



Evaluating the effectiveness of marine protected areas in New Zealand: Theme 1 - Design elements

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Prepared by:

Tom Brough
Andrew Allison
Lisa McCartain
Carolyn Lundquist

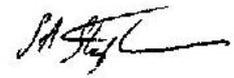
For any information regarding this report please contact:

Tom Brough
Marine Ecologist
Marine Ecology
+64 7 856 1735
Tom.Brough@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

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	Reviewed by:	Fabrice Stephenson
	Formatting checked by:	Carole Evans
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Executive summary

The Department of Conservation (DOC) contracted NIWA to evaluate the effectiveness of individual marine protected areas (MPAs) and marine protected area networks via the development of a methodology for appraising specific elements of MPA design. Seven design elements were assessed: 1) Viability; 2) Adequacy; 3) Representativity; 4) Replication; 5) Ecological Connectivity; 6) Areas of Importance; and (7) Integration with other spatial management measures. Viability concerns the ability of an MPA to protect the ecological features within it and is partitioned into assessments across shape, size and level of protection characteristics. Adequacy reports on the proportion of ecological features found within a network to evaluate whether the network is of adequate size and considers also considers network spatial distribution and level of protection. Representativity relates to the proportion of each habitat type found within an MPA or MPA network, while replication considers the number of occurrences of specific habitats or species within the MPA/network. Connectivity is related to the distance between MPAs required to maintain ecological exchanges across a range of life history stages, for a variety of taxa. Areas of importance describes the extent to which areas of known ecological significance are incorporated within a MPA or MPA network. Finally, integration relates to the degree of spatial congruence between an MPA or MPA network and other marine and terrestrial spatial management measures and areas with high/low naturalness values.

International and national primary and government literature was reviewed to inform the development of conceptual models for the assessment of each design element. Conceptual models were then converted into geospatial models using the ArcGIS Pro application ModelBuilder to calculate metrics that evaluate each design element. Each model is illustrated by an intuitive analysis pathway. Models were prepared for polygon datasets, point datasets, and raster datasets, if relevant for a particular element.

The application of the geospatial models was demonstrated at the scale of a regional network of MPAs, utilising the wider Cook Strait area as a case study. A second case study was developed for an individual MPA (Kapiti Marine Reserve). Datasets representing habitats and species were used in the case studies to illustrate how the analysis of each design element could be performed. Key decision points associated with the use of the evaluation methodology and caveats to the calculation of the metrics to evaluate the design elements are discussed.

1 Introduction

In Aotearoa/New Zealand, Marine Protected Areas (MPAs) play a central role in the conservation and restoration of the marine estate by limiting or removing the effects of some anthropogenic stressors on marine biodiversity values. MPA planning in New Zealand is directed by the Marine Protected Areas Policy and Implementation Plan (Department of Conservation and Ministry of Fisheries, 2005) which 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'. The 2005 MPA policy defined a protection standard that had to be met for an area to be considered an MPA. Two types of MPAs were considered to meet the protection standard, based on the fishing methods that the tools managed: (1) type 1 MPAs: marine reserves established under the Marine Reserves Act 1971; and (2) type 2 MPAs: MPAs where restrictions made under other legislation offered protection that met the protection standard (e.g., prohibitions on fishing methods under the Fisheries Act 1996 and prohibitions on fishing in the vicinity of submarine cables and pipelines). In this report, the term MPA is used to refer to type 1 and type 2 marine protected areas.

As a contribution to a broader programme of work to develop an improved approach to the establishment of MPAs, DOC has identified the need for the development of a process to evaluate MPA effectiveness. This process should be able to be applied during the proposal development stage, to determine the suitability of the proposed protected area or protected area network in meeting its stated objectives. Further, the process should be able to be used once protected areas have been implemented, to determine the ongoing performance of the protected area(s) in contributing to its objectives and/or those of the wider network. There are three main 'themes' in evaluating MPA effectiveness: (1) design issues related to both individual sites and protected area systems (networks); (2) the adequacy and appropriateness of management systems and processes; and (3) delivery of protected area objectives, including conservation values. The focus of this report is on Theme 1 - Design Issues.

Theme 1 is concerned with the design aspects of individual protected areas and broader protected area networks. Importantly, Te Mana o te Taiao - Aotearoa New Zealand Biodiversity Strategy 2020¹ and the United Nations Convention on Biological Diversity (CBD) include several qualitative elements directly related to Theme 1 (areas of importance; ecologically representative; connectivity and integration into the wider landscape). Additionally, the MSAG has developed MPA Network Design Guidance for New Zealand, which includes the qualitative elements of Aichi Target 11 related to protected area design alongside several additional design principles (viability of features within protected areas; adequacy of protected areas in ensuring ecological viability; replication of ecological features across protected areas). Together, these identify a range of elements that should be incorporated into evaluations of the effectiveness of protected area design, within both an international and Aotearoa New Zealand context. Formal definitions of each design element are given in Section 2.

A review of the international literature reinforces key design elements (or criteria) as best practice for the inclusion in the design of marine protected areas. These include: Areas of importance; representation; replication; ecological connectivity; viability (size, shape and level of protection);

¹ <https://www.doc.govt.nz/nature/biodiversity/aotearoa-new-zealand-biodiversity-strategy/te-mana-o-te-taiao-summary/>

adequacy (proportion of habitat protected) and integration into wider landscapes (The Ecology Centre 2009; Fernandes et al. 2012; Thomas and Shears 2013; Burt et al. 2014; Ardron, JA. et al. 2015). Additionally, type of protection and duration of protection have also been identified as important design elements (Fernandes et al. 2012; Green et al. 2014; Chollett 2017; Green et al. 2017; Munguia-Vega et al. 2018; Duarte et al. 2020). In this study we incorporate protection level under the assessment of viability, though our case studies reflect Type 1 MPAs only. The type of protection element will also be more critically examined under further national Marine Science Advisory Group (MSAG) investigations under IUCN Theme 3.

Currently, the ability to assess the design effectiveness of MPAs or MPA Networks is limited, without clear methods with which to calculate metrics that report how well an MPA meets the key elements. For example, methods that define how spatial layers reporting the distribution of biodiversity can be used to calculate whether the size and shape of an MPA is viable for promoting protection of biodiversity are currently unavailable. In the past, assessment tools for terrestrial Protected Areas (PAs) have been applied to a marine setting; however, these evaluation frameworks are limited within a MPA context and are largely opinion-based (Rodríguez-Rodríguez 2018). Two assessment frameworks that have been developed for a marine setting include the Marine Protected Area Protection Framework (MaPAF) (Rodríguez-Rodríguez et al. 2016) and the NEOLI frameworks (Edgar et al. 2014). Both frameworks are based largely on legal protection and management effort. In a review on MPA performance indicators, Miller-Meehan et al. (2020) found that indicators for effectiveness were largely skewed by management effectiveness and only few indicators were applied for the design elements of MPAs.

1.1 Aims and objectives

In this report, we present:

- A review of methods used internationally for evaluating the design aspects of individual marine protected areas and broader marine protected area networks.
- Approaches to evaluating MPA and MPA network effectiveness for each design element (as related to Theme 1) for application within the New Zealand MPA network context.
- An example application of each design element at the scale of a regional 'network' of MPAs, and for an individual MPA. We utilise representative datasets from various research projects (e.g., Lundquist et al. 2020, Lundquist et al. 2021, Stephenson et al. 2018, Stephenson et al. 2021) to illustrate application of individual design element evaluation processes.

2 Design elements – principles

Approaches for the evaluation of seven **design elements** (described in below) were developed using geospatial analysis tools:

1. Viability
2. Adequacy
3. Representativity
4. Replication
5. Connectivity
6. Areas of Importance
7. Integration with other spatial management

Metrics were provided that present the actual geospatial calculation by the analysis process used to assess each design element. Variations on metric calculations were provided to suit polygon datasets, point record datasets, and raster datasets, as relevant to each design element. Key decision points for the development of each metric were identified.

We use the term '**performance standards**' to refer to how metrics meet the requirements for effectiveness on a continuous scale. Performance standards were proposed for each design element, suggesting a range of effectiveness following a red/amber/green traffic light approach. The setting of the performance standards can be adaptable based on any prescribed requirements of an MPA planning process. In this study, we used a literature review and consultation with the MSAG to inform the development of draft performance standards.

The international and national literature was reviewed to extract key papers and reports that review implementation and evaluation processes for MPA networks, and the design elements that were used. Reviews of scientific guidelines for MPA design were also examined to summarise whether and how each of the seven design elements were used, and what performance standards were used to define each design element (Table 3-1). The review is collated by case-studies, specific to international MPA design and evaluation projects that report against the design elements that are a focus of this study. Case studies are further separated into those that are based on the implementation of a particular MPA planning processes, or those that make specific recommendations based on more wide-ranging analysis. However, most projects do not report against all seven design elements. The literature review concluded that the seven identified design elements provided appropriate and comprehensive criteria for evaluating the design effectiveness of MPAs and MPA Networks in Aotearoa New Zealand. In our review, the viability and adequacy of design elements were sometimes conflated, although each generally referred to design processes at the scale of an individual MPA or a MPA network, respectively. For this reason the literature review incorporates information pertaining to both elements under 'viability' (Table 2-1), although they equally apply to adequacy. Additionally, we found limited information on the incorporation of the integration design element within evaluation of MPA/network design, thus there is no information for that element provided in Table 2-1.

