograph 1 was the emergent pole of the first construct and the verbal description given to photograph 2 was the implicit pole of the first construct. Participants' continued providing new constructs for each of the 13 pairs of coral reef photographs or until they could not specify any further new differences.

In phase two, participants were asked to rate the 26 photographs on a presence / absence or binary scale for each of the constructs. If the coral reef depicted, matched the emergent pole of the construct it was scored with a one (1) or if it matched the implicit pole the construct was scored with a zero (0). The photographs were no longer paired, therefore, a majority of photographs could be judged as having the attributes of the explicit pole of a particular construct. The rating process continued until all constructs and photographs were judged. To clarify the assessment procedure the construct murky / clear was provided as an example for the first pair of photographs. Water clarity was chosen because it was expected to be an important construct, but did not directly reflect the condition of the coral reef community.

In summary, each participant provided a verbal description or construct of each photograph pair and all photographs were scored in relation to the presence of each construct. Through this procedure a matrix was formed which consisted of the emergent pole in the first column, binary ratings for each photograph in the body of the matrix and the implicit pole in the last column of the matrix. An individual grid was developed for each participant. On the last line of the grid the participants were asked to rate on a scale of 1-6 the health of the coral reef presented in the photograph. The relationship between the judgements of health and other constructs is explored in Chapter 5. Any construct that was inadvertently repeated by the same individual, that is the same wording was used by a single participant, was excluded from the analysis.

In the final task, participants were asked several demographic questions about themselves and about their experience of coral reef environments. Questions specifically addressing coral reef experience included, employment associated with coral reef research, management or tourism; the number of times participants had scuba dived on coral reefs and the type of visits to coral reefs. Participants were also asked where they gained information about coral reefs, for example, media, natural science presentations or aquarium visits.

Participants

Participants were selected on a convenience basis from target organisations. Convenience sampling was used to ensure people with a range of experience participated in the study. Participants were not divided into groups a priori, but chosen so that people with a range of backgrounds and experiences with coral reefs were included in the study. Participants were drawn from the towns of Townsville, Airlie Beach and Perth and included, marine research ecologists, coral reef managers, dive tourism operators and locals with no working association with coral reefs.

Townsville is a major centre for coral reef science and management and therefore provided participants with a high level of experience with coral reefs. People from Airlie Beach were chosen because this township is the closest location to the surveyed coral reefs (Figure 3.2) and these people may have local knowledge of the reefs that changed their perceptions compared with other groups. Perth was selected as a location to provide participants that were geographically isolated from the Great Barrier Reef and perhaps had not seen coral reefs before. Once the study was completed, the range of personal experiences was used to group the participants. Two distinctive groups were identified; group 1 consisted of participants who had a working association with coral reefs where participants were either, coral reef scientists, managers or dive tourist operators and group 2, were participants who had no such working association with coral reefs.

Statistical analysis

To identify the inherent structure in the data, a principal component analysis (PCA) was conducted on the matrices formed by the constructs and ratings provided by each participant group. PCA was used because the analysis extracts a small number of new components (the meanings) that explain most of the variation in the range of variables (constructs elicited) (Quinn & Keough 2002) and is the method typically used in analysing repertory grids (Walmsley & Jenkins 1993; Young 1995). A PCA identifies the important meanings ascribed to the coral reefs and how each of the individual photographs is rated for each of the meanings. The PCA used a correlation matrix and an unrotated factor solution with principal components generated for eigenvalues exceeding one. The meanings of each component were derived from the constructs, which the participants provided, that had the largest and smallest component loading values on each of the principal components. The researcher reviewed the twelve highest and lowest constructs and identified a common theme or meaning which best described each of the dimensions. Separate PCAs were conducted on the information provided by the two participant groups. The values from the structural matrix were graphed to visually identify whether the participants were separating photographs taken from coral reefs associated with different intensities of anchoring. Relationship between the meanings ascribed to coral reefs were explored using a linear regression analysis.

4.3 Results

Characteristics of participants

A total of 76 people participated in the study. Females comprised 52.6 % of the participants and the average age of all participants was 40.2 years. The participants were highly educated, with 79.0 % tertiary educated. Participants from group 1, apart from having a working association with coral reefs, were mostly experienced divers, had visited coral reefs often and attended natural science coral reef presentations (Table 4.1). In comparison, group 2 participants had little diving experience, had participated in fewer coral reef trips and gained their knowledge about coral reefs primarily from aquarium visits (Table 4.1).

Table 4.1 A comparison of the coral reef experience and personal characteristics of participants. Values show the number of participants that reported each level of coral reef experience.

Demographic character	Group 1	Group 2
Number of participants	42	34
Mean Age (± SE)	36.4 (1.3)	45.0 (2.1)
Sex (M:F)	22:20	14:20
Education		
School : Tertiary	9:33	7:27
Survey Location		
Townsville: Airlie Beach: Perth	18:22:0	12:7:15
Diving experience		
None : Medium : Advanced	9:4:29	21:10:3
Coral reef trips		
None : day: multiple visits	0:4:38	4:6:24
Coral reef information		
Presentation : media: aquarium	35:6:35	16:11:27

Meanings ascribed to coral reefs

The aim of the repertory grid technique is to elicit, from the participants, salient descriptors or constructs that are used to describe coral reef environments. For example, the differences described for photograph 23 and 24, by participant # 4 was pretty – ugly and by participant # 62 was abundant – sparse. A total of 774 constructs were elicited from the participants, 466 constructs provided by group 1 participants and 309 constructs provided by group 2 participants. A similar number of constructs were provided by each participant, with group 1 participants providing a mean of 11.8 (± 0.3) constructs and group 2 participants providing a mean of 11.2 (± 0.4) constructs.

The PCA revealed that both participant groups generated five principal components and these accounted for 59.4 % of the variation for group 1 and 61.8 % for group 2 (Table 2). There was considerable similarity in the number of components and the variance explained on each component by the two participant groups (Table 4.2); suggesting participants with different experiences may have similar views of coral reef environments. The first three components were most instructive in providing meanings for coral reefs and they are considered further. The meanings ascribed by both participant groups on the first three components were similar (Tables 4.3-4.5).

Table 4.2. Comparison of the amount of variation explained on the five principal components derived from the principal component analysis of the two grids.

Group 1			Group 2		
Component	Eigenvalues	% variation	Component	Eigenvalues	% variation
1	8.106	31.176	1	8.546	32.869
2	2.984	11.476	2	3.026	11.637
3	1.990	7.655	3	1.809	6.959
4	1.223	4.702	4	1.559	5.998
5	1.144	4.399	5	1.121	4.310

The important constructs on the principal component one were “healthy”, “colourful corals” that would provide a “good site for diving” contrasted with “murky”, “sediment covered” “dead corals” that would be “bad for diving” (Table 4.3). By reviewing these important constructs it was apparent that the participants were evaluating the coral reef environment depicted in the photographs. Therefore, the first meaning ascribed to coral reefs was an evaluation dimension.

The important constructs identified on the second principal component were “round corals”, “flat”, “no upturned corals” and “few fish” contrasted with “many fish”, “a sense of movement”, “feeding coral polyps” and “stripy fish” (Table 4.4). Therefore, on one side of component two, participants described abundant coral with irregular shape and few fish and on the other side, a sense of movement, clustering of flat or smooth corals with many or unusual fish. Therefore, the second meaning ascribed to coral reefs was an activity dimension. The constructs within this dimension were not as concise as the other two dimensions, however they were all compared high and low activity. The activity concept was a combination of descriptions of direct movement, for example coral polyps feeding and the presence of fish, and more indirect descriptions of activity through the comparison of highly structured scenes with others that were flat or lifeless.

The important constructs identified on the third principal component were “diverse”, “clustered” “complex coral structure” contrasted with “spiky”, “pointed corals” that formed “monocultures” or alternatively “bare substrate”, therefore suggesting the third ascribed meaning was a diversity dimension (Table 4.5). Participants from group 1 were more likely to use the constructs “diverse corals” compared with “branching” corals. Participants from group 2 used the constructs “lots of”, “variety”, or “different types of coral and fish”. The diversity component was consistently identified in the constructs with 15 of the 24 constructs specifically identifying variety or diversity.

Table 4.3. The twelve highest and lowest constructs provided by the participants on principal component 1. Reviewing the constructs provided the meanings ascribed to coral reef scenes, the first being an evaluation.

Constructs from participants in Group 1			Constructs from participants in Group 2		
Explicit pole	Implicit pole	Loading value	Explicit pole	Implicit pole	Loading value
Nice for dive	Not nice for dive	1.39	Healthy	Unhealthy	1.35
Undisturbed	Disturbed	1.37	Higher coral and fish species diversity	Lower coral and fish species diversity	1.33
Colourful	Dull	1.33	Colourful	Bland	1.30
Good dive	Bad dive	1.33	Depth of colour	No colour	1.29
Visibility	Silt	1.33	Weedy/coral	Sandy	1.26
Vibrant	Lacklustre	1.32	Beautiful	Ugly	1.24
Good visibility	Bad visibility	1.31	Coral covered surfaces	Rocky dead coral surface	1.24
Good live coral coverage	Little coral coverage	1.28	Thriving	Dying	1.24
Garden	Muddy	1.26	Dense	Sparse	1.23
Bright	Dull	1.23	Intense	Washed out	1.23
Exciting	Boring	1.23	Clean	Suspended particles	1.23
Vivid colour	Dull	1.23	No sediment	Sediment	1.21
Ugly	Pretty	-1.69	Murky	Clear	-1.65
Murky	Clear	-1.70	Spoilt	Unspoiled	-1.66
Murky	Clear	-1.70	Silted	More silted	-1.67
Dead	Alive	-1.73	Not recovered	Regrowth	-1.68
Murky	Clear	-1.74	Murky	Clear	-1.69
Silty	Clear	-1.75	Boring	Pretty	-1.70
Open site	Close clean	-1.75	Sandy	Not sandy	-1.73
Silty	Clean	-1.76	Sediment covered area	Clean coral	-1.73
Murky	Clear	-1.76	Blanket	Uncovered	-1.76
Water silted	Water clear	-1.79	Murky	Clear	-1.76
Unhealthy	Healthy	-1.86	Silted	Unsilted	-1.76
Smothered	Sediment free	-1.89	Dead	Living	-1.78

Table 4.4 The twelve highest and lowest constructs provided by the participants on principal component 2. Reviewing the constructs provided by the participants identified that the second meaning ascribed to coral reef scenes was activity.

Constructs from participants in Group 1			Constructs from participants in Group 2		
Explicit pole	Implicit pole	Loading value	Explicit pole	Implicit pole	Loading value
Life	No life	2.58	Shoulders	Slabs	2.41
Millepora bleached	*Millepora* not bleached	2.51	No soft coral	Soft coral	2.29
Alive	Dead	2.48	All hard coral	Some soft coral	2.29
No up turned corals	Upturned corals	2.42	Uneven	Smooth	2.08
Corals present	No coral present	2.31	Alive	Dead	2.08
No coral polyps feeding	Coral polyps feeding	2.24	Coral	No coral	2.08
Murky	Clear	2.23	No flat sheets		2.03
Hard	Soft	2.15	Uninspiring	Wonderful	2.01
No edible fish	Edible fish	2.11	No cyclone damage	Cyclone damage	1.95
No plate coral	Plate coral	2.10	Abundant	Not abundant	1.93
Going	Gone	2.06	Fragile	Not fragile	1.93
Few fish	Lots of fish	2.05	Small fish	Large fish	1.84
Fire coral	No fire coral	-2.09	Flat coral	No flat coral	-2.02
Sense of movement	Stagnant	-2.09	Lots of fish	Few fish	-2.04
Lots of fish	Few fish	-2.16	Stripy fish	No stripy fish	-2.08
Big fish	Little yellow fish	-2.17	Diverse	Simplified	-2.15
Many fish	One fish	-2.20	Isolated	Part of a larger area	-2.23
Murky	Clear	-2.22	Butterfly fish	Looks murky	-2.26
Shallow	Deep	-2.36	Closed	Open	-2.29
Stinging	Boulder	-2.44	Fan type coral		-2.38
Gully/groove		-2.46	Purple	Aqua	-2.44
Sandy patch	No sandy patch	-2.56	Smooth shell shape	Rough	-2.45
Angelfish	No angelfish	-2.60	Bommie	No bommie	-2.46
Coral bommie	Little height variation	-2.61	reddish	Whitish	-2.49

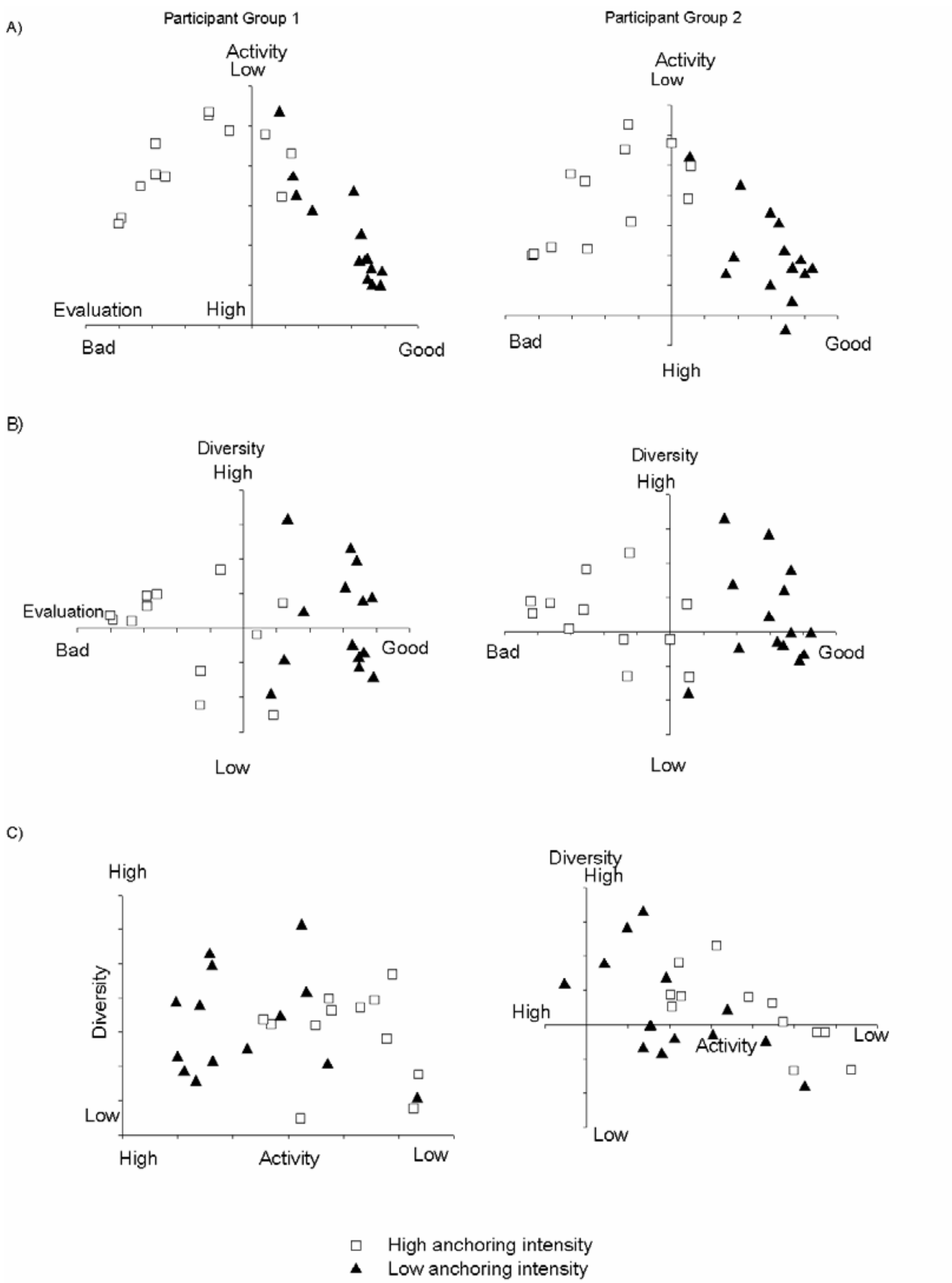
Table 4.5. The twelve highest and lowest constructs provided by the participants on principal component 3. Reviewing the constructs provided by the participants identified that the third meaning ascribed to coral reef scenes was diversity.

