New Zealand marine protected areas

Principles for network design

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Contents

1 Abstract

In this report, we provide an overview of the best practice design principles for networks of marine protected areas (MPAs) to conserve biodiversity in the New Zealand context. Recommendations for applying the design principles of representativity, replication, adequacy, viability and connectivity are presented. These principles can be applied to broad-scale habitats and to ecologically important areas to create a fully representative network of marine protected areas.

Several areas of scientific uncertainty have prevented the development of clear, quantitative targets for some of the design principles. These include ecologically relevant targets to achieve representativity, species dispersal ranges to ensure connectivity of MPAs and assessment of MPA viability.

We encourage continued efforts to:

- consider how network design principles may be applied to different categories of MPA
- revise the broad-scale habitat classification system that is currently used for MPA planning
- assess data sets against the proposed criteria for key ecological areas.

The development of individual and network MPA objectives will be vital for implementing MPAs in the future, based on a systematic conservation planning approach.

2 Introduction

2.1 Stressors in the marine environment

The New Zealand marine environment is exposed to a number of stressors that may impact biodiversity. The most wide-ranging and serious of these are climate change, fisheries removals and trawl disturbance, and sediment run-off from land (MacDiarmid et al., 2012). These stressors influence a patchwork of habitat types that differ in their biodiversity, extent, rarity and functional importance at a variety of scales.

- Climate change impacts are often widespread.
- Trawl disturbance impacted approximately 48% of habitats shallower than 250 m (from 2008 to 2012 Baird et al., 2015) decreasing to 9% of the seafloor from 1000–1200 m (as gauged from 1990 to 2016 Baird and Wood, 2018).
- Sediment impacts are widespread but focused around river mouths. They can be detected up to tens of kilometres offshore (Tuckey et al., 2006, Forrest et al., 2007).

2.2 Protected areas – roles and objectives

Overlying the stressors are a mosaic of management regulations and approaches that provide some biodiversity protection while trying to ensure sustainable use.

Protected areas are one tool for conserving biodiversity across terrestrial, freshwater and marine domains. They provide for the maintenance of essential ecological processes and the preservation of genetic diversity (Kelleher, 1999).

The role of protected areas is to represent biodiversity, and separate that biodiversity from certain processes that threaten its persistence (Margules and Pressey, 2000). To achieve this, conservation planning must locate protected areas with reference to the natural physical and biological patterns and processes that affect biodiversity, as well as the human activities that may threaten it.

The extent to which protected areas fulfil this role depends on how well they meet two objectives: to represent the full range of biodiversity (ideally at all levels of organisation), and to promote the long-term survival of the species and other elements they contain by maintaining natural processes and viable populations.

2.3 Networks of marine protected areas

Marine protected areas (MPAs) provide enhanced benefits when they function as a network (Gaines et al., 2010). Multiple MPAs can have additive effects, with an increase in conservation benefit across a network being the sum of increases that would be seen from each MPA in isolation. A set of MPAs can also have a multiplicative effect, with the overall benefit being greater than the sum of those from individual MPAs.

Network design principles provide guidance for designing a resilient MPA network to achieve pre-determined objectives, like the protection of species and habitats or the maintenance of ecological processes. Network design principles can inform a consistent, systematic approach to the addition of new protected areas to ensure each new area provides system-wide and multiplicative benefits beyond those associated with an individual area.

International guidance

A range of international best practice documents and agreements to which New Zealand is a party provide guidance for the establishment of MPA networks, all of which share some common elements. The Convention on Biological Diversity (CBD), United Nations Environment Programme and the International Union for Conservation of Nature (IUCN) all provide examples of established principles for designing MPA networks and provide advice on the network design process (see examples in Appendix 1, including network guidance developed by other nations).

At the Ninth Meeting of Parties to the Convention on Biological Diversity in 2008, parties agreed to 'Scientific guidance for selecting areas to establish a representative network of Marine Protected Areas, including in open ocean waters and deep-sea habitats'. Under this decision (Conference of the Parties to the Convention on Biological Diversity, 2008), parties agreed that the required properties and components of a representative network of marine protected areas were:

- ecologically and biologically significant areas
- representativity
- connectivity
- replicated ecological features
- adequate and viable sites.

The IUCN (IUCN-WCPA, 2008) identifies five key principles for an MPA network:

1. Include the full range of biodiversity present in the biogeographic region:
   a. representation
   b. replication
   c. representation of resilient and resistant characteristics.
2. Ensure ecologically significant areas are incorporated:
   a. protection of unique or vulnerable habitats
   b. protection of foraging or breeding grounds
   c. protection of source populations.
3. Maintain long-term protection:
   a. spillover of larvae, juveniles and adults from long-term protection
   b. adaptive strategies to long term protection.
4. Ensure ecological linkages:
   a. connectivity
   b. adult movement patterns
   c. larval dispersal.
5. Ensure maximum contribution of individual MPAs to the network:
   a. size
   b. spacing
   c. shape.

The UNEP-WCMC (United Nations Environment Programme – World Conservation Monitoring Centre) considers the following components as central to an effective network of MPAs.

Adequacy: the need to ensure that individual components of a protected area network are of sufficient size, shape and appropriate spatial distribution to ensure the ecological viability and integrity of populations and species.

Representativity: an ecologically representative network requires one or more MPAs to be established for each example of a full range of biological diversity (from genes to ecosystems) and associated oceanographic environments within a given area.

Resilience: the ability of a system or MPA network to survive natural catastrophes and major impacts, and absorb shocks.

Connectivity: refers to the linkages between sites in a network resulting from the characteristics of marine organisms (such as larval dispersal, pelagic juveniles and adults and reproduction through spawning) and from the marine environment, including the mixing of waters through wind, currents, tides and upwellings.

2.4 Approach and content of this report

This document contains:

- A summary of the systematic conservation planning process and an explanation of why it provides an adequate framework for applying the principles of MPA network design.
- A description of the habitats and key ecological areas (KEA) to which network design principles should be applied in a conservation planning process.
- A presentation of the concepts behind international best practice MPA network design principles (representativity, replication, adequacy, viability and connectivity).

Each principle is explored for its potential application to the current New Zealand ecological context and how it may be applied to different categories of MPA. A process for defining objective-related targets for each principle is also outlined.

In the absence of objectives at a network or biogeographic level, targets for each network design principle are recommended. These include minimums or a range of protection levels, which could be further refined once specific objectives are agreed.

3 Systematic conservation planning

Systematic conservation planning (SCP) is a structured, idealised approach to guide decision-making by defining the objectives of protection, identifying priorities and considering the costs and benefits of different sets of management actions (Margules and Pressey, 2000).

Biodiversity conservation goals, competing objectives and threats to biodiversity are mapped across an area in different layers. These maps are then used to assess existing protection measures and optimise the design of a protected area network.

SCP can also be part of broader marine spatial planning for an area.

3.1 Stages in the planning process

SCP comprises the following stages (modified from Margules and Pressey, 2000).

1. Compile data on the biodiversity of the planning region.
    a. Review existing data and decide which data sets are suitable as surrogates for biodiversity across the planning region.
    b. If time allows, collect new data to augment or replace existing data sets.
    c. Collect information on the localities of species considered to be rare and/or threatened in the region (these are likely to be missed or under-represented in conservation areas selected only on the basis of land classes such as vegetation types).
2. Identify protection objectives and/or conservation goals for the planning region:
    a. Identify what species, habitats or features are the highest priority for protection.

   b. Set quantitative conservation targets for species, habitats or other features that reflect these priorities. Make the goals as explicit as possible.
   c. Set quantitative targets for minimum size, connectivity and other protected area design criteria.
   d. Identify qualitative targets or preferences e.g. new protected areas should have minimal previous disturbance.
3. Map the distribution or extent of each protection objective.
   a. Use the data compiled in stage 1.
   b. Mapped objectives can be represented as density distributions or as binary ranges.
4. Identify and map threats to the protection objectives.
5. Identify and map competing objectives for the marine environment.
   a. Where these will be excluded or negatively affected by spatial protection measures, develop spatially explicit 'cost' layers
6. Review existing conservation areas:
   a. Measure the extent to which quantitative targets for representation and design have been achieved by existing MPAs.
   b. Identify the threat to under-represented features, and the threats to area that will be important for securing satisfactory targets.
7. Select additional conservation areas:
   a. Regard established conservation areas as constraints or focal points for the design of an expanded system.
   b. Identify and evaluate alternate MPA scenarios as additions to established MPAs, to achieve protection targets while minimising costs.
8. Implement conservation actions:
   a. Evaluate MPA proposals and scenarios, including appropriate protection tools and management regimes.
   b. Decide on the most appropriate management for individual areas.
   c. Decide on the timing of conservation management when resources prevent implementing the whole system in the short term.
9. Maintain the values of conservation areas:
   a. Set goals at an individual MPA level but acknowledge the values of the area in the context of the whole network.
   b. Implement management action in and around each MPA to achieve the goals.
   c. Monitor key indicators that will show success in achieving the goals. Modify management as required.

Margules and Pressey (2000) state that the SCP process is not one-directional: there are feedbacks and there may be reasons to alter decisions as part of this process. It is important to note that the SCP planning process considers both biophysical and socioeconomic factors.

3.2 Applying network design principles

The principles of network design should be applied to both broad-scale habitats and KEAs in MPA planning. They could be applied in different stages of the SCP, such as when considering how the objectives of the planning process should be met, or when evaluating MPA proposals or scenarios.

Figure 1 is an overview of how objectives, targets and network design principles could be incorporated into an MPA planning process.

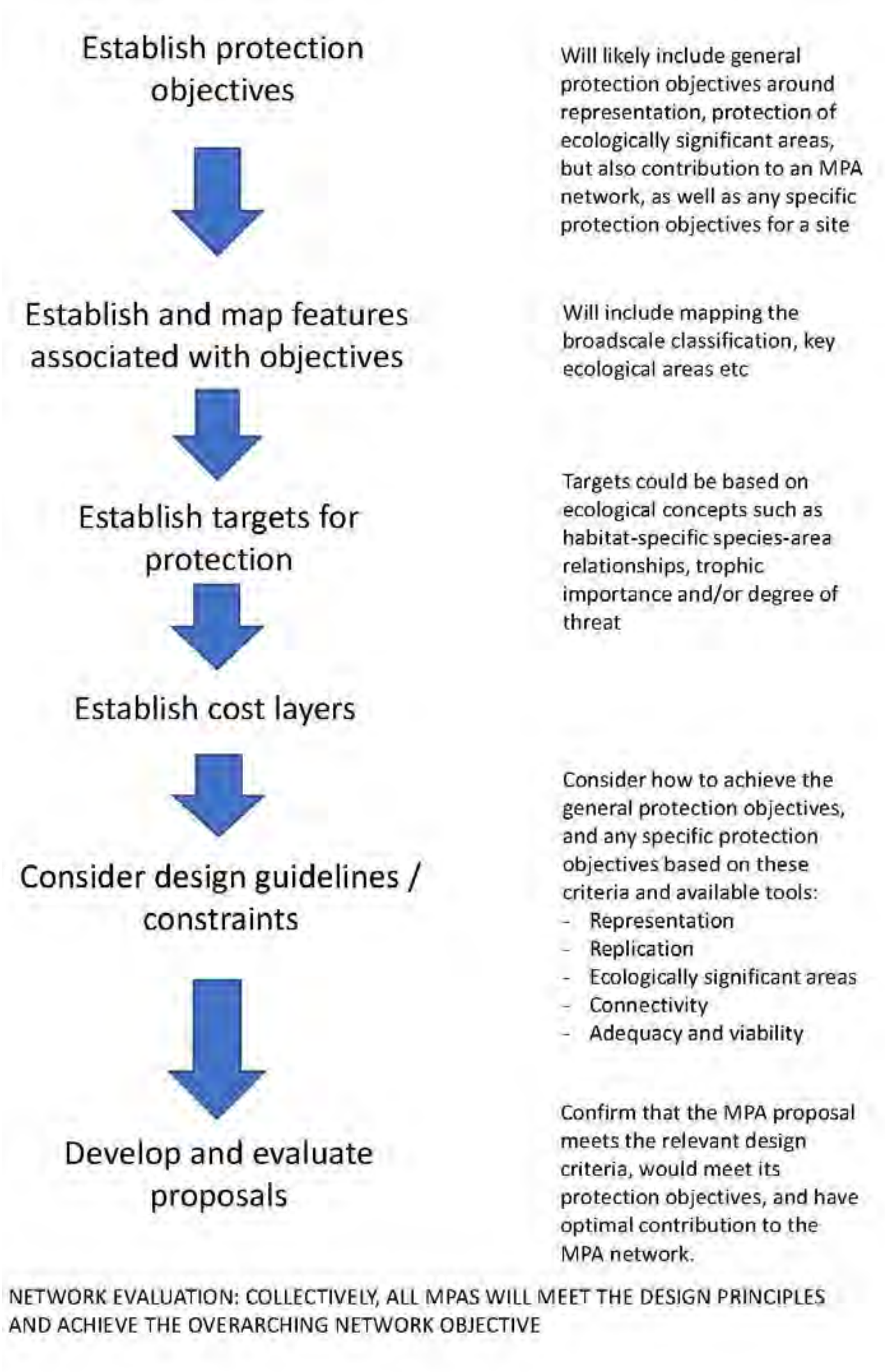

Figure 1. Overview of how objectives, targets and network design principles can be incorporated into an MPA planning process. Adapted from Sharp & Watters (2011).