2.1 Viability

Principles for MPA network design for New Zealand define viability as the ability to “*maintain the integrity of its features (i.e., populations of the species or condition and extent of the habitat) and be self-sustaining throughout natural and anthropogenic cycles of variation*” (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019b). Viability is

defined as having three main components: size, shape and level of protection. Viability is also affected by boundary configuration, replication, connectivity, the nature of the potential threats and the ability to mitigate these threats (Thrush et al. 2012).

To ensure viability an MPA should be large enough to encompass the adult home range of the majority of species within it, which would allow a proportion of recruits to remain within the MPA throughout their life cycle. For biodiversity purposes, the larger the area protected the better, as this will accommodate more species' adult ranges (Botsford et al. 2003). However, large MPAs may not be socio-economically acceptable due to the severity of restrictions on resource uses. International literature generally suggests a minimum MPA diameter that encompass (or are larger than) the average dispersal range of larvae and home range of adult focal species within the MPA to ensure viability (see examples in Table 3-1; Botsford et al. 2001; Botsford et al. 2003; Gaines et al. 2010; Pelc et al. 2010). Fernandes et al. (2012) suggests using a combination of minimum sizes and variation in MPA sizes within a network. In addition, the study recommends a minimum 5 km alongshore length (inshore) and extending at between 5 and 20 km offshore (to encompass the entire depth profile for MPAs at the Great Barrier Reef). The California MLPA Initiative recommended MPAs should be between 5-10 km but preferably 10-20 km in coastline length; these distances were considered appropriate to encompass the home ranges of a large proportion of coastal species, although may not be relevant for species occurring in other habitats (e.g., deepwater taxa) (Gleason et al. 2010).

While the Aotearoa New Zealand MPA Policy does not provide quantitative guidelines on size, it states MPAs should be of "sufficient size to provide for the maintenance of populations of plants and animals. For the same amount of area to be protected it is desirable to protect fewer, larger areas rather than numerous smaller areas" and complete rather than fragmented habitats (Department of Conservation and Ministry of Fisheries 2005).

The shape and boundary configuration of an MPA are important for ensuring viability. Boundaries are "leaky"; that is, marine life can move in and out of them as they please (Thrush et al. 2012), although some degree of "leakiness" or "spill-over" is desirable for the exchange of recruits with the surrounding area and other MPAs (Roberts 2000; Thomas and Shears 2013). "Leakiness" can be managed by the boundary length to area ratio (Thrush et al. 2012). If the purpose of an MPA is to enhance biodiversity then "leakiness" can be minimised by a low length to area ratio with shapes such as a square or circle; if the goal is to enhance neighbouring fisheries then a high length to area ratio will work best such as a rectangular shape MPA (Fernandes et al. 2012). Boundaries should also enclose habitat patches rather than fragmenting them (Thrush et al. 2012) and capture the gradient from onshore-offshore or habitat-habitat shifts of species of interest (IUCN-WCPA 2008).

MPA protection levels range in the international review from full no-take areas to buffer or replenishment zones that permit some limited activities. The type of protection of an MPA can also affect its viability, especially in conjunction with other design elements. For example Turnbull et al. (2018) found that for a network of small MPAs with a range of protection levels in New South Wales, Australia, only those fully protected (no-take) had a significant impact on fish assemblages and that partially protected areas were not effective at delivering their goals. Throughout the literature there are many examples where the effectiveness of no-take MPAs outweighed those with partial protection (Lester and Halpern 2008; Lester et al. 2009; McCook et al. 2010; Currie et al. 2012).

2.2 Adequacy

Principles for network design for New Zealand define adequacy as *“the concept of ensuring that a network of protected areas, and the proportion of features protected (broad-scale habitats and [Key Ecological Areas] 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”* (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019b).

There is some inherent similarity between viability and adequacy design elements reported in the literature, with evaluation of the one element often being synonymous with the other. Thus in Table 3-1, we collated information under the viability element, although it equally applies to adequacy. Typically, adequacy refers to the evaluation across an entire network, rather than an individual MPA.

The proportion of the total planning area required to be protected to ensure “adequacy” varies within the international literature with the majority of guidelines setting targets at 20-30% (Table 3-1; McLeod et al. 2009; McCook et al. 2010; Fernandes et al. 2012; Burt et al. 2014; Green et al. 2014; Chollett 2017; Munguia-Vega et al. 2018). When it comes to adequacy at the level of individual ecological features, similar guidelines for the percentage protected is recommended in the international literature - typically between 10 and 50% (Weeks et al. 2009; Sciberras et al. 2013; Chollett 2017; Green et al. 2017; Dunn et al. 2018). Clearly, decisions associated with ‘what is adequate protection’ for given habitats/species will be specific to their unique characteristics and will likely include considerations associated with threatened status, vulnerability, rarity and commercial/cultural/recreational value amongst others.

Current Aotearoa New Zealand MPA policy does not specify a percentage target for protected areas to be ‘adequate’ but refers more generally to a network that is comprehensive and representative (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019).

2.3 Representativity

Principles for network design for New Zealand define representativity as *“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”* (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019b).

New Zealand’s MPA Policy includes design principles to ensure representativeness through protection of “the full range of marine habitats and ecosystems” as well as those which are rare, distinctive or internationally or nationally important, within each biogeographic region (Department of Conservation & Ministry of Fisheries 2005, Ministry of Fisheries & Department of Conservation 2008). Factors that should be considered include encompassing the full range of categories across a biogeographic, habitat, or community classification, the relative intactness of habitat(s) and the naturalness of the habitat(s) (Department of Conservation and Ministry of Fisheries 2005). New Zealand marine reserves and Type 2 MPAs have been evaluated for their effectiveness with respect to representativity, updating an initial gap analysis and inventory completed in 2011 (Department of Conservation & Ministry of Fisheries 2011). The updated (2019) gaps analysis includes evaluation of the representation of habitat surrogates using the New Zealand Coastal Classification and Mapping Scheme (CCMS) (Ministry of Fisheries & Department of Conservation 2008), and demonstrates less than adequate representativity across 14 bioregions, with 2/3 of the 416 habitats not included in any

marine reserve, and 79% of habitats with <1% of their extent in a marine reserve (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019a).

Representativity is a fundamental design criterion of international MPA planning processes, with the majority of examples recommending representation of the full range of bioregions, habitats, species and processes within a network (Table 2-1). There is some variability in the use of either habitat or bioregional classifications to assess representativity, with broad scale planning processes typically assessing the element across bioregions (NMOE 2006; Fernandes et al. 2012), fine scale processes assessing habitat representativity (Ardron 2008; Gleason et al. 2010; Arafeh-Dalmau et al. 2017; Green et al. 2017), and several examples of both bioregional and habitat representativity (Cowie-Haskell and Delaney 2003; Baker 2004; Foster et al. 2017).

2.4 Replication

Principles for network design for New Zealand define replication of ecological features as meaning that *“more than one site should contain examples of a given feature in a given biogeographic area. The term “features” means here species, habitats and ecological processes contained within the broad-scale habitat and Key Ecological Areas classifications that naturally occur in a particular biogeographic area”* (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019b). Having multiple replicates of each feature reduces the risk of losing biodiversity due to a catastrophic, natural or anthropogenic disturbance (Thomas and Shears 2013).

Replication is a design element that is well represented in international MPA and MPA Network design literature (Table 3-1). The level of recommended replication varies from 1- 5 per bioregion or habitat with the majority reporting best practice as replication of ≥ 3 (Chollett 2017, Dunn et al. 2018, Fernandes et al. 2012, Fernandes, et al. 2009, Fernandes et al. 2005, Green et al. 2009, Green et al. 2017, Green et al. 2014, McCook et al. 2010, McLeod et al. 2009, Munguia-Vega et al. 2018, The Ecology Centre 2009, Thomas & Shears 2013). In New Zealand, MPAs are designed to replicate each habitat twice (within each biogeographic region); however, policy suggests additional replicate habitats should be allocated in circumstances where they are necessary to ensure the maintenance of ecosystem processes (Department of Conservation & Ministry of Fisheries 2005).

The updated (2019) gaps analysis includes evaluation of the replication of habitat surrogates using the New Zealand Coastal Classification and Mapping Scheme (CCMS) (Ministry of Fisheries & Department of Conservation 2008), and demonstrates low levels of replication, with only four bioregions having some habitats replicated in more than two marine reserves (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019a).