Constructs from participants in Group 1			Constructs from participants in Group 2		
Explicit pole	Implicit pole	Loading value	Explicit pole	Implicit pole	Loading value
Coral diversity	Only one species	2.85	Still	Moving	3.0
Robust	Fragile	2.78	Diverse	Serene	2.46
Massive	Branching	2.71	Ball shaped coral	Not ball shaped coral	2.37
Small	Big	2.44	Cluttered	Less cluttered	2.06
Bunches of coral	Devoid of corals	2.30	Flat	Inclined	2.00
Bleached	Unbleached	2.27	Diverse	Similar	1.97
Higher diversity		2.24	Flat	Spiky	1.95
Diverse	Depauprate	2.06	Falling	Rising	1.94
Variety of corals	Not varied	2.06	Bulbous	Fins	1.94
Different corals	Same corals	2.06	Little algae	Much algae	1.73
Boulder	Broken	2.04	Complex	Simple	1.71
Soft coral	Alga/hard coral	2.02	interesting	Not interesting	1.62
Branching	Barren	-2.06	Spiky	Smooth	-2.14
Few/no soft corals		-2.12	Staghorn	Rounded	-2.14
Stand of one species	No stands of one species	-2.15	Growth	Bare	-2.17
Branching	Boulder	-2.19	Sharp	Soft	-2.18
Branching corals	Barren of branching corals	-2.19	Spiky	Rounded	-2.20
Silt	Bleached	-2.19	Pointy	Puffy	-2.23
Hard	Soft	-2.22	Pointy coral	Not pointed corals	-2.25
Branched corals	Massive corals	-2.23	Twigs	Rocks	-2.28
Geometrical	Curved	-2.26	Thin coral	Flat coral	-2.39
Uniform	Variety	-2.31	Prickly	No prickly	-2.39
Many branching corals	Mainly other corals	-2.48	Spiky	Round	-2.51
Branching corals dominate	No-branching corals dominate	-2.48	spindly	Solid	-2.56

Relationship of the photographs with the ascribed meanings

To discover whether the meanings provided by both participant groups discriminated photographs from coral reefs associated with different levels of anchoring, the position of the photographs on each of the three dimensions was graphed (Figure 4.2). The most important meaning was the evaluation dimension and coral reefs associated with low anchoring intensity were positioned towards the “good” end of this dimension. In comparison, photographs from coral reefs associated with high intensity of anchoring were positioned towards the “bad” end of the evaluation dimension (Figure 4.2A). Therefore, participants distinguished the difference in coral reef condition associated with anchoring and coral reefs associated with high intensities of anchoring were perceived to be of poor visual quality. In terms of activity, coral reefs associated with both high and low levels of anchoring were perceived to have a range of activity, but higher levels of activity were identified for photographs that were evaluated highly (Figure 4.2A). Coral reef photographs differing on the evaluation dimension also displayed a range of diversity values (Figure 4.2B). There was no relationship found between the activity and diversity dimensions (Figure 4.2C).

Figure 4.2. The distribution of the 26 photographs on the three important dimensions used to describe coral reefs by the two participant groups. Photographs from the coral reefs associated with low intensity of anchoring were grouped at the "good" end of the evaluation dimension. A relationship between evaluation and activity dimensions was identified (A, group 1; $r^2 = 0.526$, $df = 24$, $P < 0.001$, group 2 $r^2 = 0.267$, $df = 24$, P = 0.004). No relationship between the evaluation and diversity (B, group 1; $r^2 = 0.074$, $df = 24$, P =0.096, group 2 $r^2 = 0.106$, $df = 24$, P = 0.103) or activity and diversity (C, group 1; $r^2 = 0.006$, $df = 24$, P =0.367, group 2 $r^2 = 0.006$, $df = 24$, P = 0.688) was established.



4.4 Discussion

Participants, regardless of their experience with coral reefs, ascribed similar meanings to the coral reef scenes. The first and most important meaning ascribed to coral reefs was an evaluation; was the scene good or bad? Did it provide interest or not? Did it have the prospect of a fulfilling experience or not? Evaluation of the environment for its possibility for action is the most important criterion driving preferences for terrestrial scenes, both natural and human-influenced (Fenton 1988; Kaplan 1988; Kaplan & Kaplan 1989; Walmsley & Jenkins 1993; Young 1995; Hagerhall 2000). In terms of action, people prefer scenes that provide information and extend their understanding and experience of the environment. Kaplan and Kaplan (1989) found even in rapid assessments, people evaluate the entire scene for its potential for actions, even though they can not carry out the actions because the scene is presented photographically. In this coral reef study, people assessed each scene for its ability to provide benefits, such as excitement or a good diving experience. The process was obviously similar to the way people assess terrestrial scenes, where they prefer scenes that provide further information and a desirable experience (Gibson 1979; Appleton 1988).

The initial assessment of the coral reef scenes by people whose occupation has a level of interaction with the coral reef environment and those that have no such association was an evaluation. The second and third dimensions of meaning ascribed to coral reefs focused more-so on the biophysical components. The second dimension of meaning described the amount of activity in the scene, where the movement of large numbers of fish and the complexity of the corals added to the perception of activity. The third dimension of meaning was diversity were both groups of participant were consistent in their description of highly diverse scenes in comparison to scenes with coral that display a single growth morphology. Similarly, Höge (1990) found that art historians express a personal preference about an artistic object, similar to the evaluation dimension in my study, prior to describing technical details such as artistic merit or value. This suggests that the two assessments, preferences or evaluation and detailed judgments, use different components within the scene. The finding that there are evaluation, activity and diversity dimensions ascribed to coral reef scenes also supports research findings undertaken since the late 1950’s, which demonstrated, using the semantic differential technique, that there are three major components of meaning in natural language which could be defined as evaluation, activity and potency (Osgood *et al.* 1957).

Kelly's repertory grid method was useful in identifying the underlying meanings people ascribed to the coral reef environment. Importantly, this method allows the participants to provide their own meanings rather than being constrained by terms that are provided by the researcher, which is a common approach in much social research. In a management context, this technique could identify the underlying meanings of the environment held by different stakeholders, potentially identifying shared meanings and values. Understanding the different meanings people hold for the environment can be used to develop understanding and communication amongst stakeholders and enhance the decision making processes (Robertson & McGee 2003). For example, Fenton and Syme (1989) used a repertory grid to identify meanings held for the coastal strip of Western Australia. The information provided was used to identify locations where development was perceived to be appropriate and those areas that required conservation (Fenton & Syme 1989).

The consistency in meanings ascribed by the two participant groups was surprising. Not only did participants provide similar constructs, their rating of the photographs was similar, as were the components and the importance given to each component. The consistency in views for particular environments suggests that people have a stereotypical image of coral reef environments, similar to that described in a study of day tourists perceptions of coral reefs (Fenton *et al.* 1998). Essentially, broad sections of the community, including scientists and lay people, evaluated the coral reef environment in the same way. In contrast to the stereotypical views identified in the coral reef study, a relationship between people's perceptions and prior experience was established in studies of people's perceptions of forest and native vegetation (Kaplan & Kaplan 1989; Purcell 1992). In the forests study, participants given prior information about a tree disease rated photographs showing disease symptoms as less preferred compared with participants without such knowledge (Kaplan & Kaplan 1989). Native vegetation was preferred by participants who were members of a native wildflower group, whereas participants without the association gave equal preference to native and non-native forested scenery (Kaplan & Kaplan 1989). People's perceptions of scenes where they had a positive recreational experience caused them to rate scenes associated with the experience highly, in comparison to other landscape scenes (Mugica & Vicente de Lucio 1996). Agricultural scenery was preferred by farmers in comparison to non-farming locals and visitors who preferred more natural scenes (van der Berg *et al.* 1998). Therefore, understanding people's perceptions of the environment would be useful in the promotion of a common understanding between stakeholders, which is important for developing co-management of the environment (Huntington *et al.* 2002).

The classification and description of the environment using perceptual and cognitive descriptors, concurrently with biophysical descriptors, provides useful and additional information for the purpose of environmental management and planning. The ecological assessment of these coral reefs identified that higher levels of damage and lower coral cover of some coral groups occurred on coral reef sites with higher levels of anchoring (Dinsdale & Harriott 2004) and participants judged these same coral reefs as being of poor quality. Therefore, in terms of assessing a location, integration of social and biophysical information provides a more complete picture of the environment. The ecological information showed a loss in an important habitat and the social information showed a loss in visual quality. People's perceptions of the environment has identified that there is a level at which a change in environmental condition becomes unacceptable. Therefore, a compelling argument for the implementation of mitigation strategies can be presented. Similarly, Zanetell & Knuth (2002) identified knowledge partnerships, between local and scientific communities, could provide better explanations of environmental phenomenon and increase the credibility and clout of both groups in the management process. The relationship between the perceptual meanings and ecological measures is explored further in Chapter 5.

The meanings provided by participants were useful in describing changes in coral conditions associated with anchoring intensity. Participants therefore have a capacity to discriminate changes in environmental condition, even in unfamiliar situations like that of underwater coral reef environments. Similarly, Hillery *et al.* (2001) in a study of environmental condition at Uluru, Central Australia, identified that tourists rated environmental condition lower at sites with a higher intensity of tourism impacts and Faulkner *et al.* (2001) identified that resident's perceptions of water quality after remedial work was similar to results of biological monitoring. These findings suggest that perceptual information has the potential to provide information about environmental condition and could be used for monitoring purposes. Monitoring by community volunteers is useful for environmental management because it extends the spatial and temporal replication of data beyond those collected by professionals alone (Carr 2002). Reef Check, for example, mobilised 5000 volunteers to measure coral reefs around the world (Hodgson & Liebeler 2002). Monitoring techniques are generally developed by scientists and modified to suit the skill and financial level of the community. In the reef check example scientists trained the volunteers, and supervised monitoring and data collation (Hodgson & Liebeler 2002). However, selection of indicators with greater local meaning than the standard scientific measurements could increase community understanding and awareness of change in environmental condition. For instance, Gasteyer & Flora (2000) found that community action was stimulated when water turbidity was measured by the community using familiar terms. The coral reef case study suggests that by simply asking people to visually assess the environment would accurately describe broad changes in coral reef condition.

The development of knowledge partnerships and the involvement of people in monitoring are not only important for the acquisition of information, but have potential for increasing the involvement of people in the management process. The involvement of people in environmental management is the key to collaborative resource management and achieving benefits for both the environment and the community involved (Christie *et al.* 1994; Carr 2002; Chuenpagdee *et al.* 2002; Olsson *et al.* 2004). Identifying the meanings people ascribe to coral reefs has the potential to encourage participation in environmental management by 1) providing a value judgement for different types of coral condition, 2) identifying indicators for monitoring that have greater community meaning and 3) providing an understanding of how people with different experiences and backgrounds view coral reefs, potentially building understanding between stakeholders.

This chapter identified that people ascribe three important meanings to the coral reef environment and the meanings were useful for describing changes to the condition of coral reefs associated with anchoring. Because of the accuracy of the descriptions, people's perceptions would provide useful information for management. The next chapter adds the third dimension in assessing the ecosystem health concept by asking participants to provide a health judgement for the coral reef sites studied in Chapters 3 and 4.

CHAPTER 5

CORAL REEF HEALTH INDICATORS: ECOLOGICAL AND PERCEPTUAL ASSESSMENTS OF ANCHOR DAMAGE

5.1 Introduction

This chapter conducts the third stage of exploring the ecosystem health concept by comparing the participant's judgements of health with the ecological measures and perceptual meanings identified in the previous two chapters.

The holistic nature of environmental management has required the integration of information about the environment, people's associations with the environment and their desires for the type of environment condition. The integration of these knowledge fields is problematic and the legitimacy of each source of knowledge has been questioned (Policansky 1998; Bellamy *et al*. 1999; Hull *et al*. 2003; Failing *et al*. 2004). Tensions exist in environmental management between science, values and uncertainties in both the natural and social systems being assessed. Problems in the integration of these systems arise because information acquired by scientists compared with that provided by lay communities is collected using techniques based upon different epistemologies.

Science conducted from a positivist viewpoint where the environment, which is separate from social practices and human experiences, has the power to produce unambiguous, observable and rectifiable outcomes (Macnaghten & Urry 1998; Robertson & Hull 2001; Song & M'Gonigle 2001; Tress 2002). Using a positivist epistemology, scientific knowledge is collected using value-free objective observations and only experts trained in scientific methods are qualified to measure and describe the natural phenomena (Zanetell & Knuth 2002). Because of this epistemology, science, and in particular natural sciences, was seen as the basis for managing the environment and information provided by scientists was often more highly regarded than information provided by other stakeholders (Lele & Norgaard 1996). However, the information collected by scientists using a positivist viewpoint often lacked usefulness for managers because it provided only the facts and no information on what the desired state might or might not be, i.e. there can be no adversary position in positivist science (Robertson & Hull 2001; Ehrlich 2002; Lachapelle *et al.* 2003). However, the data provided by scientists, collected in a positivist manner, is used by others to argue positions in natural resource management issues, thus giving the positivist science an adversary position.

Positivist science often focuses on one aspect of the resource, in a reductionist way, which often ignores flow-on effects and other complex linkages (Hollings *et al.* 2000; Lackey 2003). Humans are sometimes seen as intruders into the environment and the only relationship they have with the environment is to cause impacts and degradation (Grumbine 1994; Endter-Wada *et al.* 1998). Modern science also neglects or rejects those aspects of the world that can not be quantified, thereby removing some aspects of how people see or experience the world as a way of describing nature (Gunderson *et al.* 1995; Hollings & Meffe 1996; Tress 2002). In some cases the use of Western science, in the absence of local knowledge and community involvement, has exacerbated social and natural resource problems and also threatened the loss of original solutions derived from local cultural situations (Salas 1994; McNeely 1995b; Hollings & Meffe 1996; Zanetell & Knuth 2002; Pretty 2003b). In the Andes for example, the introduction of Western science and agricultural practices to develop more productive potato crops, focused on low land species ignoring the more important highland areas where most of the production occurs (Salas 1994). The scientists developed a potato crop which grew well, but required high levels of mechanisation and nutrient input, minimising the role of social and cultural knowledge systems and activities. The potato research also monopolised genetic resources and ignored ecological diversity, which was well known and used by the Andean cultivators, who have developed 82 % of the potato varieties used in agriculture. Therefore, Salas (1994) suggested that in this case Western science exacerbated the major problems of society and threatened to erase original solutions derived by local knowledge.

The singular view of positivist science in environmental management has given way, to some degree, to a post-normative science, where scientists identify that science is a cultural action and values are embedded in scientific activities (Meffe & Viederman 1995; Patterson

& Williams 1998; Robertson & Hull 2001; Song & M'Gonigle 2001; Lachapelle *et al.* 2003). Scarce (1999), for example, describe how research on salmon was influenced by government policy and public views. The post-positivist view of science recognises that multiple interpretations and types of knowledge exist (Hollings *et al.* 2000). Post-positivist approaches to environmental management are distinctive in stating that knowledge is not the exclusive province of experts, but local people or communities may possess a non-scientific, but detailed and useful knowledge of local environmental conditions (Bryant & Wilson 1998; Berkes *et al.* 2000; Berkes & Folke 2000; Lachapelle *et al.* 2003; Pretty 2003b). Information in environmental management therefore can be provided by many people and integrated in the environmental management process.

