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The Representative Areas Program for Protecting Biodiversity in the Great Barrier Reef World Heritage Area

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Abstract Existing no-take areas within the Great Barrier Reef Marine Park reflect a historical focus on coral reefs and remote 'pristine' areas. The Representative Areas Program (RAP) aims to enhance protection of the region's biodiversity by developing a network of no-take areas that represents the range of habitats and communities within the Marine Park. A comprehensive range of biological and physical information was used to define 70 reef and non-reef bioregions across the World Heritage Area. The Great Barrier Reef Marine Park Authority is identifying options for no-take area networks using a combination of expert opinion, stakeholder involvement and analytical approaches. Marine reserve design software has been adapted and expanded for use in the RAP. The aim in selecting the final no-take area network is to maximise biodiversity protection whilst minimising economic, cultural and social costs. The RAP is therefore being undertaken with comprehensive public participation involving all interested parties.

Keywords Marine biodiversity, No-take area, Representative area, Bioregion, Marine protected area, Great Barrier Reef

Introduction

Evidence shows that no-take areas, which may include no-go areas, help to protect marine biodiversity (Sobel 1996; Roberts and Hawkins 2000; Halpern, in press). However, most marine and terrestrial no-take areas fail to adequately represent the range of biological diversity even at small scales (Margules and Pressey 2000). While the location of many no-take areas has been influenced by the best available information, it has often been biased towards supporting threatened species, high profile habitats or 'pristine' areas in remote localities. Globally, there is a growing realisation that managers of protected areas need to identify and protect representative examples of the diversity of habitats, communities and processes, rather than focusing on individual species or specific habitats (Hackman 1995; Ray 1999).

Since its declaration in 1975 as the world's largest marine park, the Great Barrier Reef Marine Park (GBRMP) has provided different degrees of protection for different habitats within its boundaries. A variety of management tools (e.g. zoning, permits, management plans, public education) (Day in press; Skeat et al this volume), and collaboration with watershed and fisheries management agencies, have been used to help achieve ecological protection and other management objectives. A multiple-use zoning approach has provided high levels of protection for specific areas whilst allowing other uses, including certain fishing activities, to continue in other zones. Pressey and McNeill (1996) consider that multiple use zoning models are more effective than only small, isolated, highly protected areas for three reasons*:*

(1) ecologically, it recognizes the temporal and spatial scales at which marine ecosystems operate;
(2) practically, it is easier to manage, and potentially buffers and dilutes impacts of activities in areas adjacent to strictly protected areas; and
(3) socially, it helps to resolve and manage conflicts in the use of natural resources.

About 16,000 km^2 of the GBRMP is currently zoned as 'no take', including 'no go', zones. This equates to only 4.7% of the Marine Park and reflects an historical focus on coral reefs and more remote 'pristine' areas.

Coral reefs are the best known habitats in the region, but 25 years ago they were perceived as fragile and were regarded in isolation. Scientists have now conveyed to managers more about the region's ecosystem, the significance of interconnectivity across the reef and adjacent non-reef areas, and the importance of other habitats that may have lesser public appeal (Cappo and Kelley 2000).

This relatively recent awareness of the importance of an ecosystem-approach and interconnected habitats is reflected in protocols at international (eg. Convention on Biological Diversity), national (eg. the National

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Representative System of Marine Protected Areas, ANZECC 1998; Australia's Oceans Policy, Commonwealth of Australia 1998) and regional scales (e.g. the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area, GBRMPA 1994).

The Representative Areas Program (RAP) at the Great Barrier Reef Marine Park Authority (GBRMPA) also reflects this new awareness and is relying on collaboration between scientists, managers and stakeholders to help protect the range of biological diversity within the GBRMP. The RAP aims to help:

- maintain biological diversity at the ecosystem, habitat, species, population and genetic levels;
- allow species to function undisturbed in some areas
- provide an ecological safety margin against human-induced and natural disasters;
- provide a solid ecological base from which threatened species or habitats can recover or repair themselves; and
- maintain ecological processes and systems.

If representative areas of all known habitat and community types can be identified and adequate examples protected within a network of no-take areas, then these areas should conserve examples of most species together with the habitats and ecological processes upon which they depend. We know astonishingly little about marine biodiversity (De Fontaubert et al. 1996) and a considerable proportion of marine species have yet to be discovered. A holistic approach will help ensure protection for the species we know and will minimise the risk of failing to protect biodiversity that we have not yet classified or discovered.