2.5 Connectivity

Principles for network design for New Zealand highlight the role of connectivity in allowing 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”* (Department of Conservation, Ministry for the Environment & Ministry for Primary Industries 2019b).

Ecological connectivity is a commonly used criterion in international MPA and MPA Network design (Gaines et al. 2010). Magris et al. (2018) showed that consideration of connectivity can maximise MPA efficiency and there are a range of genetic and landscape/seascape studies that have identified the need to improve connectivity through increasing size, relocating or adding MPAs to existing networks (Bors et al. 2012; Guizien et al. 2012; Nakajima et al. 2017). Despite this evidence, the

consideration of ecological connectivity in the design of MPAs is limited, with other criterion such as representativeness taking priority (Balbar and Metaxas 2019). The ability to incorporate ecological connectivity in MPA Network design is often limited by data availability. Connectivity can be estimated during the planning stage through patterns of water movement such as currents, physical bottlenecks, migration routes, species dispersal patterns, or functional linkages (Thomas and Shears 2013). When available, genetic data can be used to assess the connectivity of a system (e.g. Bors et al. 2012). There are several spatial planning tools that have been used to incorporate connectivity in MPA planning including: Marxan; Zonation; MarxanConnect and the R toolbox 'best MPA'; the same tools can be used to evaluate the effectiveness of connectivity (Balbar and Metaxas 2019).

Internationally there have been several approaches taken to include connectivity, with the approach used often depending on the goals of the MPA or MPA Network (e.g., Arafah-Dalmau et al. 2017, Chollett 2017, Weeks et al. 2010). In NZ, Type 1 MPAs are primarily tools for biodiversity conservation. However if the goal is to enhance fisheries in neighbouring areas then the spacing of MPAs should be within the dispersal range of the target species (for example connectivity design criteria for yellowtail snapper, conch and lobster in the Northern Honduras network (Chollett (2017))). If the goal is biodiversity conservation, then a more conservative approach may be necessary to encompass the dispersal range of the majority of species within a habitat. Fernandes et al. (2012) suggests 1-20 km minimum distance to encompass the significant variability in larval dispersal on the Great Barrier Reef.

If species-specific dispersal distances are unknown, several standards are suggested throughout the literature, e.g., 40-80 km for the United Kingdom MCZ project (Thomas and Shears 2013). Similarly, the Californian MLPA Initiative required reserves to be sited within 50-100 km of each other, to account for the dispersal range of most commercial or recreational groundfish or invertebrate species (Gleason et al. 2013).

While New Zealand MPA policy recognises the need to maximise connectivity in the design process, there is no guidance on how to do so in the absence of genetic or dispersal data that can be used to inform patterns of connectivity.

2.6 Areas of importance

There are a number of instances where it has been demonstrated that protection of representative habitats alone may not adequately represent areas of particular biodiversity importance, e.g. Williams et al. (2008). To ensure a comprehensive, adequate and representative marine protected area network, the selection of representative species and habitats should be complemented by the identification of sites of particular significance for biodiversity conservation. The former is intended to ensure that species and habitats are protected through inclusion of biodiversity surrogates in protected areas, including in data poor areas. The latter ensures that features of known importance for biodiversity are also included in protected area networks; without this, there is a risk that representativity alone will not adequately protect the full suite of species, habitats and ecosystems (although some definitions of "representativeness" do include reference to a full suite of biodiversity, which would include features that are, for example, rare, important or unique). To guide marine protected area planning, an objective and consistent approach to the identification of sites of particular importance for biodiversity is required. Internationally, there have been several attempts to achieve this. These include a global standard for the identification of "key biodiversity areas" prepared by the IUCN (IUCN 2016) and 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). The MSAG agreed the CBD Ecologically and Biologically Significant Areas (EBSA) criteria provide a strong, practical, scientific basis for informing protected area planning that could be applied in the New Zealand (domestic) context. The MSAG developed Key Ecological Area (KEA) criteria that includes the seven EBSA criteria, plus two additional criteria relating to ecological function and ecosystem services. The KEA criteria can be used to map areas of importance, against which the performance of MPA design can be evaluated (well-designed MPAs would help protect areas of importance).

2.7 Integration with other spatial management

This final design element identifies the importance of integrating MPAs with other conservation and spatial management tools, such as fisheries management or terrestrial conservation and management of land-based sources of pollution such as sediments and nutrients. Other considerations for this element include potential cumulative impacts stemming from climate change, ocean acidification, ocean noise, and pollution (Juffe-Bignoli et al. 2014, Rees et al. 2018). While several studies discuss the importance of integrating MPAs within the wider mosaic of spatial management (Ardron et al. 2015; Burt et al. 2014; Fernandes et al. 2012; The Ecology Centre, 2009), we could find no examples of where integrating MPAs within wider spatial management measures has been explicitly undertaken. There is also a lack of scientific investigations into the biodiversity benefits of integrated management zoning.

Table 2-1: Review of international literature on MPA and MPA network design criteria. Updated literature review from that presented in Lundquist et al. (2015). Review information is separated into 1) implementation assessments – where, as part of the implementation of a particular spatial planning process, information pertaining to the various design elements is available and 2) explicit recommendations, where studies typically take a more holistic view of design elements often reviewing several case studies.

Case study	Category of analysis	Implementation assessments					Viability - shape	Areas of importance
		Representativity	Replication	Connectivity	Viability - size	Viability - dimensions		
Australia - Great Barrier Reef Marine Park (Fernandes et al. 2005; Fernandes et al. 2009)	Implementation of MPA Network	All bioregions (70)	3-4	Recommended 70-100 km	average size of no take areas 700 km ²	Alongshore >10 km for coastal, >20 km for offshore		
California MLPA (see Gleason et al. (2013) and other references in this Special Issue)	Implementation of MPA Network	All 'key' habitats (13)	at least 3-5	Recommended 50-100 km	25.0 km ²	Alongshore at least 5-10 km of coastline but preferably 10-20 km (planning area includes all the states marine waters to the 3-mile limit)		
Norway – Barents Sea – Lofoten Area (Norwegian Ministry of the Environment (NMOE) 2006; Norwegian Ministry of the Environment (NMOE) 2011)	Implementation of MPA Network	All 4 bioregions			7,120.7 km ² on average (n = 12)			
Florida Keys (Keller et al. 2006; Cowie-Haskell and Delaney 2003; Office of	Implementation of MPA Network	All of the five unique bioregions,			28.3 km ²			

Case study	Category of analysis	Implementation assessments						
		Representativity	Replication	Connectivity	Viability - size	Viability - dimensions	Viability - shape	Areas of importance
National Marine Sanctuaries. 2011)		and five key habitat types						
Belgium (Cliquet et al. 2007)	Implementation of MPA Network	2 habitats of key importance			619.5 km ²			
England (Jackson et al. 2008; UK Department for the Environment 2012)	Implementation of MPA Network	Representation of all habitat at EUNIS level 4	3-5		613.4 km ²			
Australia – South West Bioregion (Baker 2004; AU Department for the Environment 2012)	Implementation of MPA Network	Representative of all 9 bioregions and 16 seafloor types	≥ 1		36,328.9 km ² on average, range – 574 – 111,052 km ² (n = 14)			
Wadden Sea (Common Wadden Sea Secretariat 2016)	Implementation of MPA Network	All key habitats, features and processes						
Northern Honduras network of Replenishment Zones (Chollett 2017)	Implementation of MPA Network	20% of each major habitat type	≥ 3 per major habitat	maintain connectivity of focal species		at least 2 km across to protect focal species	compact shapes	Protect areas of importance for focal species
Baja California (Arafeh-Dalmau et al. 2017)	Implementation of MPA Network	Every “key” marine habitat should be represented in the MPA network by	≥ 2	Recommended 50–100 km		Alongshore distance of 23–100 km extending from		

Case study	Category of analysis	Implementation assessments						Areas of importance
		Representativity	Replication	Connectivity	Viability - size	Viability - dimensions	Viability - shape	
		protecting 10-30% of its extent					intertidal to deeper waters	
England (Jackson et al. 2008; UK Department for the Environment 2012)	Implementation of MPA Network	Representation of all habitat at EUNIS level 4	3-5			613.4 km ²		
Philippines (Weeks et al. 2010)	Implementation of MPA Network	Target of 10% of Reef in all 6 bioregions.		84% of MPAs are within 1-20 km and more than 70% are located within 5 km of another reserve		23.60 km ² on average, range 0.01 – 2789 km ² (n = 604)		
Commonwealth marine reserves network, Australia. (Sciberras et al. 2013)	Implementation of MPA Network		≥1	Inclusion of connectivity corridors and biological dispersal patterns within and across marine reserves		Smaller number of larger marine reserves rather than many small marine reserves		Simple boundary lines
Celtic seas MPA (Foster et al. 2017)	Implementation of MPA Network	All 6 biogeographic provinces 3.7-9.6% of each, all habitat types	≥ 6 each habitat type	Recommended ≤80 km		1-23,000 km ² (median 5.3 km ² of 553 MPAs)		