Information from communities about the environment or local ecological knowledge is experiential, gained by continual observation and constructed by community values and beliefs (McNeely 1995a; Burroughs 1999; Berkes & Folke 2000; Olsson & Folke 2001). Unlike scientific information, local knowledge has a strong cultural component and is often revealed in stories, myths or events. Local knowledge is a subjective description of world phenomena that is shaped by, and shapes, cultural attitudes and activities (Zanetell & Knuth 2002). It is assumed that every society has its own means and adaptations to deal with its natural environment and this knowledge could be useful when integrated with scientific knowledge for environmental management (Berkes & Folke 2000). For example, elders in Venezuela described the relationship between crocodiles and tropical fish abundance, which had received little scientific research and therefore, identified the unexpected contribution of crocodile hunting to the decline of fisheries (Zanetell & Knuth 2002). In Sweden, local people identified the effects of acidic rain on the lakes in their local area and implemented a monitoring and mitigation strategy preceding the national monitoring scheme by several years (Olsson *et al.* 2004). The basis of the discussion for including knowledge, other than scientific, in environmental management is that people may have developed knowledge and practices that are appropriately adapted to the ecological systems in which they occur, thereby potentially bringing different and innovative practices into environmental management (Berkes *et al.* 2000; Berkes & Folke 2000; Wilson 2003). Therefore, the use of local knowledge has the potential to develop better management outcomes and empowers communities to be involved in environmental decisions. Of equal importance, for local ecological knowledge to be maintained new context for it use need to be created (Davidson-Hunt & Berkes 2003).

Several types of ecological knowledge are recognised; local ecological knowledge, traditional ecological knowledge, indigenous knowledge and neo-traditional knowledge. Local ecological knowledge is held by a specific group about their local ecosystem, it can be a mix of scientific and practical knowledge, it is site-specific and often involves a belief component (Olsson & Folke 2001). Local knowledge differs from traditional ecological knowledge because it lacks a historic or cultural perspective (Berkes 1999), but both can be informative about environmental conditions and provide useful information for the management processes. For the purposes of the present study, information about the environment provided by people from a contemporary society is considered as local ecological knowledge and the relationship of this knowledge with more objective scientific assessment and measurement is explored within the ecosystem health concept.

Ecosystem health is one concept proposed to manage the environment from a holistic perspective, examples of the use of the concept including being mentioned in the Rio Declaration on Environment and Development and being a focus area of environmental audits conducted in Australia and Canada (Rapport 1995; Boesch & Paul 2001; Rapport 2003). However, the concept is also embroiled in arguments concerning scientific knowledge and value judgements. The ecosystem health concept was reviewed in Chapter 1. The underlying conceptual approach of the ecosystem health concept is to encourage people to be involved in management and care for the environment, because it uses languages that people relate to and invokes a societal value. People value their own health and health in others and by extension it is assumed that people will instinctively envisage a healthy ecosystem and be motivated to maintain the ecosystem in a healthy state (Lackey 2003). The ecosystem health concept is highly integrated, recognising that people affect the health of the environment and that the health of the environment affects the health and well-being of people (Kusel & Alder 2003; McMichael *et al*. 2003). Parks Victoria (www.parkweb.vic.gov.au), for example, has used the ecosystem health concept to encourage people to use and be involved with the management of the national parks in Victoria, Australia, acknowledging that having people actively using the environment is good for the health of the parks and the people.

Adopting an ecosystem health concept as a way to manage the environment has caused contention (Suter 1993; Wicklum & Davies 1995; Wilkins 1999; Lancaster 2000; Fitzsimmons 2003). The contention, as described earlier, is mostly related to linking information about the environment obtained using ecological measures, with people's subjective value judgements. The proponents of ecosystem health, for example, describe the concept as a method for encouraging people to be involved in environmental management, thus achieving positive outcomes for both people and the non-human environment (Orr 2002). For example, native grasslands in California managed with an ecosystem health goal have integrated conservation, grazing and tourism to achieve positive outcomes for biodiversity, ranchers income and visitor experiences (Hamilton 2003; Reiner 2003). Those opposed to the concept describe it as a system for managing the environment using emotive value judgments, not independent scientific reality (Suter 1993).

Examining the ecosystem health concept further reveals that both terms "ecosystem" and "health" are difficult to define and require some subjective interpretation (Chapter 1). The proposed advantage of the ecosystem health concept is that a range of people can describe the environment, thereby, providing a way to integrate local and scientific ecological knowledge into environmental management. Achieving integration broadens understanding of environmental condition and identifies the effect a change in condition has on the value people place on the environment (Ross *et al.* 1997; Slocombe 1998; Robertson *et al.* 2000; Ura 2003). By using terms that people readily understand when discussing the environment, a range of people with various backgrounds can discuss, on an equal basis, environmental decisions and potentially provide strategies to mitigate change. The resulting environmental management decision is then developed through a negotiated process among a range of people, achieving greater community ownership and acceptance. Furthermore, the use of knowledge provided by people with different interests and backgrounds is an important step in overcoming institutional barriers to implementing integrated approaches to environmental management (Burroughs 1999; Huntington *et al.* 2002).

The ecosystem health concept, as described in Chapter 1, relies on a description of the environment using two dimensions; biological condition and human influence (Karr 2000) (Figure 1.1). The state of the environment is described as a continuum from pristine to one where no life exists. A pristine or integral environment is one which supports a biota that is the product of evolutionary and biogeographic process with little or no influence from humans. A healthy environment is deemed sustainable and able to supply requirements for both human and non-human communities. Conversely, an unhealthy environment is considered unsustainable and requires a change in people's activities to improve its condition and re-establish the supply of products (Karr 1999; Karr 2000). An environment may still be deemed healthy, even when it has moved some distance from pristine, because of societal values. At some stage however, the change in the condition of the ecosystem is such that the environment switches from one that is considered healthy to one deemed unhealthy. Describing the change in condition along the health continuum and identifying where the environment is deemed to have changed from healthy to unhealthy are the major problems encountered in applying the ecosystem health concept in environmental management.

The research, described in this chapter, explores the tension between scientific and local judgements of coral reefs associated with different intensities of anchoring. My research uses anchor damage on coral reefs as a case study to identify the relationship between (i) objective ecological measures, (ii) perceptual meanings and (iii) health judgements.

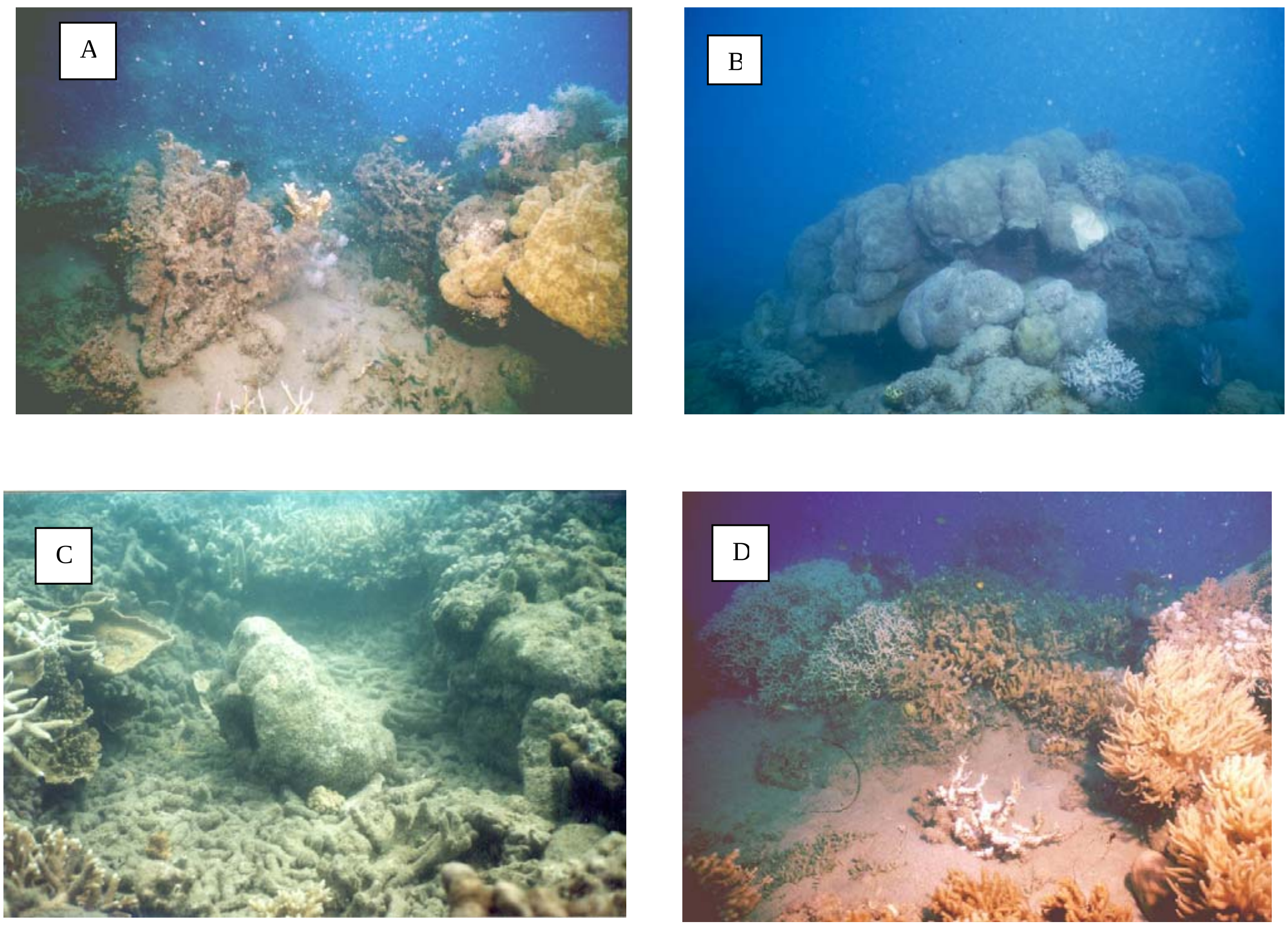
5.2 Methods

Assessments of coral reefs using the three individual measures

To investigate the relationship between scientific and local knowledge, assessments of coral reefs associated with different intensities of anchoring were conducted using three epistemologically distinct measures. Coral reefs surveyed to identify the environmental indicators (described in Chapter 3) were photographed for people to provide their descriptions (described in Chapter 4). Three types of measures were obtained from the photographs and compared: objective measures, which included typical ecological information; perceptual meanings, which are how people describe the reef and are equivalent to local knowledge; and a judgement of health, which is a normative value judgement. The objective ecological measures were obtained from the photographs rather than the field because the photographs are exactly what the participants were viewing. However, the ecological measures taken from the photographs were representative of coral reef condition measured in the field.

To obtain the ecological measures from the photographs, a point survey was conducted using a $2cm^2$ grid which was laid over each photograph displayed on a 32.5cm computer screen, providing 126 points to be measured. The coral reef structure underlaying each point was recorded (Fenton 1984). The numbers of points underlaid by five coral condition components were measured. The five coral components were; cover of branching corals and cover of massive hard corals, cover of soft corals, amount of damage, which including overturned corals, breaks, fragments, gouges and rubble (definitions of damage types presented in chapter 3 and Figure 5.1) and fish were measured. Therefore, the ecological measures were presented as the percent cover of each component in the photographs. A comparison of Figure 5.1 and Figures 3.3 and 3.4 will show that the slides had the same general characteristics of coral damage and cover as the field observations.

Figure 5.1 Types of damaged to corals caused by anchoring and associated chain. A) A coral colony has been overturned to the left of the photograph and rubble is present in the around the colony. B) The centre right portion of the coral colony shows gouging (bright white) that has occurred as an anchor has scraped across the colony, in comparison to the left of the photograph the coral colony has an intact living surface. C) The coral around the edge of this photograph is not damaged, but extensive damage has occurred in the centre of the photograph, where a great deal of the coral cover has been removed and an overturned coral colony surrounded by rubble remains. D) A coral fragment is depicted in the centre of this photograph and the fragment has also suffered some bleaching causing it to turn white.



To explore people's knowledge of coral reefs, a modified repertory grid method was used (Kelly 1955) and the full methods are provided in Chapter 4. Participants were asked to describe the difference between pairs of coral reef photographs to obtain perceptual meanings of the coral reef. Participants in the perceptual study were separated into two groups depending on their experience of coral reef environments; participants in group 1 had a working association with coral reefs (that is their occupation involved a level of interaction with coral reef environments), whereas, participants in group 2 had no such association. The responses from the two participant groups were analysed separately using two principal component analyses. Three important perceptual meanings were identified from the analysis and the value for each description was obtained from the component matrix (Chapter 4). The perceptual meanings did not identify differences between photographs taken at different depths therefore depth was removed as a factor from further analysis.

As the last part of the perceptual study, which was described in Chapter 4, participants were asked to judge, on a scale of 1 - 6, the health of the coral reefs depicted in each of the photographs, where 1 was unhealthy and 6 was healthy. The judgements provided by the two participant groups were used to obtain an estimate of the health of coral reefs associated with different levels of anchoring intensity. An analysis of variance was conducted on the health ratings with anchoring intensity (high and low) and coral reef sites as fixed factors. The health judgements provided by the two participant groups were analysed separately. Coral reef sites were nested within the anchoring treatments and the interaction terms were not tested because the sampling design was not fully orthogonal. Of the forty-two participants in group 1, thirty-two provided usable health judgements, as did twenty-eight participants from the thirty-four in group 2. Unusable health judgements occurred because participants failed to read the instructions and provided a health judgement on a 1 - 0 scale rather than the required 1 - 6. A reliability analysis was conducted to identify whether participants were judging the health of the photographs in a consistent manner. In general, the concept of reliability refers to how accurate, on the average, the estimates of the scores are within the population. The Alpha model used, identified internal consistency based on the average of inter-item correlation.

Analysis of the relationship between local knowledge and health judgements

To establish the usefulness of the ecosystem health concept, the relationship between the perceptual meanings and health judgements provided by participants was identified. It was hypothesised that if health was an inherent judgement, there should be a clear relationship between these two assessments of coral reefs. A multiple linear regression analysis of the responses provided by each participant group, was used to explore the relationship between these measures. The perceptual meanings (identified in chapter 4) were used as predictive variables and regressed against the mean health ratings. Predictive variables were entered into the models in a stepwise fashion to identify the most important predictor(s) of the health judgements. Values for the perceptual meanings were derived from the component matrix of the principal component analysis conducted on the repertory grid data in chapter 4. Assumptions of normality and heterogeneity were met by all variables in the analysis.

Analysis to identify environmental cues

A regression tree analysis was conducted to identify the components or environmental cues that were consistent with a description of a healthy coral reef. Regression trees are generally used to explore, describe and predict the relationship between multiple species and environmental variables (De'ath & Fabricius 2000; De'ath 2002). In my research, the regression tree was used to predict the relationship between environmental cues and judgements of the health of the coral reef sites. Because the multiple linear regression analysis conducted in the previous section revealed a near perfect relationship between the evaluation dimension and health judgements, the evaluation dimension will be used as the health measure. For the regression tree analysis, the evaluation dimension provided a more accurate description of health because it was an elicited dimension, not one constrained by a term that the researcher provided to participants.