3.3 Setting objectives in MPA planning

An important part of the SCP process is agreeing on objectives for protection. This helps identify types of relevant data and informs the design phase of the process (e.g. size, configuration and number of MPAs required to achieve the objectives). To ensure the MPA network objectives are met, they should ideally be developed first. Individual MPAs or regional MPA processes can then be developed, taking the defined wider context into account.

In the past, little consideration has been given to how individual MPAs will contribute towards achieving New Zealand's MPA network objectives. For example, objectives for marine reserves have been relatively high-level and focussed around achieving protection of unique or rare features, or ensuring the range of habitats in a region are represented within the reserve. In some cases, objectives related to providing support for customary, recreational or commercial fishing or other values have been identified (e.g. Wilson et al., 2007).

Increasingly, more detailed objectives for MPAs are being established as part of conservation planning processes. This can bring benefits such as targeting protection towards important features, taking account of values that matter to communities, and inform assessments of how well the objectives are being achieved (see case study 1 for an example).

New Zealand's current approach to MPAs has a focus on biodiversity conservation. Internationally, the objectives for individual MPAs can be diverse and include enabling the recovery or maintenance of biodiversity, providing for eco-tourism and supporting adjacent fisheries through export of adults or larvae (Halpern and Warner, 2003, Hockey and Branch, 1997). The current New Zealand MPA policy includes some consideration of an MPA's contribution to a broader network (Department of Conservation & Ministry of Fisheries, 2005), but has little specific guidance on how to undertake that consideration. Further development of how this can be achieved is required.

3.4 Cost layers

The importance of developing robust cost layers (see stage 5a above) as part of the planning process is emphasised. Here, 'cost' means *the cost to other users of declaring protection in a particular location.* This could include fishing, mining and shipping lanes. Information on costs should be presented and incorporated in the planning process at as fine a resolution as possible. It should include all the existing activities that may be displaced or negatively affected in some way by creating a protected area.

Case study 1: Protection objectives for the Ross Sea region Marine Protected Area

The Ross Sea region MPA came into effect on 1 December 2017, following a lengthy scientific and political process through the international Commission for the Conservation of Antarctic Marine Living Resources.

The MPA design was informed by a SCP process that was designed and originally proposed by New Zealand – this provided a scientific basis for the subsequent international negotiations. The choice of protection objectives, the underpinning scientific data relating to the biological or physical features associated with those objectives and the defined targets, were key elements of the scientific process used to design this MPA. The SCP method is described fully in Sharp and Watters (2011).

The Ross Sea region MPA proposal included 11 objectives consistent with the SCP guidelines. Of these, objectives i–iii were spatially generic and applied equally at all locations. Objective iv referred to habitat representativeness, which was implemented using separate benthic and pelagic habitat classifications. Objectives v–x were defined with reference to specific mapped features judged to be of particular priority for inclusion within MPAs (see Figure 2). The two habitat classifications in objective iv and the mapped features in objectives v–x are what drove the SCP process. Objective xi was added after the SCP process and provided a specific zone for research on krill.

The objectives were:

(i) To conserve natural ecological structure, dynamics and function throughout the Ross Sea region, at all levels of biological organisation, by protecting habitats that are important to native mammals, birds, fishes and invertebrates.

(ii) To provide reference areas for monitoring natural variability and long-term change, and in particular a special research zone, in which fishing is limited to better gauge the ecosystem effects of climate change and fishing, to provide other opportunities for better understanding the Antarctic marine ecosystem, to underpin the Antarctic toothfish stock assessment by contributing to a robust tagging program, and to improve understanding of toothfish distribution and movement within the Ross Sea region.

(iii) To promote research and other scientific activities (including monitoring) focused on marine living resources.

(iv) To conserve biodiversity by protecting representative portions of benthic and pelagic marine environments in areas where fewer data exist to define more specific protection objectives (benthic and pelagic bioregions).

(v) To protect large-scale ecosystem processes responsible for the productivity and functional integrity of the ecosystem: Ross Sea shelf front intersection with seasonal ice, polar front, Balleny Islands and proximity, Ross Sea polynya marginal ice zone and eastern Ross Sea multi-year ice.

(vi) To protect core distributions of trophically dominant pelagic prey species: Antarctic krill, crystal krill and Antarctic silverfish.

(vii) To protect core foraging areas for land-based top predators or those that may experience direct trophic competition from fisheries: Adélie penguins, emperor penguins, Weddell seals and type C killer whales.

(viii) To protect coastal locations of particular ecological importance: southern Ross Sea shelf, persistent winter polynya, recurrent coastal polynyas, Terra Nova Bay, Victoria Coast platelet ice formation zone and Pennell Bank polynya.

(ix) To protect areas of importance in the lifecycle of Antarctic toothfish: sub-adult toothfish settlement areas on the Ross Sea shelf, dispersal corridors for maturing toothfish and adult toothfish feeding areas on the Ross Sea slope.

(x) to protect known rare or vulnerable benthic habitats: Balleny Islands and adjacent seamounts, Admiralty seamount, Cape Adare slope, southeast Ross Sea slope, McMurdo Sound and Scott seamount and adjacent underwater features.

(xi) To promote research and scientific understanding of krill, including in the krill research zone in the northwestern Ross Sea region.

A range of data layers relating to ecological features were mapped to each of these objectives (see Figure 2 2 for examples) and provided the scientific basis for ensuring the protection objectives could be achieved and monitored on an ongoing basis. Regular reviews of the how well the objectives are being achieved allow for ongoing revision of the MPA boundaries and management regime.

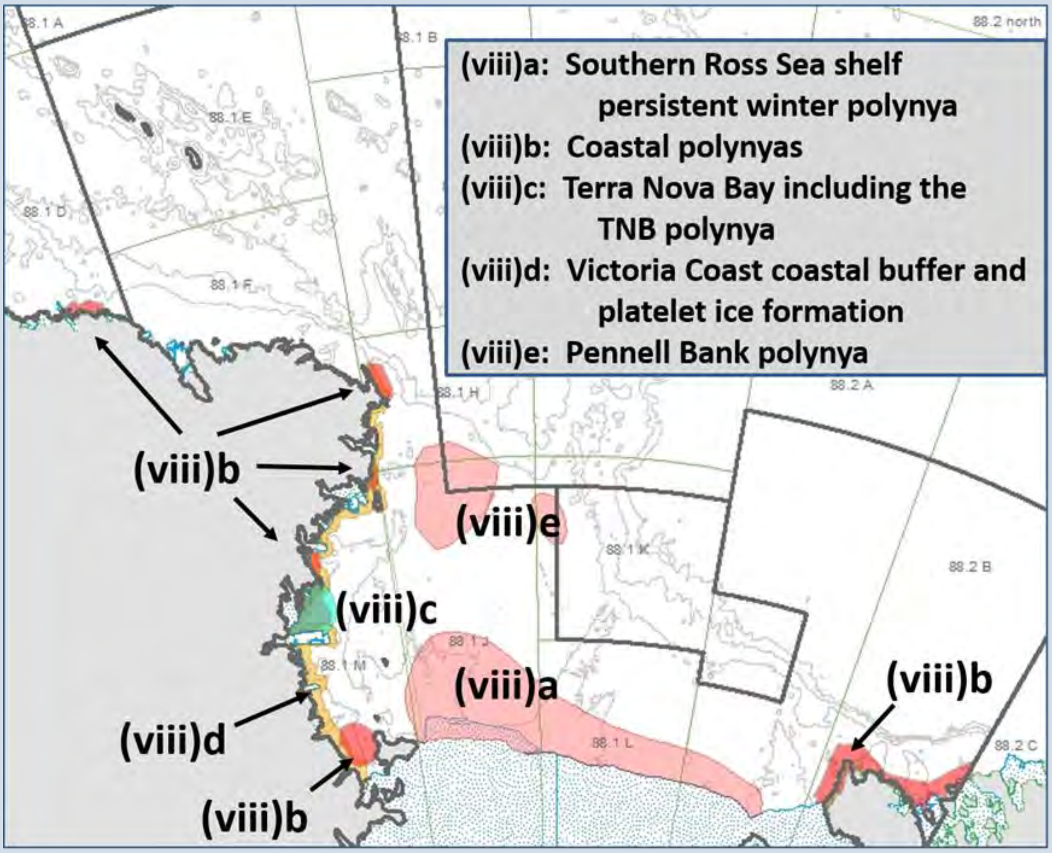

Figure 2. Example modified from Sharp and Watters (2011) of how ecological features can be mapped to ensure achievement of defined protection objectives for a marine protected area. This example shows coastal or localised areas of particular ecological importance to the Ross Sea shelf ecosystem.

4 Representing biodiversity in MPAs

The representation of broad-scale habitats in MPAs can ensure a large proportion of biodiversity is included in an MPA network. However, this approach should be complemented by considering the ecologically and biologically significant areas (or features) that are known to be important for biodiversity. The features may be rare, unique, important for particular life-history stages, threatened, particularly vulnerable, highly productive, particularly diverse or have a high degree of naturalness.

4.1 Broad-scale habitat classification

The marine environment has a diverse range of biota, including kelp forests, sponge gardens, shellfish beds and deep-water coral communities. These are connected via complex interactions between biological and physical processes. Any attempt to classify marine ecosystems into categories needs to be based on detailed knowledge of the physical and biological components in the area of interest.

A full inventory of the habitats and species in an area is generally either not in existence, is incomplete or is at insufficient resolution. Even where more detailed biological information is available, it rarely extends to the entire planning region. An alternative approach is often needed to identify where to place representative protected areas.

One alternative approach is to classify the marine environment according to physical 'drivers' that are known to influence patterns of biodiversity, such as depth, exposure and substrate type. Classifications emerging from these drivers are known as broad-scale classifications and can produce information at a scale relevant for MPA planning processes.

A broad-scale habitat classification system for New Zealand is described in the Marine Protected Area Classification, Protection Standard and Implementation Guidelines (Ministry of Fisheries & Department of Conservation, 2008). This system is a hierarchy of five levels that are all related to the physical environment.

The first level of the classification is the biogeographic region, of which New Zealand has 14. Behind this level of classification is the assumption that physical habitats and ecosystems, if separated by enough space (hundreds to thousands of kilometres), will contain different biological communities. Differences are due to a combination of factors such as water temperature, oceanography, current dynamics, large-scale latitudinal gradients, climate or barriers to dispersal.

The second level of classification is the environment – estuarine and marine. This recognises the fundamental differences in biology associated with estuarine and marine environments.

The third, fourth and fifth levels of the classification are depth, exposure and substrate type, as these three factors are thought to most strongly influence a site's biology. Within each biogeographic region and environment, combinations of depth, exposure and substrate type represent a total of 44 habitats to be considered for protection in each bioregion, although not all of these will be present in every biogeographic region.

Limitations

A limitation of broad-scale classification is that regional patterns of biodiversity may also not be adequately reflected. This does not negate the usefulness of the classifications, but regional variability and local or traditional knowledge should be incorporated when seeking to represent biodiversity at a regional level.

Also finer-scale knowledge, including that held by local communities, tends to be incorporated poorly. Broad-scale habitat classification should be augmented with local knowledge and additional information (where available) during the planning process. Without this detail it is unlikely to adequately represent the biological features and habitats of a region.

For example, some of the classification levels do not account for changes in biological habitats across depth ranges, so the broad-scale classification here fails to be an adequate surrogate for biodiversity. Rowden et al. (2018) reviews some of the shortcomings of the current classification system.

4.2 Ecologically and biologically significant areas

The ninth Conference of the Convention on Biological Diversity (2008) defined 'ecologically and biologically significant areas' as 'geographically or oceanographically discrete areas that provide important services to one or more species or populations of an ecosystem, or to the ecosystem as a whole, compared to other surrounding areas or areas of similar ecological characteristics.'

Protecting ecologically significant areas is a common design principle for networks of MPAs (see Appendix 1). An objective and consistent approach to identifying sites of particular importance for biodiversity is preferred in MPA planning. Attempts to achieve this internationally include:

- A global standard for the identification of 'key biodiversity areas' prepared by the IUCN (IUCN, 2016).
- Criteria for the identification of 'ecologically and biologically significant areas' developed as part of the scientific guidance for selecting areas to establish a representative network of MPAs, under the Convention on Biological Diversity (UNEP/CBD/COP/DEC/IX/20).

Recent reviews by Asaad et al. (2016) and Dunn et al. (2014) provide useful analyses of a range of international initiatives and associated criteria for identifying areas with important biodiversity. Asaad et al. (2016) found eight criteria that were commonly used to identify areas for biodiversity conservation. These identified areas that: contained unique and rare habitats (1), included fragile and sensitive habitats (2), were important for ecological integrity (3) and were representative of all habitats (4). The remaining four were based on species' attributes, including the presence of species of conservation concern (5), the occurrence of restricted-range species 6), species richness (7) and importance for life history stages (8).

Individual countries have developed guidance for their own protected area planning initiatives. For example, the Australian Commonwealth Marine Area's 'key ecological features' and 'biologically important areas' were included in the development of bioregional plans that informed MPA planning in their waters.