We outline the process and some outputs of the RAP at GBRMPA. This paper describes some of the science and management behind the various phases of the RAP but primarily focuses on the initial phases.

Methods

General principles

RAP is guided by a suite of general principles developed by the Australia and New Zealand Environment Conservation Council (ANZECC 1998) to guide development of a national representative system of marine protected areas. These principles include the precautionary principle[7] as well as a requirement that any network be comprehensive, adequate and representative (the 'CAR' principles) (Thackway 1996):

> *Comprehensive* means including, in no-take areas, the full range of diversity across the marine environment as recognised at an appropriate scale (i.e. ecosystem, habitat, community, population, species and genetic diversity). Special or unique biological communities, habitats or species comprise one part of the full range of diversity.

> *Adequacy* refers to the size, configuration, replication and level of protection offered within a protected area network to ensure the maintenance of ecological viability, to allow sufficient levels of connectivity between populations, species and habitats, and to safeguard the integrity of natural processes.

> *Representative* means an area is typical of its surroundings at some chosen spatial scale (i.e. at the scale of habitat, community or population). A representative area within a particular region therefore has similar physical features, oceanographic processes and ecological patterns to elsewhere in that region, and is likely to have similar biological communities and/or species to other areas when mapped at that scale.

When applying the CAR principles, especially representativeness, very different boundaries can be drawn around any biological or biogeographic unit(s) depending on the scale of analysis (TFMPA 1999). For this reason, definition of scale is important. The scale of analysis for the GBRMP is defined in the results section.

The general principles defined by ANZECC (1998) also state that the final selection of sites for inclusion in a CAR network should include public consultation to address current and future cultural, economic, social and other issues.

The Great Barrier Reef Marine Park Authority's Representative Areas Program

The RAP is implementing these general principles in phases:

- *Classification* - describe the biological diversity of the entire GBRMP.
- *Review* - evaluate the adequacy of the existing network of no-take areas.
- *Identification* - identify potential networks of no-take areas which achieve the biological objectives of RAP.
- *Selection* - select from amongst the potential networks to maximise beneficial and minimise detrimental impacts considering social, economic, cultural and management implications.
- *Draft zoning plan* - prepare a draft zoning plan to implement the results of RAP to be released for public comment.
- *Final zoning plan implemented*
- *Monitoring* - monitoring of effectiveness of final network of no-take areas.

These phases overlap and run concurrent with extensive public consultation to bring information into the decision-making process as well as to deliver information about the program. The methods applied in each of these phases are described below.

Independent advice and guidance on the methods and data being used in RAP was sought from two external Steering Committees that have been established:

- a *Scientific Steering Committee* with expertise in reef and non-reef habitats and communities to

[7] Lack of scientific certainty about where no-take areas should be located, how large they should be, or how many are needed, should not prevent establishment of a marine representative areas network.

provide input on the classification, review and identification phases;

- a *Social, Economic and Cultural Steering Committee* with expertise in social science, economics, enforcement issues, public participation, management of cultural values, Indigenous and stakeholder viewpoints. This group is guiding the selection phase and communication and consultation throughout the program.

In addition to these steering committees, an *Analytical Working Group,* with expertise in conservation biology, reserve optimisation and spatial analysis, assists with quantitative analysis in the identification and selection phases of the program. This group is currently refining a number of marine reserve selection tools developed or tailored specifically for RAP.

Two panels of experts (reef and non-reef experts) were also convened to provide expert knowledge on the distribution of different taxonomic groups to assist with the classification and the identification phases.

Classification Phase

To protect biodiversity within no-take areas requires information on its composition and its spatial distribution. Nine broad 'meso-scale' regions across the GBRMP had previously been described (ANZECC 1998), but this regionalisation was not at an appropriate scale for planning the location of no-take areas using the CAR principles within the GBRMP.

Initially over 60 scientists around Australia with research experience in the Great Barrier Reef (GBR) Region, were interviewed with the aim of describing:

- major patterns in distribution of organisms and communities and their habitat requirements;
- environmental factors which were the major driving forces of these patterns;
- datasets which could be used to describe these patterns (Kerrigan et al. 1999)
- areas of special importance for the maintenance of marine biodiversity and function; and
- ecological reserve design principles for marine protected areas.