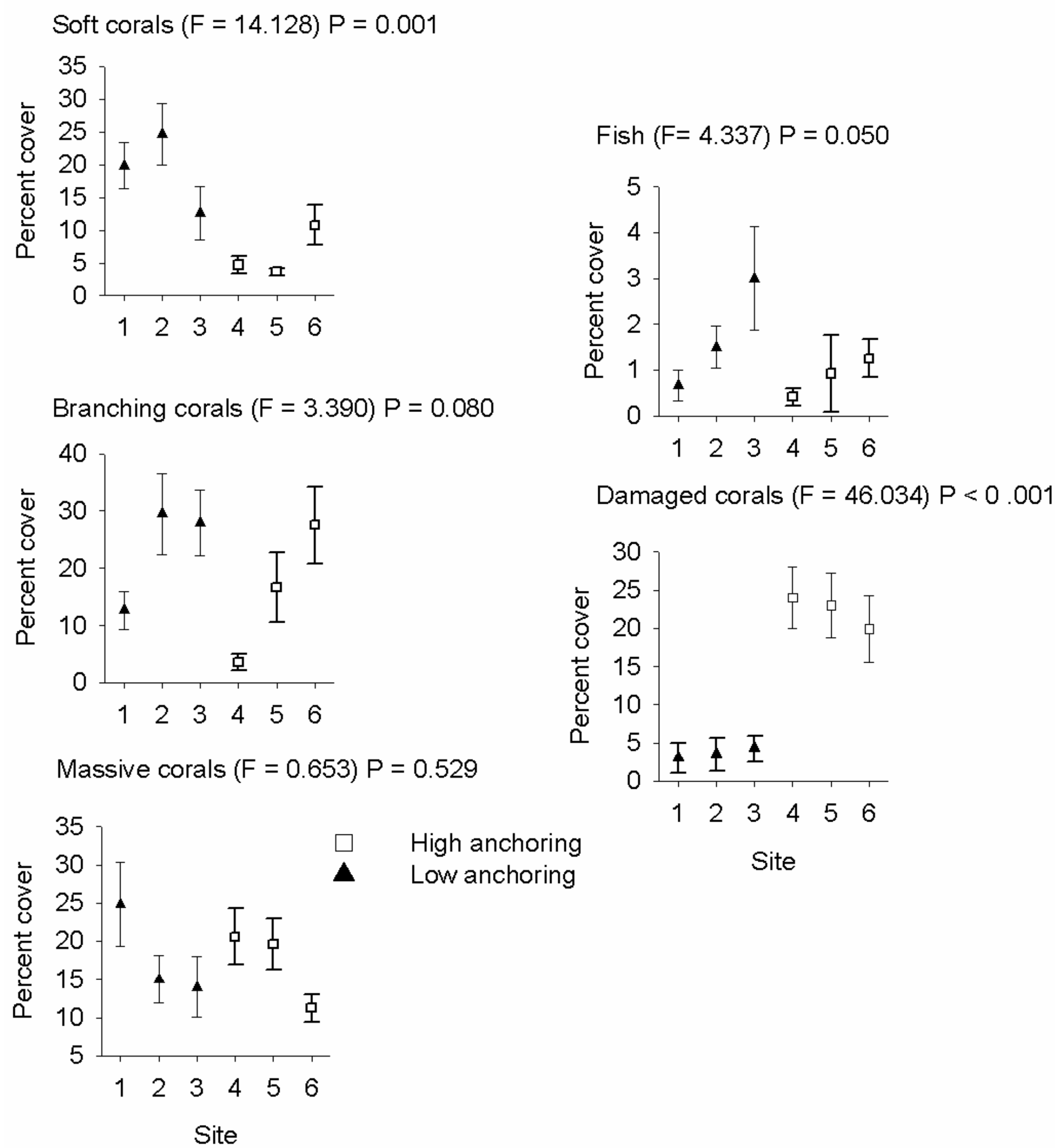
A regression tree analysis splits the data into mutually exclusive groups that are as homogeneous as possible. The final groupings are characterised by a mean value of the response variable i.e. the analysis divides the photographs into groups that are rated similarly for health or evaluation. The response variable for the regression tree analysis was the evaluation dimension and the predictive variables were the five ecological measures; i.e. percent cover of damage, soft, branching and massive corals and fish and the two remaining perceptual meanings; activity and diversity dimensions. The predictive variable that is most important in each of the resultant groups is identified on the branches of the tree and the amount of variance explained by each split in the tree is represented graphically by the relative lengths of the vertical lines associated with each split. The number of splits in the tree is identified by using cross-validation technique (De'ath & Fabricius 2000). Cross validation provides an estimate of the prediction error for trees of a given size. Using a plot of the relative error, the best tree size is the smallest tree such that its estimated error rate is within one standard error of the minimum. The information provided by the two participant groups was tested in two separate regression tree analyses.

5.3 Results

Assessments of coral reefs using three measures

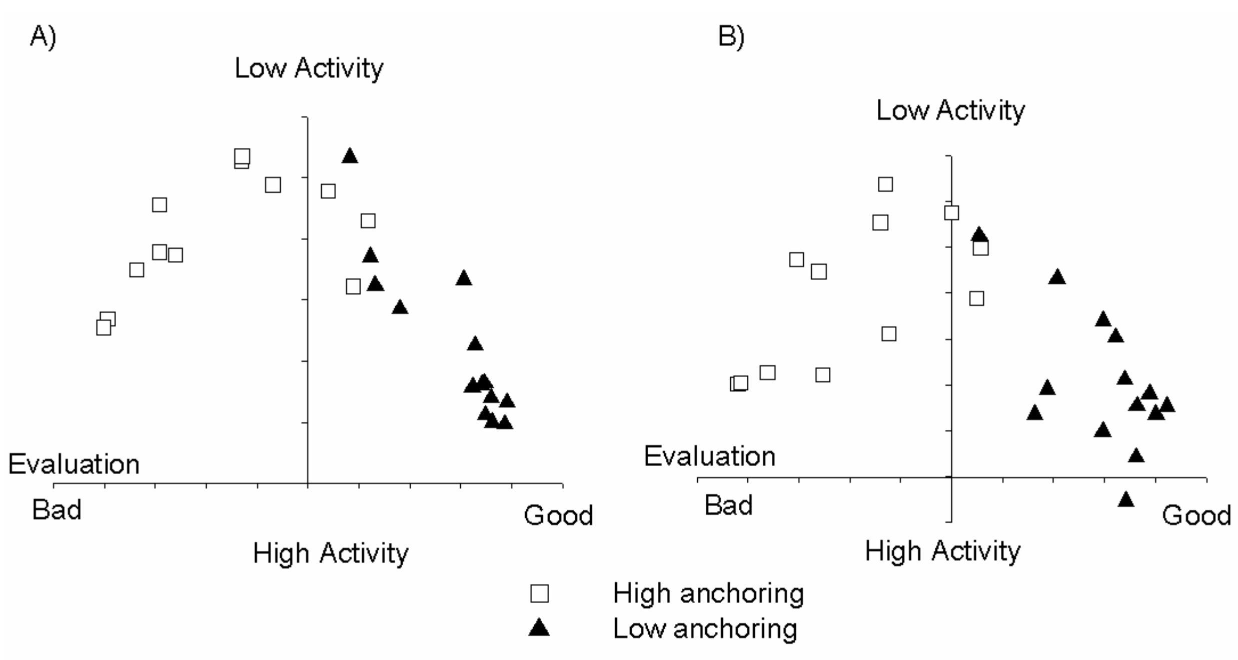
The three types of descriptions of coral condition, i.e. ecological measures, perceptual meanings and health judgements, all identified a difference with coral reef sites associated with high and low intensities of anchoring (Figures 5.2-5.4). The ecological measures identified that the cover of soft corals was higher at sites associated with low anchoring intensities. The cover of branching and massive corals fluctuated between sites within the two anchoring treatments, but showed no consistent trend with anchoring intensity. The amount of coral damage was higher at sites associated with high anchoring intensity (Figure 5.2). These characteristics of the coral condition measured in the photographs were representative of coral condition measured in the field (Chapter 3 Figures 3.3 & 3.4).

Figure 5.2. The separation of coral reef sites associated with high and low anchoring intensity by the objectives measures of mean cover (± SE) of each coral community component. Results of MANOVA are presented, degrees of freedom are 1:4:20. Note the difference scale on the y-axis.



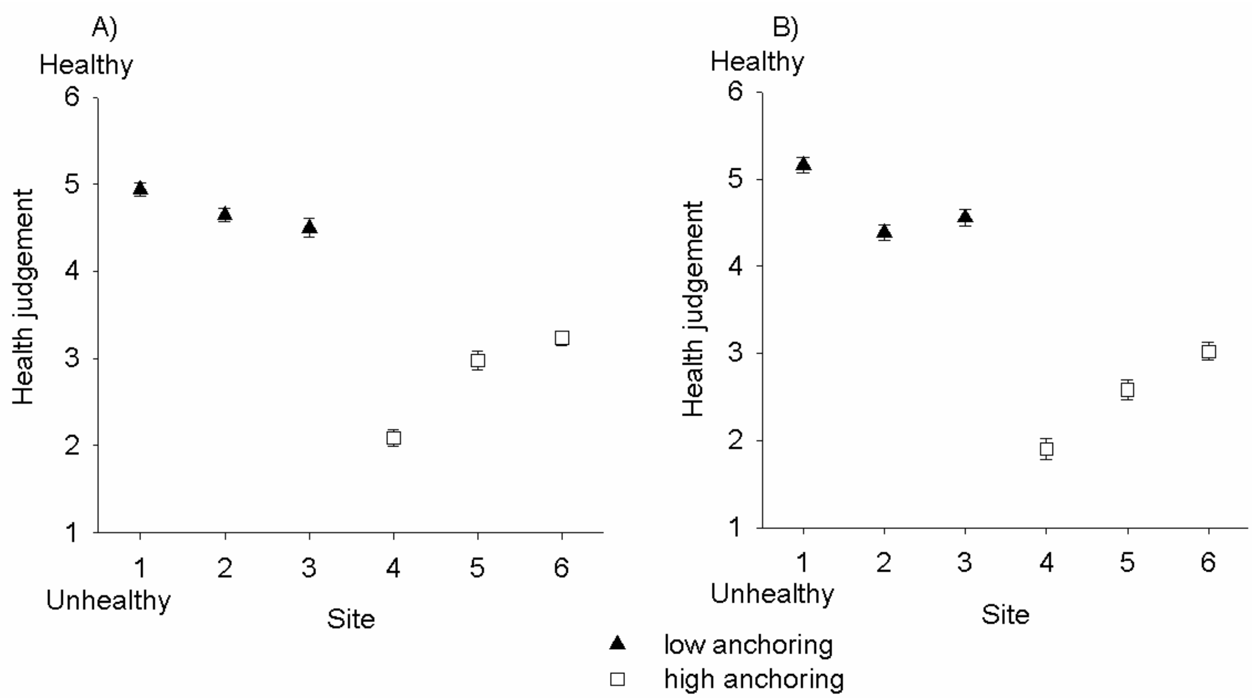
Analysis of the perceptual meanings of the coral reef photographs provided by participants identified three important meanings that people ascribe to coral reefs. The most important meaning was evaluation, whether the scenes were perceived positively or negatively. The second ascribed meaning was activity, whether the scene depicted movement through variation in the number of fish and types of coral. The third ascribed meaning was diversity, describing highly diverse scenes compared with monocultures of branching corals. Participants with and without a working association with coral reefs ascribed these meanings and had a remarkably consistent conceptualisation of coral reefs. Using the perceptual meanings, participants grouped the coral reef sites associated with low anchoring intensities towards the "good" end of the evaluation component. In contrast, photographs from high anchoring sites were evaluated as "poor" (Figure 5.3). Photographs from sites with both high and low levels of anchoring intensity had a range of perceived activity, however slightly higher activity was identified at sites with lower levels of anchoring intensity (Figure 5.3).

Figure 5.3. The separation of coral reef sites associated with high and low anchoring intensity by perceptual meanings provided by the two participant groups, A) group 1 and B) group 2 participants.



The judgements of health from the two participant groups showed a difference between sites associated with low and high anchoring intensities (group 1: $F = 611.9$, *df* 1:5:847, $P < 0.001$, group 2: $F = 7033.8$, *df* 1:5:720, $P < 0.001$). Coral reef photographs taken from sites associated with low anchoring intensity were given a higher health rating than those from sites with high levels of anchoring (Figure 5.4). The health ratings of the coral reef sites provided by participants in group 1 were slightly more conservative than those provided by participants in group 2, but overall the trends were very similar between the participant groups (Figure 5.4). Furthermore, there was remarkable similarity between the health ratings provided by each participant within the participant groups (Cronbach reliability coefficient, group 1: Alpha = 0.98, group 2: Alpha = 0.98), suggesting participants were very consistent in their health judgement of each photograph.

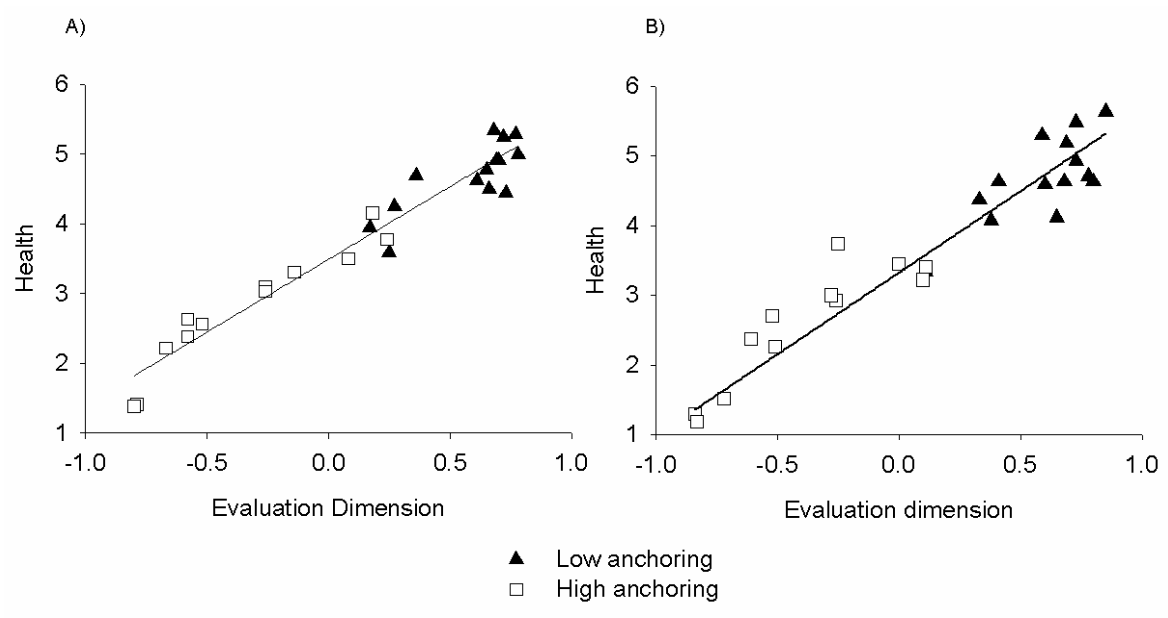
Figure 5.4. The separation of coral reef sites associated with high and low anchoring intensity by the mean health ratings (± SE) provided by the two participant groups, A) group 1 and B) group 2.



Relationship between local knowledge and health judgements

To identify the relationship between participant's health judgements and perceptual meanings, a separate multiple regression analysis was conducted on the information provided by each participant group. The mean health rating for each participant group was compared against the values from the component matrix for the evaluation, activity and diversity dimensions. The three perceptual meanings explained 94.3 and 93.7 % of the variation in the health ratings for group 1 and group 2, respectively (group 1 $r^2 = 0.943$, $F = 139.4$, $df = 3: 22$, $P < 0.001$; group 2 $r^2 = 0.937$, $F = 124.2$, $df = 3:22$, $P < 0.001$). Health ratings provided by both participant groups were highly correlated with the evaluation dimension (Figure 5.5). For group 1 participants, the evaluation dimension was the single best predictor of the judgement of health and the activity and diversity dimensions do not explain any additional variance in the model (Group 1 participants: health judgement = 3.5 + 2.1 (evaluation dimension)). For group 2 participants, the evaluation dimension was highly correlated with the judgement of health also, but activity and diversity dimensions improved the model (Group 2 participants: health judgement = 2.9 + 2.3 (Evaluation dimension) + 1.2 (activity dimension) + 1.1 diversity dimension)). However, the amount of variance explained by the activity and diversity components was minimal (1.8 % and 1.1 % respectively). Therefore, for both participant groups the most important perceptual meaning of the coral reef environment is an evaluation judgement and this is equivalent to a judgement of health (Figure 5.5).

Figure 5.5. The relationship of coral health ratings and the evaluation dimension of the perceptual meanings provided by A) group 1 and B) group 2 participants respectively.

