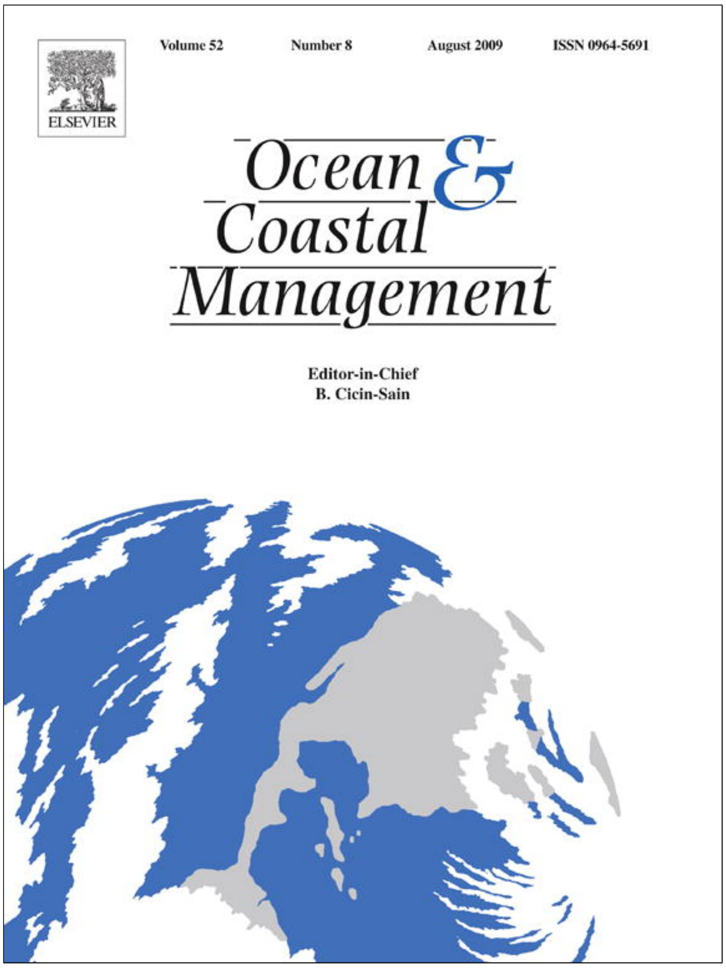
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Recent developments

A process to design a network of marine no-take areas: Lessons from the Great Barrier Reef

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ABSTRACT

In the absence of consensus on the quantity and level of zoning protection required for coral reef and lagoon ecosystems, which process can guide decision makers? The Great Barrier Reef Marine Park Authority (GBRMPA) worked with experts in a collaborative process to develop a set of Biophysical Operational Principles to guide the design of a network of no-take areas. First, 82 expert scientists were asked to provide data and advice on the physical, biological and ecological dimensions of the Great Barrier Reef ecosystem. They recommended that an independent Scientific Steering Committee (the Committee) was set up. How this Committee worked successfully with the GBRMPA staff is detailed here in a manner to enable other resource managers to adopt the process if they are working in data-limited marine environments.

1. Introduction

Marine resource management encompasses many approaches and tools including fisheries management, water quality improvement and regulation of multiple use. One approach for conserving marine biodiversity is to establish no-take marine protected areas [1]. Establishing no-take areas involves taking decisions about how much, how many, how big and where to locate no-take marine protected areas. The Great Barrier Reef Marine Park Authority (GBRMPA) recognised that the delivery of enhanced biodiversity conservation through no-take areas (in the Representative Areas Program) required balancing conservation with social, economic and cultural values and political and institutional constraints [2]. However, in the absence of any consensus on the quantity and level of zoning protection, how could the GBRMPA proceed?

Decisions about locating no-take marine protected areas are not easy to arrive at, in part, due to the paucity of good data. Data are scarce on the distribution, abundance, life history, physiology, migration paths, dispersal patterns and tropho-dynamics of relevant taxa and on their vulnerability to different threats and impacts [3]. Even if these data did exist, it would be likely that different design parameters would suit different species e.g. see Refs. [4–6].

This leaves practitioners with a challenge, especially if the objective is to protect, as far as possible, the entire range of biological diversity and not just one or two species. For most marine park managers it is an enormous shift in conceptual approach to design marine protected areas which not only include areas of high public interest, such as pristine coral reefs, but to protect areas that represent each of the different systems in their park. For example, this may mean the inclusion of open muddy seabed and systems in deep water, where scientific understanding of the processes

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occurring is very poor, and public knowledge of these systems and their values is virtually non-existent.

General advice from the literature is often not helpful because managers cannot implement the advice as given [7–9]. At best, implementing advice requires data that may or may not be available, in order to enter into formulae that may or may not apply to multiple species e.g. see Ref. [10]. This makes sense scientifically, as each marine environment and species is different and no one set of quantitative principles can be universally applied [11]. Meanwhile, habitat degradation and resource use and overuse often continue with inadequate management and uncertainty about the future of the resource [12].

The Great Barrier Reef Marine Park (the Marine Park) is one of the world's largest marine protected areas (Fig. 1) with a total area of 344,400 km^2. It is bigger than many countries and includes a range of inter-connected habitats from coastal to deepwater environments off the continental shelf. It is managed as a multiple-use area to protect environmental values while allowing for reasonable use. The kinds of use allowed in each of seven zones graduate from a no-go zone (<1% of the entire area), to a no-take zone (which was 4.6% of the area), to a no-trawling "habitat protection" zone (which was 16% of the area) through to a general use zone (which was 78% of the area) that allowed for most activities including trawling [13]. In the earliest stages of developing Zoning Plans, the GBRMPA conducted a preliminary study of zoning options for the Capricorn-Bunker Group of reefs at the southern end of the Great Barrier Reef (GBR). As subsequent sections of the Marine Park were zoned, ecosystem assessments were conducted with external experts. The approach presented here, of seeking external scientific and other advice, built upon a tradition of similar approaches applied at the GBRMPA, although it was considerably more substantial and comprehensive [14].