The ANZECC (Australian and New Zealand Environment and Conservation Council) guidelines for establishing a representative network of MPAs in Australia and New Zealand (ANZECC-TFMPA, 1998) provide a range of criteria to identify candidate sites: representativeness, comprehensiveness, ecological importance, national or international importance, uniqueness, productivity, vulnerability assessment, biogeographic importance and naturalness.

This approach recognises that the contribution of a feature to representativeness can be distinct from its contribution to other criteria (such as naturalness). As noted in a Canadian report about identifying areas of important biodiversity, giving an area legal protection based solely on it being representative may mean that the area is not especially unique, host particularly high concentrations of species or habitat features or be a site for critical life history activities (DFO, 2004).

4.3 Marine protected areas in New Zealand: guidelines and practice

In New Zealand, processes for establishing marine reserves have mainly been driven by the criteria included in the current Marine Reserves Act, as well as domestic policy and implementation guidance that identify the types of features that could be considered in protected area planning. The Marine Reserves Act 1971, Section 3(1) refers to (emphasis added) 'underwater scenery, natural features, or marine life, of such **distinctive quality**, or so **typical**, or **beautiful**, or **unique**'.

In practice, marine reserves that are either representative (or typical) of the broader marine environment and/or contain features considered as unique or special have been established. For example, the Poor Knights Islands, Kermadec and Volkner Rocks (Te Paepae Aotea) Marine Reserves are examples of MPAs providing protection to 'unique' features, whereas Te Angiangi and Te Tapuwae o Rongokako Marine Reserves are examples of 'representative' sites.

The current New Zealand Marine Protected Areas Policy (Department of Conservation and Ministry of Fisheries, 2005) and accompanying implementation guidelines (Ministry of Fisheries and Department of Conservation, 2008) provide guidance around the criteria for selecting MPAs. For example, the policy provides guidance that sites with outstanding, rare, distinctive or internationally or nationally important habitats and ecosystems are expected to be set aside as marine reserves.

The MPA policy also calls for protection of the 'full range of marine habitats and ecosystems' as well as those that are rare, distinctive, or internationally or nationally important. At the time the policy was developed, however, it was noted that while biophysical surrogates are a useful and cost effective method for identifying marine biodiversity over large areas, they do not provide for detailed aspects like adult home ranges, critical habitat and trophic relationships (Ministry of Fisheries and Department of Conservation, 2008). (Biophysical surrogates are the biological or physical features of an environment that provide a proxy for the actual biodiversity at a site, and represent the distinctiveness between marine habitats and ecosystems.) These aspects may need to be considered separately from the representation of broad-scale habitats.

An interagency Interim MPA Science Advisory Group recommended that criteria for what have been termed key ecological areas (KEA) be used to help identify ecologically significant areas as part of MPA planning in New Zealand (Freeman et al., 2017). These criteria, along with broad-scale habitat representation, replication, adequacy and connectivity should be considered in MPA planning processes.

The KEA criteria were based on the CBD's EBSA criteria (Conference of the Parties to the Convention on Biological Diversity, 2008) and are shown in Table **1**. Note that the availability and quality of data for these criteria varies considerably. For example, spatial data exists for only a subset of ecosystem services in the New Zealand marine environment, and the data for many of New Zealand's threatened marine species are inadequate.

Table 1. Proposed criteria for determining key ecological areas in New Zealand, for informing protected area planning. Definitions are from CBD (2008) where relevant.

Criteria	Definition	Rationale	New Zealand examples
Vulnerability, fragility, sensitivity, or slow recovery	Areas that contain a relatively high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery	In the absence of protection, associated biodiversity may be vulnerable	Biogenic habitats, including bryozoan beds, sponge communities and cold-water corals. Low fecundity / high longevity (fish) species including bramble sharks, hapuku, king tarakihi, orange roughy.
Uniqueness / rarity / endemism	Area contains: (1) unique ('the only one of its kind'), rare (occurs only in a few locations) or endemic species, populations or communities, and/or (2) unique, rare or distinct, habitats or ecosystems, and/or (3) unique or unusual geomorphological or oceanography features.	Areas contain biodiversity that is irreplaceable, and non-representation in protected areas may result in loss or reduction in biodiversity or features. These areas contribute towards larger-scale biodiversity.	Hydrothermal vents, seeps, areas containing co-occurring geographically restricted species, biogenic habitats.
Special importance for life history stages	Areas required for a population to survive and thrive.	Particular requirements make some areas more suitable for species to carry out life history stages.	Fish spawning or nursery grounds, pinniped breeding colonies, migratory corridors, sites where animals aggregate for feeding.
Importance for threatened / declining species and habitats	Area containing habitat for the survival and recovery of endangered, threatened, declining species or area with significant assemblages of such species.	Protection may enable recovery or persistence of these threatened / declining species or habitats.	Estuaries with populations of threatened shorebirds, and foraging areas for marine mammals and seabirds.
Biological productivity	Area containing species, populations or communities with comparatively higher natural biological productivity.	Areas can support enhanced growth and reproduction, and support wider ecosystems.	Hydrothermal vents, frontal zones, areas of upwelling.
Biological diversity	Area contains comparatively higher diversity of ecosystems, habitats, communities or species, or has higher genetic diversity.	Areas are important for evolutionary processes, for species' and ecosystem resilience and contribute towards large-scale biodiversity.	Structurally complex communities such as deepwater sponge and coral communities, seamounts. Areas with

			diverse demersal fish species.
Naturalness	Area with a comparatively higher degree of naturalness because of the lack of or low level of human-induced disturbance or degradation.	Provides enhanced ability to protect biodiversity in better condition; reduces need to rely on recovery from a degraded state; areas may include species and/or habitats that do not occur or are not well represented in more degraded areas; important role as reference sites.	Remote areas, marine areas adjacent to protected terrestrial areas, areas not impacted by bottom trawling or invasive species.
Ecological function	Area containing species or habitats that have a comparatively higher contribution to supporting how ecosystems function.	Some species, habitats or physical processes play particularly important roles in supporting how ecosystems function – their protection provides coincidental protection for a range of other species, and ecosystem health	Soft sediment habitats containing high densities of bioturbators, areas of high functional trait diversity.
Ecosystem services	Area containing diversity of ecosystem services and/or areas of particular importance for ecosystem services.	Provides for ability to protect species and habitats that offer particularly important services to humans. Provides ability to better contribute to CBD Aichi Target 11.	Areas containing dense populations of filter-feeding invertebrates. Areas important for seafood provisioning. Areas that support or regulate ecosystem services (e.g. areas of nutrient regeneration, biogenic habitat provision, carbon sequestration, sediment retention, gas balance, bioremediation of contaminants, storm protection) and deliver provisioning or cultural ecosystem services.

5 Principles of network design

The network design principles that the authors consider should be applied to New Zealand's future MPA planning processes are representativity, replication, adequacy, viability and connectivity.

This section of the report addresses each principle and sets out a definition, rationale, supporting information and a summary of how the principle is relevant in the New Zealand context. Recommendations for implementing each principle as part of a conservation planning process are also stated here.

5.1 Representativity

Representativity is the inclusion of biodiversity within a MPA according to an agreed habitat or community classification system. To be representative, the habitat must be of sufficient extent and quality to maintain biological diversity at habitat and ecosystem levels in a healthy, functioning state.

Rationale

Representativity ensures that all elements of biodiversity are included in a protected area network. It is a fundamental aspect of protected area design in all ecological domains.

Virtually all modern MPA processes refer to representation. It is a core principle of the Convention on Biological Diversity (CBD) Aichi Target 11 (Secretariat of the Convention on Biological Diversity, 2011) and is included in domestic policy like the New Zealand Biodiversity Action Plan (Department of Conservation, 2016) as well as international guiding documents (see Appendix 1).

Representativity ensures that all habitats are included in an MPA network, not just 'hotspots' or areas over which there is least conflict. It recognises, for example, that areas with lower species richness are as important to include in a network as those with greater richness. Ensuring representation of all habitat types in an MPA network also maximises the biodiversity gains and minimises the total area that needs to be protected to achieve the same biodiversity protection.

Choosing representative areas

Figure 3 illustrates seven different MPA options (A–G). At first glance, and driven by the desire to encompass the greatest degree of biodiversity, it is intuitive to select the most diverse sites first, those labelled A and B. This illustrates a common ad hoc approach of selecting biodiversity hotspots of at the expense of other habitats. This is often not the most efficient approach, and here wold require three MPAs – including site C – to represent the full range of biodiversity.

If a systematic approach was taken, the same biodiversity representation could be achieved by choosing only sites C and E. This approach is often referred to as complementarity because the two MPAs complement each other and achieve the goal. Representation therefore has important consequences for planning efficient MPAs.

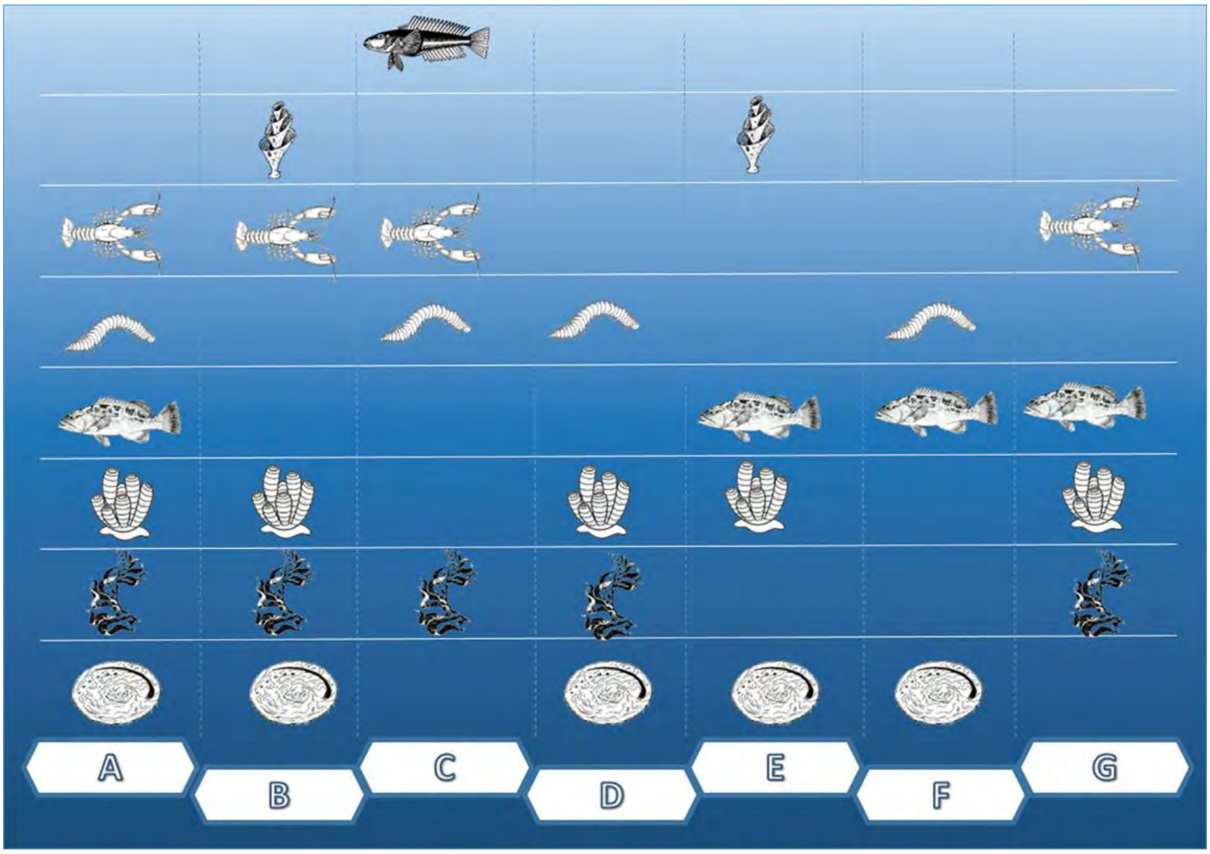

Figure 3. Representativity of species and habitats in MPAs. A-G show different potential MPA sites, with the symbols representing different species or habitat types. (Redrawn and adapted from Marxan 'How to choose marine reserves' video by J McGowan and HP Possingham https://www.youtube.com/watch?v=1IDeKJJO7s8).

Information for site selection

Ideally, representation would be based on actual biodiversity information (like the distribution of species and their habitat requirements), the relative health of habitats and species, and the relative intactness of habitats and naturalness. This information is not always available so surrogates, which try to approximate biodiversity from alternative sources of information, are often used when planning MPAs.

One common surrogate for biodiversity is a classification system that defines different types of habitat within an area. Achieving representation across the range of habitats is then assumed to adequately represent actual biodiversity. (See also adequate representation in section 5.3). This approach can complement targeted protection for known important or rare habitats and features, including those defined using KEA criteria.

As well as increasing the area of protection offered to biodiversity, including all habitats increases the likelihood of preserving ecosystem processes that operate across habitats. While the focus of marine protection is often benthic habitats, the CBD recognises the importance of ensuring representation of pelagic habitats (Conference of the Parties to the Convention on Biological Diversity, 2008).