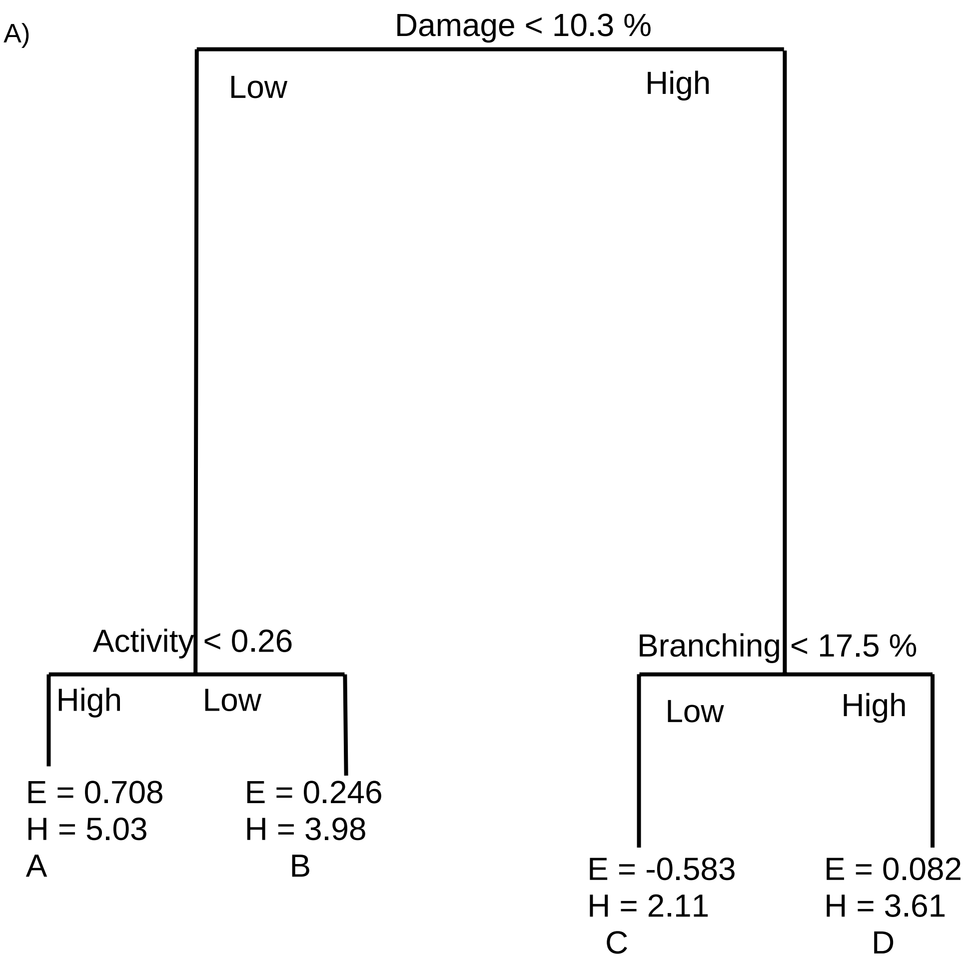


Environmental cues that are important in describing coral reef health

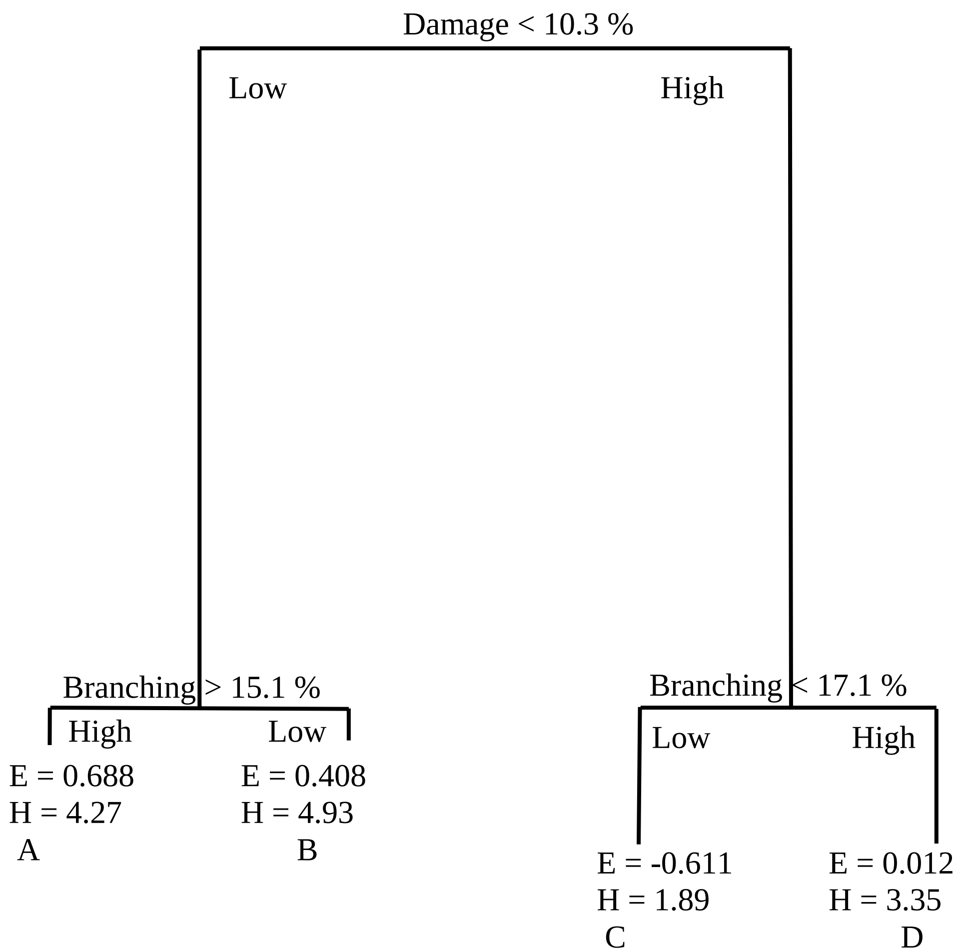
The near perfect relationship between the evaluation dimension and the judgements of health, suggests that people's first response to the environment is to judge its health. Because the relationship between the evaluation dimension and health judgements was so strong, the evaluation dimension is a more appropriate estimator of the health of a coral reef compared with a parameter provided by researchers. Therefore, the regression tree identified the relationship between the evaluation dimension and the five ecological measures and two remaining perceptual meanings were used as the predictor variables. The regression tree analysis initially divided the coral reef photographs into two broad groups, depending on the percent of coral damage present in the photographs (Figure 5.6). Both groups of coral reef photographs were further subdivided and the environmental cues that predicted the subdivision were different for each participant group. For participants from group 1, the low damage photographs were divided by the amount of activity present and the high damage photographs were divided by the percent of branching corals present (Figure 5.6A). For participants from group 2, the two groups of photographs were both sub-divided by the percent of branching corals depicted (Figure 5.6B). In both cases the regression tree analysis separated the photographs into four health groups (labelled A-D), and 88.3 % and 85.2 % of the variance was explained by the trees constructed using the data provided by group 1 and 2 participants, respectively.

Figure 5.6. The relationship of evaluation dimension to the five objective measures and two subjective descriptions provided by the regression tree analysis for (A) group 1 and (B) group 2 participants. The values of the predicted variables for the ecological measures provided on the tree are the percent cover and for the perceptual meanings the value from the component matrix. The mean evaluation score (E) and the mean health rating (H) of each health group that was determined by the regression tree analysis is provided.

A)



B)



For regression trees, the proportion of the sums of squares explained by each split is represented graphically by the relative length of the vertical lines. Therefore, the amount of damage was the most important environmental cue used to describe the health of the coral reefs depicted in the photographs. For group 1 participants, photographs depicting less than 10.3 % coral damage and high perceived activity were evaluated highly (group A mean = 0.7 Figure 5.7A) and when the perceived activity dropped so did the evaluation (group B mean = 0.3 Figure 5.7B). The lowest evaluation occurred when damage was greater than 10.3 % and cover of branching corals was less than 17.1 % (group C mean = - 0.6). When damage was high, but cover of branching coral was also high, a medium health rating was given (group D mean = 0.1). In health group C photographs, the corals depicted were mostly overturned (Figure 5.7C) and in health group D photographs, the corals depicted in the photographs had structural damage such as breakages of branches (Figure 5.7D).

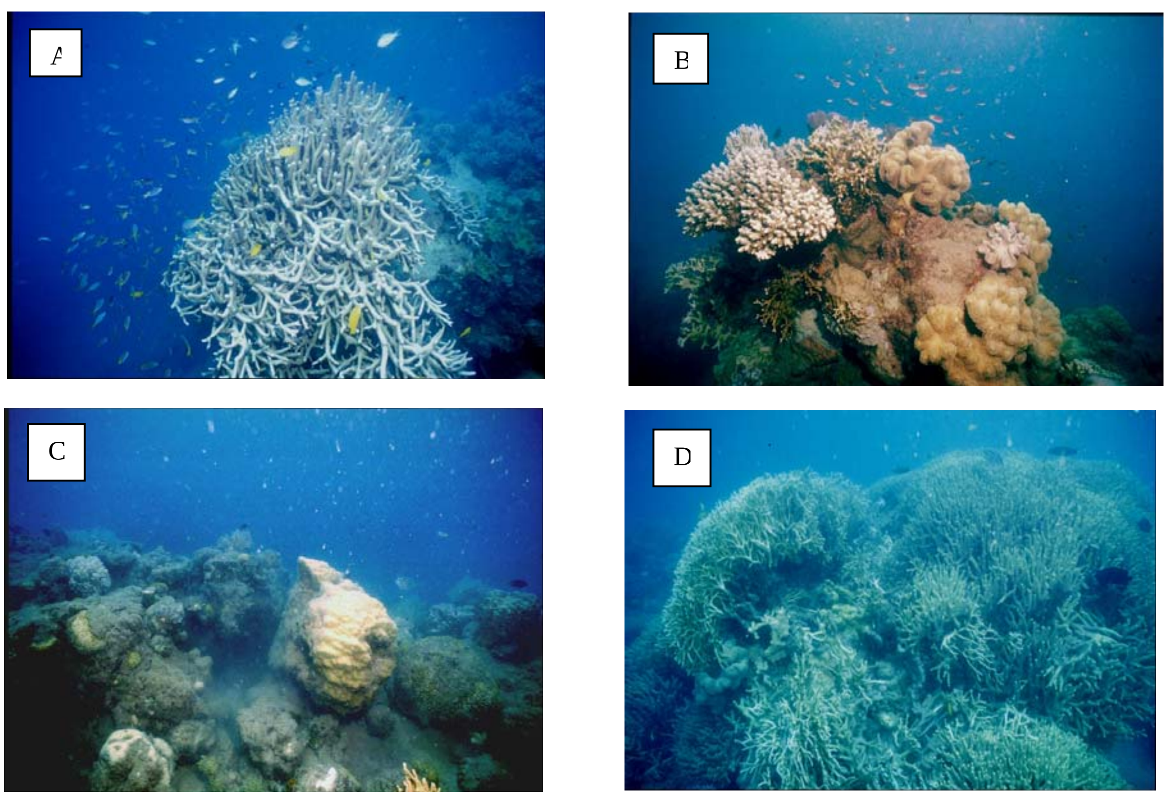
The regression tree developed using the evaluation dimension from group 2 participants showed that once again the amount of damage played the most important role in defining the four groups formed (Figure 5.6B). Lower level splits were caused by the amount of branching coral depicted in the photographs. The highest evaluation was provided for when damage was low and cover of branching corals was higher than 15.1 % (group A mean = 0.688) and where cover of branching corals was less than 15.1 % a lower evaluation was given (group B mean = 0.4 (Figure 5.6B)). The lowest evaluation (group C mean = -0. 6) was given for photographs with high damage and low cover of branching corals. Photographs depicting high damage, but also higher coral cover, received a higher health rating (group D mean = 0.01).

In both regression trees, the photographs from the sites associated with high anchor intensities were grouped to the high damage side of the tree either in groups C or D, except for one photograph from site 6 (Table 5.1). Photographs from the sites associated with low anchoring intensities were grouped into the low damage side of the tree either in groups A or B, except for one photograph from site 2. The distribution of photographs into the health groups was consistent between the two participant groups, except for the positioning of photographs from the sites 1 and 2, which are associated with low anchoring intensities and were switched between the health groups A and B by the two participant groups (Table 5.1).

Table 5.1. The number of photographs distributed into each "health group" as defined by the two participant groups in the regression tree analysis.

Anchoring	Participant group 1 Health Groups				Participant group 2 Health Groups			
(sites)	A	B	C	D	A	B	C	D
Low (1)	3	1	0	0	1	3	0	0
Low (2)	3	2	0	1	4	1	0	1
Low (3)	3	1	0	0	3	1	0	0
High (1)	0	0	4	0	0	0	4	0
High (2)	0	0	2	1	0	0	2	1
High (3)	0	1	1	3	0	1	1	3

Figure 5.7. A representative photograph for each health group identified by the regression tree analysis: A) health group A, depicts low damage and high branching corals or perceived activity; B) health group B, depicts low damage and low cover of branching corals or perceived activity; C) health group C, depicts high damage and low cover of branching corals, note also the overturned corals D) health group D, depicts high damage and higher cover of branching corals, note the damage consists of broken branches.



5.4 Discussion

The strong relationship between the health judgement and the evaluation dimension demonstrates that people's first and most important assessment of the environment is to judge its health. The health judgements provided by people clearly described changes in coral condition. The similarity of the health judgements between participant groups suggests that the ability to determine the health of an environment is innate and does not appear to be determined by prior experiences. Kaplan and Kaplan (1989) have described the consistency in people's preference for terrestrial landscapes. The types of landscapes preferred by people are consistent with those that provide people the opportunity to explore the environment, but remain safe. From an evolutionary perspective it is important that people can identify environments that provide for their survival (Appleton 1988; Kaplan & Kaplan 1989). Obviously, in a terrestrial environment where people have a long association with the landscape it is not unreasonable to expect they would be able to determine an environment that was healthy and one that was not. But the underwater environment is not known in an evolutionary sense and identifying a healthy underwater environment does not have immediate survival benefits. This research identified that the participants could accurately describe changes in the health of a relatively unknown environment and their ability to describe the environment was not influenced by contemporary experiences, as both expert and lay groups provided similar descriptions. These two findings, suggest that people have an innate ability to determine the health of an environment and that the cues people use may cross ecological boundaries. Whether people possess a generic set of cues for describing the health of the environment, regardless of whether that environment is a deserts or a coral reef requires further investigation.

One of the major assumptions of the ecosystem health concept is that people have an inherent sense of personal health and can therefore instinctively envisage a healthy environment (Lackey 2003). My research supports this hypothesis because participant's first impression of the environment was to make a health judgement and furthermore, the judgement was consistent with measurable changes in environmental condition. Because of the strong link between the evaluation dimension and health judgements, describing the health of an environment or ecosystem is a concept that people readily understand and use. Similarly, Williams & Cary (2002) identified a relationship between environmental preferences and ecological quality of terrestrial landscapes.

The three measures which collected information about environmental condition from different epistemologies described the change in coral condition associated with different levels of anchoring. Although the terms used to interpret the condition of the environment differed, a consistent theme was provided by both expert opinion and local knowledge. Coral reefs associated with high levels of anchoring had lost condition, whether described as having an increase in damage and decrease in coral cover or reduction in perceived value or health. This study has shown that, information provided by lay communities is useful in describing the coral reef environment. Similarly, other studies of local knowledge have found people have a good understanding of the environment (Robertson *et al.* 2000; Robertson & McGee 2003). In some cases important ecological knowledge, such as knowledge of fish spawning aggregations, relationships between trophic levels, changes in sea-ice patterns and facilitative activities of co-existing organisms (Berkes & Folke 2000; Olsson & Folke 2001; Zanetell & Knuth 2002; Gadgil *et al.* 2003) is only available from local communities. The close association of the information provided by both scientist and lay communities legitimises the use of local knowledge to provide descriptions of environmental condition for management purposes.