This paper outlines a systematic approach to define the Biophysical Operational Principles required to create a network of no-take areas given specific management objectives, the GBR ecosystem, and the available knowledge about it and about marine reserve design. The following procedure was adopted: i) review the existing protection, ii) gather expert (including scientific) advice and data, iii) establish a biophysical Scientific Steering Committee, iv) define the biological objectives, and v) combine the data, research and expertise. This systematic approach will have general application to resource managers who want to implement zoning strategies underpinned by sound biophysical principles and guidelines but where data are lacking.

2. Methods

Since the initial zoning of the Marine Park 28 years ago, new information relevant to management concerning the GBR

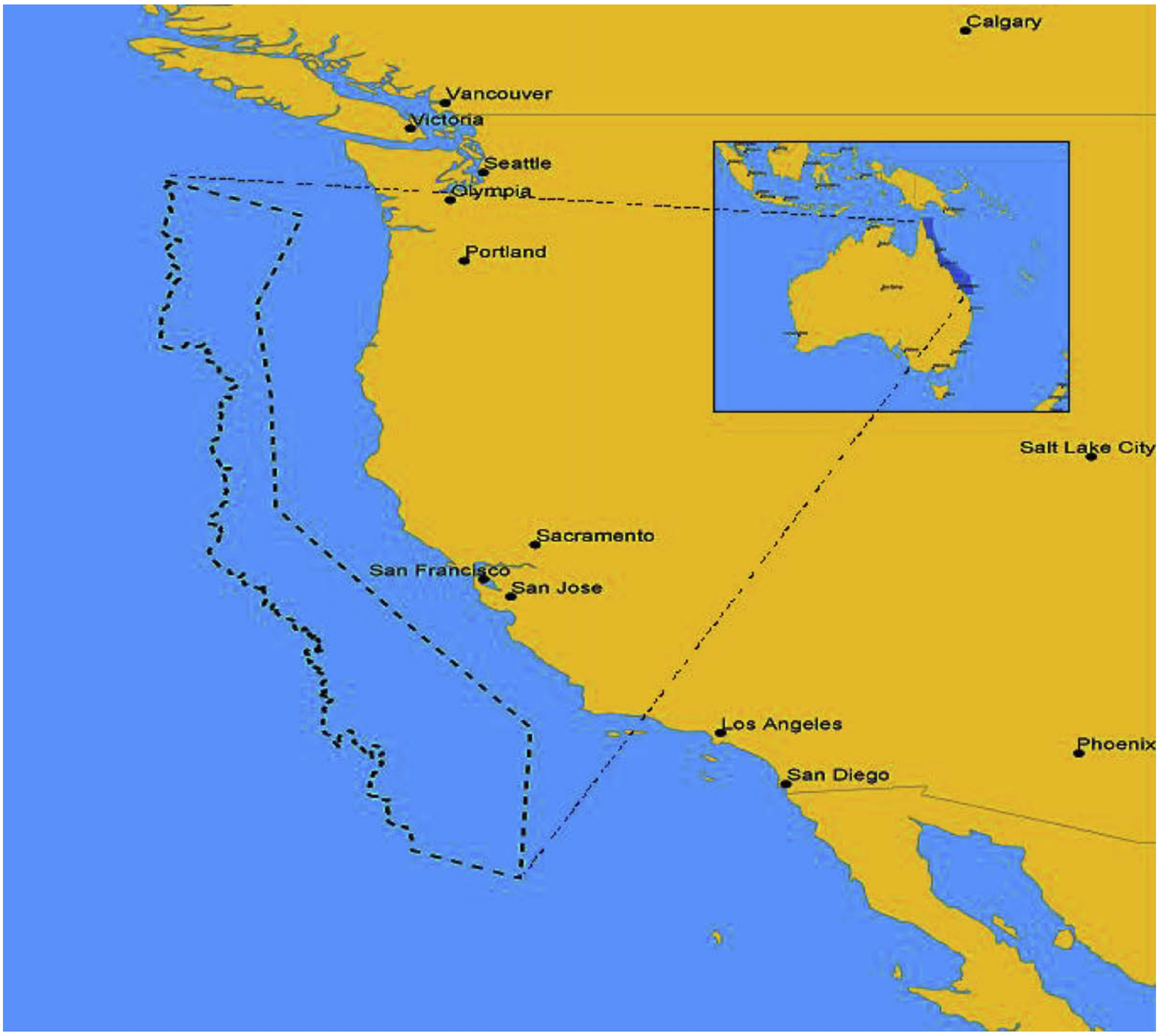

Fig. 1. Size of the Great Barrier Reef Marine Park compared with the west coast of the U.S.A.

ecosystem, levels and increases in threats and uses, connectivity of marine habitats, functioning of no-take marine protected areas, and global threats to, and declines of, coral reef ecosystems, has emerged. This new knowledge provided the basis for reviewing the adequacy of the zoning of the Marine Park by the Representative Areas Program at the GBRMPA.

The main objectives of the Representative Areas Program were to help:

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

To address the problem caused by the lack of definitive scientific advice on the amount and type of zoning needed to ensure the future of the Great Barrier Reef ecosystem, Authority staff interviewed 82 experts, including scientists who had worked on different aspects of the physical, biological and ecological systems of the Reef. A semi-structured interview format was used with questions about the availability of data, environmental factors that were correlated with spatial patterns of biodiversity, threats to species, reserve design for those organisms and other management requirements were asked. An open-ended question concluded the interview: Do you have any other relevant data, information or references you would like to provide?

Based on the recommendations of the scientists interviewed, the Authority established a biophysical Scientific Steering Committee (the Committee) (Table 1). Members volunteered their time and had complete independence and freedom to offer any critique or advice they deemed appropriate. The Committee met on an as-needed basis (eight meetings over a two year period). Approximately one year of data collation, preparation and analysis was undertaken in order to prepare suitable background information for the Committee's first meeting.