Representativity in New Zealand

Representativity has been a core principle of New Zealand's approach to marine protection for many years. Before the MPA policy (Department of Conservation and Ministry of Fisheries, 2005) was implemented, protecting typical areas across New Zealand's geographical extent was an important criterion for marine reserve status under the Marine Reserves Act 1971. The 1998 ANZECC guidelines for establishing a representative system of MPAs (ANZECC-TFMPA, 1998) provided context for why representation is important.

The MPA policy and accompanying implementation guidelines (Ministry of Fisheries and Department of Conservation, 2008) contain information about how representativity can be achieved. The guidelines have a focus on representation within a network of MPAs for coastal and marine habitats using a defined classification scheme. The fundamental assumption of this approach is that protecting habitats, as defined by the habitat classification scheme (see section 4.1), will adequately represent the biodiversity associated with the area.

Applying the current coastal and marine habitat classification in some MPA planning processes (e.g. West Coast South Island, Subantarctic Islands, Southeast) identified several issues, including (Rowden et al. 2018):

- The effectiveness of habitat classification being a surrogate for biodiversity has been questioned in some regions (Freeman et al., 2011).
- There is no consideration of pelagic habitats, in contrast to the guidance of the CBD (Conference of the Parties to the Convention on Biological Diversity, 2008).
- Mapping of habitats at a national level may not adequately represent the spatial extent and distribution of habitats at local scales.

A recent study demonstrated how a systematic approach to MPA planning in New Zealand could have achieved a representative network of MPAs more efficiently, in terms of representing defined biodiversity features (Geange et al., 2017). Leathwick et al. (2008) also showed that such an approach could provide for representation of biodiversity while minimising costs to existing users.

Case study 2: Assessing representativity in New Zealand's MPAs

A 2011 inventory and gaps analysis of New Zealand's MPAs mapped habitats in coastal and marine areas that met the MPA protection standard, and identified habitats that were not represented in any MPAs. The analysis used surrogates derived from environmental drivers such as depth, substratum, exposure and habitat forming organisms (Ministry of Fisheries and Department of Conservation, 2008) (Department of Conservation and Ministry of Fisheries, 2011).

The gaps analysis did not assess outstanding, rare, distinctive, internationally or nationally important habitats or ecosystems, or finer scale species associations and ecosystem processes. Also, because the classification scheme was mapped at a national scale, a lot of finer-scale regional and local data (that may have been more accurate) could not be incorporated.

It did, however, provide a mechanism for targeting efforts to address the gaps in representation in the New Zealand MPA network.

Case study 3: Implementing MPAs to achieve representativity

A stakeholder forum to develop MPA proposals for the subantarctic islands biogeographic region was convened in 2008. The existing coastal classification system (Ministry of Fisheries and Department of Conservation, 2008) was applied to the territorial seas and the habitats and ecosystems in each subantarctic island group (Subantarctic Marine Protection Planning Forum, 2009). This enabled adequately represented and underrepresented habitats and ecosystems to be identified.

The forum noted that there was no information about the full extent of each habitat within an island system and that it was therefore highly likely that some habitats had not yet been recorded. It also acknowledged the factors that make the subantarctic region distinct from mainland New Zealand, which include species diversity and endemism, importance of the sea around the islands to terrestrial life, marine mammals and nesting seabirds, and the region's world heritage status.

Rather than identifying underrepresented habitats for marine protection across all island groups, the forum agreed to consider each island group on its own and create MPAs that were representative of the ecosystems and habitats of each island (Subantarctic Marine Protection Planning Forum, 2009).

Recommendations

To achieve representation of New Zealand's biodiversity in MPAs, broad-scale habitat types and key ecological areas should be included in network design.

A robust habitat classification system that is a better surrogate for biodiversity should be developed. A well-designed classification could be used for broad-scale as well as finer-scale habitat mapping.

A process for identifying KEAs should be developed and the results translated into maps.

Local and regional-scale data sets with robust biodiversity information should be incorporated into the MPA planning process. This would ensure that decisions were based on the best information available. Ongoing effort to collect and collate these data should be encouraged.

Initiatives to help identify the proportion of habitats required to achieve adequate representation should be promoted.

Representativity should not be considered in isolation but alongside the other principles, particularly viability and adequacy.

Each broad-scale habitat and KEA should be represented in the MPA network at a level that makes the network viable, based on the principles of replication (5.2), adequacy (5.3) and viability (5.4).

5.2 Replication

Replication of ecological features means that more than one site within an MPA network should contain examples of a feature in a given biogeographic area. The term 'features' in this context refers to the species, habitats and ecological processes in the broad-scale habitat and KEA classifications that naturally occur in a particular biogeographic area.

Rationale

Replicating representative habitats and ecologically significant features within a network of MPAs promotes ecological resilience and acts as an 'insurance policy' for biodiversity. Ecological resilience is the ability of a population or community to return to a natural state after a disturbance. Multiple replicates of each feature provide a safeguard against local environmental disaster and reduce the risk of losing biodiversity due to local natural or anthropogenic disturbances. If one example of a feature is destroyed by natural or human-derived events, healthy habitat in other places remains, which can resupply the impacted area once conditions improve (see Figure 4).

Replication also provides areas that can act as 'stepping stones' for the dispersal of marine species, potentially increasing connectivity between sites.

The distance between replicate features could be in the order of metres, kilometres or tens of kilometres, and is dependent on the species present, their movement and mode of dispersal. Good connectivity is important for replication and recovery dynamics. If replicate MPAs are too far away from the impacted area, the benefits of a replicate are diminished (Cowen et al., 2007). Re-colonisation may also occur via biodiversity in the areas between MPAs, as long as the features of the impacted MPA are not unique.

Replication of features in MPAs also allows a more robust assessment of how well MPAs are fulfilling their protection objectives – it is difficult (if not impossible) to interpret changes detected within just one MPA.

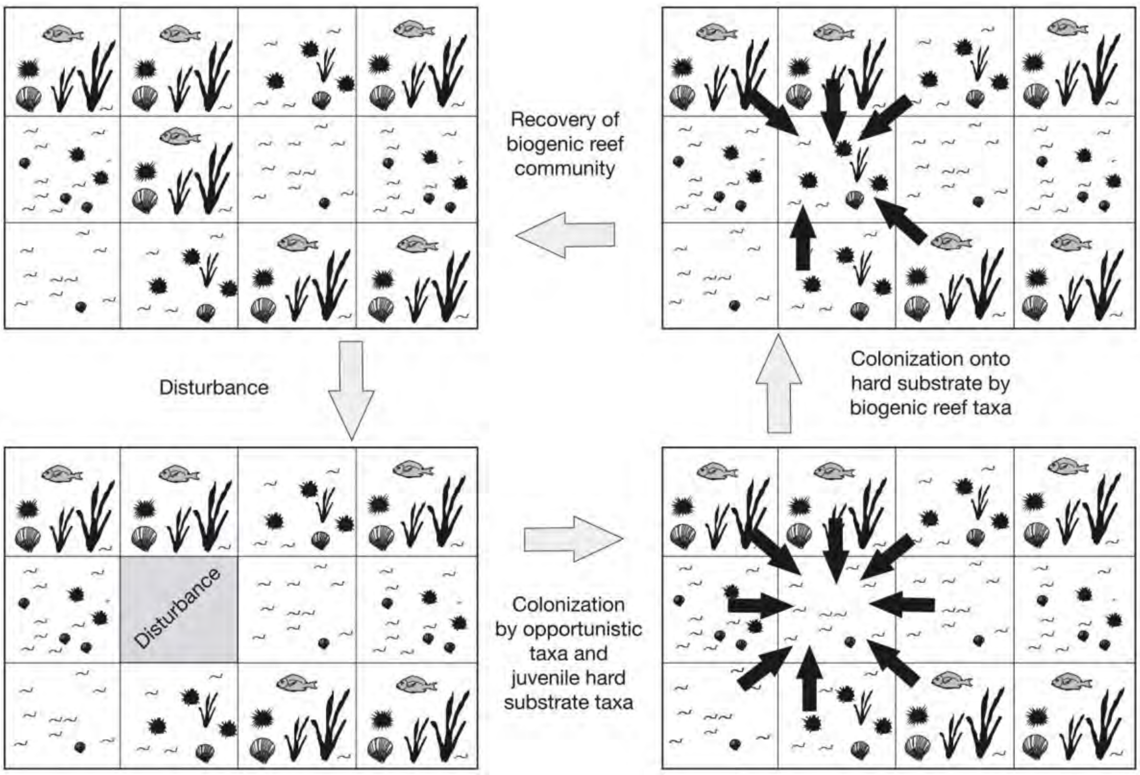

Figure 4. Illustration of the effect of replication on disturbance and recovery of marine ecosystems. The schematic shows patches of biogenic habitat undergoing disturbance and recovery (Lundquist et al., 2010). If a patch is disturbed, its recovery is determined by the presence and proximity of habitats that can recolonise the area.

Level of replication

The level of replication should account for uncertainty, natural variation and the possibility of catastrophic events. Species or habitats that exhibit less natural variation or are precisely defined, may require less replication than features that are inherently highly variable or are only very generally defined (Conference of the Parties to the Convention on Biological Diversity, 2008). A relatively stable habitat like a rhodolith bed, for example, may require fewer replicates in an MPA network than a more mobile habitat like a shellfish bed.

Internationally, most MPA processes include replication as a key principle. Processes such as the California Marine Life Protection Act, Great Barrier Reef Marine Park and the UK's Marine Conservation Zones suggest including 2–5 replicates depending on the feature and its sensitivity to disturbance. Highly sensitive features have higher replication, but broad-scale habitats have at least two replicates.

When determining levels of replication, it is essential to consider the size of the MPA, the size of features and the scale of potential impacts. If an MPA is large enough, it may have viable and adequate replication to sustain itself.

Assessing the level of replication should take the following into account:

- Viability of the feature – is it self-supporting?
- Potential impacts of natural and anthropogenic disturbances, and their scale.
- Protection status of the feature – sufficient protection is in place to meet the objectives for that feature.

For example, a coastal MPA may have two similar patches of habitat. If the main risk to these habitats is sediment run-off from land and if they are both affected by the same catchment, both patches should be treated as one example of that habitat. However, if the two patches are in different catchments they could be considered viable replicates (if there are no other impacts operating at the same scale).

Replication in New Zealand

While MPA implementation in New Zealand has focused on representation and protection of high value areas, the principle of replication has also featured in the overall strategy. The current MPA policy states that the number of replicate MPAs included in a network will usually be two, but that where a habitat or ecosystem is particularly vulnerable to irreversible change, more replicates may be established as a national priority.

The policy also requires that when several replicates of a habitat or ecosystem are to be protected within a planning area, only the first replicate must be protected by a marine reserve (Type I MPA). Any additional replicates can be protected by any type of MPA (Type I or II). Replicates are only viable, however, if the level of protection allows each feature to meet the conservation objective. The condition, size and degree of modification would also need to be considered when assessing how well a particular MPA replicates a habitat or ecosystem.

Although the 2011 MPA habitat gaps analysis (Department of Conservation and Ministry of Fisheries, 2011) analysed the level of habitat representation in New Zealand's MPA network , it did not explicitly address replication. Recent MPA planning processes have considered levels of replication, including those for MPAs on the South Island's West Coast (see case study 4).

Replication as a research tool

The existence of multiple MPAs with similar features has been a powerful research tool in some regions of New Zealand. In the northeast, studies of species' responses to protection were carried out at Cape Rodney-Okakari Point, Tāwharanui and Te Whanganui-a-Hei Marine Reserves. The resulting conclusions were strengthened by replicating the MPAs and their component habitats.

In another example, only when studies of trends in lobster abundance were undertaken in more than one MPA (such as Kelly et al., 2000) could they be conclusively attributed to the area's protection status (Willis, 2013). The study of Willis et al. (2003) used the three marine reserves mentioned above to demonstrate the effect of protection on size and abundance of snapper. Shears et al. (2008) showed that studies of multiple MPAs provide a mechanism for understanding and documenting fishing-related changes in habitats.

Case study 4: Implementing MPAs on the South Island's West Coast

A stakeholder forum to develop MPA proposals for the West Coast South Island biogeographic region was formally convened in 2005, and led to the establishment of five highly protected marine reserves and three associated type 2 MPAs in 2013. Guided by New Zealand's MPA policy, the forum recognised 17 marine habitat types in the region. With a primary aim of protecting an example of each habitat type in a marine reserve, the forum recommended a '…package of sites [including a range of options that together with some existing estuarine MPAs covered] fifteen of the seventeen identified habitat types.' (WCMPF, 2010)

The forum considered whether their recommendations for MPAs would also protect replicates of each type. It was '…unable to identify and recommend protection of a suitable replicate for 2 of the remaining 15 habitat types – intertidal cobble and subtidal mud. These two types are relatively uncommon in the West Coast region, and replicates would have had significant adverse impacts on existing users.' (WCMPF 2010)

In the end, the established MPAs included 15 of the 17 habitat types. Eleven of those were replicated in more than one MPA, but two replicates (intertidal gravel and deep subtidal sand) covered only a small proportion (<0.5%) of the region's full complement of those habitat types and so were 'unlikely to satisfy the representativeness and viability criteria of the MPA policy' (Department of Conservation, 2012).