Information collated included:

- Geographic Information System layers of 31 biological and 35 physical datasets describing broad-scale distribution patterns of habitats, plants and animals across the GBRMP;
- major environmental patterns and processes in geomorphology and oceanography which influence productivity, biogeography, community composition and life histories of the region's biodiversity; and
- special or unique reefs, islands and other areas for consideration when selecting the location of no-take areas. These areas contain outstanding and unique communities, habitats and processes that are critical to species at various stages of their life cycles or to ecosystem functions.

Systematic broad-scale survey data for soft corals, hard corals, reef macro-algae, reef fishes, epibenthos, deepwater seagrasses and sediments were analysed using classification and regression tree analyses to spatially cluster areas of similar species composition (De'ath 1999; De'ath and Fabricius 2000). These analyses, together with many individual data sets were displayed and analysed in workshops of expert scientists using Geographic Information System images projected onto an electronic white board. Reef and non-reef experts used their experience in the GBR Region, the physical and biological datasets, and the classification and regression tree analyses to classify the biodiversity of the GBRWHA at a scale that they considered appropriate to reflect the gradients of change. Experts decided to map diversity at the scale of 10s to 100s of kilometres because this was a scale over which habitats change markedly, it was a scale at which much relevant information was available and it was also a meaningful scale for subsequent planning and management.

Areas of relative homogeneity were labelled bioregions (Edyvane 1996) to facilitate communication with stakeholders. Bioregions were defined as areas within which habitats, communities (e.g. areas of seagrass) and physical features (e.g. sediment type, depth) would be more similar to each other than to similar habitats (or communities) occurring in other bioregions. While some bioregion boundaries were distinct and easy to define (e.g. the windward edge of a string of ribbon reefs), others had imprecise boundaries that divided ecological continua or that reflected incomplete data.

A workshop with reef and non-reef experts determined that the reef and non-reef bioregions could not be combined because they were too different.

Review Phase

Once the overall bioregional diversity of the GBRMP had been described, the current level of protection of each bioregion was reviewed based on the number, size, distribution of no-take areas and proportion of the bioregion area in no-take areas.

Identification Phase

Biophysical operational principles (see Results - Box 1) were developed through literature searches, interviews with scientists and over 12 months of iteration between the Scientific Steering Committee and expert panels. Implementation of these principles are intended to identify networks of areas that could meet the biodiversity objectives of RAP and comply with the CAR principles.

The biophysical principles included recommendations for amounts of 'no-take' areas for each bioregion and each known habitat type. Given the uncertainty about what amounts would be adequate for effective conservation, the recommendations were considered to be the minimum, in the context of global experience with marine reserves. Specific recommended amounts differed between habitat types and bioregions. Reef experts described the minimum amount in terms of minimum numbers of reefs, distribution of reefs, proportion of reef area and of reef perimeter for each bioregion. Non-reef experts considered the minimum and maximum sized bioregions, their limited knowledge of viable population

sizes and habitat diversity to define a proportion of each bioregion to be protected. In all cases, they recommended replication throughout the bioregion, wherever the size of the bioregion permitted.

To implement the biophysical operational principles, decision support systems for marine reserve selection were developed. This included modifications to existing reserve design software (SPEXAN, Ball and Possingham 2000). The new software (named MARXAN, being a marine version of SPEXAN) uses an objective function designed to implement most of the operational principles outlined in Box 1 and some from Box 2. MARXAN uses simulated annealing to identify networks of areas that optimise the objective function (Possingham et al 2000). Another software program (TRADER) was developed to assist in network design, explore reserve concepts, and to assist public understanding of network design and selection of areas (De'ath 2000).

To integrate multiple data sets for analysis and interactive display, the entire GBRMP was divided into 16,332 planning units—arbitrarily located spatial units that are small in relation to the presumed size of intended no-take areas. Individual reefs were treated as separate planning units and non-reef areas were divided into 10km^2 or 30km^2 hexagons, depending upon the level of available information. The smaller planning units were applied in reefal areas and near-shore areas where more information was available.