The first request of the Committee was for the development of more detailed objectives than those provided (above), to enable them to understand exactly what the GBRMPA intended to achieve with the Representative Areas Program.

Each of the primary objectives was broken down into a detailed set of sub-objectives by reference to the relevant legislation, such as the GBRMPA Act [15] and regulations, the GBRMPA Corporate Plan [16], GBRMPA's internal Strategic Work Plan, and the 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area [17]. Interview data from more than 200 stakeholders, including GBRMPA personnel, was also considered in the development of the objectives. Before being finalised, these detailed objectives were reviewed and revised through discussion with GBRMPA staff and stakeholders.

Table 1
Expertise of the scientific steering committee.

Expertise
Soft seabed benthos
Seagrasses/epibenthos
Modelling/statistics
Dugong, marine mammals
Reef and pelagic fish
Coral reefs
State government counterpart
Fishing impacts/design issues
Reserve design

The Committee was asked explicitly whether there was sufficient biophysical information to proceed with a major review of the zoning of the Marine Park. Although the Committee evaluated this information as highly patchy and incomplete, in light of the threats, the current level of protection, the knowledge that was available, and the possible consequences of inaction, members recommended proceeding with the review of zoning as soon as possible. The Committee understood that the legislation underpinning the Marine Park and its management allowed for future reviews if improved information became available.

Next, the Biophysical Operational Principles (the Principles) were developed taking into account: (1) the biological objectives of the program, (2) available knowledge of the Reef ecosystem, (3) available data on the science of marine reserve design, and (4) communication between experts on the Great Barrier Reef and non-reef ecosystem and on reserve design. Some relevant references are listed online at http://www.gbrmpa.gov.au/__data/assets/pdf_file/0019/7318/bops_refs.pdf.

GBRMPA staff had reviewed published and unpublished research on reserve design and adequate levels of protection. They had included research conducted in fisheries, and international and national scientific accords. This assisted the deliberations of the Committee.

Based on these reviews, information from GBRMPA and their own information, the Committee recognised the following: (1) no perfect set of principles, that could ensure adequate protection of the Marine Park, had been documented in the literature; (2) the best way forward was to draw upon the available expertise and knowledge to provide guidance; and (3) any new Zoning Plan can be reviewed as new information becomes available.

The Committee insisted that the Principles be carefully qualified and contextualised. Scientists feel more comfortable providing advice when research has provided clear answers; there was little such research available. Often managers cannot wait until peer reviewed papers, with the 95% confidence limits defined for every parameter of interest, are published. A middle ground was sought whereby the scientists were comfortable offering management advice, on the condition that the caveats associated with that advice were co-documented.

Once defined, the implications of the Biophysical Operational Principles in terms of the quantum of likely required changes to zoning, were presented to the senior managers of the GBRMPA. After gaining their endorsement, the implications were presented to the national Minister for the Environment who had to carry ultimate responsibility for accepting the new Zoning Plan and bringing it into the Australian parliament to be passed into legislation.

The Biophysical Operational Principles were then made public, together with the Social, Economic, Cultural and Management Feasibility Operational Principles developed simultaneously by similar procedures [18]. Next, the public was invited to comment on any aspect of the rezoning process. In particular, the public was asked which areas might be best protected as no-take areas (and why), and which areas might be best left available to fishing (and why).

3. Results

Through the interview process, 82 scientists had provide data and advice on an appropriate scientific process to help ensure adequate zoning protection. They also contributed by commenting on the distribution and abundance of species or attributes with which they were familiar, and on the design of an adequate level and type of protection according to their perspective. A recommended independent expert Committee which reflected the advised variety of biophysical expertise, was established (Table 1).

The terms of reference developed for the Committee clarified that its role was one of providing guidance and advice to support decision-making by the GBRMPA and the federal government (Table 2).

The terms of reference of the Committee helped deliver two outcomes: it re-enforced the Committee's independence and ensured that members understood that their advice would not always be adopted in full.

After reviewing the five main biological objectives of the rezoning program, the Committee stated that more detailed objectives were required to enable the delivery of operational principles to help achieve those objectives. GBRMPA then detailed each single objective to comprise about 10–20 sub-objectives specific to the Great Barrier Reef Marine Park. For example, the objective "to provide a solid ecological base from which threatened species or habitats can recover or repair themselves" was detailed to include:

Habitat sites that were

Depleted
- "Endangered"
- Otherwise threatened habitats

Species such as

- Dugong
- Hump-backed dolphin
- Irriwaddy dolphin
- Whales
- Hump-headed Maori Wrasse
- Potato cod
- Seabirds
- Triton shell
- Turtle
- Other degraded species stocks

In sum, ninety detailed objectives were defined and these provided better specification in terms of the 5 broad ecological objectives of the Representative Areas Program. These detailed objectives accurately described the conservation outcomes that GBRMPA was aiming to achieve. In addition, they were considered adequately detailed for the consideration of the Committee to provide advice.

When the Committee reviewed the pre-existing zoning against threats and in light of existing knowledge, they considered it was unlikely to be adequate to protect the entire range of biodiversity of the Great Barrier Reef Marine Park (the Marine Park). This zoning included a network of 135 no-take areas encompassing 4.6% of the total area of the Marine Park (i.e. ~15 842 km^2). Only one of these areas was relatively large, with a diameter of more than 20 km. Nineteen of the 70 biologically distinct regions, defined by reef and non-reef experts and the Committee, had zero no-take areas (see the bioregions online at http://www.gbrmpa.gov.au/__data/assets/pdf_file/0016/7315/bioregions_2001_06.pdf. Over 70% of the no-take zones protected only coral reefs, a habitat type that comprises only 6% of the area of the Marine Park [19].

Table 2
Terms of reference for the scientific steering committee.