The forum's decision to include replicated examples of MPAs along the full 600km of coastline allowed the latitudinal and sub-regional variability of sites to be better provided for in the MPA network. However, replication was not fully achieved and did not always integrate other MPA design principles such as adequacy (i.e. habitat size) with all of the replicates.

Recommendations

Where possible, each feature should have at least two replicates protected by the highest level of protection (e.g. a marine reserve) in each biogeographic area. The replication criteria could potentially be met within a single large MPA, but this would need to take viability and the risk of natural and anthropogenic disturbances into account.

Where the main threat to a feature can be mitigated by a lower level of protection, replicates could also have a lesser level of protection. Where features are sensitive to disturbance, or are considered KEAs, a greater level of replication should be considered.

Each broad-scale habitat and key ecological area should have at least two replicates in a highly protected area (e.g. marine reserve) in each biogeographic region, except when the MPA is large or the key threats to biodiversity can be effectively mitigated using a lower level of protection.

Where features are considered sensitive to disturbance or have high vulnerability, more replicates should be included in the biogeographic region. These should have sufficient protection to meet the maintenance and recovery requirements of the feature (see viability Section 5.4).

5.3 Adequacy

Adequacy is the concept of ensuring that a network of protected areas, and the proportion of features protected (broad-scale habitats and KEAs), are of sufficient size, spatial distribution and management regime to ensure the ecological viability and integrity of the ecosystems for which they were selected. Adequacy is generally measured as a proportion (percent) of the feature that is protected.

Rationale

The CBD's scientific guidance for selecting areas to establish a representative network of MPAs (Conference of the Parties to the Convention on Biological Diversity, 2008) notes that 'all sites within a network should have size and protection sufficient to ensure the ecological viability and integrity of the feature(s) for which they were selected'. The guidance states that adequacy and viability will depend on the size, shape, buffers, persistence of features, threats, surrounding environment (context), physical constraints, the scale of features/processes and spillover/compactness.

Species-area relationship

The ecological concepts around species-area relationships are well understood and thought to be particularly relevant to MPA planning (Neigel, 2003). The number of species (species richness) tends to increase with increases in area. The relationship between area and species richness is also broadly consistent across habitat types and geographical area. This observation can be modelled or measured using species accumulation curves (Figure 5.). The slope of the curve can be quite different across habitats and between types of organism.

Therefore, for different habitat types or species, a greater or lesser area is required to represent biodiversity at the same level. This becomes an important consideration when investigating cost/benefits and trade-offs, as the steepness of the curve determines how quickly the benefits are realised with minimal area protected.

International protection targets

Internationally, there is little consensus on what percentage of spatial protection should be applied as a target to adequately represent biodiversity (Agardy et al., 2003). Many organisations and researchers have defined their own targets, which range from 10 to 50% of habitats. Some examples follow: Bohnsack et al. (2000) proposed a target of a minimum of 20–30% to conserve coral reef systems; for the Californian Channel Islands, a target of 30–50% was established (Airame et al., 2003); Roberts and Hawkins (2000) note that protection from fishing of 20–50% would greatly reduce the risks of exploitation and fishery collapse and that 20–40% is likely to substantially increase long-term yields of over-exploited species; and the World Parks Congress proposed preserving 30% of each habitat type (World Parks Congress, 2014).

The CBD's Aichi target on protected areas (Target 11) of 10% of coastal and marine areas to be conserved[1] was proposed to ensure the survival of 50–70% of the species within an area[2]. Other researchers have proposed targets of 20 -50% (depending on the type of habitat) to protect 70–80% of the species within the area.

In the UK, the Joint Nature Conservation Committee and Natural England suggested that habitat-specific conservation targets were required to meet the MPA network objective of adequacy (Rondinini, 2010). Habitat-specific species-area curves were developed to inform target setting, protecting 11% and 33% of Habitats of Conservation Importance.[3] Between 20% and 32% of EUNIS Level 3 habitat types4 were necessary to represent 75% of the species associated with those habitats.

Habitats and species can be disproportionately important in terms of their value to the provisioning of ecosystem functioning. For example, although sediments on marine continental shelves account for 7% of all marine sediments, their associated infaunal communities are responsible for 52% of the global mineralisation of organic matter by marine sediments (Thrush et al., 2012). To ensure adequate and viable MPAs and MPA networks, therefore, levels of protection may need to be species and/or habitat specific (Roberts and Hawkins, 2000).

Adequacy in New Zealand

Neither the current New Zealand MPA policy (Department of Conservation and Ministry of Fisheries, 2005) nor the New Zealand Biodiversity Action Plan (Department of Conservation, 2016) specify a percentage target for protected areas but refer more generally to

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[1] The Aichi Target 11 is broader than marine protected areas. It states: 'By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscape and seascapes'.

[2] Although some nations have expressed a view that the CBD 10% targets have no compelling ecological rationale, and have identifed higher targets domestically, e.g. South Africa (Government of South Africa 2008. National protected area expansion strategy for South Africa 2008: Priorities for expanding the protected area network for ecological sustainability and climate change adaptation).

[3] Habitats of Conservation Importance were identified from the Initial OSPAR List of Threatened and/or Declining Species and Habitats and the UK List of Priority Species and Habitats, Rondinini, C. 2010. Meeting the MPA network design principles of representation and adequacy: developing species-area curves for habitats..

[4] The EUNIS habitat classification provides a hierarchical typology for habitats of Europe and its adjoining seas. Davies, C.E., Moss, D., Hill, M.O., 2004. EUNIS Habitat Classification Revised 2004.

representation[5]. A focus on representation as a complement to percent of spatial protection is crucial as there are gaps in representation of habitats and species within existing protected areas, and some fail to offer adequate protection to many species and ecosystems. However, Thomas and Shears (2013) suggested that not specifying a percentage target in New Zealand's domestic MPA policy was responsible, at least in part, for the small areas of no-take marine reserves established on the South Island's West Coast.

Leathwick et al. (2008) provided an analysis of the extent of protection of New Zealand's exclusive economic zone (EEZ) that would be required to achieve different levels of protection. They found, for example, that protecting 10% of the EEZ under a particular scenario would protect 20% or more of the geographic ranges of half of the 96 fish species included in the analysis.

There are limited data available in New Zealand to assess species–habitat relationships in terms of defining habitat-specific protection targets. New Zealand has had experience with determining numerical targets for protection in Antarctica, based on ecological importance and level of threat (see case study 5). This approach could also be applied to New Zealand marine habitats. Comparable coastal and marine habitats overseas, however, may provide guidance for species–area relationships and could be used to inform habitat-specific targets.

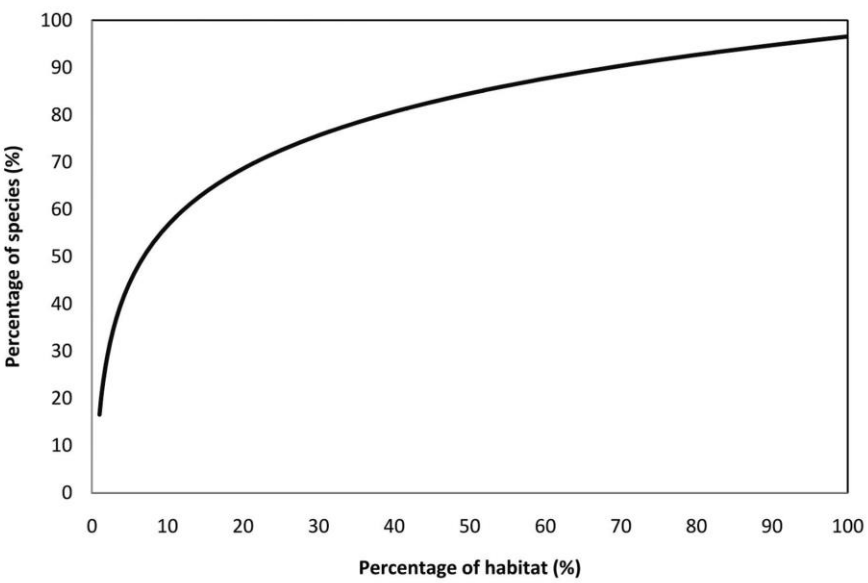

Figure 5. Species-area relationship for intertidal sediments in the United Kingdom (Rondinini, 2010). In this example, the proportion of species protected increases with the proportion of habitat protected, following a power function.

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[5] The current MPA policy has an objective to: Protect marine biodiversity by establishing a network of MPAs that is comprehensive and representative of New Zealand's marine habitats and ecosystems (Department of Conservation and Ministry of Fisheries 2005. Marine protected areas policy and implementation plan. Wellington, New Zealand: Department of Conservation, Ministry of Fisheries.). The NZ Biodiversity Action Plan has a national target of "A growing network of marine protected areas, representing more of New Zealand's marine ecosystems" (Department of Conservation 2016. New Zealand Biodiversity Action Plan 2016–2020, Wellington, New Zealand).

Case study 5: Targets for protection in the Ross Sea region MPA

As a key component of the systematic conservation planning method applied in the development of the proposal for the Ross Sea region MPA, quantitative protection targets were defined for each priority area, reflecting their relative ecological importance and the level of threat from fishing to each specific objective (Sharp and Watters, 2011) (see also Case Study 1 in this paper).

The level of protection required was highly dependent on the particular type and mechanism of plausible threat. Where threats are potentially severe, unpredictable and/or irreversible, near 100% protection of the priority area or feature was considered to be required to guarantee accordance with the terms of Article II(3) of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). For other threats, protecting only a minor portion of the priority area or feature was considered to be sufficient (Delegations of New Zealand and the USA, 2013). The first New Zealand scenario for the MPA, for example, included 100% protection for all identified coastal or spatially constrained areas of particular ecosystem importance and all identified rare or vulnerable benthic habitats (Sharp and Watters, 2011).

To represent benthic and pelagic habitats, a target of 30% was set for the Ross Sea region. This was consistent with emerging international best practice for marine ecoregional planning at that time (Beck, 2003, The Nature Conservancy and World Wildlife Fund, 2006) and was supported by information on species–area relationships (Beck, 2003, Tear et al., 2005).

Achieving protection targets was just one component of the planning for this MPA. Other considerations included the effects of the MPA on fishing catch and effort, and aspects of protected area design that provided for effective management (such as boundaries that follow lines of latitude and longitude). The proposal was also refined after consultation with other members of CCAMLR.

Recommendations

To meet the adequacy principle, a network of MPAs needs to protect a defined proportion of the habitats and species being considered for protection. Some species exert a substantial influence on the ecology of the area through biogenic or trophic interactions and should receive special attention. Ideally, each ecological feature considered in MPA planning should receive a protection target expressed as a percentage of its overall size or extent. Such species-specific or habitat protection targets would improve the adequacy of protection. However, data to work out such targets is not currently available for most features.

Without information to develop species accumulation curves and defined targets, it is recommended that at least 10% is used as an interim measure to assess adequacy. This provides, at a minimum, consistency with the CBD target[6]. It is also recommended that further work be undertaken to define ecologically relevant targets for different features via

[6] **Target 11** By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

expert knowledge workshops, data gathering and compilation of existing data. (Note: this work should not be any delay MPA implementation). New knowledge developed around target setting could be taken into account by implementing an adaptive management approach to MPAs.

At least 10% of each biogeographic region (across each broad-scale habitat), and at least 10% of each KEA should be protected as a minimum. This is to adequately represent the biodiversity associated with that habitat or KEA.

Targets for each biodiversity feature should be developed and used to revise the 10% minimum target.

5.4 Viability

For an MPA to be viable it must be able to maintain the integrity of its features (i.e. population of the species or condition and extent of the habitat) and be self-sustaining throughout natural and anthropogenic cycles of variation. Viability has three main components: size, shape and level of protection.

If an MPA is not viable, it cannot contribute to the representation, adequacy or replication of habitats in a planned network.

Rationale

MPA networks should be self-sustaining and maintain populations and ecosystems through cycles of variation. The MPA sites should be independent (as far as possible) of activities occurring in the area surrounding them. For an MPA network to be viable it must include enough of each habitat to sustain the ecological objectives of the network (related to adequacy), must have appropriate levels of protection (protection standard) and be of an appropriate size and shape to maintain populations (related to connectivity).

Size of individual MPAs

The size of a species home range and how it is managed outside the MPA will determine the level of protection it is afforded in an MPA. That is, the size of the MPA will determine what subset of the species present may benefit from the protection measures.

A modelling study of fish home range and protected areas (Kramer and Chapman, 1999) concluded that to reduce fishing mortality to 2% of that occurring outside a reserve, a reserve should be at least 12.5 times larger than the home range of the species. Another study examined the movement distances of mature adults of 72 species of invertebrate, fish and seaweed taxa and found that approximately 80% of these species moved less than 10 km after reaching maturity (Roberts et al., 2010). This led the authors to suggest 10 km as a minimum dimension for MPAs to offer ‘good’ protection to these species.

Figure 6 represents this finding graphically for a species with a large home range (red arrow). Assuming fishing occurs close to the boundary, the potential benefit from scenario A is greatly reduced due to the daily movements of the species that make them available to fishing for some of their activity. In a larger reserve (scenario B), exposure to fishing may still occur but in the core area the species has low vulnerability to being caught. Beyond this area, a gradient in abundance occurs across the reserve boundary (edge effect).