Combinations of information from both scientific and lay communities in environmental management has provided a more complete picture of environmental circumstances than information collected from one perspective alone (Hill *et al.* 1999; MacKinson 2001; Johnson & Graber 2002; Robertson & McGee 2003; Camilleri 2004). In this coral reef case study, the ecological measures describe a change in the condition of the coral reefs associated with anchoring and the perceptual meanings describe that the coral reefs had lost their visual quality. By combining these measures, management has a stronger case that action is required to reverse the changes occurring. The importance of the health description identified in this study suggests that expressing the change in the health status of the coral reefs may be motivational and increase people’s responses to the change in condition. Similarly, the combined scientific and local knowledge was useful in identifying the exact locations that required remedial action in a Swedish lake (Olsson & Folke 2001). Furthermore, Failing *et al.*(2004) described the usefulness of expert knowledge and stakeholders values to design appropriate adaptive management regimes. The combination of the multiple types of knowledge was effective in clarifying people's expectations and identified test regimes, which were initially thought to be useful, as too risky to warrant the expense of testing (Failing *et al.* 2004). Fisheries management has used local fishers' knowledge combined with scientific data to obtain a more complete understanding of fish population dynamics (MacKinson 2001).

One of the difficulties in using the ecosystem health concept is identifying when an environment is considered healthy or not (Schaeffer 1996; Scrimgeour & Wicklum 1996; Boulton 1999; Norris & Thoms 1999). Identifying environmental cues to assess the health of an environment by linking judgements of health with ecological and perceptual measures reinforced the dual role of societal values and biophysical elements in the ecosystem health concept. This emphasis is rarely considered in the development of environmental cues, which are commonly developed from an ecological perspective only (Bunn *et al.* 1999; Fairweather 1999; Karr 1999; Hilty & Merenlender 2000). In the coral reef case study, participant's health judgements were affected primarily by the level of damage and then by the cover of branching corals or perceived activity, making these variables important environmental cues to assess the effects of anchoring. The regression tree analysis predicts that when coral damage rises above 10.3 % of the area under examination, the health of the coral reef has declined. A further decline in health of the coral reef will occur if the damage is coupled with a loss of coral cover, particularly corals with branching morphology.

Two levels of health rating were given for the high damage photographs. By reviewing the types of damage depicted in the photographs, the lowest health rating was associated with overturned colonies and a medium health rating was associated with structural type of damage, such as breakage and fragmentation. The difference between the two health ratings is potentially associated with the participant's perception of the severity of the two types of damage. Overturned colonies suggest a high level of impact and an extensive recovery time

(Done 1992a). In comparison, breaks to branching coral colonies are frequent and the time to recover from loss of a coral branch is less (Hall 1997; Marshall 2000). The fragments that are generated by physical damage have the ability to re-attach to the substratum and grow, although the survival rate of fragments is low compared with an intact colony (Smith & Hughes 1999). Resilience and recovery are important factors influencing the health of a system (Rapport *et al.* 1998b; Whitford *et al.* 1999) and the ability of corals to recover from damage is a criteria that people are potentially using in their health judgements.

High health judgements were given to coral reef photographs that had low coral damage and activity or high cover of branching coral. The activity dimension, which is important to participants with a working association with coral reefs, was related to the whole system, identifying whether there were numerous fish, multiple types and shapes of corals and movement such as, feeding coral polyps. The use of the activity dimension suggests that these participants were interested not only in what type and how much coral was present, but whether the system appeared to be functioning. Measuring condition of the whole landscape is an important feature identified by other studies, for example the multimetric index of biological integrity as described by Karr (1999) and Ulanowicz (2000) model for describing resilience by estimating intra-system exchanges, such as prey / predators relationships.

Participants without a working association with coral reefs also focused on the amount of coral damage as the major difference between healthy and non-healthy coral reefs. The amount of branching corals was the next most important environmental cue used by these participants. The amount of branching corals described changes associated with both high and low levels of anchoring intensity. Therefore, the participants with no working association were focusing on the major structural component of coral reefs. Why participants focused on branching corals as opposed to other coral types is unknown and requires further investigation. However, the focus may be related to images portrayed in the media or the perception that branching corals look fragile, therefore the environment is healthy if they are present and intact.

The most critical issue in management of human activity is being able to identify whether the effect of these activities is good or bad for the health or integrity of the environment (Karr 2000). My research suggests it is possible to identify environmental cues that describe changes to the state of the environment. Furthermore, these environmental cues can be identified from either an ecological or social perspective. Developing environmental cues from a social perspective is advantageous because changes in the environment are described in terms that people identify and may motivate a change in people's behaviour to restore environmental health. An improvement in community participation occurred when environmental condition was measured in terms that people could understand rather than technical terms that carried no local meaning (Gasteyer & Flora 2000; Blann *et al.* 2003). In my research, the participants' descriptions provided useful information of coral reef condition, similar to the local knowledge that was used in other studies to describe water quality (Folke 2003), landscapes degradation (Robertson *et al.* 2000; Robertson & Hull 2001) and wetland rehabilitation (Robertson & McGee 2003). The health descriptions of the coral reefs provided by the participants gave accurate information about the reefs' condition. Therefore asking people that visit a coral reef for a health judgement could provide a simpler and cheaper assessment of the reef compared with conducting an ecological survey using the indicators identified in Chapter 3.

Apart from the information being accurate, local knowledge is beneficial for management agencies because communities access a wider number of sites, on a more continuous basis than is possible for scientists or managers alone; thus obtaining a more continual record of environmental conditions (Carr 2002). Community ideas and organisations increase the complexity of management structures therefore increase flexibility and in some cases speed of management responses (Ostrom *et al.* 1999). Involving the community in environmental management maintains values and traditions, reinforces community identity, promotes stability and enhances the ability of the community to adapt to new situations (Michaelidou *et al.* 2002). Therefore, asking people that visit a reef to provide a health judgement will provide useful and timely information to managers and allow the community to play a role in preserving a highly valued resource.

Fitzsimmons (2003) argued that the ecosystem health concept was “nebulous and uncertain” and did not provide a “cogent foundation for government action”. However, my research suggests that for coral reef environments, people’s vision of a healthy environment is consistent and reliable. Descriptions of the environment using either experiential or scientific methods provide usable information about the condition of the environment. People were able to detect changes occurring and these changes altered their perception of the coral reefs environment. Because the environment lost value, changing from one that was healthy and evaluated highly to one which was unhealthy and evaluated poorly, people may be motivated to change their behaviour to reverse the declining trend and promote a healthy coral reef ecosystem.

In this chapter, the health judgements provided by people were particularly instructive in describing the coral reef environment, suggesting that people have an innate abiltiy to describe the health of environments. In the next chapter, the health judgement and the three ecological measures identified in Chapter 3 are used to assess a management strategy. The assessment is conducted to show the usefulness of the ecosystem health indicators in evaluating the effectiveness of a management strategy.

CHAPTER 6

EVALUATION OF THE REEF PROTECTION PROGRAM USING ECOSYSTEM HEALTH INDICATORS

6.1 Introduction

In this chapter, the ecosystem health indicators identified in the previous three chapters are used to evaluate the effectiveness of a management strategy designed to protect coral reefs from the effects of anchoring.

Recent information on the deterioration of the state of marine resources (Pauly 2000; Jackson *et al*. 2001; Hughes *et al*. 2003; Pandolfi *et al*. 2003; Pauly *et al*. 2003; Bellwood *et al*. 2004) has increased momentum for the establishment of marine protected areas and other management strategies. However, for management strategies to improve the condition of the marine environment they must be effectively managed (Alder 1996; Allison *et al*. 1998; Day *et al*. 2003). To effectively manage a marine protected area, the condition of the environment needs to be measured and assessed against the goals and objectives of the management plan, thus determining whether the objectives have been met. Evaluation of management strategies are discussed briefly here, but have been reviewed in Chapter 3. Evaluation enables a more systematic and transparent assessment of management actions, identifies gaps in knowledge or actions that can be rectified and builds understanding of uncertainty (Walters & Holling 1990; Dudley *et al.* 1999b). Most importantly, evaluations provide evidence for which management strategy is working well and those that are not (Hockings 1998; Hockings *et al.* 2000; Hockings 2003). Dissemination of the results of evaluations is critical in maintaining public support and enthusiasm for the management process (Alder *et al*. 2002). Furthermore, evaluations can increase understanding about the relationships between management actions, the environment and people’s behaviour, thus building better management processes (Hockings *et al.* 2000; Parrish *et al.* 2003).

Selecting key environmental variables or indicators to conduct evaluations of management strategies has proven difficult and until recently evaluations have focused on the implementation and process of management rather than measured improvements in environmental condition (Alder 1996; Attwood *et al*. 1997; Hershman *et al*. 1999; Alder *et al*. 2002). The choice of indicators is critical to how people construct and solve environmental problems (Machlis 1992). Indicators should be chosen that evaluate management objectives and also raise awareness and encourage conservation. To raise awareness and encourage community ownership and participation in marine environmental management, identifying indicators that are familiar and important to people may prove more useful than measuring the environment using objective based ecological measures. There may be elements of the marine environment or way of describing the environment that are important to local communities and would make appropriate indicators. Fishers asked about the effectiveness of no-take reserves have identified increases in catches, which is important indicator to them and can be related to more formal ecological assessments (Russ & Alcala 1996; Katon *et al.* 1999; Roberts *et al.* 2001).

The Reef Protection Program (RPP) implemented by the Great Barrier Reef Marine Park Authority (GBRMPA) in the Whitsunday region was used as a case study to demonstrate the evaluation of a management strategy using indicators that were developed from both ecological and social perspectives (Chapters 3, 4 and 5). The objectives of the RPP are to protect the fringing reefs of the Whitsunday region from the cumulative impacts of anchoring, so that natural coral communities are maintained (Simmons & Marshall 1999). The RPP consists of moorings and marked no-anchor areas. The no-anchor areas are delineated with triangular buoys that mark the seaward extent of coral reef growth and anchoring is not permitted shoreward of these markers. The RPP encourages people to drop their anchors in locations where there are few corals, thus limiting damage to the reef. Guidance provided by the markers and the availability of moorings, should reduce the number of damaging anchor drops on to the coral reef structure, therefore reducing anchor damage without necessarily reducing the number of visitors to the sites.

The implementation of the RPP had high levels of community involvement, for example local dive groups installed and maintain the markers. Tourist operators and other locals provide information to visitors about the RPP, both prior to commencing their trip and once on water. While there was good community support, the activities people normally conducted at the locations were affected by the implementation of the strategy. Therefore, to foster good community relationships and ensure continued support, the effectiveness of the RPP needs to be reported in terms that are familiar to the whole community.

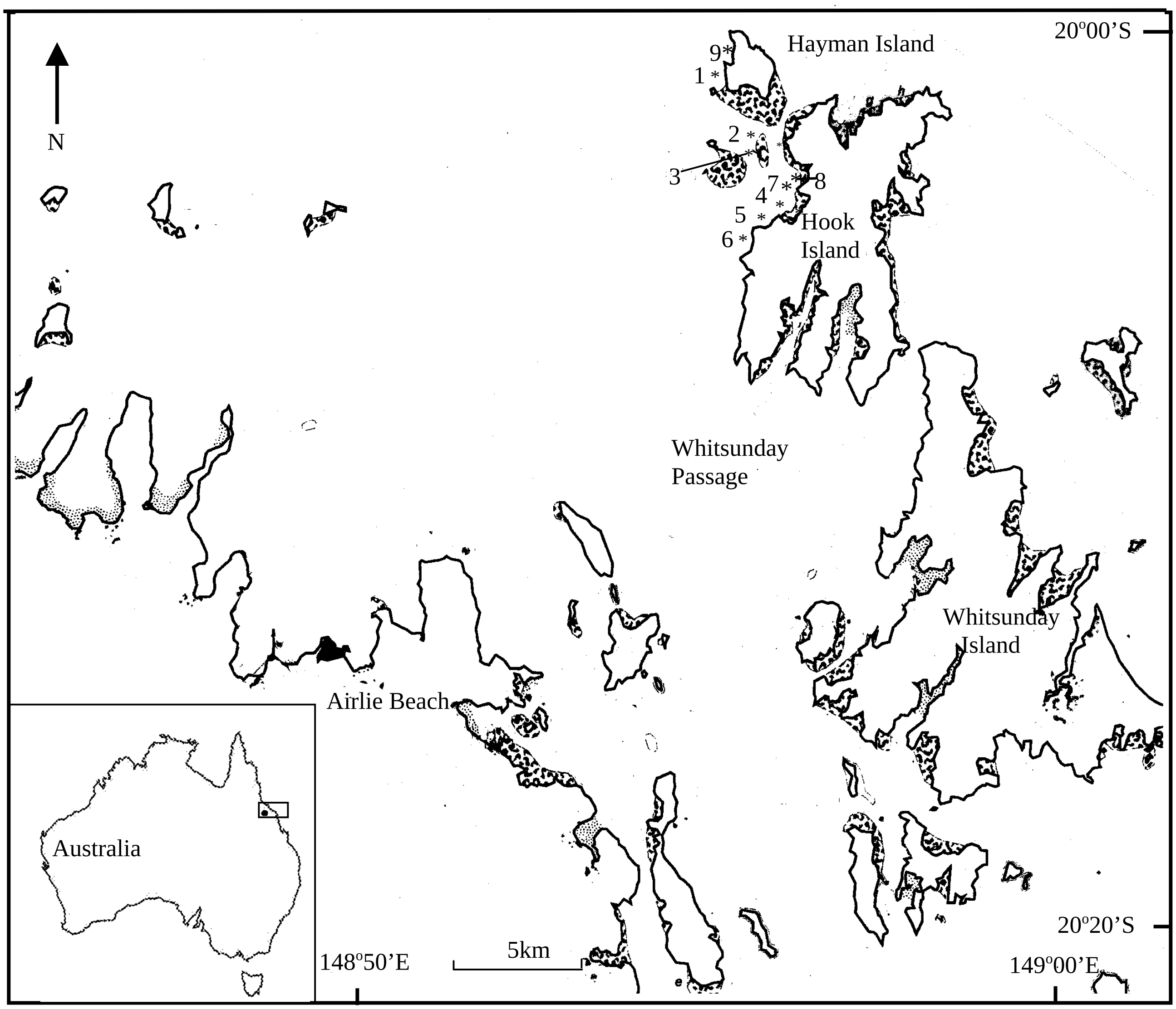
The most appropriate way to evaluate the effectiveness of a management strategy is to assess the condition of the site (including control sites) prior to implementation of the strategy. However, good baseline information is rarely available and very few evaluations have used a Before - After design (Willis *et al.* 2003). Without the before - after data the selection of indicators becomes difficult. In this study, therefore, indicators to evaluate the RPP were developed by comparing the value for a range of coral condition indicator at two reference treatments, coral reef sites with high and low intensities of boating use (Chapters 3, 4 and 5). Three important ecological indicators; the number of overturned corals, the cover of soft corals and the cover of corals in the family Acroporidae were identified by field-testing a range of variables and then evaluation each variable against a set of selection criteria (Chapter 3). Unlike many evaluations of management strategies, this research also developed indicators using people's perceptions, enabling people to be involved in assessing the sites and ensuring that data could be presented in familiar terms. The perceptual study identified that asking people to judge the health of the coral reef sites provided an accurate estimate of the coral reef condition. Furthermore, the health judgement was comparable between people with different backgrounds and experiences (Chapter 5).

The aim of the research was to examine the usefulness of coral reef health indicators developed from ecological and perceptual studies by evaluating the effectiveness of the RPP, a management strategy implemented to protect coral reefs from anchor damage associated with high levels of boating activity.