1. Provide advice to GBRMPA on scientific issues, programming and priorities relating to the Representative Areas Program.
2. Identify data sets and provide advice on information gaps and the quality of data.
3. Assist in an initial spatial description of the marine diversity of GBRMPA as part of the Representative Areas Program.
4. Review and comment on methods and outputs and assist GBRMPA to achieve the best possible outcomes of the Representative Areas Program, consistent with known timetable and resourcing constraints.

Broad principles and steps to guide protection of the marine environment had already been offered to Australia's marine resource managers in the form of the Australia and New Zealand Environment and Conservation Council's (ANZECC's) Guidelines to a National Representative System of Marine Protected Areas (NRSMPA) [20]. This advice was also provided to the Committee.

The ANZECC principles state, amongst other things, that development of a National Representative System of Marine Protected Areas (NRSMPA) should be based upon comprehensiveness, adequacy and representativeness [19]. While these terms were generally defined by ANZECC, their interpretation had been debated and formed the basis of three initial actions under the implementation of the NRSMPA: "understanding comprehensiveness", "understanding adequacy" and "understanding representativeness" [21]. The Committee, for the purposes of the GBRMP, defined comprehensiveness to include examples of every bioregion, habitat, community or natural feature. Representativeness was taken to mean that the example of every bioregion, habitat, community or natural feature to be included should be typical of the feature and not an outstanding or rare or unique example. Special or unique biological sites or features were dealt with explicitly and separately to the requirement of "representativeness". The Committee struggled, however, to define "adequacy" in a meaningful manner for the management of the entire range of biodiversity of the Great Barrier Reef ecosystem.

One of the tasks of the Committee was to examine threatening processes, including the impacts of climate change [22]. The Committee considered how to manage threats and degraded habitats via the following questions:

1. Should larger areas be protected if the habitat or species was degraded or under threat?
2. Should degraded areas be avoided because they are poor examples or non-representative of the habitat?

There were confounding factors in this discussion: some of the degraded habitats, for example those exposed to poor water quality, were also relatively distinct habitats as they are naturally exposed to freshwater run-off from catchments. Ultimately, the Committee recommended that existing sea uses and adjacent land uses be taken into consideration so that, all else being equal, areas of greater natural integrity (or adjacent to land of greater natural integrity) should be included in new no-take areas. Minimum levels of protection, including replication, were also defined with some inherent acknowledgement that the protection should be sufficient should further threats or disturbances come to bear.

Further questions were then considered by the Committee:

3. Do larger bioregions require a lower percentage of protection?
4. Should bioregions that have more internal variability have more replication or a greater percentage protection?
5. How can one ensure that spatially large or long bioregions have adequate protection throughout their extent?

The Principles defining minimum size requirements of new no-take zones were part of the outcome of the debate on how to ensure adequacy. The minimum size requirements in the Principles took account of: (1) the (limited) information available on (a) patterns of distribution of habitats and (b) patterns of larval dispersal and recruitment within the Great Barrier Reef ecosystem; (2) edge effects; (3) the experience of the Committee that patterns of variation were finer-scaled inshore and (4) the vastness of the Marine

Park [23–27] (see also list of references online at http://www.gbrmpa.gov.au/__data/assets/pdf_file/0019/7318/bops_refs.pdf).

Once the principles were generally defined, the adequacy of different levels of replication and amount of no-take areas were considered explicitly and separately for each of the 70 bioregions. Using reserve design software and GIS mapping [28] the options for ensuring adequacy were developed. The resultant geographical representations of the draft Biophysical Operational Principles were the basis for review and discussion by reef, non-reef and reserve design experts who met outside of, and with, the forum of the Scientific Steering Committee. This way, the spatial implications of implementing options for ensuring that the Principles addressed the Committee's interpretation of 'adequate protection' were reviewed, iteratively, in the context of a map of the Marine Park and its bioregions.

The Committee had previously supported describing the diversity of the Great Barrier Reef Marine Park by division of the whole area into bioregions, as this insured against the possibility of protecting only sites where data had been collected [19]. However, this approach risked omitting known specific habitats (e.g. sponge habitats, seagrass beds) in the final network of no-take areas. Accordingly, the Committee developed an explicit principle to protect at least minimum amounts of the entire range of habitats about which there was knowledge of their distribution (see Ref. [29] for one example of this).

Within most marine environments, including the Great Barrier Reef, there are biophysically special and/or unique places. Protecting only representative examples of every habitat or bioregion, almost by definition, will exclude these places; this was not seen as desirable by the Committee. A separate process was initiated by the Committee to derive a list of unique places that required special protection. Within a World Heritage Area one could argue that everything is special and unique so the process of creating this list was subjective, but guided by criteria related to (1) the justification (2) references (3) number of sources (4) geographic explicitness of the area being described and (5) relevance to existing national or international obligations.

The Committee asked GBRMPA staff to execute various planning scenarios to enable them to visualise how their entire set of Principles might translate geographically. A plenary expert workshop (including analytical design, reef and non-reef experts as well as the Committee) reviewed these results and finalised the Principles based upon these analyses (Table 3). A key factor that simplified the finalisation of the Principles was that an almost infinite number of configurations of networks of no-take areas could be applied to implement the Principles. There was significant flexibility in the Biophysical Operational Principles to accommodate many of the Social, Economic, Cultural and Management Feasibility Operational Principles also being developed.

The context and the qualifications for this advice, together with the complete set of Principles are provided online at: http://www.gbrmpa.gov.au/__data/assets/pdf_file/0020/7337/tech_sheet_06.pdf

The Authority asked the Committee to prioritise the Principles because, despite their flexibility, it might not be possible to achieve every aspect of each Principle. The Principles advocating a minimum level of no-take protection per bioregion were given the highest priority.

Senior managers of the GBRMPA and the Federal Minister for the Environment were convinced that reviewing the old Zoning Plans to implement anything less than the minimum recommendations provided by the Committee would be futile. Despite the challenges and problems associated with implementing the recommended principles, they considered minimising risks to the social, economic and environmental values of the Great Barrier Reef to be a priority.