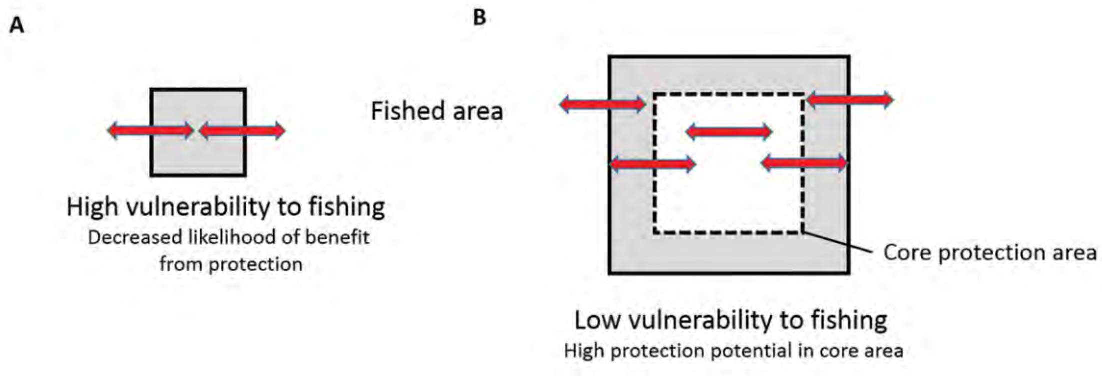

Figure 6. Adult exposure to fishing from MPAs of different sizes (as indicated by the box with the solid border). In scenario A, the small MPA size compared to the fish home range results in high vulnerability to fishing, even within the MPA. Scenario B has a core protection area (white square) where vulnerability to fishing is very low, with a gradient of increasing fishing vulnerability towards and across the MPA boundary.

Placement of MPAs

Protection of whole habitats is another consideration relating the size of an MPA to its vulnerability to fishing. In some cases, there are natural barriers to species' movements, like a reef system surrounded by sand. Some reef-associated species do not move across bare sand and are therefore restricted to their home reef. Here, a smaller reserve may provide better protection than a reserve where the reef is intersected by the reserve boundary. In Figure 7, for a species where sand is a barrier, scenario A has a larger core protection area than scenario B even though the reserve is the same size.

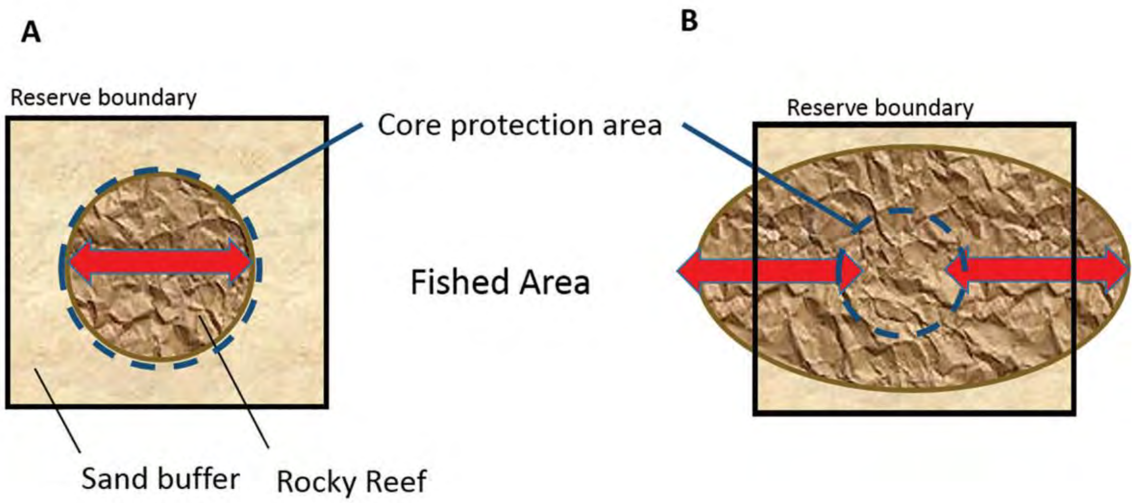

Figure 7. The effect of different habitat structures on MPA effectiveness. Scenario A has a natural buffer of sand around a rocky reef within an MPA. Scenario B has a reef that crosses the MPA boundary.

International research

A recent global analysis showed that size (greater than 100km^{2}in particular) was a key contributing factor to MPA effectiveness, along with the MPA being no-take, well-enforced, old and isolated by deep water or sand (Edgar et al., 2014).

Internationally, a number of guidelines relating to MPA size have been used in MPA processes, based largely on species' ranges. These include:

- California: MPAs should have an alongshore span of 5–10 km (California MLPA Master Plan Advisory Team, 2006).
- England: MPAs should have 5 km minimum diameter dimension, with the average size being 10–20 km in diameter (Natural England and the Joint Nature Conservation Commitee, 2010).
- Australian Great Barrier Reef Marine Park: No-take areas should have a minimum size of 20 km along their smallest dimensions, except for coastal bioregions where 10 km is the minimum dimension (Day et al. 2016).
- Baltic Sea: MPA sizes should be 30 km^2 minimum (Baltic Marine Environment Protection Commission (HELCOM, 2013)).
- Canada: 10–20 km minimum dimension (Jessen et al., 2011).

Protection standard

A viable MPA must have enough protection to be self-sustaining. The IUCN identifies six levels of protection (IUCN, 2012), with the highest level corresponding to no-take marine reserves. Depending on the objective of the MPA and its features, a lower level of protection may be appropriate and contribute to a viable network.

The viability of an MPA in terms of vulnerability to fishing, is mostly relevant to marine reserves, where the emphasis is on completely removing fishing pressure. Multiple-use MPAs may give exploited species some vulnerability to fishing, regardless of the size of the MPA. These areas tend to emphasise habitat protection and large-scale processes, rather than fishing.

Viability at a network level

MPA viability is important at an individual feature level, a whole MPA level and in a network. The size, protection standard and connectivity in a network operate cooperatively and synergistically, enabling benefits that are greater than the sum of individual MPAs.

Aspects of an inshore reef (e.g. pāua habitat) may be adequately protected by a small MPA, but this small size may not contribute significantly to representation, replication or connectivity for soft sediment habitats.

The size of MPAs in a network must allow for the movement of eggs, larvae or other propagules, juveniles or adults. This has implications for connectivity across a network. The optimal size and spacing of MPAs in a network is therefore governed by the movements of the species the network is protecting.

The consequences of movement differ dramatically depending on when movement occurs during a species lifecycle. When adults leave a marine reserve, they are at risk of becoming part of a fishery. When larvae leave a reserve, they can disperse without elevated risk because of their size and limited exposure to the fishery. The size of a reserve size therefore needs to account for the home range of adults and facilitate the successful settlement and recruitment of dispersing larvae and juveniles.

It may be desirable in some cases for MPAs to be large enough to retain larvae from local populations. Size is therefore an important component of the viability criteria, and also adequacy and connectivity. For example, a network of MPAs made up of small MPAs may suffer from poor connectivity compared to one with a mixture of MPA sizes because each MPA is a small place for dispersing larvae to settle.

Viability in New Zealand

Network design principle three in the MPA policy states that 'the MPA network should be viable'. It also states that 'viability will depend on matters including: the nature of the protection; the presence of replicate MPAs protecting particular habitat and ecosystem types; connectivity between MPAs; the nature of actual or potential threats to a particular habitat; and the amenability of those threats to mitigation using MPA management measures'. While size is not considered here, further guidance related to size is provided in the guidelines document and states '...should be of sufficient size to provide for the maintenance of populations of plants and animals'.

A number of New Zealand studies have explored the effect of MPA size and design on the effectiveness of protection (Diaz Guisado et al., 2012, Pande et al., 2008). While there are some data on species' habitat use and movement ranges (including home ranges and seasonal migrations), in many cases these vary spatially – the size of a home range for a species in one New Zealand region may differ from that in another region. Despite the lack of information on habitat use and movement patterns for many species, these have been used to inform protected area design in the past and are a component of the current approach to MPA establishment under the MPA policy.

The influence of management on adequacy has also been evaluated in New Zealand studies. Shears et al. (2006) assessed how effectively the partially-protected Mimiwhangata Marine Park was restoring lobster populations. They concluded that recreational fishing in MPAs limited the benefits of protection to populations of exploited species such as lobsters. Denny and Babcock (2004) similarly showed that snapper had failed to recover within the same marine park and concluded that partial closures were ineffective conservation tools for this species.

Case study 6: Snapper movement, Cape Rodney-Okakari Point Marine Reserve

Parsons et al. (2010) used acoustic telemetry to track the movements of snapper within and outside Cape Rodney-Okakari Point Marine Reserve. They found that resident snapper in the reserve had home ranges of about 900 m (linear distance). Some fish outside the reserve had a different type of home range, with two separate modes and a linear distance of over 2 km.

The authors suggested that some aspect of the marine reserve environment encouraged extreme residency by either modifying the behaviour of individuals or removing selective exploitation. They also noted that as the size of a reserve increases relative to the movement range of an exploited species, a different mix of behaviour types would be contained within that reserve. Knowledge about animal behaviour (including behavioural diversity) may be required to anticipate the full impact of reserves and inform protected area design.

Babcock et al. (2012) found that this particular marine reserve was too small (5 km^2) to fully protect the resident snapper population. Thomas and Shears (2013) suggested that 5 km^2 should be considered a minimum for no-take areas in New Zealand.

Case study 7: Marine reserve boundaries and species movement in Te Tapuwae o Rongokako Marine Reserve

A study tagging several thousand lobsters within and surrounding Te Tapuwae o Rongokako Marine Reserve north of Gisborne, revealed useful information about the home range size and seasonal movement patterns of this species (Freeman et al., 2009).

The study showed that while seasonal inshore-offshore migrations associated with moulting and reproduction took place, these movements were largely confined to reef habitats. Few movements took place across the sandy channels that separated the main reef systems (Figure 8). The within-reef movements were usually around 2 km.

The southern and seaward boundaries of this marine reserve aligned with these natural barriers to movement, resulting in low levels of movement across the boundaries. However, the northern boundary of the reserve bisected a reef system, which was associated with much higher cross-boundary movement by the tagged lobsters and reduced abundance of lobsters on the reef.

Given the significant spatial variation in movement patterns in this species around the New Zealand coast, it may be difficult to extrapolate these results to other regions. Regional information about seasonal movement patterns would help inform the design and placement of protected areas where lobsters are a component of the area's values.

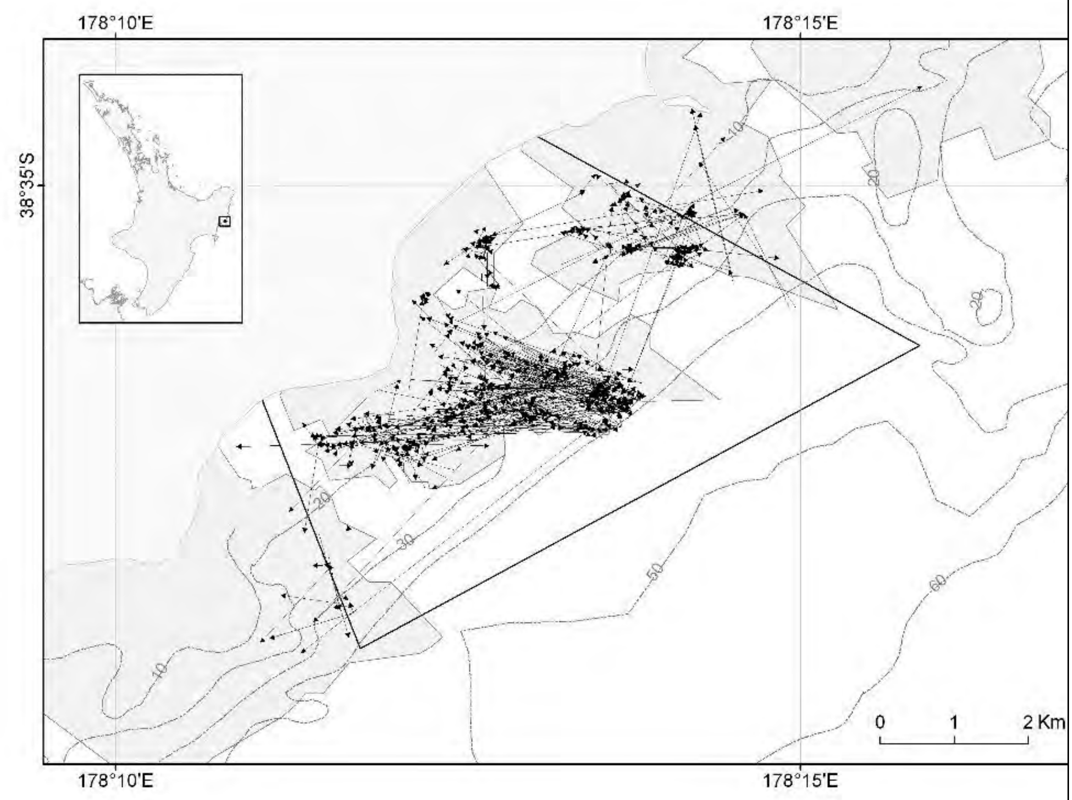

Figure 8. Map showing the movements of tagged lobsters, within and surrounding Te Tapuwae o Rongokako Marine Reserve, in relation to the distribution of reef habitat (shaded areas) and the reserve boundaries.