All available data will be used in a process known as 'post-hoc accounting' designed to validate broad-scale network configurations against specific, though sometimes spatially or statistically limited, input data and knowledge of the GBRMP. For example, network configurations based on bioregions, epibenthos and seagrass data will be assessed to identify how well they sample these conservation features, and how well they sample, by coincidence, areas known to be important for specific organisms such as dugong and billfish.

The identification phase will identify a number of different networks of no-take areas, with each network achieving a biologically adequate sample of bioregions and other conservation features. These areas are adequate in that they would conform with the biophysical operational principles.

Selection Phase

In this phase, GBRMPA and its stakeholders must select areas that best protect the biodiversity while also minimising detrimental impacts and maximising beneficial impacts for existing users and interested parties. Final selection of sites for inclusion in a CAR network needs to address the social, economic and cultural aspects according to the ANZECC principles (1998), as well as management issues of feasibility and practicality. This complements GBRMPA's secondary objectives within the RAP to maintain or enhance cultural values, economic benefits, and social amenity values, as well as fulfil legal and other obligations.

To achieve these objectives in accordance with the ANZECC principles, more detailed guidance was needed.

After a year of research, discussions and iterations, a final set of social, economic and cultural operational principles was defined and agreed by the Social, Economic and Cultural Steering Committee. Ongoing social, economic and cultural data collection and public consultation will contribute to assessment of alternative reserve networks according to the RAP principles.

MARXAN can incorporate 'costs' or 'benefits' associated with the selection of any particular area using social, economic or cultural data in its objective function (Ball and Possingham 2000). The objective function is a combination of how well each solution complies with the principles and minimises costs to other users. For example, areas which support extractive activities can be weighted highly, so that the objective function in MARXAN is optimised by avoiding those areas if other areas exist which mean the network still achieves the requirements expressed in the biophysical operational principles. Qualitative assessment of options for no-take area networks will involve stakeholders, expert panels and detailed analyses of public submissions.

The remaining phases in this process (Draft zoning plan, Final zoning plan implemented, and Monitoring: see above) are scheduled to be undertaken in the future.

Results

Classification Phase

The classification phase resulted in the division of the 343,500 km^2 of the GBRMP and the 2,990 reefs into 70 bioregions: 30 in reef and 40 in non-reef areas that include 8 poorly known offshore areas. The bioregions ranged in area from 2.31 km^2 (for a reefal area) to 29,300 km^2 (for a non reefal area). These bioregions can be viewed currently as a "hot issue" on the GBRMPA website at www.gbrmpa.gov.au.

The bioregions were finalised only after numerous iterations and advice from the experts, the various steering committees, and public input. They reflect the huge diversity of habitats and communities within the GBRMP and the variation between reef and non-reef areas, north and south, and inshore and offshore. Most of the boundaries between the reef and non-reef bioregions were classified as 'fuzzy' due in part to an understanding of the connectivity of the regions and in part due to incomplete knowledge (Table 1).

Fuzziness class	Number of reef bioregion boundaries	Number of non-reef bioregion boundaries
1. Clearly defined physically	9	6
2. Clearly defined biologically	4	2
3. Clearly defined both physically & biologically	9	6
4. Fuzzy boundary due to continua in environment	3	14
5. Fuzzy boundary due to the limited data	25	2
Combination 4/5	0	36

Table 1 Classification of bioregion boundaries

Review Phase

In the present zoning system, there are currently 135 no-take areas (including no-go areas) in the GBRMP varying from 0.04 - 9155 km^2 and totalling approximately 16,000km^2. Assessment of existing no-take areas (Table 2) shows that 14 bioregions contain none, 24 bioregions have <1-5% of their area in no-take zones but 13 bioregions currently have >25% of their area already within no-take zones. Note the bias towards the protection of reef bioregions although the reefs cover less than 6% of the GBRMP.

Only one no-take area in the GBRMP has 20km as its minimum dimension (see Box 1) and four have a size greater than 400km^2 overall. Table 3 shows that thirty bioregions have less than three replicate no-take areas of any size or shape. These data clearly indicate that the existing network of no take areas within the GBRMP needs to be improved.

Identification Phase

If implemented, experts considered that the following biophysical principles would maximise the likelihood that GBRMPA would achieve the biological objectives of RAP by delivering a comprehensive, adequate and representative network of highly protected areas (Box 1).