Case study	Category of analysis	Implementation assessments						
		Representativity	Replication	Connectivity	Viability - size	Viability - dimensions	Viability - shape	Areas of importance
Channel Islands National Marine Sanctuary, California (Sciberras et al. 2013)	Implementation of MPA Network	3 Bioregions, 30-50% of all representative habitats	1-4 reserves per bioregion	Recommended 50-100 km	Zones designed to accommodate species home range			

Explicit recommendations								
Case study	Category of analysis	Representativity	Replication	Connectivity	Viability -size	Viability- dimensions	Viability- shape	Areas of importance
Suggested guidelines for a network of replenishment zones for the Mesoamerican Reef system (Green et al. 2017)	Review of guidelines in scientific literature	Goal of 20-30% of each major habitat. National commitments: Belize, 10%; Honduras, 20%, Guatemala, 2 fully protected reef systems; Mexico, 10%	≥ 3 per major habitat	Consider larval and adult dispersal ranges of focal species	> twice the size of the home range of adults and juveniles of focal species for protection	> twice the size of the home range of adults and juveniles of focal species for protection	Compact shapes rather than elongated ones.	
Kimbe Bay , West New Britain, Papua New Guinea (Green et al. 2009)	Review of guidelines in scientific literature	20% of each habitat type	≥ 3 per habitat	Recommended 15 km	10 km ²	10-20 km in dimension		
Canada's Northern Shelf bioregion (Ardron et al. 2015)	Review of guidelines in scientific literature	Represent each habitat type in planning region. Sub-regions/ feature dependant ranging from <5 - 100 %. 20% of planning region	3-5	Dependent on objectives but use MPA Spacing ≤ $9 \cdot ((\text{Area1} + \text{Area2})/2)0.5$	Dependent on objectives (target species or not), at a minimum, should be 5-150 km ² in size, majority of MPAs should be at least 50 km ²		Dependent on objectives	

Explicit recommendations

Case study	Category of analysis	Representativity	Replication	Connectivity	Viability -size	Viability- dimensions	Viability- shape	Areas of importance
Review (Burt et al. 2014)	Review of guidelines in scientific literature	30% of all habitats	≥ 3 per feature	Recommend 20-100 km or closer	23-80 km ² but governed by objectives, larger MPAs to protect more mobile species , look at life history. Variety of sizes			
Mid-ocean ridges (Dunn et al. 2018)	Review of guidelines in scientific literature	30-50% of key all habitats, 100% of active hydrothermal vent ecosystems	3-May	Regional connectivity: 6 – (max distance between cores/75th percentile median dispersal distance) Network connectivity: 6 – mean gap ratio (that is, the mean distance between cores/mean core length)	30-50% of the management unit. Large enough to maintain minimum viable populations	200 km		

Explicit recommendations

Case study	Category of analysis	Representativity	Replication	Connectivity	Viability -size	Viability- dimensions	Viability- shape	Areas of importance
Coral triangle (Fernandes et al. 2012)	Review of guidelines in scientific literature	≥35% for each habitat	≥3 of every habitat	Recommend 1 to 20 km	Variety of sizes to suit the requirements of individual habitats	Minimum of 5 km in alongshore length; the width should span the entire depth profile if possible (at least 5 km); further offshore, a minimum diameter of ~20 km should apply to no-take areas.	Use more square or Circular shapes	
Tropical ecosystems (Green et al. 2014)	Review of guidelines in scientific literature	20-40% of each major habitat	≥3 of every habitat in separate MPAs	Recommend 1-15 km	Apply minimum and variable sizes (e.g., 0.5–1 km and 5–20 km across) to marine reserves, depending on focal species		Compact shapes	
Review (McLeod et al. 2009)	Review of guidelines in scientific literature	20-30% of each habitat	≥ 3 per habitat	Recommend 500-200 km apart	Bigger is better	Minimum diameter 10-20 km	Simple, minimise edge effects (squares or rectangles)	

Explicit recommendations

Case study	Category of analysis	Representativity	Replication	Connectivity	Viability -size	Viability- dimensions	Viability- shape	Areas of importance
Gulf of California (Munguia-Vega et al. 2018)	Review of guidelines in scientific literature	30% of each major habitat	≥ 3 per habitat	Recommend 50-200 km	Consider movement of species (most covered by 100 km ²)	Most commercially important fish covered by minimum length of 10 km many will be covered by minimum diameter of 5 km.	Compact shapes (squares, circles)	
California MLPA (Saarman et al 2013)	Review of guidelines in scientific literature	Every “key” marine habitat should be represented in the MPA network.	Key habitats replicated in multiple MPAs across environmental and geographic gradients	Recommend 50-100 km	Minimum MPA size range: 23-47 km ² Preferred MPA size range: 47-93 km ²	alongshore span of 5-10 km of coastline and preferably 10-20 km and should extend from the intertidal zone to deeper waters offshore (offshore dimension constrained by the limits of state jurisdiction)		

Explicit recommendations								
Case study	Category of analysis	Representativity	Replication	Connectivity	Viability -size	Viability- dimensions	Viability- shape	Areas of importance
Australia (The Ecology Centre 2009)	Review of guidelines in scientific literature	minimum 30% of each habitat	at least 3 times	inter MPA distance up to 200km	larger rather than smaller			

3 Design elements – Evaluation methods

The following section illustrates methods to evaluate the seven MPA design elements through the calculation of standardized metrics. For the methods to be easily used by future users with varying levels of experience with spatial analysis, it was agreed in consultation with the MSAG that the evaluation methodology should be implemented in GIS software. Such software provides an intuitive graphical interface and is generally more accessible than applications that require coding (e.g., *R*, *Python*). The methods outlined below were developed in ESRI's ArcGIS Pro (v 2.8.1) using the ModelBuilder tool to automate analyses and create toolboxes that can be applied in any evaluation of individual MPAs or MPA networks. Models were constructed that allow for a standardised calculation of evaluation metrics (see below), while minimising the need for user intervention as much as possible. All terminology on spatial functions and processing routines are as per ESRI's standard definition for ArcGIS Pro.

The output metrics across each design element that are generated from the automated assessment are compared against the performance standards that deem whether recommendations for a design element have been met. The metrics are collated across each individual MPA or network as specified by the design element, and the distribution of metrics plotted using boxplots overlaid upon colour coded performance standards on a continuous scale. Where possible, the performance standards have been informed by the review of case studies from international MPA planning/review processes (Table 2-1). It is anticipated, however, that several performance standards will be further refined to suit a NZ setting.

A first step in the evaluation of the design elements is the delineation of the MPAs/network to be evaluated and the 'planning area' in which it is situated. In real-world applications, the planning area will likely be based on the requirements for MPA development and evaluation within prescribed regional settings (e.g., South East Marine Protection Forum, Sea Change). However, careful consideration should be given to the boundaries of the planning area as the calculation of metrics across each design element will be strongly influenced by the area's extent.

3.1 Viability (individual MPAs)

Viability is the first 'gateway' for assessing whether an individual MPA (or single MPAs within a network) can protect the integrity of key features within them. Where a MPA is not viable for a key feature it is unlikely to contribute to meeting representativity objectives for that feature, or the replication or connectivity objectives across a broader MPA network. Viability is assessed according to metrics across three MPA design characteristics: 1) size; 2) shape; and 3) level of protection. Viability is assessed at the level of each MPA within a network, with metrics calculated for the three viability characteristics for each MPA.

3.1.1 Viability – MPA size

Viability in terms of MPA size can be best appraised in relation to the size of the home range of key taxa within the planning area (e.g., covering at least a minimum proportion of the full range), or by covering a minimum proportion of key habitat features. Although accurate home range data is not available for most taxa, information is available for some key species and it is anticipated that existing gaps will be filled in the future. In this study, we use species specific information on home range size where available (e.g., Shaffer & Rovellini 2021), and use information for similar species as a proxy in a small number of cases. As we aim to demonstrate an analysis routine to calculate

viability-size metrics rather than deliver accurate metrics for the specific case-studies, having some inaccuracies the home-range information is deemed appropriate. Due to the lack of home-range information on many species it is envisioned that future MPA evaluation processes may need to draw on expert knowledge to derive the necessary information.

Spatial datasets in different formats hold variable types of information on the range or extent of species/habitats, thus we have developed three approaches for appraising viability metrics of MPA size: 1) for polygons; 2) for point datasets; and 3) for raster datasets

Polygon datasets

Polygon features may represent the presence or known extent of a species or habitat. If polygons represent species/habitat presence, it is important to account for potential range/extent around such presences using information on home range/habitat patch size. Viability is calculated as the proportion of the total extent of a feature that is found within an MPA, with two processes used depending on whether an input feature represents presences (e.g., predictions from distribution models) or known extents (e.g., mapped habitat type). Limited information on accurately mapped extents are currently available, thus analyses for this metric in this study is undertaken using presence data only. However, the polygon analysis routine for mapped extents is provided in Appendix C.