Home ranges and MPA size

MPAs will generally be most effective if they are larger than the distance that most individual adults, juveniles or larvae move within and across habitats. Where information on species movement ranges and habitat use is available, this should be incorporated into MPA planning.

Unfortunately, there is limited information on the home range of many species in New Zealand waters, as well as the habitats that species associate with in different life history stages. In these instances, we need to rely on general information and evidence from other countries that can be applied in New Zealand.

International research suggests that many invertebrates only move small distances, and relative to wider ranging species, may benefit at the sub-population level from smaller reserves. The effectiveness of a small reserve for other components of the community would also need to be considered. Creating a network of variable sized and connected MPAs that account for the spatial distribution and size of features is most likely to ensure that protection is afforded to the widest range of species, while minimising impacts on existing users.

The optimal design of an MPA also depends on its protection objectives. If the objective is to conserve 'natural' biological communities, then the boundaries should follow barriers to species movement (e.g. muddy sediments for lobster – see case study 7). If the objective is to allow the export of individuals associated with certain habitat, then the MPA could be designed so its boundaries intersect that habitat.

Where information on species movement and habitat association is available for a region where MPAs are being planned, relevant information should be used to inform the MPAs' protection objectives.

Applying the MPA protection standard

To meet the protection standard (the standard for an area to meet to be considered an MPA for planning and reporting purposes) stated in the MPA policy, "a management tool must enable the maintenance or recovery of the site's biological diversity at the habitat and ecosystem level to a healthy functioning state. In particular, the management regime must provide for the maintenance and recovery at the site of:

A) physical features and biogenic structures that support biodiversity

B) ecological systems, natural species composition (including all life-history stages), and trophic linkages

C) potential for the biodiversity to adapt and recover in response to perturbation."

Interpreting the protection standard has been a challenge to date. It is ambiguous in some areas and does not adequately consider any impacts on biodiversity other than those associated with particular fishing methods. Generally, only part A is fully addressed, leaving B mostly un-addressed. It is considered that if (a) and (b) are satisfied, then (c) will have been provided for.

The protection standard cannot literally be met: this would require megafaunal recovery to its pre-settlement state, including cetaceans and pinnipeds. Also the information required to determine if certain fishing methods are compatible with part B also cannot be met in most cases.

The standard is currently applied in a way such that any restriction beyond the minimum to meet part A requires a case-by-case assessment. This determines whether an activity does, or does not, allow the area to meet the protection standard. Due to the almost universal lack of information on finer scale fisheries extraction, the natural species composition and the trophic interactions, this test invariably cannot be met.

Recommendations

The minimum size for an MPA should be set by the ranges of key species ranges and the objectives of the MPA. In some cases, a small reserve may meet specific objectives, but generally larger reserves are more likely to be viable over multiple species and habitats and with changing environmental parameters.

The ambiguity of the current MPA policy protection standard has created issues around its interpretation. We recommend a revision of how it is applied to ensure national consistency.

Minimum sizes should be related to specific objectives for the feature they protect. A 5 km minimum dimension should be considered unless a smaller MPA can be proven to meet the objective of the MPA. Representativity, adequacy and connectivity should also be part of MPA size determination.

Clarify how any protection standard would be applied before starting an MPA planning process.

5.5 Connectivity

In an MPA network, connectivity allows for larval and/or species exchanges and functional links from other sites. Individual sites in a connected network benefit one another and are greater than the sum of the benefits from individual MPAs.

Rationale

Many New Zealand and overseas studies of species connectivity or oceanographic processes provide information to help with MPA planning for an individual MPA, and for incorporating connectivity in an MPA network. Fewer studies have looked at the connectivity between existing MPAs.

Connectivity and recruitment

Maintaining a supply of recruits is important for the resilience of a habitat, whether they come from another MPA or from habitats outside the network. Ensuring that MPAs are connected maximizes the benefits of protection on the levels of recruitment.

In some circumstances, an MPA may have a demographic deficit (deaths + immigration > births + emigration). These areas are termed 'sinks' and rely on the immigration of recruits from 'source' habitats where there is a demographic surplus (births + emigration > deaths + immigration) (Figure 9). Reserves at sink locations have lower resilience and would experience local extinction without the immigration of recruits from other areas.

Protecting an area that is acting as a species sink may have ecological value, but is only viable in the long term if its source habitats are also protected. (Protecting a source could be achieved through existing management using tools other than MPAs.)

A network is, however, designed to maintain and restore areas such as these through adequate larval recruitment, alongside other management tools. Being clear about the objectives of both an individual MPA and the wider network is important for determining how connectivity should be taken into account (Marine Protected Areas Federal Advisory Committee, 2017).

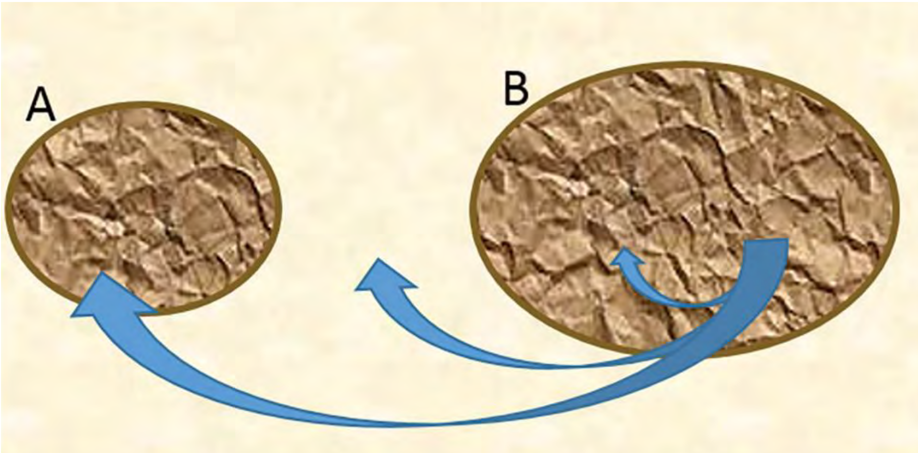

Figure 9. Schematic of the source and sink populations concept. Habitat A is a sink because it relies on external recruitment for a particular species, while B is the source of recruitment.

Connectivity and recovery

The recovery of a disturbed area depends on the availability of a recruitment source, and the length of time it takes is related to the area's connectivity to its regional species pool. As illustrated in Figure 4 recovery usually progresses through multiple stages, with each stage dependant on access to recruitment (e.g. initial recovery by intermediate or opportunistic species followed by recolonisation of the original habitat species).

If habitats that provide the recruitment source to a disturbed area for the intermediate and final stages of recovery do not exist or are too far away, recovery will take a long time and may not happen at all. If the disturbance regime is greater than the rate of recovery, then a permanent shift in community structure and function may occur.

To ensure connectivity, the optimal distances between habitats would ideally be based on information about species dispersal. This information would be biological (e.g. time in the water column, habitat requirements), physical (e.g. ocean currents, physical bottlenecks, isolation such as seamount communities) and about the key source and sink populations. Although connectivity is an important factor in MPA network design, the information to make these kinds of assessments is very limited and results in generalised guidance about connectivity being provided.

Larvae dispersal

Some larvae (particularly fish and crustacean) can swim long distances, both aligned with oceanographic features and going against dominant currents. This knowledge allows for greater self-recruitment than the previous assumption that larvae were passively transported, and has implications for the size and spacing of reserves.

MPAs in a network should be close enough so larvae can disperse from one to the next. Ideally an MPA would be large enough to enable a proportion of the larval recruits to be retained (for self-recruitment within the MPA) and within reach of another reserve (for emigration of recruits to adjacent MPAs).

The challenge for MPA network design is the substantial variability that different species have in their potential for larval transport.

Figure 10 shows the range in the number of days that larvae are in the water column. Note that the actual distance that larvae move depends on multiple factors including currents and their behaviour, but Anderson & Lundquist proposed that algae would disperse from 1 m to 5 km, invertebrates 10 m to 1000 km and fish 1 km to 1000 km. They also noted that important habitat-forming species tended to have lower dispersal potential – a key consideration for MPA design when the objective is to maintain biogenic habitats (e.g. bryozoan beds).

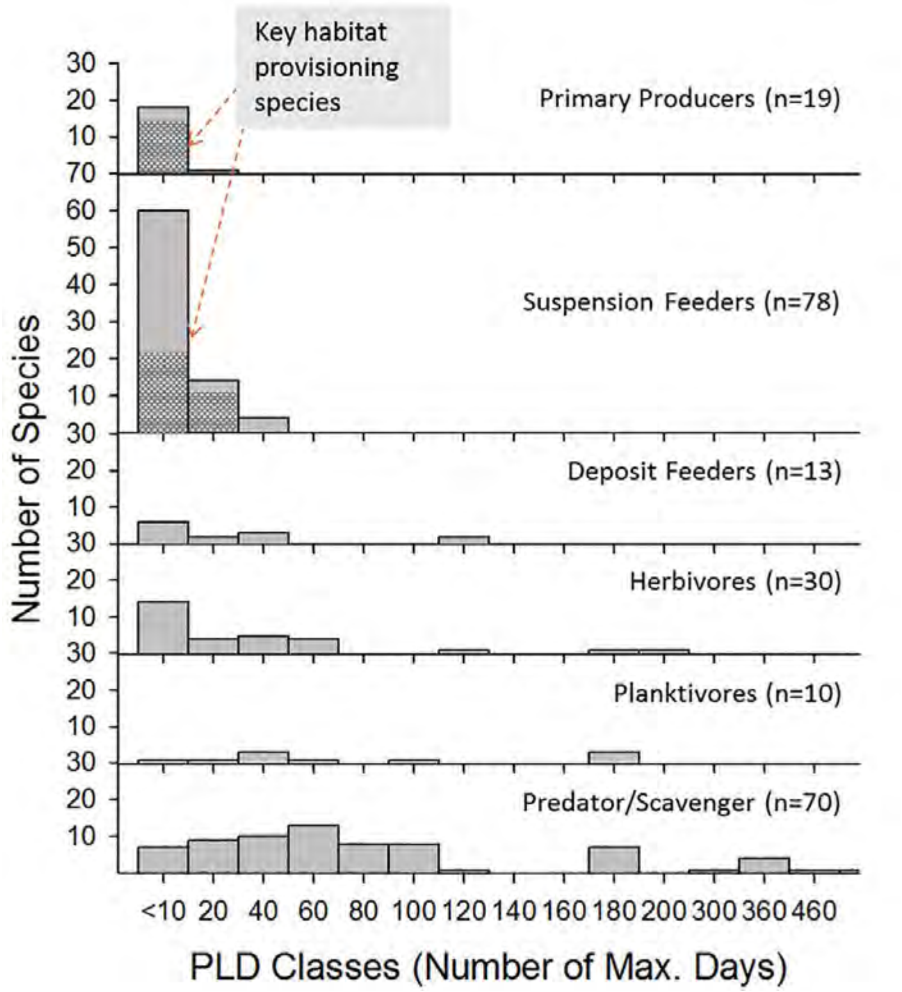

Figure 10. Number of days larvae are in the water column for different functional groups. Key habitat forming species usually have low dispersal potential (Anderson & Lundquist, unpubl.).

If individual MPAs in a network are too small for self-recruitment and too far apart for inter-MPA recruitment, the ability for the network to be self-sustaining and meet network objectives is likely to be compromised. An MPA network will, however, usually receive larvae from non-MPA areas (unless the network protects the only examples of species or habitats), which reduces the need for it to be self-sustaining.

Ideal spacing

What works for one species with a particular dispersal regime may not work for other species that have shorter or longer dispersal distances. No single size and spacing guidance is likely to benefit all species. Recommendations are therefore usually given as a range of distances between MPAs, to allow for as much variability as possible (and benefit as many species as possible).

A number of guidelines for MPA spacing have been used in international processes, including:

- Californian Marine Life Protection Act: 50–100 km (California MLPA Master Plan Advisory Team, 2006)
- UK Marine Conservation Zones: 40–80 km (Natural England and the Joint Nature Conservation Commitee, 2010)
- Australian Great Barrier Reef Marine Park: 70–100 km (Day et al.)
- Canada: 20–200 km (Jessen et al., 2011).

Connectivity in New Zealand

Connectivity has been considered in several New Zealand MPA planning processes to date, at an individual MPA scale and a multiple MPA scale.

Research and monitoring have largely been focussed on the degree to which the larvae and adults of particular species move within or between protected areas, and on the mechanisms of dispersal (both biological and physical means). Such studies have used methods like direct monitoring of species movement in and around MPAs using tags or transmitters (Cole et al., 2000, Parsons and Egli, 2005); indirect studies (inferring movement) using spatial patterns in species size and abundance (Freeman et al., 2009); and model simulations based on species ecology and/or oceanography (see case study 8).

Genetic techniques are becoming useful tools for assessing connectivity in populations of New Zealand coastal and marine species. , including in relation to spatial management (see case study 9, Bors et al. (2012)).