Experts further defined principles 3, 5 and 6 for each bioregion depending upon bioregion size, latitudinal extent and other characteristics. Proportionately more protection was recommended for smaller bioregions. Numbers of replicates recommended by the experts varied from none in the smallest bioregion to five in the largest. Each potential no-take area may span several bioregions, hence one no-take area could represent several bioregions. At the time of publication, recommended values for “x” were still undergoing GBRMPA’s internal approval processes.

The analytical process has enabled thousands of spatially different networks of areas for potential protection to be generated, each of which operationalise the biophysical principles. However, each network is similar in that it is spread throughout the 343,500 km^2 of the GBRMP. In bioregions where existing no-take areas fulfil the biophysical operational principles, new no-take areas would not be required.

Some planning units recur more frequently in different potential networks than others. Some planning units cannot be avoided within the final set of no-take areas because, for example, they contain the only instance of one or more conservation features, or contain so much of an important feature, so that the reservation goal can no longer be achieved if the unit is not reserved. The extent to which these units are critical to a final network can be assessed by determining the frequency with which each occurs across a series of potential networks. This frequency of inclusion is a measure of the importance of a planning unit for the final network, and, across all planning units, is an estimate of the level of flexibility that can be ascribed to the need for a specific planning unit to meet the biophysical principles. An analysis of the frequency of selection (flexibility) can produce a map indicating the likelihood that any particular planning unit will be needed as part of a reserve network that meets the biophysical principles.

This concept of the relative importance of a planning unit is similar to the concept of irreplaceability (Pressey et al. 1994) but is considered here in its simplest form as flexibility, meaning the flexibility of a planning unit to be replaced by another in achieving the required target for the conservation features.

Where measures of flexibility are low, there are few or no options to reserving specific planning units, but for higher levels of flexibility, there are more options available. The flexibility to allocate a planning unit into the network of no-take areas will vary in a graded way from none (must be included) to a lot (many planning units could substitute and provide the same conservation features in the no-take area network).

Networks of no-take areas which meet the biodiversity objectives of the program are presently being developed. It will then be necessary to select from amongst those networks and refine the boundaries.

Selection Phase

If different configurations of no-take networks satisfy the biophysical principles, the option which provides the most benefit and imposes the least cost to the community will be recommended for subsequent negotiation with stakeholders. Some habitat types may be protected in a no-take network equally well at a number of locations. In these cases there will be considerable scope for resolving potential conflicts with all interested parties. GBRMPA requested specific guidance upon how to conduct this selection process from the Social, Economic and Cultural Steering Committee, resulting in the following principles (Box 2).

GBRMPA has about 30 cultural, social and/or economic datasets, for which objectives have been defined, to assist in the selection process.

Table 2 Number of bioregions which have the indicated percentage of area highly protected

% protected / Bioregion type	Zero no-take areas	<1 - 5%	>5 - 15%	>15 –25%	>25%	Total
Reef bioregions	1	8	9	3	9	30
Non-reef bioregions	13	16	4	3	4	40
Total	14	24	13	6	13	70

Box 1 Biophysical operational principles

As far as is possible* :

1. *Have no-take areas whose minimum size is 20km along their smallest dimensions (except for coastal bioregions for which 10km is the minimum dimension).*
   A 10 km diameter core was recommended given knowledge about:
   - the scale at which patterns of diversity in plants and animals vary;
   - small scale connectivity between adjacent habitats; and
   - viability of plant and animals populations.