In ModelBuilder, the calculation of the size metric using polygon datasets begins with a *feature class iterator* that iterates through polygon datasets for focal taxa and habitats within a prescribed geodatabase (e.g., Feature store (Figure 3-1)). The analysis pathway continues through a *calculate field* function where the name of the feature dataset is added to the attribute table for each feature. Next, the features that overlap all MPAs under consideration (e.g., DOC_MR_STU; Figure 3-1) are extracted using the *intersect* tool, which calculates areal overlap between the polygon features and each MPA. Following this step, a new field is added and the function *calculate geometry* is applied to this field to calculate the area of each feature (in km²) that is located within an MPA. The *buffer* tool is then used to calculate home range size polygons for inputs that represent taxa presence. The buffer tool can take different values for home range size that can be called from an attribute field within each feature class. The resultant home range polygons are then clipped to the study area to remove extrapolation onto land. The buffer step is disabled for polygon features with a pre-defined spatial extent.

The proportion of the range of a feature found within each MPA is then calculated and the process repeated for each feature class in the geodatabase. The function *collect values* retains the final outputs for each polygon dataset, allowing their export for the visualisation of results.

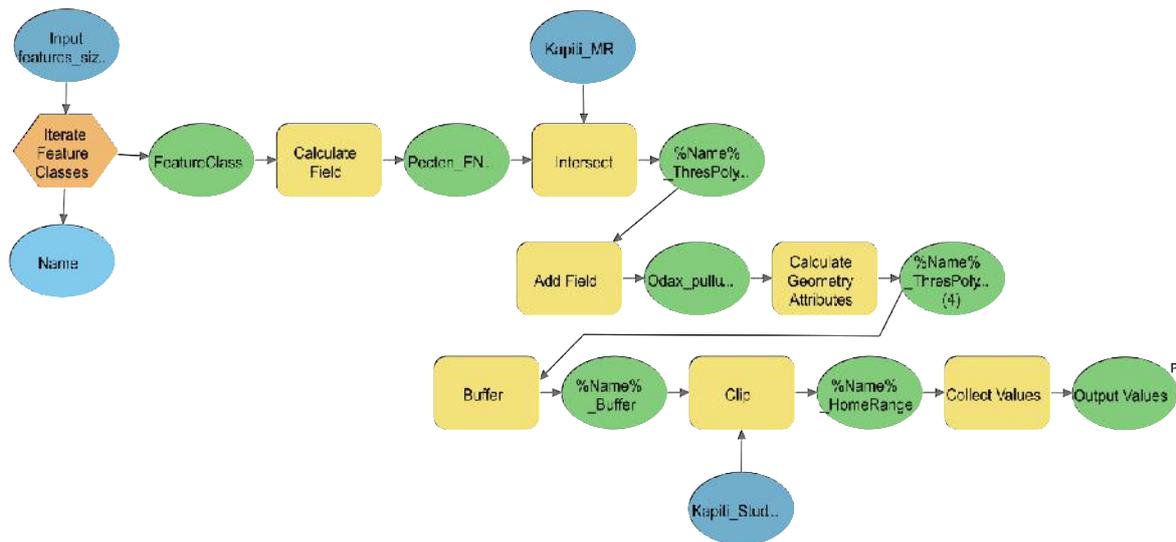


Figure 3-1: Model pathway for viability - size metric for polygon datasets. ModelBuilder analysis pathway used to calculate an evaluation metric for polygon datasets for the viability element.

Point datasets

Point datasets typically represent the presence of an ecologically meaningful feature, but often have no associated information on the feature’s extent. Point datasets are often used to indicate important areas (or at least occurrences) for rare or threatened taxa for which there are insufficient data to produce a spatially explicit model. The evaluation of MPAs should consider these data when higher resolution information is not available. We propose a simple solution using available information on the home range size of individual taxa which is used to create a buffer around each point feature. The proportion of each home range buffer that is attributable to a point feature that occurs inside an MPA can be calculated to evaluate viability of an MPA’s size for the given taxa.

An alternative is to perform density analyses (e.g., kernel density) on the point datasets, and extract hotspot polygons for the resulting density rasters (e.g., McCartain et al. 2021). However, density analyses require a reasonable level of data coverage; given our point datasets are typically those that have been unable to be utilised for spatial modelling, this approach may not be relevant in most cases.

The analysis pathway in ModelBuilder for point datasets begins with a *feature class iterator* which iterates through each point dataset in a defined geodatabase (e.g., input points.gdb) (Figure 3-2). The model extracts the point features from each input that overlap with MPAs using the *intersect* tool. A *buffer* is then applied that calculates the home range for each point given the specific taxa it represents. The home range buffer is then clipped to the study (planning) area. The model then runs parallel processes to calculate the area of each home range buffer within the individual MPAs (top branch) and merges this information (using a *join* tool) with the overall size of the home range buffer (bottom branch). The final results from each point dataset are collated for export and used to calculate the proportion of points within each MPA area.

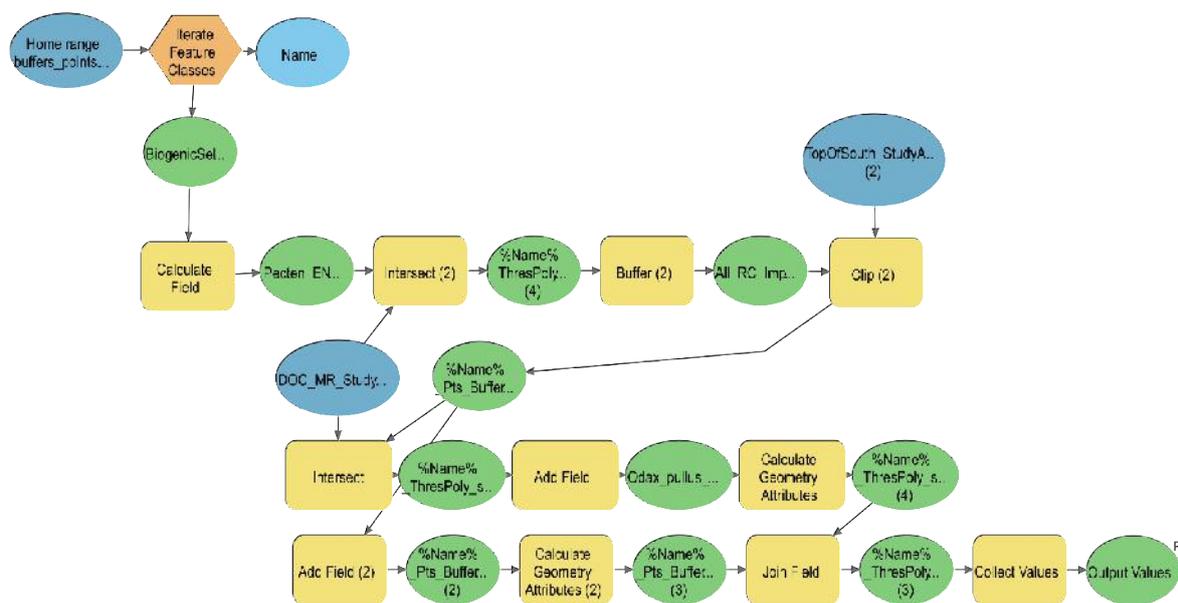


Figure 3-2: Model pathway for viability - size metric for point datasets. ModelBuilder analysis pathway used to calculate an evaluation metric for point datasets under the size component of the viability element.

Raster datasets

Gridded raster datasets are often used to represent a continuous prediction surface from a spatial model or gridded observational data. In a MPA evaluation process, such datasets may include prediction surfaces from species distribution models, macro-ecological models, models of ecosystems service provision, and gridded bathymetric or oceanographic data. A common method for calculating the distribution of value for raster datasets is to sum the value of grid cells inside and outside of areas of interest. For the viability metric, we are interested in appraising how individual MPAs afford protection of the features contained within them, thus we first need to determine individual features from the continuous raster surface. Several methods exist for the determination of features from raster datasets. For habitat suitability/species occurrence models, the prediction surface may be thresholded to approximate presence/absence based on the calculation of a threshold habitat suitability value using the receiver operator characteristic curve (Thuiller et al. 2016). All presence cells can then be converted to polygon extents to represent the boundaries of areas where a species may occur.