In the first formal Community Participation phase, the bioregions, biophysical and social, economic and cultural operational principles were made public. Many of the 10,000 submissions from the public regarding the Representative Areas Program at this phase, responded directly to the principles. Very few argued against their validity. Most responses to the principles took the form of descriptions or maps identifying areas users would like to see zoned no-take and areas they would prefer remained available for fishing.

At various times scientists involved in the process were asked to explain the scientific background of the process to key decision makers and the community; this was very helpful as their independence from the Authority added to the credibility of their argument.

The Great Barrier Reef Marine Park was rezoned effective July 2004. The level of achievement of the entire set of Principles was high [18]. The Zoning Plan resulted in 33% of the Marine Park being 'no-take' and a further 33% having significant habitat protection through the exclusion of activities such as trawling. The total area thus protected from extractive activities was over 100,000 km^2. More importantly, at least 20% of each of the 70 bioregions in the Marine Park was included in the no-take zoning.

4. Discussion

The motivation for the development of the Biophysical Operational Principles was to assist managers to make transparent planning decisions that would achieve their stated objectives and enable explicit recognition of the trade-off between biophysical and socio-economic considerations. There were two dimensions along which the Committee was required to define Biophysical Operational Principles: what parameters should be considered in planning, given the objectives; and what performance levels of those parameters would be considered ecologically adequate. These parameters are likely to be common to designing networks of marine protected areas elsewhere although the performance levels, less so.

The process for developing the Biophysical Operational Principles was important in helping to create the broader social context and understanding necessary to implement sound biophysical zoning strategies. A similar process, adapted locally to other regions, could provide similar benefits. Components in the process that contributed to delivery of these benefits included: the development of operational principles to guide a particular planning program; publicising those principles to the interested community; raising awareness and understanding to enable a level of acceptance of the principles; and then, quite transparently, using the principles to guide decision-making [30].

We found it useful to ask the Scientific Steering Committee to consider only biological, physical and ecological factors in developing the Principles for four reasons:

1. it was their area of expertise and this focus helped them maintain scientific rigour;
2. another independent committee with appropriate expertise was charged with developing explicit social, economic, cultural and management feasibility operational principles;
3. the need to minimise the risk of unwittingly failing, *a priori*, to achieve the biological objectives by recommending Biophysical Operational Principles that were inherently compromised due to social or economic factors; and
4. the need to make any compromises against biophysical factors explicit so that the Authority could demonstrate its willingness to accommodate people's uses and values.

This reasoning supports the differentiation of biophysical from socio-economic factors, as advocated by workers in reserve design [31,32].

Table 3
Biophysical operational principles for the Great Barrier Reef Marine Park Authority Representative Areas Program. NTA = no-take area.

Biophysical operational principle	Explanation
1. *Ensure local integrity*	
No-take areas (NTAs) should be at least 20 km long on the smallest dimension (except for coastal bioregions)[a]	While no-take areas (NTAs) may be various shapes and sizes, 20 km should be the minimum distance across any NTA in order to ensure that the size of each area is adequate to provide for the maintenance of populations of plants and animals within the NTA, and to ensure against edge effects resulting from use of the surrounding areas.
2. *Maximise amount of protection*	
Have larger (versus smaller) NTAs	For a given amount of area to be protected, protect fewer, larger areas rather than smaller areas, particularly to minimise 'edge effects' resulting from use of the surrounding areas. This principle must be implemented in conjunction with principle 3.
3. *Replicate*	
Have sufficient NTAs to insure against negative impacts on some part of a bioregion	'Sufficient' refers to the amount and configuration of no-take areas and may be different for each bioregion depending on its characteristics. For most bioregions, 3–4 NTAs are recommended to spread the risk against negative human impacts affecting all no-take areas within a bioregion. For some very small bioregions fewer areas are recommended, whilst for some very large or long bioregions, more no-take areas are recommended.[b]
4. *Avoid fragmentation*	
Where a reef is incorporated into NTAs, the whole reef should be included	Reefs are relatively integral biological units with a high level of connectivity among habitats within them. Accordingly, reefs should not be subject to 'split zoning' so that parts of a reef are 'no-take' and other parts are not.
(b) Represent a minimum amount of each non-reef bioregion in NTAs	In each non-reef bioregion, protect at least 20% of the area. Two coastal bioregions[3], which contain finer scale patterns of diversity due to bays, adjacent terrestrial habitat and rivers require special provisions. The number and distribution of NTAs is described in principle 3.
6. *Maintain geographic diversity*	
Represent cross-shelf and latitudinal diversity in the network of NTAs	Many processes create latitudinal and longitudinal (cross-shelf) differences in habitats and communities within the GBR World Heritage Area. This diversity is reflected partly in the distribution of the bioregions, but care should be taken to choose NTAs that include differences in community types and habitats that cover wide latitudinal or cross-shelf ranges.
7. *Represent all habitats*	
Represent a minimum amount of each community and physical environment type in the overall network[c]	This principle is to ensure that all known communities and habitats that exist within bioregions are included in the network of NTAs. Communities and habitats were identified for protection in no-take areas based upon the reliability and comprehensiveness of available data. Habitat-specific objectives[4] help implement this principle, which is intended to ensure that particularly important habitats are adequately represented in the network of NTAs.
8. *Apply all available information on processes*	
Maximise use of environmental information to determine the configuration of NTAs to form viable networks	The network of areas should accommodate what is known about migration patterns, currents and connectivity among habitats. The spatial configurations required to accommodate these processes are not well known and expert review of candidate networks of areas will be required to implement this principle.
9. *Protect uniqueness*	
Include biophysically special/unique places	These places might not otherwise be included in the network but will help ensure the network is comprehensive and adequate to protect biodiversity and the known special or unique areas in the GBRMP. The aim was to capture as many biophysically special or unique places as possible.
10. *Maximise natural integrity*	
Include consideration of sea and adjacent land uses in determining NTAs	Past and present uses might have influenced the integrity of the biological communities and the GBRMPA should consider these effects, where known, when choosing the location of NTAs. For example, existing NTAs and areas adjacent to terrestrial National Parks are likely to have greater biological integrity than areas that have been used heavily for resource exploitation.