6.2 Methods

To evaluate the Reef Protection Program (RPP), I added a further three coral reef sites to the survey design and compared the values of each of the indicators of the three new sites to the six coral reef surveyed during the development of the indicators (Chapters 3 & 4), providing a total of nine coral reef sites surveyed (Figure 6.1). The nine coral reef sites were divided into three groups depending on the level of boating activity and protection they were afforded. The three groups including three sites that were subject to; 1) low levels of boating activity and no RPP (mean boats per day = 1.3), 2) high levels of boating activity and no RPP (mean boats per day = 3.7) and 3) high levels of boating activity and protection provided by RPP (mean boats per day = 6.6). In the results these three treatments are labelled as low, high and protected respectively. The sites where the RPP was installed were associated with high levels of anchoring prior to implementation of the management strategy. The level of boating activity was estimated using direct observations, discussion with community groups and data collected by GBRMPA. In each of these treatments, two depths (crest and lower slope) on three coral reef sites were assessed. To reduce confounding effects, all sites were within the Great Barrier Reef Marine National Park A Zone, in which recreational line fishing is allowed, but commercial line fishing, trawling, netting or spear fishing are not allowed (zoning regulations have changed since conducting the field research). Furthermore, sites selected were similar with respect to ambient environmental conditions, such as distance from shore, protection from prevailing wind and wave action.

Figure 6.1. Location of survey sites in the Whitsunday Islands. Survey sites are indicated by an asterisks (*) and low levels of boating activity occurred at sites 1-3, high levels of boating activity occurred at sites 4-6 and high levels of boating activity with protection occurred at sites 7-9. Note the similarity of the nine sites with respect to distance from shore and protection from south-east prevailing winds. Coral reefs are the darkly stippled areas and mangrove areas are lightly stippled



The four indicators measured at each site were; the number of overturned corals, cover of soft corals, cover of coral in the family Acroporidae and a judgement of health. The number of overturned corals were counted in ten 10*1m belt transects and the percent coral cover was estimated using ten, 10m line intercept transects (Full methods in Chapter 3). The evaluation of health occurred at two stages; 1) photographs of coral reef sites associated with high and low intensities of anchoring but not protected by the RPP (i.e. treatments 1 and 2) were provided to 76 participants to judge the health (Chapter 5) and 2) the coral reef sites protected by the RPP (i.e. treatment 3) were judged in the field. The health of the reef was judged on a score of 1 - 6, where 1 is unhealthy and 6 is healthy. Photographic judgements were conducted on 26 photographs and field judgement were provided at three positions along the transect line; 0, 5 and10m. The field judgements were made by 2 people, myself and my non-expert assistant. Judgements made by any more personnel in the field were not possible because of Work Place Health and Safety Rules. Judging the health of the coral reefs using these two techniques was expected to be comparable because of previous research conducted by Shuttleworth (1980), which identified that perceptual judgements of an environment presented photographically are comparable with those made in the field. Furthermore, my research identified that 1) the assessed condition identified in the field was similar to that described by the photographs and 2) a range of people provided similar health judgements, so judgements provided by the researcher and other participants are comparable (Chapter 5). The RPP was implemented in 1996 and my research has evaluated the outcomes of the strategy eight years after implementation.

A multivariate analysis of variance (MANOVA) was used to compare the three treatments. Coral reef sites were nested within each treatment and interaction terms were not calculated because the sampling design was not fully orthogonal. If the management strategy is effective, indicators measured at protected coral reef sites should change over time to resemble values for corals reefs with historically low intensities of anchoring. Following MANOVAs, mean values of each indicator were compared using Tukey’s HSD tests, to identify the relationship between the three treatments. Depths were tested separately and normality of the data was achieved by conducting a log (x + 1) transformation on the numeric data and arc-sin square root transformation on the percent cover data (Underwood

1997). A canonical discriminant analysis was conducted to combine the four indicators and graphically demonstrate how the condition of the coral reefs protected by the RPP differs to coral reefs associated with both high and low intensities of boating activity.

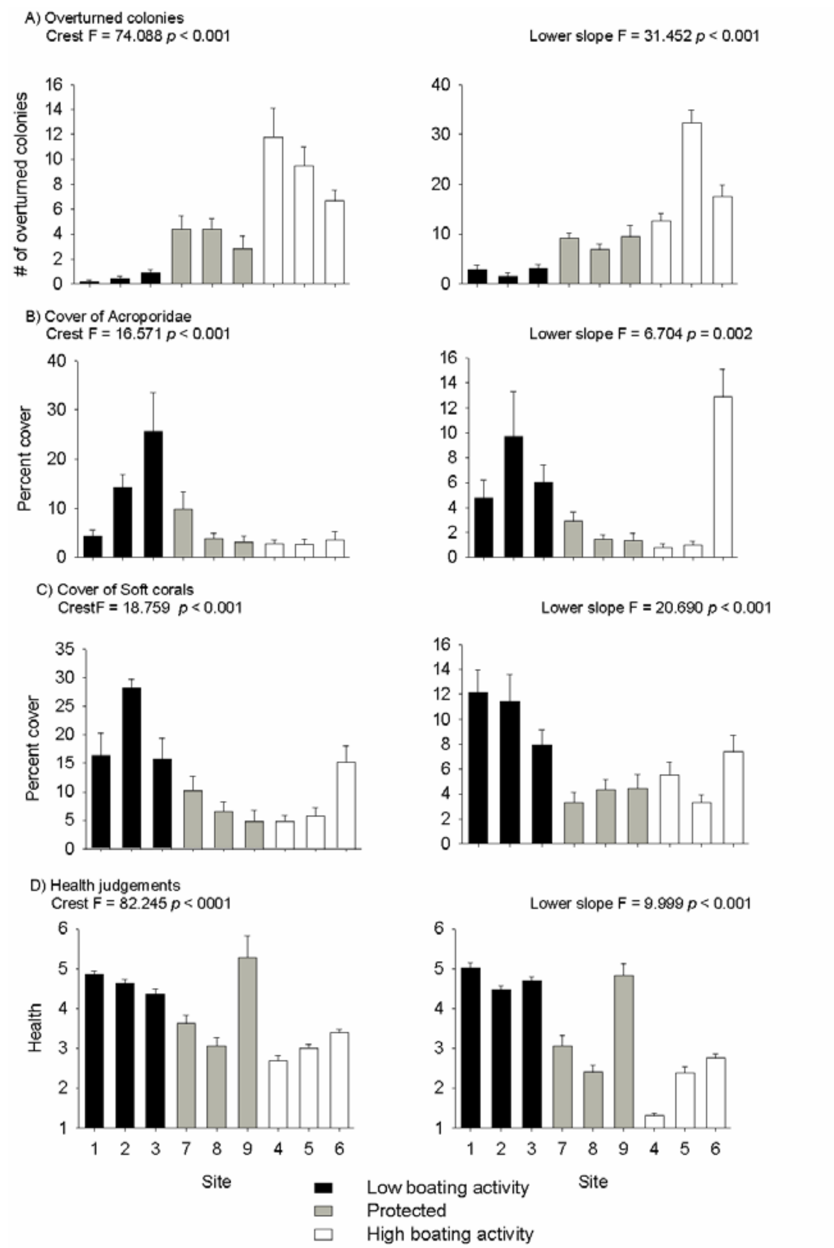
6.3 Results

The condition of the coral reef sites protected by the Reef Protection Program was different to the condition of coral reef sites associated with high levels of boating activity. The three protected coral reef sites had fewer overturned corals compared with the three coral reef sites associated with high levels of boating activity and the trend was seen on both the crest and lower slope (Figure 6.2A). The Tukey's test separate all three treatments, therefore the number of overturned colonies was reduced, but not to the level recorded at the coral reef sites associated with low levels of boating activity (Tukey's test: low boating < protection < high boating $P < 0.001$ for number of overturned colonies on both the crest and lower slope).

The cover of corals in the family Acroporidae and soft corals varied between the three treatments (Figure 6.2B & 6.2C). The cover of these coral groups was generally highest on the coral reefs associated with low level of anchoring and was lower on both the protected coral reef sites and sites associated with high anchoring intensities. On the crest, the protected coral reef sites and coral reef sites associated with high levels of boating activity displayed similar cover of both coral groups (Tukey's test: low boating > protection = high boating, $P < 0.001$ for cover Acroporidae corals and soft corals) suggesting the cover of corals had not yet proceeded towards the condition described at the sites with historically low levels of boating activity (Figure 6.2C). On the lower slope, there was an overlap in cover of Acroporidae between all nine sites within the three treatments (Figure 6.2B Tukey's test: low boating = protection = high boating, $P < 0.001$ for cover of Acroporidae corals), suggesting high levels of variation within treatments. The cover of soft coral on the lower slope of protected sites was similar to the sites with high levels of boating activity and no-protection, suggesting that there was no recovery of soft corals on the lower slope (Figure 6.2C Tukey's test: low boating > protection = high boating, $P < 0.001$ for cover of soft corals).

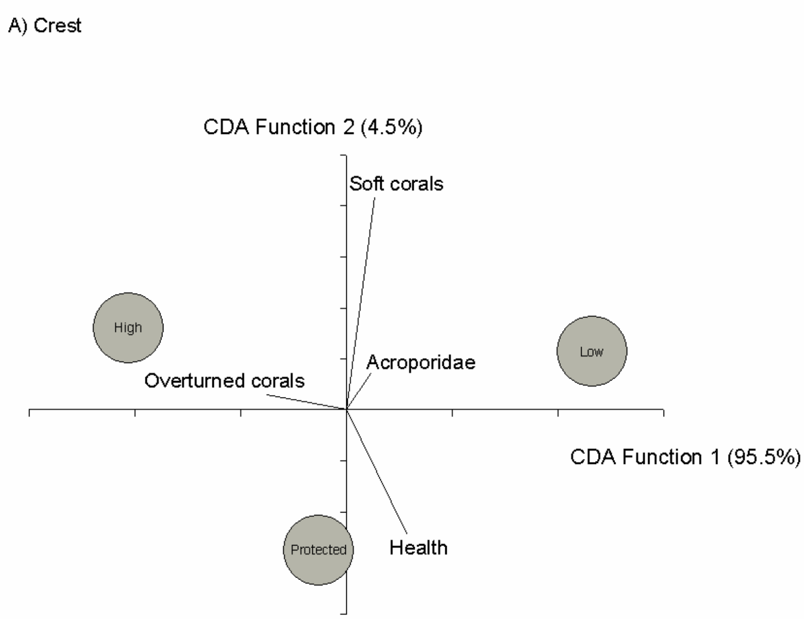
The three protected sites were perceived to be healthier than the coral reefs sites associated with high levels of boating activity, but less healthy than the three sites associated with low levels of boating activity and this pattern occurred at both depths (Figure 6.2D Tukey's test: low boating > protection > high boating, $P < 0.001$ for judgements of health on the crest and lower slope).

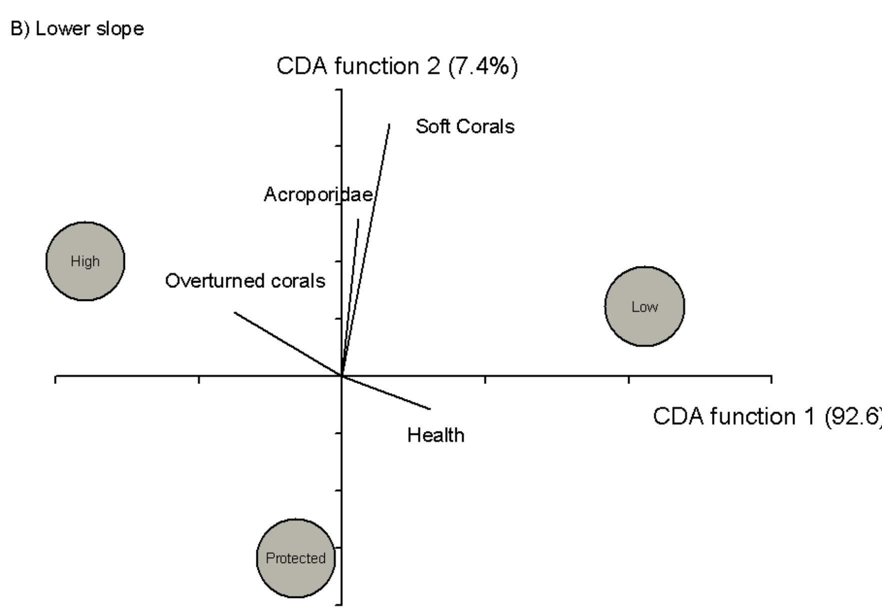
Figure 6.2. Mean measure (±1 SE) of coral reef condition on the crest and lower slope of coral reefs associated with the three treatments. Results of the MANOVA are presented, degrees of freedom are 2:6:81 and alpha levels were set at $P = 0.05$. Note the scale and units on the y axis vary. Note the protected coral reef sites have been graphed between the two other treatments to allow ease of comparison.



Combining the four indicators in a Canonical Discriminant Function analysis showed that the protected sites were intermediate between the sites with low and high anchoring activity (Figure 6.3). The first function was the most important in characterising the coral reef sites and explained 95.5 and 92.6 % of the variation occurring on the crest and lower slope, respectively. The separation of the treatments along the horizontal axis was influenced by the number of overturned coral colonies on the crest and a combination of overturned coral colonies and health judgements on the lower slope. The position of the protected coral reef sites away from the soft coral and Acroporidae cover variables is consistent with the lack of response of these variables identified in the MANOVA.

Figure 6.3. Results of Canonical Discriminant Function analysis using the four indicators of coral reef health to separate the coral reef sites associated with low levels of boating activity (low), high levels of boating activity (high) and high levels of boating activity plus protection (protected). The length and direction of the bi-plot lines reflects the relative influence of each variable on the positioning of the sites. The group centroid for the three coral reefs within the three treatments is at the centre of the circles and the diameter of the circle represents one standard error. A) crest, B) lower slope.





6.4 Discussion

The Reef Protection Program was effective in reducing coral damage associated with anchoring without reducing the number of boats that accessed the area, thus protecting the coral reefs and maintaining benefits of boating. The numbers of overturned corals were reduced and the coral reefs were perceived to be healthier, where the Reef Protection Program was implemented, in comparison to the coral reef sites that were associated with high levels of anchoring activity and had no protection. However, the cover of the two coral groups did not change with reef protection. Possible explanations for lack of difference in coral cover are; that the damage still being observed is sufficient to retarded growth, thereby keeping cover low; that recruits of these two groups have not settled or survived in the protected sites and therefore have not added to the cover; or that corals in other groups have grown into the space made available by the damage. Rogers & Garrison (2001) identified that corals could recruit onto areas damaged by anchoring, but the newly settled coral had low survival rates because of the unstable substratum that was left by the anchor damage and coral cover had not returned to ambient levels ten years after the anchor damage occurred. The response of coral cover to other management strategies has also varied. Some evaluations have recorded an increase in coral cover on protected coral reefs and others have found coral cover has remained the same between protected and non-protected sites (Epstein *et al.* 1999; Hawkins *et al.* 1999; McClanahan *et al.* 1999; Williamson *et al.* 2004). The variability of coral cover indicators suggest that they are not as sensitive as other indicators, such as damage indicators in describing changes to coral reef condition, as was also identified in Chapter 3.

The most persuasive way to evaluate a management program is to measure the conditions of the environment, at both proposed protected sites and relevant reference sites, prior to the implementation of the strategy and then measure again after implementation and compare the results. However, as is the case with many management strategies, measurement of the condition of coral reefs prior to implementation of the RPP was also limited (a pilot study was conducted at two sites only). The survey design of this study compensated for the limited before data by having multiple reference sites, which included coral reefs associated with different levels of the anchoring intensity. The reduction in numbers of overturned colonies at coral reef sites protected by the management strategy confirms the preliminary results by Malcolm (1998), which suggested that coral damage was reduced with the installation of no anchor areas. Evaluation of the results suggests that most people are respecting the no anchor areas, however, the presence of some damage within the protected areas, suggest that either damage present prior to installation of the RPP still persists or that a few anchors are being placed inappropriately.