Alternatively, the raster values may be thresholded based on the calculation of a summary statistic (e.g., upper quartile), or an arbitrary high value (e.g., a habitat suitability value of 0.9), with the thresholded rasters then being converted to polygons for an evaluation of areal overlap. In selecting a summary statistic or raster value with which to threshold a raster dataset, it is important to investigate how such subjective decisions influence the calculation of the viability-size metric via the change in size of the ‘features’ that are used to represent a taxa or habitat’s distribution. When available, we recommend using the ROC threshold approach which calculates a threshold based on the underlying model’s specificity and sensitivity (although other methods exist – e.g., Liu et al. 2013). For abundance/density surfaces, the use of percentage volume contouring may be useful for defining hotspots within raster surfaces (e.g., Brough et al. 2019).

To calculate a viability-size metric from raster datasets we develop a simple ModelBuilder pathway that thresholds the habitat suitability model layers to a ROC threshold, clips the raster datasets to our planning area, and then export polygons to reflect the location of key areas (Figure 3-3). We have also included an optional step to threshold a raster surface based on a user defined value (e.g., a high HSI value). The analysis pathway starts with a *raster dataset iterator* that iterates through each dataset in a geodatabase (e.g., SDMs to clip). The model then uses the *clip* tool to clip a raster's extent to the planning area. This clipped raster is then used as an input to a *raster calculator* tool, which contains code to threshold the raster to a user-defined value; values below the threshold are set to 0, and values above the threshold are set to 1. This step can be disabled if it is not required. Next, the *raster to polygons* tool is used to build polygons features based on the thresholded raster values and the *make feature layer* and *delete* tools are used to remove polygons that are below a minimum size. This last step is often required when creating polygon features from raster datasets if thresholding results in small (e.g., single cell) features that are not ecologically meaningful. The final polygon feature class from each raster dataset is then saved to a new geodatabase which is used as the input database to the polygon viability-size analysis pathway described in Figure 3-1.

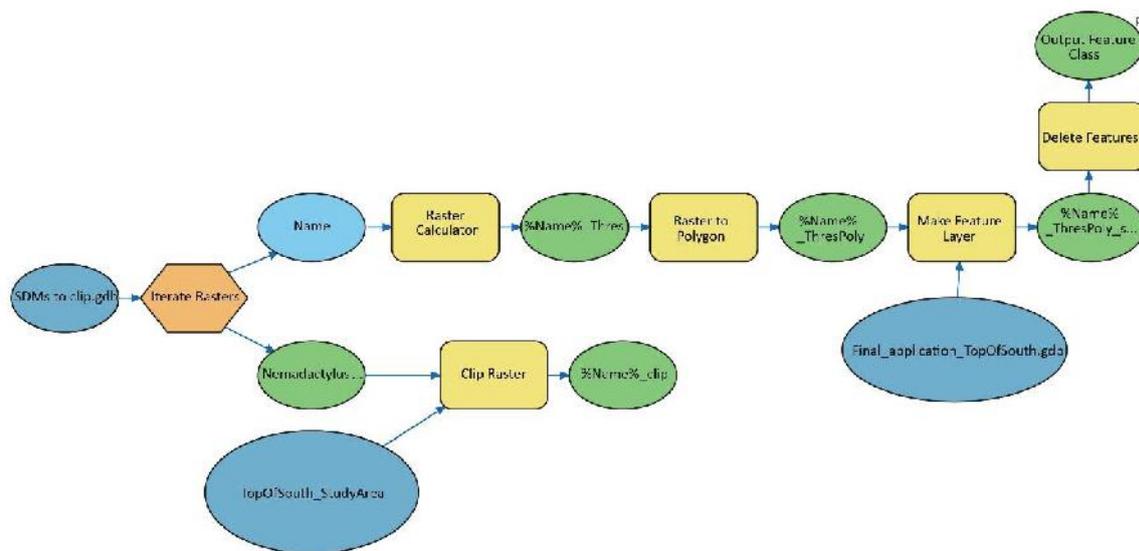


Figure 3-3: Analysis pathway for raster datasets. ModelBuilder pathway used to convert raster datasets to polygons for the calculation of the viability - size metric.

3.1.2 Viability – MPA shape

The shape viability metric reports whether an MPA has shape characteristics that are conducive to enhancing the benefits of an MPA through the minimisation of edge effects. The majority of literature that evaluates MPA shape refers to a need for ‘compactness’ rather than elongated areas with low area to boundary ratio. We develop a shape viability metric for each MPA in a network by calculating the area to boundary ratio. MPA shapes that are most compact (and therefore more viable for achieving protection targets) will have a high area to boundary ratio, while less viable shapes have a low ratio.

In ArcGIS Pro, a feature class dataset containing polygons for each MPA is the only input required to calculate the shape metric. The area of each MPA is calculated automatically by ArcGIS Pro (as the field value ‘*Shape_Area*’). The perimeter (boundary) of each MPA can be added to the dataset by adding a new field to the attribute tables, calling this field ‘*boundary*’. The length of the boundary is

added to this field using the *calculate geometry* tool in the attribute table view, selecting '*perimeter*' as the geometry to calculate, and ensuring the units are the same as the areal geometry (i.e., metres). A new field is then added to the attribute table '*Area_Boundary_Ratio*', and the *calculate field* tool used to populate this field. The entire attribute table can then be exported as a *.csv file for the visualisation of results.

In some cases, it may be necessary to remove some portions of a MPA's boundary from the above-mentioned calculation. For example, MPAs with boundaries that are defined mainly by a convoluted adjacent coastline (e.g., an estuary where the only marine boundary is a narrow estuary mouth) would be highly penalised in the above calculation, while the true edge effects are apparent over the marine boundaries only. In these cases, the boundaries along the coastal margin can be removed by converting the MPA polygons to line feature classes and deleting the line segments within 10 m of the coastline. The subsequent line length can then be added as a new field to the MPA polygon feature class and an area to boundary ratio calculated that includes marine boundaries only. The boundaries to be included in the evaluation of the viability-shape metric should be carefully considered as there are likely circumstances where land-boundaries should be included and vice versa. See Appendix B for an example of the viability shape metric for the full national MPA network using calculated using all MPA boundaries, or marine boundaries only. In any given evaluation process, it is important that a consistent approach be undertaken for the calculation of shape-viability for each MPA/network under appraisal.

3.1.3 Viability – MPA protection level

Whether the existing or proposed level of protection is sufficient to protect the features within MPAs should be evaluated based on a pre-defined standard of what benefits are provided by a particular level of protection. Here, we provide an example using a pre-existing review of expected species/habitat class responses to various types of protection in NZ (Lundquist et al. 2015). Further work with respect to IUCN Theme 3 (delivery of protected area objectives, including conservation values) can replace this prior analysis with revised estimates of delivery of protection for particular protection levels. The Lundquist et al. (2015) review provides a matrix documenting the likely responses of different taxa and habitat classes to a wide variety of MPA types and management strategies (Table 3-1). In cases where the matrix is lacking a specific class/management combination, we recommend reviewing the scientific literature for specific examples on management effectiveness. In order to quantify and visualise the viability of MPAs given their protection status, we recommend the creation of a matrix for each MPA that includes each of the key ecological features it contains (i.e., a list generated from the viability-size assessment). Users can then review the Lundquist et al. (2015) matrix or revised IUCN Theme 3 guidance, and code whether each feature is fully protected (2, Y in table 3-1), is partially protected (1, Y* or Y** in Table 3-1), or is not protected (0, N in table 3.-1) by the existing or proposed level of protection.

Table 3-1: Matrix of biological features and threat mitigation and the level of protection afforded by different management interventions (from Lundquist et al. 2015) used to define the protection status metric of the viability element. * indicates limited benefits for wide-ranging or migratory species. ** indicates that some provisions could provide benefits.

<i>Biological feature protected / Threat mitigation</i>	No-take MPA	BPA	Seamount reserve	Marine Park	Customary management tools	Marine mammal sanctuary	Cable and pipeline zones	Fisheries Act provisions	Shipping lane/Transport restrictions
Biodiversity (entire ecosystem)	Y*	N	N	N	N	N	Y*	N	N
Marine mammals	Y*	N	N	N	N	Y	Y*	N	Y
Seabirds and shorebirds	Y*	N	N	N	N	N	Y*	Y**	N
Benthic fishes	Y	Y	Y	N	Y**	N	Y	Y**	N
Pelagic fishes	Y*	N	N	N	Y**	N	Y*	N	N
Benthic invertebrates	Y	Y	Y	N	Y**	N	Y	N	N
Flora	Y	Y	Y	N	N	N	Y	N	N
Benthic habitats	Y	Y	Y	Y**	N	N	Y	Y**	N
Fishing – direct impacts	Y	Y**	Y	N	Y**	N	Y	Y**	N
Mining	Y	N	Y	Y**	N	N	Y	N	N
Oil and gas exploration	Y	N	Y	Y**	N	N	Y	N	N
Benthic impacts	Y	Y	Y	Y**	Y**	N	Y	Y**	N
Oil spills and other hazards	N	N	N	N	N	N	N	N	N
Land-based sediments, nutrients, and other pollutants	N	N	N	N	N	N	N	N	N
Climate change	N	N	N	N	N	N	N	N	N

3.1.4 Viability performance standards and results

For each metric, we recommend that results of the viability analyses be represented as boxplots to visualise the spread of the results across various MPAs, taxa and habitat groupings. The raw outputs of the model pathway described in the figures above provide the inputs for the boxplots, though users may wish to add their own categorical groupings (e.g., taxa groups or habitat classes) to partition the results (e.g., Figure 4-3).