[a] Coastal bioregions: Coastal Strip-Sand (NA1) – protect at least six no-take areas, each at least 10 km in length, spaced approximately every 70–100 km apart. (This bioregion is approx. 800 km long); and High Nutrient Coastal Strip (NA3) – at least eight no-take areas, each at least 10 km in length, spaced approximately every 70–100 km apart. (This bioregion is approx. 1400 km long).

[b] GBR bioregions which are excepted: Capricorn-Bunker Mid-Shelf Reefs (RCB2) – include one of the inner 2 and one of the outer 2 reefs. This exception exists because RCB2 has only 4 reefs; Deltaic Reefs (RA1) – minimum 25% and minimum 15 reefs in one continuous area. This exception exists because the bioregion is too small for multiple no-take areas; High Continental Island Reefs (RHC) – 20% of reef perimeter only. This exception exists because reef perimeter makes more biological sense for fringing reefs; and Central Open Lagoon Reefs (RF2) – 3 reefs. There are very few reefs in this bioregion.

[c] Data and objectives to implement principle 7: ***Halimeda* beds** – ensure no-take areas represent 10% of known *Halimeda* beds; **shallow water seagrass** – ensure no-take areas represent 10% of shallow water seagrass habitat; **deep water seagrass** – ensure no-take areas represent 10% of known deep water seagrass habitat; **algae** – ensure no-take areas represent 10% of known algal habitat; **epibenthos** – ensure no-take areas represent different faunal classes (5% each of echinodermata, sponges, bryozoans, solitary corals, soft corals, foraminifera, brachyura); **dugong** – ensure no-take areas represent identified dugong habitat areas summing to about 50% of all high priority dugong habitat; **cays** – where cays exist within a bioregion, try to include at least two examples of them in potential no-take areas; **reefs size** – capture 5% of reef area in each of five reef-size classes; **inter-reef channels –** capture at least one inter-reef channel in bioregions where they exist; **exposure –** ensure the entire network captures 5% of reef and non-reef areas in each of five wave exposure classes; **islands** – where islands exist within a bioregion, try to include one example in no-take areas; **oceanographic diversity in water quality** – ensure representation of reefs within the 'natural' diversity of water quality (5% of reef and non-reef area in each of nine oceanographic 'bioregions'; 5% of reef and non-reef area in each of four flood frequency classes); **adjacent coastal and estuarine habitats** (including islands) – locate no-take areas adjacent to mangroves, wetlands and protected areas rather than adjacent to suburbs; and **major turtle sites** – ensure no-take areas include known major turtle nesting and foraging sites (100% of about 30 sites of the 115 identified – these include both nesting sites and foraging sites).

The development of Social, Economic, Cultural and Management Feasibility Operational Principles (SEC Principles) followed a similar approach at the same time as development of the Biophysical Operational Principles [18]. The SEC Principles were also essential to the process of rezoning the Marine Park for two reasons:

(1) clear, specific, independent guidelines on how to address social, cultural, economic and management feasibility issues were needed, consistent with the process adopted for the ecological objectives; and
(2) the process needed to be transparent in balancing socio-economic factors with biophysical factors.

Ultimately, management of natural resources is about people, and incorporating their needs and values into decision-making is vital to ensuring the success of any management decision [33–35]. The SEC principles were coupled with the Biophysical Operational Principles in all decision-making and presentations of the program. They were a key part of ensuring, as far as possible, accordance with people's uses and values and part of building support for the process. This close coupling of biophysical with socio-economic principles is likely to be important for other resource managers.

The initial advice from the Committee to provide more details on the five main objectives of the Representative Areas Program required a level of judgement as to how much detail was required. At one extreme, the ecological processes, habitats, genetics, distribution and threats associated with every species within the Great Barrier Reef ecosystem could be listed per species. This would have led to a list of thousands of objectives, which would not have been helpful. The Committee was finally asked to judge whether the level of detail subsequently provided was adequate for them to provide advice and implement the program. They confirmed that the detail of the objectives, as refined by the managers, was adequate, however, they recognised that further work would be needed to develop performance indicators for these objectives. Therefore, the level of detail derived in the objectives for a particular management program will be unique to the program, the experts and the managers involved [36].

Allison et al. [37] advocated application of an "insurance factor" to any area that might be considered for reserve design, in the event of severe disturbance. Their examples of two disturbance types (oil spills and cyclones) in the south of the U.S.A., determined insurance factors varying from 1.1 to >4.0 depending, in part, on the assumed recovery time. Overall, for the Great Barrier Reef, an insurance factor of about 1.65 was applied, with the result that 33% of the Marine Park was protected by no-take zones (i.e. $1.65 \times 20\%$). Additionally, generation of the minimum recommendations themselves took inherent, if not quantitative, consideration of threats such as cyclones, pollution events, climate change impacts and other disturbances. However, not every part of the Marine Park has, equally, 65% more of it protected than the required minimum. Some areas have higher levels of no-take zoning protection while others only have the minimum. Inshore areas and highly fished areas received only a minimum level of protection due to higher level of conflict with social and economic values.

The support of senior managers at the management agency, GBRMPA, was essential to the delivery of the Zoning Plan for two reasons: (1) such a large undertaking required resources from across the agency, including within each Directorate group; if the Director was not supportive of the approach he or she would have been unlikely to deliver the required resources as readily; and (2) the anticipated difficulties and challenges to the proposal from some lobby groups to protect more of the Marine Park required a united and coordinated commitment by GBRMPA staff.