   Coastal areas vary at a finer scale hence the smaller minimum dimension.
   Enforcement experts, as well scientists' anecdotal evidence, also recommended that a no-take area should include a 5km 'buffer' around core areas to ensure their integrity is maintained.
2. *Have larger (versus smaller) no-take areas.*
   For the same amount of area to be protected, scientists recommend protection of fewer larger areas rather than more smaller areas.
3. *Have sufficient replication*
   Experts advise that "sufficient" refers to the amount of replication, size of replicates and configuration of replicates, where a 'replicate' is recognised as a sample of the GBRMP intended to achieve similar biodiversity protection goals and where each would contain a similar range of species, biological communities and habitats. This principle will provide an ecological safety margin against human-induced and natural disasters (Done 1996), and will assist in maximizing the capture of biodiversity, both within and across bioregions.
4. *Include only whole reefs within no-take areas.*
   Reefs form natural biological units – the different parts of which rely upon each other.
5. *Per reef bioregion, have at least 5 reefs and x%[#] of reef area included.*
   This principle ensures the 'within-bioregion' diversity is sampled in the network and also assists with principle (3). The figure 'x' was subsequently defined as an environmental bottom line per bioregion by reef experts.
6. *Per non-reef bioregion, have at least x%[#] of non-reef area included*
   This principle ensures the 'within-bioregion' diversity is sampled in the network and also assists with principle (3). The figure 'x' was subsequently defined as an environmental bottom line per bioregion by non-reef experts.
7. *Include x%[#] or x number of each community type and physical environment type in the overall network (e.g. diversity of depths, reef sizes, submerged reefs).*
   This is to sample habitat and environmental diversity that is known to occur within bioregions. For each dataset that provides information about habitats or communities, scientists defined specific, network-wide objectives that should be achieved (e.g. ensure seagrass habitats are sampled).
8. *Maximise the use of environmental information to determine the best configuration of no-take areas.*
   Where information about currents and patterns of connectivity are known, it will be used in the analytical process; however this is more likely to be implemented in a manual process of expert review.
9. *Include biophysically special/unique places (e.g. significant nursery sites).*
   These are outstanding places, important for the maintenance of biodiversity and achieving comprehensiveness and will be used in the selection phase when refining network options.
10. *Consider sea and adjacent land uses in determining no-take areas.*
    The location of no-take areas for protection of biodiversity needs to consider the uses/threats as these can have major implications for the maintenance of biodiversity. Past and present uses may have impacted upon the integrity of various biological communities and this principle ensures this is taken into account.
11. *Capture GBR regional diversity across the continental shelf and latitudinally.*
    Locating no-take areas in each bioregion will ensure this principle is implemented, because of the spatial arrangement of the bioregions; it also reinforces principles (3), (5) and (6).

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* These principles cannot be unconditionally applied in all instances; rather they are recommendations to be implemented as far as is practicable in the planning process. These principles are not in any order if priority.

[#] Variable per bioregion (see Identification Phase above)

Table 3 Number of existing highly protected areas per bioregion

# no-take areas/ bioregion	0	1	2	3	4	5	>5
# bioregions	13	5	12	8	6	6	22

Box 2 Cultural, social, economic and management feasibility operational principles (not in any priority order)

From potential no-take area networks which meet the biodiversity objectives of the program, as far as possible, ensure community acceptability of RAP processes by

1 Maximising complementarity of no-take areas with human values, activities and opportunities by placing them in locations which:
- have been identified through a consultative process which is participatory, balanced, open and transparent.
- Traditional Owners have identified as important and need high levels of protection.
- minimise conflict with Indigenous people's aspirations for their sea country.
- protect areas which the community identifies as special or unique e.g. places of biological, cultural, aesthetic, historic, physical, social or scientific value.
- minimise conflict with non-commercial extractive users such as recreational fishers.
- minimise conflict with commercial extractive users.
- minimise conflict with all non-extractive users .
- ensure that final selection of no-take areas recognises:
  - relative social costs and benefits including community resilience.
  - spatial equity of opportunity within and between communities (including Indigenous clan estates).
  - planned and approved future activities.
- consider requirements for monitoring the effectiveness of the RAP in choosing placement of no-take areas.

2. Maximising placement of no-take areas in locations which complement:
- existing or proposed zoning or management plans being developed for marine areas by federal, state or local government authorities.
- existing or proposed tenure and management of coastal areas (mainland and islands) in the region.
- Native Title claim areas and issues.

3. Maximising public understanding and acceptance of no-take areas, together with ease of enforcement of no-take areas by, as far as possible:
- Having no-take areas which are simple shapes.
- Having no-take areas whose boundaries can be easily identified by coordinates and/or landmarks.
- Having fewer and larger no-take areas rather than more and smaller areas.

Application of the social, economic and cultural data will significantly constrain the number of networks which can fulfil the biological principles. In some instances, the analyses will highlight potential conflicts between areas required to fulfil the biological objectives and areas which are important for extractive activities.