The performance standards proposed for the viability-size analyses are based on the proportion of the area protected for each ecological feature found within each MPA. Values of 0 to 0.1 are deemed not viable, 0.1 to 0.3 being marginally viable, and above 0.3 being viable.

The performance standards for the shape metric are based on the area to boundary ratio for each MPA where a ratio less than 1 is non-viable shape, between 1 and 2 is a marginally viable shape, and above 2 is deemed a viable shape. On average, marine boundaries represent approximately half of the total perimeter of type 1 MPAs for NZ marine reserves. Thus, we recommend doubling these performance standards when the calculation of this metric uses marine boundaries only; 0 – 2 non-viable, 2 – 4 is marginally viable and above 4 is a viable shape (e.g., Appendix B).

The performance standards for the protection level metric are based on the codes afforded to each feature using the matrix as illustrated in Section 3.1.3, where 0 indicates no benefit of the management intervention, 1 indicates partial or limited benefits, and 2 indicates a benefit from the management intervention.

While the level of the current settings for performance standards of viability were developed with input from the MSAG, they are subjective. There was limited information available in the literature to provide a scientific basis for the level of these settings that may be accurate across a range of taxa/habitat groups. See Section 6.1 for additional detail.

3.1.5 Viability decision points

- The key ecological features used as inputs for the analysis of the size and protection level metrics, and whether certain feature groupings require different performance standards.
- The information used to represent the full range of ecological features (e.g., home range, patch size) used to calculate the viability – size metric.
- The minimum size of ecological features represented by polygons derived from gridded raster datasets.

3.2 Adequacy (network only)

The assessment of the design element adequacy differs from that for viability in that adequacy is assessed to ensure the proportion of features are of sufficient size, spatial distribution and management regime to ensure ecological viability across an entire network of MPAs (rather than at the individual MPA level as per viability). Therefore, viability at the site level is a pre-requisite to contributing to adequacy across the MPA network. Adequacy has three main metrics: size, spatial distribution, and level of protection.

3.2.1 Adequacy – Network size

For the size metric of the adequacy element, we are interested in the proportion of key ecological features (e.g., species distribution, habitat extent) occurring in the planning region, that are protected with viable MPAs within the MPA network.

The calculation differs from *Viability* in that we are concerned with the adequacy of the network for all key features that occur within it, rather than just those features that occur within individual MPAs. Additionally, the process differs from *Areas of Importance* where we are solely interested in areas that are deemed as high value; adequacy analyses the full distribution of species or habitats found within the planning area. As per *Viability*, we have developed different analysis pathways in model builder for spatial datasets in the three main formats (polygon features, point features, and raster datasets).

Polygon datasets

For polygon datasets, the pathway begins with a *feature class iterator* that iterates through each dataset in a defined geodatabase (e.g., Input polygons) (Figure 3-4). Similar to the method outlined for the viability – size metric, we include an optional first step includes the creation of a home-range *buffer* around polygons that represent distribution (i.e., those derived from SDMs). The pathway then splits into two parallel processes where the polygons are *Intersected* with either the MPA network (top pathway) or with the planning area (e.g., TopOfSouth_StudyArea). The polygons are then *dissolved* into single features which allows a calculation of the total area (*Add field* and *Calculate geometry*) of each taxa or habitat class found within the MPA network and within the planning area. The pathways are then rejoined based on the network ID, the final values collated for export, and the proportion of the area found within the network calculated.

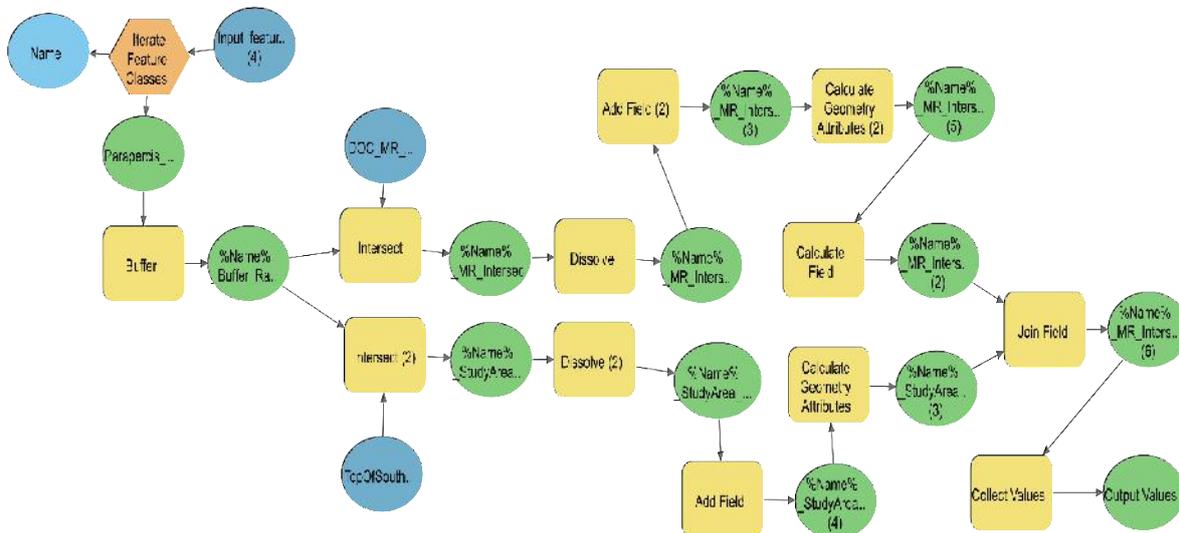


Figure 3-4: Analysis pathway for adequacy - size metric of the polygon datasets. ModelBuilder analysis pathway used to calculate an evaluation metric for polygon datasets under the size component of the adequacy element.

Point datasets

The analysis pathway for point datasets under the adequacy- size metric similarly begins with a feature class iterator that iterates through each point dataset in a defined geodatabase (Figure 3-5). As per viability, we then use information on the home range/patch size of species or habitats to represent the likely extent of the ecological feature with a *buffer* tool. The resultant polygons are then clipped to the marine zone of the study area (Figure 3-5). The pathway then splits into two parallel processes, where the top process determines the area of each feature that is found within the network and the bottom process identifies the total area for features found within the planning area (via the *Intersect* tool). The MPA network pathway sums the full area (in km²) found within the network with the *dissolve* tool and adds the feature dataset's name to the attribute table with *calculate field*. The two processes are joined (*join field*) allowing the calculation of the proportion of area of ecological features that occur within the planning area that is found within the network. The results of each iteration are then collated for export.

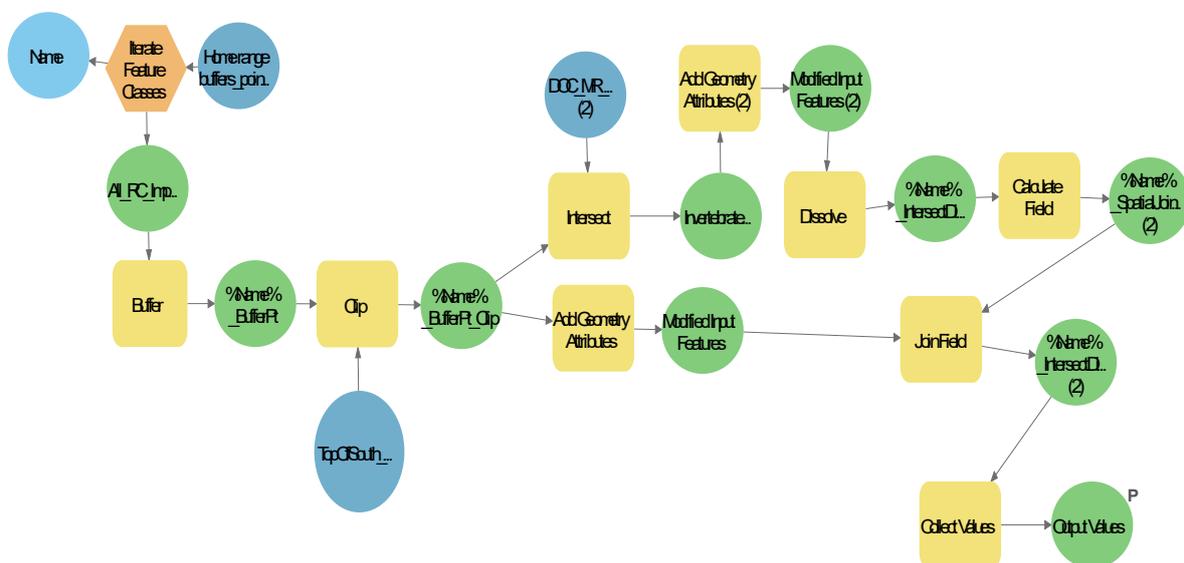


Figure 3-5: Analysis pathway for adequacy - size metric of the point datasets. ModelBuilder analysis pathway used to calculate an evaluation metric for point datasets under the size component of the adequacy element.