A lack of management resources, coordination, willingness and confidence to act has long been identified as a source of natural resource management failure [38–41]. The scientific expertise underpinning the recommended changes provided senior managers at the GBRMPA with a high level of confidence to accept and adopt the Representative Areas Program. This approach of integrating the best available knowledge and science into management, so that the managers are responsive in complex and uncertain environments, has been discussed in the literature, but rarely applied successfully [42,43].

Ministerial support was also essential, as some short-term, specific and negative localised views were anticipated to have some political sway. This situation is common to many marine resource management scenarios. In this case, it was expected that some local Marine Park users and local federal members of parliament would have concerns about the proposed changes to zoning. Ministerial support was essential to deliver the greater social, economic and environmental benefits, because willingness was required to address concerns regarding lobbying as well as perceived and actual costs. This requirement for political support and advocacy is often mentioned, but rarely given sufficient priority or space in the literature, and its absence has led to the downfall of many natural resource management initiatives [43,44]. Again, the scientific basis for the proposed way forward was instrumental in convincing the Federal Minister for the Environment. The fact that the scientists were then available to him for query and critique added strength to the information already provided.

Involving relevant scientists early in the rezoning process had the added advantage of raising their awareness and support for the proposed improvements in protection. Their support was useful throughout the process, especially during the more contentious phases, as many scientists were willing and able to state their unbiased views to the community, politicians and the media.

5. Conclusion

The following features were found to be successful in developing the Biophysical Operational Principles to design a network of marine protected areas:

1. well-defined, detailed biophysical objectives,
2. early involvement of local experts including scientists,
3. an independent expert panel with clear terms of reference,
4. separate panels of natural science and social science experts,
5. the examination of the adequacy of the existing level of protection and existing level of information weighed up against threats to the system under question,
6. the establishment of principles addressing issues of how much, how big, how many, distribution, and of principles that take account of all that is known and not known,
7. internal scrutiny of, and multi-level support for, the implications of implementation of the principles prior to finalisation, and
8. public availability of the principles for scrutiny before decisions were made about location of no-take areas.

Respecting the requirement of experts to qualify their recommendations and ensuring the capacity to review any management decisions as new information comes to light can also be of great importance [45]. The process applied in the case of the Great Barrier Reef Marine Park could have been improved by external, independent, peer review of the final principles.

It is recognised that the final Zoning Plan is a significant output, however, it is not an outcome. Real success is being achieved due to ongoing compliance with the new rules, and monitoring to assess any changes that occur under the new Zoning Plan [46]. Ensuring adequate compliance and monitoring of the Zoning Plan are now priority tasks for the Great Barrier Reef Marine Park Authority.

The biophysical operational principles and social, economic, cultural and management feasibility operational principles are available as Technical Information Sheets online at: www.gbrmpa.gov.au/corp_site/management/representative_areas_program/rap_publications/info_sheets.