A number of New Zealand studies relating to species connectivity could be used to inform MPA design and placement. The studies cover knowledge of sources and sinks for the larvae of particular species (Chiswell and Booth, 2008), genetic connectivity and barriers (Hannan et al., 2016), information on eddies and currents (Heath, 1985, Chiswell et al., 2015), species movement patterns (Bonfil et al., 2010) and habitat associations (Morrison et al., 2012). To date there has been no effort to collate such information to inform MPA network planning in New Zealand.

Case study 8: Pāua dispersal from Te Angiangi Marine Reserve

The dispersal potential of pāua on the east coast of the North Island were modelled from the existing Te Angiangi Marine Reserve and the non-reserve Porangahau Taiapure (Oldman et al., 2005, Stephens et al., 2006). Pāua larvae reached settlement maturity 4–80 km from the marine reserve depending on local climate and currents. A 'typical' larval transport of 10–30 km from the marine reserve was based on a 9-day planktonic phase before being able to settle.

It was proposed that spacings of 10–30 km between undisturbed adult populations (e.g. in a MPA) would be optimal for maintaining larval supply for species like pāua.

Case study 9: Snapper larvae dispersal from Cape Rodney-Okakari Point Marine Reserve

A novel approach to describing the potential recruitment of snapper to areas outside the Cape Rodney-Okakari Point Marine Reserve was presented by Le Port et al., 2017. The research used genetic and hydrodynamic techniques to model the export of snapper larvae. It estimated that adult snapper in the marine reserve contributed 10.6% of newly settled juvenile snapper to approximately 400 km^2 around the reserve. The study found no decreasing trend in larval contributions up to 40 km from the reserve.

The authors concluded that MPAs can provide recruitment subsidies at magnitudes and spatial scales relevant to fisheries management. Their findings could inform the design of MPA networks to enhance fisheries management.

Recommendations

Information about species' dispersal, both biological (e.g. time in the water column, habitat requirements) and physical (e.g. ocean currents) and any knowledge of key source and sink populations should be incorporated into MPA planning wherever it is available. This information is particularly important if individual species have been identified as a component of the MPA's objectives, or if particular network objectives include species' connectivity between MPAs.

We recommend collating data that will inform how to design New Zealand's MPA network to meet the requirements for connectivity.

Maximum spacing between MPAs should be based on the dispersal and movement of key species.

Data relating to the movement and dispersal patterns of New Zealand species should be collated.

In the absence of information on species dispersal, a range of distances between MPAs should be considered in MPA network design.

6 Recommendations for further work

6.1 Applying MPA network design principles in New Zealand

New Zealand uses a range of protection and management tools in its coastal and marine environment. The way these contribute to a network of protected areas varies from tool to tool, and according to the MPA's management regime. An assessment of the relevance of the design principles to different categories of MPA should be undertaken to fully assess the state of New Zealand's protected area network. If new protection tools are developed in this country to contribute to an MPA network, they should be assessed against the network design principles described here.

The way a design principle is implemented can depend on the type of MPA and its protection objectives. For example, incorporating the principle of connectivity into the design of an MPA will depend on whether the focus is on recovery within the protected area's boundaries and/or on ensuring connectivity with another MPA or managed area (Marine Protected Areas Federal Advisory Committee, 2017 provides a good overview of this issue).

Including different types of MPA

Different types of MPA may be considered to protect New Zealand's biodiversity in the future. Therefore, the proposed design principles may need to be applied differently to each type – their application depends on aspects like the possible management measures (and degree of protection afforded to biodiversity) and the potential spatial scale.

If an MPA has a management regime that allows for harvesting, this MPA may contribute less to a network because of its lower resilience or reduced ability to provide for the ecological viability of populations and species. More intact ecosystems (i.e. those not subjected to extractive use or disturbance) appear to be more resilient to perturbation, according to some evidence in the literature (e.g. Micheli et al., 2012).

Including land-based habitats

The interface between marine and terrestrial environments within an MPA may also be relevant to the application of network design principles. An MPA that provides spatial protection to land-based habitats as well as coastal and marine habitats may contribute more in terms of adequacy and viability. This is because it protects a wider range of habitats that may be important for different life history stages.

The application of some network design principles (representativity in particular) to protected areas aimed at species such as marine mammals and seabirds should therefore be considered further. For example, seabirds and marine mammals need terrestrial habitats to moult and rear young, so ensuring protection of these habitats (as well as the marine habitats that are important for foraging), would enhance the viability of these populations.

6.2 Setting targets and objectives

Developing targets related to MPA network design principles needs to take account of network and regional objectives (e.g. at a biogeographic region or local level). At the broadest scale, network-level objectives should be identified and mandatory minimum targets developed to allow those objectives to be achieved. This may include setting quantitative targets for representativity, replication, adequacy, viability and connectivity at the network scale.

These targets should be used in regional planning processes to achieve the network-level objectives and could be augmented to achieve any additional regional-level objectives. For example, a network-level objective might be to ensure that a sensitive feature has 30% of its extent protected to meet the viability principle; while a regional-level objective might be to ensure greater protection because that feature is also an important nursery habitat for a commercial fish species.

In practice, this may mean working through steps 1–4 in figure 1 to develop national-level objectives and targets, and repeating it for each region. Importantly, network-level and regional-level objectives may conflict, so it should be determined which have precedence before planning begins. Objectives and targets, at both the network and regional level, should be developed as part of future MPA planning processes.

Allowing for the effects of climate change

Climate change has implications for achieving a representative network of MPAs in New Zealand's marine environment. Further work is needed to determine how the network design principles described in this paper may be influenced by climate change. Effects such as sea level rise, shifts in species' distributional ranges and in oceanographic regime will influence how principles such as representativeness, viability and connectivity can be best implemented as part of a planning process. This may include, for example, including climate change refugia in an MPA network (e.g. Green et al., 2014).

MPAs offer valuable opportunities to study environmental change in the absence of other pressures, and to generate ecological resilience. A number of countries have explored how MPAs can be part of climate change adaptation programmes. The Government of South Africa (2008) and the IUCN has provided some guidance on this issue (Simard et al., 2016, Gross et al., 2016).

6.3 Review usefulness of broad-scale habitat classification system

The current nearshore habitat classification (Ministry of Fisheries and Department of Conservation, 2008) has been applied to several New Zealand MPA planning processes and used as a tool for assessing gaps in the MPA network (Department of Conservation and Ministry of Fisheries, 2011). These have, however, identified a number of issues that could constrain its use to create a fully representative network of MPAs. (See section 4.1).

A review of the issues has recently been completed (Rowden et al. 2018) as well as an overview of other classification systems that have been used in protected area or other spatial management processes. The review should form a basis for considering if a more robust system for mapping spatial patterns in biodiversity should be developed.

6.4 Identify key ecological areas

Work is being commissioned by the Department of Conservation to collate and map available data to help identify KEA based on a suite of criteria. Once complete, this analysis should enable ecologically important areas to be identified, which could then be considered in future MPA planning. It may also identify where such areas are already well-represented in New Zealand's MPA network.

The authors recommend that the criteria for identifying KEA are used for mapping areas of ecological significance at a national scale. Regional data, including local ecological knowledge, is also important to incorporate into MPA network planning processes. KEA should be included in assessments of representation, replication, adequacy and connectivity in MPA network design, along with identified broad-scale habitats.

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8 Appendix 1: Summary of MPA design principles

'Best practice guidelines for MPA network design and evaluation', a report prepared for the Ministry for the Environment by Lundquist et al. (2015), states that MPA network objectives should broadly consider ecological, economic and socio-cultural contexts. It proposed the following essential aspects for MPA network design:

- Ensure representation and replication of habitats and biodiversity.
- Design, size, shape and spacing of MPAs ensures network resilience.
- Ensure ecological linkages and connectivity (larval, juvenile and adult dispersal).
- Minimise threats to biodiversity, including threatened, rare, unique and vulnerable habitats and species.
- Determine proportion of area required based on MPA objectives.
- Consider existing users in the design of MPA networks.

The **IUCN** (IUCN-WCPA, 2008) identifies five key principles for an MPA network:

1. Include the full range of biodiversity present in the biogeographic region
    a. representation
    b. replication
    c. representation of resilient and resistant characteristics.

2. Ensure ecologically significant areas are incorporated
    a. protection of unique or vulnerable habitats
    b. protection of foraging or breeding grounds
    c. protection of source populations.

3. Maintain long-term protection
    a. spillover of larvae, juveniles and adults from long-term protection
    b. adaptive strategies to long term protection.

4. Ensure ecological linkages
    a. connectivity
    b. adult movement patterns
    c. larval dispersal.

5. Ensure maximum contribution of individual MPAs to the network
    a. size
    b. spacing
    c. shape.

The **CBD Scientific Guidance** (Conference of the Parties to the Convention on Biological Diversity, 2008) for choosing areas to establish a representative network of MPAs lists the following required network properties and components:

- ecologically and biologically significant areas
- representativity

- connectivity
- replicated ecological features
- adequate and viable sites.

In the **New Zealand MPA policy** (Department of Conservation and Ministry of Fisheries, 2005), design principles and planning principles for a representative network of marine protected areas are both addressed

Design principles:

1. The MPA network will protect examples of the full range of natural marine habitats and ecosystems.
2. MPAs should be designated based on a consistent approach to classification of natural marine habitats and ecosystems.
3. The MPA network should be viable.
4. National priorities for additions to the MPA network will be developed and reviewed on an annual basis.
5. An evaluation programme will be undertaken.
6. A monitoring programme will be undertaken.

Planning principles (abbreviated descriptions):

1. Representative of one or more habitats or ecosystems.
2. Sufficient to meet the protection standard.
3. Relationship between the Crown and Māori provided for.
4. MPA establishment in a transparent, participatory and timely manner.
5. Adverse impacts on existing users of the marine environment minimised.
6. Management tools should be consistent, secure and adaptable.
7. Best available information will be taken into account for decision making.
8. Decision making on management actions will be guided by a precautionary approach.
9. The management regime must be enforceable.
10. Research will be effectively planned and coordinated.

The Natural England & Joint Nature Conservation Committee have jointly developed **Ecological Network Guidance for MPAs** (Natural England & Joint Nature Conservation Committee, 2010). This guidance was based on the best available evidence and was reviewed extensively. It provides specific guidelines for stakeholder groups to identify sites that would protect the range of marine biodiversity within a region and contribute to an ecologically coherent MPA network.

The design principles used in the UK are:

- Replication: the protection of the same feature across multiple sites within the MPA network, taking biogeographic variation into account. All features should be replicated within the MPA network and replicates should be spatially separate.

- Representativity: an MPA network needs to protect the range of marine biodiversity found. This can be achieved by grouping species and habitats into broad-scale habitat types and protecting examples of these across the MPA network. This principle also includes protecting those features of conservation importance that are known to be rare, threatened, or declining.
- Adequacy: to be considered adequate, an MPA network needs to be of sufficient size and include a large enough proportion of features in order to deliver the network's ecological objectives and enable the feature's long-term protection and recovery. Adequacy refers to both the overall size of an MPA network and the proportion of each feature protected within the network.
- Viability: for an individual MPA to be viable it must be able to maintain the integrity of its features (i.e., population of the species or condition and extent of the habitat), and be self-sustaining throughout natural cycles of variation. Viability is determined by the size and shape of individual MPAs in conjunction with their effective management.
- Connectivity: the extent to which populations in different parts of a species' range are linked by the movement of eggs, larvae or other propagules, juveniles or adults. Seeking to maximise connectivity between MPAs will improve the ecological coherence of the network and may be crucial for effective conservation and persistence of features within MPAs.
- Protection: to achieve network aims and site conservation objectives, levels of protection should range from highly protected areas where no extraction, deposition or other damaging activities are allowed, to areas where only minimal restrictions on activities are needed to protect the features.
- Best available evidence: uncertainties in our knowledge should be recognised and taken into account throughout the process. However, decisions will need to be taken based on the best available evidence and lack of full scientific certainty should not be a reason for postponing proportionate decisions on sites selection.

The guidance also separates ecological and practical principles for a network:

Ecological:

- threatened, declining or rare species and habitats
- important species and habitats
- ecological significance
- high natural biological value
- sensitivity
- naturalness
- size and position of site.

Practical:

- synergies with other sectors
- size
- potential for recovery
- degree of consensus
- potential for success of management measures
- scientific value

- accessibility.

Principles for the MPA network in **British Columbia, Canada** (Governments of Canada and British Columbia, 2014) include: ecology, planning, social, economic and cultural and general operating principles, as set out below.

Ecological network design principles:

- include the full range of biodiversity present in Pacific Canada
- ensure ecologically and biologically significant areas are incorporated
- ensure ecological linkages
- maintain long-term protection.

Planning principle:

- ensure maximum contribution of individual MPAs: size, spacing and shape.

Social, economic and cultural network design principles:

- recognize and consider the full range of uses
- maximize the positive
- minimize the negative
- enhance management effectiveness and compliance to maximize benefits and minimize costs.

General operating principles:

- work with people
- respect first nations' treaties, title, rights, aspirations and worldview
- foster ecosystem-based management
- apply adaptive management
- build on existing MPAs, other management tools and marine planning initiatives
- include a full range of protection levels
- take a precautionary approach.