Many indicators have been developed to measure the health of an environments (Rapport *et al.* 2003), most of these however were developed from a natural science perspectives. The assessment of the RPP identified that the judgements of health provided a useful indicator to describe the differences between protected and non-protected coral reefs. Asking people to judge the health of the environment therefore provides useful information and presents a way for people to be involved in monitoring, potentially furthering collaboration with management authorities. The health judgement was the most important assessment people made of the coral reef (Chapter 5), suggesting that health is an important value people hold for the environment. Therefore, if the environment is assessed as being of poor health people may be motivate to conduct their activity in accordance with management strategy to ensure the environment regains its health. Involving people with the environment and its management is one of the aims of the ecosystem health concept and when people are involved, both the community and the environment benefits (Martin & Lockie 1993; Berkes *et al.* 2000; Berkes & Folke 2000; Papageorgiou 2001).

The evaluation of the RPP identified that both scientific and lay judgements provided information about the condition of the environment. Similarly, Moller *et al.* (2004) found scientific and local knowledge complementary and importantly using both types of knowledge improved understanding between stakeholders, strengthened partnerships and helped the community reach a consensus. Furthermore, involving local wildlife users in monitoring allowed them to evaluate scientific predictions on their own terms. Science is expensive, which potentially reduces the spatial and temporal extent of assessments. In comparison locals, particularly tourist operators, access marine protected areas on a regular basis and can provide daily or regular information about the condition of the environment that could be useful for management decisions. Furthermore, people that have a long associated with the area may have specific local knowledge about irregular phenomena, anomalies and rare events, which is difficult to obtain using conventional survey methods (Robertson & Hull 2001).

The Whitsunday region of the Great Barrier Reef is a successful coral reef management area. The research presented here shows that the Reef Protection Program is effective in reducing damage and maintaining the health of coral reefs within no anchor areas. The factors leading to these successes include, clear regulations and signage, adequate patrolling and high levels of community involvement and education within the region, similar to the factors important in successful terrestrial tropical parks (Bruner *et al.* 2001). The RPP was initiated by community groups and local people were involved in installing the no anchoring markers and conduct regular maintenance (Simmons & Marshall 1999). The ownership of the program by the locals means they provide information to other users, both on water and prior to leaving port therefore people have awareness, understanding and willingness to support the management strategies. The evaluation of the RPP demonstrated the usefulness of indicators developed from an ecological and social perspective, so that the effectiveness of the management strategy is described in terms that managers, scientists and local people can readily interpret.

CHAPTER 7

GENERAL CONCLUSIONS

7.1 General Conclusions

There is wide recognition that managing the environment requires a holistic approach (Grumbine 1994; Endter-Wada *et al.* 1998) however; this creates problems in integrating research from different disciplines. Each disciplinary area has its own concepts, theories and methods, and crossing boundaries between disciplines questions the underlying concepts of the individual discipline. The ecosystem health concept is particularly vulnerable to its legitimacy being questioned, because the concept clearly links a scientific idea with a value judgement (Rapport 2003). Health is a normative value and therefore can not be objectively measured. To use the ecosystem health concept in environmental management, the target condition of the environment is derived from a negotiation between stakeholders using value judgements (Callicott *et al.* 1999). Therefore, the target condition could be manipulated by different stakeholder groups to meet their own requirements rather than that of a healthy environment. The clear advantage of the ecosystem health concept is the value judgement, because people value health in themselves and others, and therefore it is expected that a healthy environment would also be valued. My research explored the ecosystem health concept by crossing disciplinary boundaries and identifying the relationships between ecological measures, perceptual meanings and health judgements of the coral reef environment.

The framework developed to identify the ecological measures provided a means of screening a wide range of variables and selecting those that would provide an effective and efficient evaluation of a management strategy designed to protect coral reefs from the effects of anchoring. The framework developed was transparent enabling all stakeholders to see why each indicator was chosen. The indicators selected need to be believable and important to all members of the community, thus developing a transparent mechanism to select the indicators will reduce a potential area of conflict between stakeholders. The framework was transferable to other management situations and would help solve the lack of data collected prior to implementation of the management strategy, which is a common design problem affecting evaluations of the effectiveness of many management strategies (Willis *et al.* 2003). The development of the ecological measures used "the ease of measurement" as one of the selection criteria, with the view that identifying indicators that were easy to measure would enable local communities to participate in monitoring, thus increasing community participation in environmental management.

While, indicators selected to evaluate management strategies are generally developed using ecological studies (Belnap 1998; Lorenz 1999; Dale & Beyeler 2001; Carr 2002) similar to the research conducted in Chapter 3, few have used perceptual information. The perceptual study (Chapter 4 & 5) identified that asking people to judge the of health of the coral reef provided a good description of the condition of the reef, particular in describing changes associated with anchoring. Therefore, people who are visiting coral reefs could provide information on the condition of the reef that would be useful for environmental management. A description of the health of the coral reef provided a simple and cost effective indicator that could be used to monitor changes to coral reef condition. Projects such as, Reef Check (Hodgson & Liebeler 2002) and Bleachwatch (GBRPMA 2004a)are encouraging the public to be involved in collecting information about the condition of coral reefs around the world. The information is expanding the knowledge base and provides an early warning of changes in coral condition, which may help identify the local causes of changes in coral condition and allow management programs to be implemented quickly.

The most important advantage of using a health judgement for monitoring changes in the environment is that people are likely to value a healthy environment and may be motivated to change their activities to ensure the environment remains in a healthy condition. However, the relationship between people's knowledge and their behaviour has not been convincingly established. For example, Medio *et al* (1997) found briefings reduced the number of times divers contacted coral reefs and Williams and Cary (2002) found that preference for landscape of relatively high ecological quality is associated with protective resource behaviours. In contrast, Alessa *et al.* (2003) found people with higher levels of environmental education caused more damage on rocky shores because they wanted to share their knowledge with other people. An extension to this research would be to provide photographs of anchor damaged reefs to people visiting the reefs and identify whether increasing people's knowledge of negative environmental outcomes will change their behaviour.

The ecosystem health concept uses familiar terms to motivate people to change their behaviour to promote conservation. Because the health of the coral reef scenes was the most important meaning people attributed, it suggests that implementing management strategies for coral reefs within ecosystem health concept will work well. Other successful projects have been established using motivational power to change people's behaviour. The Humane Society of the United States for example identified that people appreciate and enjoying seeing wildlife within their daily lives and has successfully capitalised on these feelings and beliefs of people to change their behaviour in ways that enhanced wildlife in urban areas (Grandy & Rutberg 2003). On the Great Barrier Reef for example, new partnerships have been established between local governments, schools and the management authority. The projects, termed reef guardians, have identified the relationship between actions on the land and the health of the reef and motivated schools and local community groups to initiate projects, such as the production of calico bags to reduce plastic waste, cleaning up waterways and monitoring water quality to ensure clean water is moving from the catchment to the reef (GBRPMA 2004b).

My research identified how environmental degradation affected the meanings people ascribed to the coral reef environment. People described the coral reefs as being interesting, good for diving etc, at sites associated with low level of anchoring intensity and these useful or more positive values for the coral reef were lost as anchoring intensity increased. This highlighted that people have an attachment not only to the coral reef environment, but a certain condition within that environment. The loss of value has also been expressed about environmental degradation occurring on farming land for example. Several studies have suggested that the sense of loss people feel when their land is degraded may have a direct effect on their health and well-being (Robertson *et al.* 2000). Recently, management strategies implemented to solve land degradation have included community action as part of the strategy. This approach is seen as a way to address the environmental problems, and allow the community to be empowered and take responsibility for their past actions; thus initiating a process of rebuilding environments and communities (Martin 1991; Robertson *et al.* 2000). Hatcher and Hatcher (2004) identified that the many tangible benefits that people obtain from a healthy coral reef ecosystem are eroded with reef degradation. Because people have an ability to determine changes in coral reef condition, a loss in condition may potentially impact on the non-tangible benefits of coral reefs and also affect the psychological well-being of associated communities.

One of the major assumptions of the ecosystem health concept is that people have an innate sense of personal health and can therefore instinctively envisage a healthy environment (Lackey 2003). The relationship between people's health judgement and the evaluation dimension reported here supports this underlying assumption of the ecosystem health concept. Furthermore, the similarity between the health judgements provided by participants with different experience with the coral reef environment suggests that the ability to determine the health of the environment is innate. From an evolutionary perspective it is important to be able to identify environments where the chances of personal survival are high, i.e. environments that are healthy. Humans have a long association with the terrestrial environment and people's preference for that environment is related to human evolution (Kaplan & Kaplan 1989). The ability of people to describe the underwater environment suggests that people have a capacity to process information and identify changes in the health of an environment even for relatively unknown environments. These findings suggest that there are potentially a set of cues that transfer across environments, which people are using to make their judgements. Environmental cues that appear important to health judgements are the presence of structural elements, such as branching corals for coral reefs or trees for terrestrial examples and the presence of activity and movement such as fish and movement associated with currents and feeding corals or birds, tidal changes for terrestrial situations (Kaplan & Kaplan 1989). Identifying the existence of a set of environmental cues that are compatible across ecological boundaries warrants further research.

When discussing whether people's ability to describe the environment is innate or not, the influence of other present day experiences, such as presentation of the environment in the media, must be considered. The participants in the current research were mostly highly educated and potentially have high exposure to the coral reef environment through cultural outlets, such as tourist advertising, television documentaries, environmental education at schools and universities. Therefore, to extend the work and identify the relationship between innate ability and cultural influence including participants who are isolated geographically and culturally from coral reef environments would be useful.

There are several ways which individuals and groups could differ in their cognitively ability to describe different concepts, including; 1) the number of factors required to account for their judgements, 2) the relative weights given to the same set of factors or 3) the nature of the factor used (Osgood *et al.* 1957). Most interestingly, the participant's judgements of coral reefs were very consistent for all three of these variables. In comparison, some variation in cognitive ability has been identified in terrestrial situations. For example, Walmsley & Jenkins (1993) identified that older people, and those assumed to have greater experience, provided more constructs to describe the environment compared with younger participants. Coral reef ecological research in comparison to terrestrial ecology is relatively young, providing only a short time for coral reef specific terms and concepts to develop. Therefore, the difference between scientific and local concepts may not have had time to emerge. The ability of people with a wide range of experience to detect differences in the environment also identifies that attention needs to be paid to the types of photographs that are presented to people in perceptual research. Perceptual studies should provide participants with small changes in environmental condition, so subtle difference in people's interpretation of the environment can be explored.

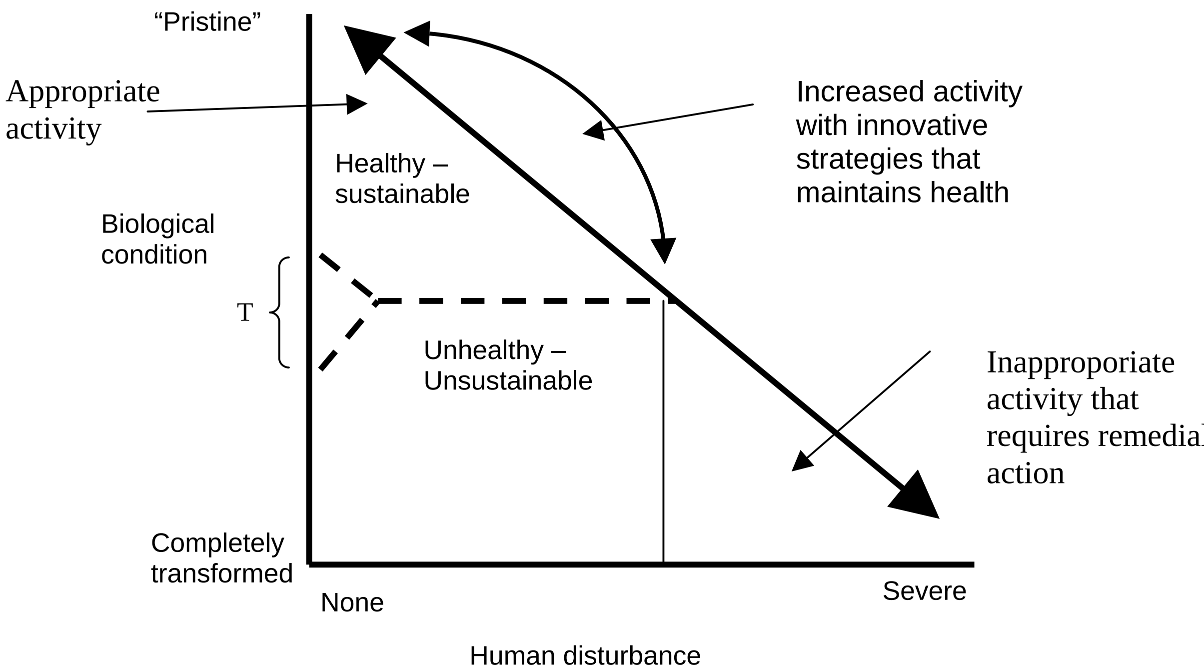
The research provided a highly successful way of exploring how different people describe the environment and would be useful for broadening the basis of information gathered for environmental management. Integrating descriptions provided by different people identifies elements of the environment that are valued, which would allow sharing and understanding of stakeholders' perspectives and therefore enhance communication. For successful co-management of the environment, stakeholders need to feel their contributions are respected and exploring people's perceptions of the environment is a way to enable discussions to be conducted using common meanings.

The research explored the healthy – unhealthy dichotomy and similar techniques could be used to explore the relationship between other important concepts applied to the environment such as, natural – unnatural, pristine – degraded, sustainable – unsustainable, integral and totally transformed. These terms and concepts are commonly used within the environmental management literature and policy development, but remain poorly defined and not integrated. Westra (2003), for example, discussed the relationship between ecological integrity and ecosystem health. The exploration of these terms would allow an understanding of the connection between the concepts and which is the most readily understandable and appropriate concept for managing the environment.

The evaluation of the effectiveness of the Reef Protection Program showed that the ecological health indicators developed in the research were useful in describing the movement of the environment along the ecosystem health continuum and identified the point at which the coral reef was considered healthy or not. For the coral reef environment the important environmental cues were the percent cover of coral damage and cover of branching corals. When the percent cover of damage was higher than 10 % and the cover of branching corals was below 17 % the coral reef site was described as unhealthy. The coral reef sites used in this research were from an inshore location and an interesting extension to the research would be to identify if similar levels of damage and cover correspond to an unhealthy judgement in other coral reef environments, such as coral reefs from different latitude or cross-shelf position, which vary with respect to the structural components (Harriott & Banks 2002).

Three ideas within the ecosystem health concept were confirmed. First, people's first and most important judgement about the environment is a description of its health. Second, people's ability to describe a healthy environment appears to be innate (as it crossed a range of experience conditions). Third, with appropriate management an environment can be subject to ongoing or increased use and its health maintained. Therefore the ecosystem health concept is an appropriate concept for describing and discussing environmental management policies. The model describe by Karr (2000) (Figure 1.1) however could be improved conceptually (Figure 7.1). The y - axis may be more appropriately described as varying from pristine to one that is totally transformed, because it is possible to have an environment that is natural and without life, for example within a volcano. Furthermore, I believe that if the ecosystem is managed with respect to its health, environmental condition should not be allowed to fall below the healthy / unhealthy threshold. Conceptually appropriate activity is shown in the top triangle and these activities are conducted without causing an unhealthy outcome. However, with increased population growth and development these activities are likely to increase and to allow that to occur innovative management strategies are implemented to maintain environmental condition (curved arrow). Identification of innovative strategies requires input from multiple stakeholders. The bottom triangle identifies inappropriate activities that should not be conducted and if the environment has declined to this extent remedial action is required.

Figure 7.1. The ecosystem health concept, redrawn to show that the environment should be managed to allow an increase in use, but not change the biological condition (curved line). The y- axis is a description of biological condition from pristine to completely transformed and x- axis describes human disturbance. The biological continuum is depicted with an arrowed line and the point (in vicinity of T) at which the environment changes from healthy to unhealthy was identified for the coral reef environment to be an interaction between amount of coral damage and coral cover.



The ecosystem health concept provided a well understood normative judgement, which is related to ecological measures. People with a range of environmental experience have a similar notion of what constitutes a healthy environment, even in the relatively unknown environment like that of a coral reef habitat. Therefore, the ecosystem health concept has the potential to make an important contribution to environmental management.

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