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References

[1] Lubchenco J, Palumbi SR, Gaines SD, Andelman S. Plugging a hole in the ocean: the emerging science of marine reserves. Ecological Applications 2003;13(1 Suppl.):S3–7.
[2] Fernandes L, Day J, Jago B, Hall J, Sampson K, Cameron D, et al. J Weaving an "ideal" design of no-take Marine Protected Areas into the real world: the Great Barrier Reef case study. In: Proceedings of tenth international coral reef symposium, Okinowa, Japan, 2004; 2006. p. 1511–6.
[3] Botsford LW, Micheli F, Hastings A. Principles for the design of marine reserves. Ecological Applications 2003;13(1 Suppl.):S25–31.
[4] Roberts CM. Sources, sinks, and the design of marine reserve networks. Fisheries 1998;23(7):16–9.
[5] Grantham BA, Eckert GL, Shanks AL. Dispersal potential of marine invertebrates in diverse habitats. Ecological Applications 2003;13(1 Suppl.): S108–16.
[6] Shanks AL, Grantham BA, Carr HM. Propagule dispersal distance and the size and spacing of marine reserves. Ecological Applications 2003;13(1 Suppl.): S159–69.
[7] Ray GC. Coastal-marine protected areas: agonies of choice. Aquatic Conservation: Marine and Freshwater Ecosystems 1999;9:607–14.
[8] Roberts CM, Branch G, Bustamante RH, Castilla JC, Dugan J, Halpern BS, et al. Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecological Applications 2003;13(1 Suppl.):S215–28.
[9] Roberts CM, Andelman S, Branch G, Bustamante RH, Castilla JC, Dugan J, et al. Ecological criteria for evaluating candidate sites for marine reserves. Ecological Applications 2003;13(1 Suppl.):S199–215.
[10] Browman HI, Stergiou KI. Marine protected areas as a central element of ecosystem-based management: defining their location, size and number. Marine Ecology Progress Series 2004;274:271–2.
[11] Salm R, Price A. Selection of marine protected areas. In: Gubbay S, editor. Marine protected areas: principles and techniques for management. London: Chapman & Hall; 1995. p. 15–31.
[12] Jackson JBC, Kirby MX, Wolfgang WH, Bjorndal KA, Botsford LW, Bourque BJ, et al. Historical overfishing and the recent collapse of coastal ecosystems. Science 2001;293:629–38.
[13] Day J. Zoning – lessons from the great Barrier reef marine park. Ocean & Coastal Management 2002;45:139–56.
[14] Kenchington RA. Managing marine environments. New York: Taylor & Francis; 1990. p. 238.
[15] Commonwealth of Australia. Great barrier reef marine park act; 1975.
[16] Great Barrier Reef Marine Park Authority. Great Barrier reef marine park Authority Corporate Plan 2004–2009. Townsville: Great Barrier Reef Marine Park Authority; 2004. p. 25.
[17] Great Barrier Reef Marine Park Authority. The 25 year strategic plan for the great Barrier reef world Heritage area. Townsville: Great Barrier Reef Marine Park Authority; 1996. p. 64.
[18] Fernandes L, Day J, Lewis A, Slegers S, Kerrigan B, Breen D, et al. Establishing representative no-take areas over 1/3 of the Great Barrier Reef: large-scale implementation of Marine Protected Area theory with lessons for global application. Conservation Biology 2005:1733–44.
[19] Day J, Fernandes L, Lewis A, De'ath G, Slegers S, Barnett B, et al. The representative areas program-for protecting biodiversity in the great Barrier reef world Heritage area. In: Proceedings of the ninth international coral reef symposium Bali, Indonesia, 2000; 2002.
[20] Australian and New Zealand Environment and Conservation Council Task Force on Marine Protected Areas (ANZECC, TFMPA). Guidelines for establishing the national representative system of marine protected areas. Canberra: Environment Australia; 1998. p. 15.
[21] Australian and New Zealand Environment and Conservation Council (ANZECC). Strategic plan of action for the national representative system of marine protected areas: a guide for action by Australian Governments. Canberra: Environment Australia; 1999. p. 80.
[22] Salm R, Coles SL, editors. Proceedings of the workshop on mitigating coral bleaching impact through MPA design, 2001. Honolulu: Bishop Museum; 2001. p. 107.
[23] Arnold PW, Birtles RA. Distribution of trophic groups of epifaunal echinoderms and molluscs in the soft sediment areas of the Central Great Barrier Reef Shelf. In: Choat JH, Barnes D, Borowitzka MA, Coll JC, Davies PJ, Flood P, Hatcher BG, editors. Proceedings of the sixth international coral reef symposium. Townsville, Australian 1988; 1988.
[24] Burrage DM, Steinberg CR, Skirving WJ, Kleypas JA. Mesoscale circulation features of the Great Barrier Reef region inferred from NOAA satellite imagery. Remote Sensing Environment 1996;56(1):21–41.
[25] Poiner IR, Blaber JM, Brewer DT, Burridge C, Caeser D, Connell M, et al. Final report on effects of trawling in the far Northern section of the great Barrier reef: 1991–1996. Final report to the GBRMPA and FRDC. Cleveland: CSIRO Division of Marine Research; 1998. p. 554.
[26] Wolanski E, editor. Oceanographic processes of coral reefs: physical and biological links in the Great Barrier Reef. USA: CRC Press; 2001. p. 356.
[27] James MK, Mason LB, Bode L, Armsworth PR. The structure of reef fish metapopulations: dispersal and retention patterns for reef fish larvae. Proceedings of the Royal Society of London B 2002;269:2079–86.
[28] Possingham H, Ball I, Andelman S. Mathematical methods for identifying representative reserve networks. In: Ferson S, Burgman M, editors. Quantitative methods for conservation biology. New York: Springer-Verlag; 2000.
[29] Dobbs K, Fernandes L, Slegers S, Jago B, Thompson L, Hall J, et al. Incorporating dugong habitat into the marine protected area design for the great Barrier reef marine park, Queensland, Australia. Ocean and Coastal Management 2008;51:368–75.
[30] Watson-Wright WM. Policy and science: different roles in the pursuit of solutions to common problems. Marine Ecological Progress Series 2005;300:291–6.
[31] Margules CR, Pressey RL, Nicholls AO. Nature conservation: cost effective biological surveys and data analysis. In: Margules CR, Austin MP, editors. Selecting nature reserves. East Melbourne: CSIRO Publications; 1991.
[32] Ray GC, McCormick-Ray MG. Critical habitats and representative systems in marine environments: concepts and procedures. In: Agardy T, editor. The science of conservation in the coastal zone. New Insights on how to design, implement and Monitor marine protected areas. Gland: IUCN; 1995.
[33] Fiske SJ. Sociocultural aspects of establishing marine protected areas. Ocean & Coastal Management 1992;18:25–46.
[34] Mascia MB. The human dimension of coral reef marine protected areas: recent social science research and its policy implications. Conservation Biology 2003;17(2):630–2.
[35] Christie P. Marine protected areas as biological successes and social failures in Southeast Asia. American Fisheries Society Symposium 2004;42:155–64.
[36] Weber M, Eisenfuhr F, von Winterfeldt D. The effects of splitting attributes on weights in multiattribute utility measurement. Management Science 1988;34:431–45.
[37] Allison GW, Gaines SD, Lubchenco J, Possingham HP. Ensuring persistence of marine reserves: catastrophes require adopting an insurance factor. Ecological Applications 2003;13(1 Suppl.):S8–24.
[38] Brethes J-C. The Canadian Atlantic groundfish experience and the constraints to the conservation of fisheries resources: a perspective. Ocean and Coastal Management 1998;39:135–50.
[39] Clark TW. Interdisciplinary problem solving: next steps in the Greater Yellowstone ecosystem. Policy Sciences 1999;32(4):393–414.
[40] Jameson SC, Tupper MH, Ridley JM. The three screen doors: can marine "protected" areas be effective? Marine Pollution Bulletin 2002;44(11): 1177–83.
[41] Heikkila T. Institutional boundaries and common-pool resource management: a comparative analysis of water management programs in California. Journal of Policy Analysis and Management 2004;23(1):97–117.
[42] Olsson P, Folke C. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken watershed, Sweden. Ecosystems 2001;4:85–104.

[43] Caddy JF, Seijo CJ. This is more difficult than we thought! The responsibility of scientists, managers and stakeholders to mitigate the unsustainability of marine fisheries. Philosophical Transactions of the Royal Society B 2005;360:59–75.
[44] Cochrane KL, Douleman DJ. The rising tide of fisheries instruments and the struggle to keep afloat. Philosophical Transactions of the Royal Society B 2005;B360:77–94.
[45] Rice JC. Implementation of the ecosystem approach to fisheries management – asynchronous co-evolution at the interface between science and policy. Marine Ecological Progress Series 2005;300:265–70.
[46] Russ GR, Cheal AJ, Dolman AM, Emslie MJ, Evans RD, Miller I, et al. Rapid increase in fish numbers follows creation of world's largest marine reserve network. Current Biology 2008;18(12):R514–515.