Public Participation

Public participation is an essential part of RAP and comprises on-going informal consultation and two formal and statutory phases of public participation. The first formal phase allows input into the drafting of a new zoning plan to implement the results of RAP for the whole of the GBRMP. The second formal phase occurs after the draft zoning plan is available for comment. After GBRMPA has considered all the public comments, a final plan will be submitted for Ministerial and Parliamentary approval.

The public has been encouraged to ask questions throughout the entire program, provide information on places of special value and to comment on the areas selected for future protection. Considerable public participation programs have been undertaken to date including mailed information, hundreds of public presentations, web site information, and distribution of brochures and booklets.

Discussion

When selecting marine protected areas, Ray (1999) admits there are serious challenges in a scientific approach, but considers "there is no better way to identify and help select areas, to address uncertainty, to increase accountability and to involve the public via generation of credible information". Some of the challenges and limitations of GBRMPA's RAP are discussed below.

The data and knowledge being used to describe patterns of diversity are always limited and are, in the RAP, being used as surrogates for information about the entire spectrum of organisms, including those with weak or no data. However, few models of surrogacy appear to be robust across scales of space, time and taxonomy in undisturbed marine (or terrestrial) ecosystems (Vanderklift et al. 1998; Ward et al. 1999; Andelman and Fagan 2000; Olsgard and Somerfield 2000). A major part of the difficulty in identifying useful surrogates for biodiversity is the dynamic and broad nature of the concept of biodiversity itself (Hawkesworth 1995; Gaston 1996; Lister 1998; Garcia-Charton and Perez-Ruzafa 1999). Given the spatial, temporal and taxonomic scales on which biodiversity must be measured, as well as the diversity of processes that create and maintain biodiversity, it is unlikely that precise surrogates will ever be found for many aspects of marine biodiversity. Nonetheless, at broad scales, there are useful correlates of a number of aspects of marine biodiversity that are useful for representing the broad scale patterns of biodiversity. Such correlates are most robust for the shallow water environments, because many species and assemblages have been well studied in near-shore waters, and on reefs in shallow water. For example, depth and substrate type are commonly cited as environmental correlates of the distributions of soft sediment fauna and flora (Cohen et al. 2000) Also, taking a seascape view of biodiversity (*sensu* Garcia-Charton and Perez-Ruzafa 1999), biophysical habitats show promise as useful surrogates and are increasingly being proposed for the purposes of improving marine ecosystem management (Done and Reichelt 1998; Mumby and Harborne 1999; Ray 1999; Ward et al. 1999). This latter approach was adopted in the RAP.

There is an issue of equity associated with the establishment of most no-take areas and this applies within the GBRMP as well. Local fishers often bear more of the immediate burden of no-take areas, but as documented in many instances they are likely to also reap the benefits in the medium and long term of spillover and recruitment effects from no-take areas to adjacent fished areas (Attwood and Bennett 1994).

Another of the challenges facing GBRMPA is the fact that fishing and collecting effort will not be removed from the region once more no-take areas are in place, but that effort will be displaced. Studies exploring the effects on fish populations outside these reserves have not found harmful effect of displaced fishing effort (Roberts and Hawkins 2000). The only evidence on this topic (at Apo Island in the Philippines and St. Lucia, Caribbean) points to increases in populations of target fish outside reserves despite displaced effort (Russ and Alcala 1996; Roberts and Hawkins 1997). Crowder et al. (2000) also strongly support the implementation of marine protected areas with biodiversity conservation goals, reasoning that such areas can produce detectable benefits to fisheries and so gain public support. Nonetheless, the recent destructive events in the Galapagos Islands show the importance of ensuring that reserves are respected by stakeholders.

There is also the problem of imperfect compliance with the ’no-take‘ rule. No marine protected area in the world, including GBRMP, can ensure complete compliance to its natural resource management rules. Halpern (in press) reviewed 89 studies of reserves and found that failures in compliance do not render highly protected areas ineffective.

Conclusions

GBRMPA has, therefore, adopted the approach of using surrogates to describe, and hence protect, biodiversity because perfect information was not available, and is never likely to be available, to support the program. To improve the basis for management and decision-making, it will be important to gather future data about variability in the patterns of biodiversity in bioregions and the success of no-take areas to protect biological diversity. GBRMPA will be working collaboratively with scientists from many organizations to ensure programs are in place to deliver these data and to review and monitor the new network of no-take areas.

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