Raster datasets

The size metric calculated using raster datasets for adequacy differs from the method used for viability as we are no longer concerned solely with ecological feature that occur within individual MPAs. Rather, we can sum the value of raster cells themselves, without converting to polygons, to determine the proportion of value contained within viable MPAs within the MPA network. When using habitat suitability models, it is recommended that the ROC thresholded raster layers (see Section 3.1.1) be used, and thus the outputs of the threshold-clip raster model were used as inputs in our analyses. The analysis pathway begins with a raster iterator that iterates through each raster dataset within a defined geodatabase (Figure 3-6). The pathway then splits into two parallel processes that are used to sum the value of raster cells within the MPA network (top pathway) or within the planning area (bottom pathway), using the tool *zonal statistics as table*. The name of the raster dataset is then added to MPA network table using *calculate field* and the two pathways are

merged using the *join field* tool that allows the calculation of the proportion of summed raster value within the entire network. The results from each raster dataset are then collated for export.

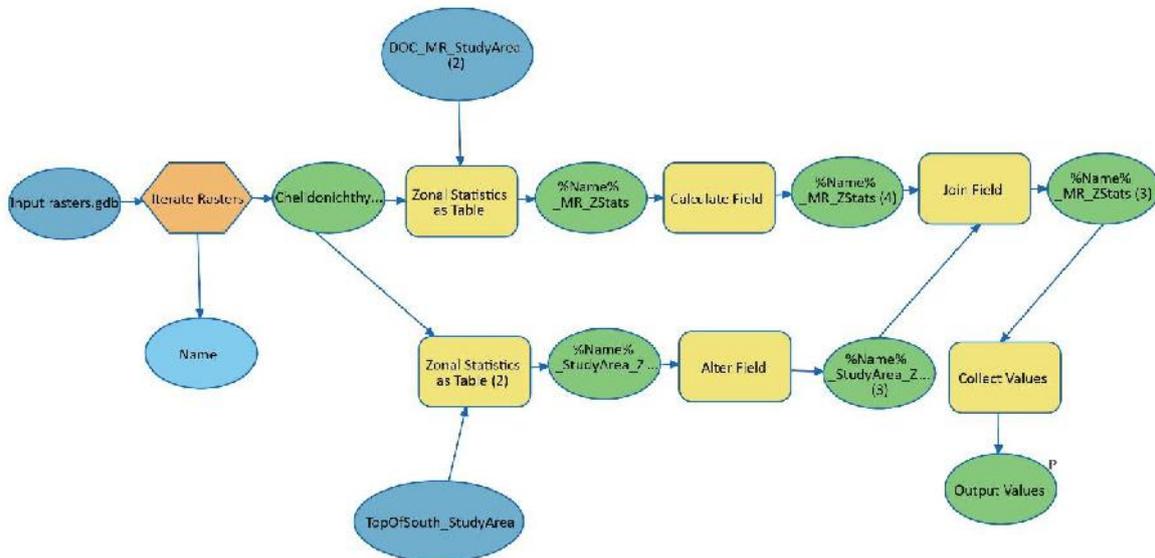


Figure 3-6: Analysis pathway for adequacy - size metric of the raster datasets. ModelBuilder analysis pathway used to calculate an evaluation metric for raster datasets under the size component of the adequacy element.

3.2.2 Adequacy – Spatial distribution

The spatial distribution metric for adequacy evaluates the distribution of MPAs within a network to assess whether they are evenly distributed throughout a planning area. The analysis uses built in functions within ArcGIS and no ModelBuilder automation is required for this evaluation metric, with the only inputs required being a polygon feature class dataset of the MPAs’ extents. A measurement for the compactness of a distribution is provided by the tool *standard distance*, which calculates the spatial spread of feature dataset around the mean centre of the of its features. The output of the *standard distance* analysis is a polygon which is typically overlaid the input features to visually identify clustered/dispersed features. Using a standard distance calculation of 1 standard deviation, approximately 63% of the features should fall within the standard distance polygon (Mitchell 2005). To assess the dispersion of each MPA within the network, we calculate a ratio between the standard distance and the measured distance between the centroid of each MPA and the mean centre for the network (calculated using the *mean centre* tool). The distance between each polygon centroid and the mean centre can be calculated using the *near* tool. MPAs that are highly dispersed have a high dispersion ratio (e.g., above 1.5), while those that are clustered around the mean centre have a low dispersion ratio (e.g., less than 0.5).

3.2.3 Adequacy – Network protection level

As per viability (Section 3.1.3), the network protection metric for adequacy can be evaluated using a matrix that describes whether the existing or proposed level of protection is sufficient to protect the key features within the MPA network. We illustrate network adequacy using a previously developed matrix that links ecological features and management interventions (Table 3-1, Lundquist et al. 2015). To quantify and visualise the adequacy of the network under varying levels of protection, we will use the same matrix of individual MPAs, ecological features and management interventions

generated under viability. The codes attributed to each feature are then merged and plotted in a single boxplot representing the spread of the protection level metrics across the entire MPA network, which can be compared against the performance standards.

3.2.4 Adequacy performance standards

For each metric, it is recommended that results of the adequacy analyses be represented as boxplots to visualise the spread of the results across the MPA network. The raw outputs of the model pathways described above provide the inputs for the boxplots, though users may wish to add their own categorical groupings (e.g., taxa/habitat classes) to partition the results (e.g., Figure 4-3).

The performance standards proposed for the adequacy-size metric are based on the proportion of ecological features found within each network, with values of 0 to 0.1 being deemed as not adequate, 0.1 to 0.3 being marginally adequate, and above 0.3 being adequate.

The performance standard proposed for the adequacy-shape metric is based on a ratio that indicates the dispersion of MPAs within a network. MPAs that are found outside of the standard distance have a ratio >1 . A 'good' measure of dispersion are those MPAs with a dispersion ratio between 0.5 and 1.5. MPAs are considered highly dispersed if they have a dispersion ratio (e.g., above 1.5), while those that are highly clustered have a low dispersion ratio less than 0.5 (e.g., less than 0.5).

The performance standards for the protection level metric are based on the codes afforded to each feature using the matrix as illustrated in Section 3.2.3, where 0 indicates no benefit of the management intervention, 1 indicates partial or limited benefits, and 2 indicates a benefit from the management intervention.

3.2.5 Adequacy decision points

- The key ecological features used as inputs for the analysis of the size and protection level metrics and whether certain feature groupings require different performance standards.
- Determining the most appropriate threshold (e.g. ROC) to use for the calculation of the adequacy – size metric using raster outputs from habitat suitability or probability of occurrence models.
- Whether the network should aim to achieve evenly distributed MPAs and thus place an emphasis on the adequacy – spatial distribution metric, or whether the protection of key features (regardless of their distribution) be prioritised.

3.3 Representativity

Representativity is the design element used to determine how well a network or individual MPA represents the various habitat classes within the planning area. The evaluation metric for this element is the proportion of each habitat class found within an MPA or a network of MPAs, out of the total found within the planning area. The metric is calculated using a defined and accepted habitat/community classification system and may be either thematic or numeric (Rowden et al. 2018). More than one classification may be used to assess the representativity of a network at different scales (e.g., the New Zealand Seafloor Community Classification (SCC) (Stephenson et al. 2021), or regional thematic classifications that report habitat types if available). The New Zealand SCC represents different communities of seafloor taxa, referred to here as "habitats". However, the relationship between the SCC's community composition and habitat types has not yet been

established. Habitat patches occurring in MPAs must be above a minimum proportion to be counted as representative. Proportion metrics are calculated for each of the selected habitats in a classification, for each MPA, and for the entire MPA network (if applicable).

The evaluation method for representativity requires habitat classification layers presented as polygon feature classes, where each habitat class is distinguished by a unique identifier in the attributes table. The model analysis pathway begins with a *feature class iterator* that iterates through each habitat classification layer in a defined geodatabase (Figure 3-7). The pathway then splits into two processes. The top process uses a *intersect* tool to identify the habitat class polygons found within individual MPAs and then applies *dissolve* to determine the area of each unique habitat contained at the level of the entire network. The bottom process similarly uses *intersect* to identify those habitat classes that occur within the planning area, adds a MPA network identifier with the tool *calculate field*, and then uses the *dissolve* tool to sum the area of each habitat class within the planning area. The processes are then joined with *join field* (using the network identifier). The proportion of each habitat classes within the planning area that is protected within the network is then calculated and the results of each iteration are collected for export.

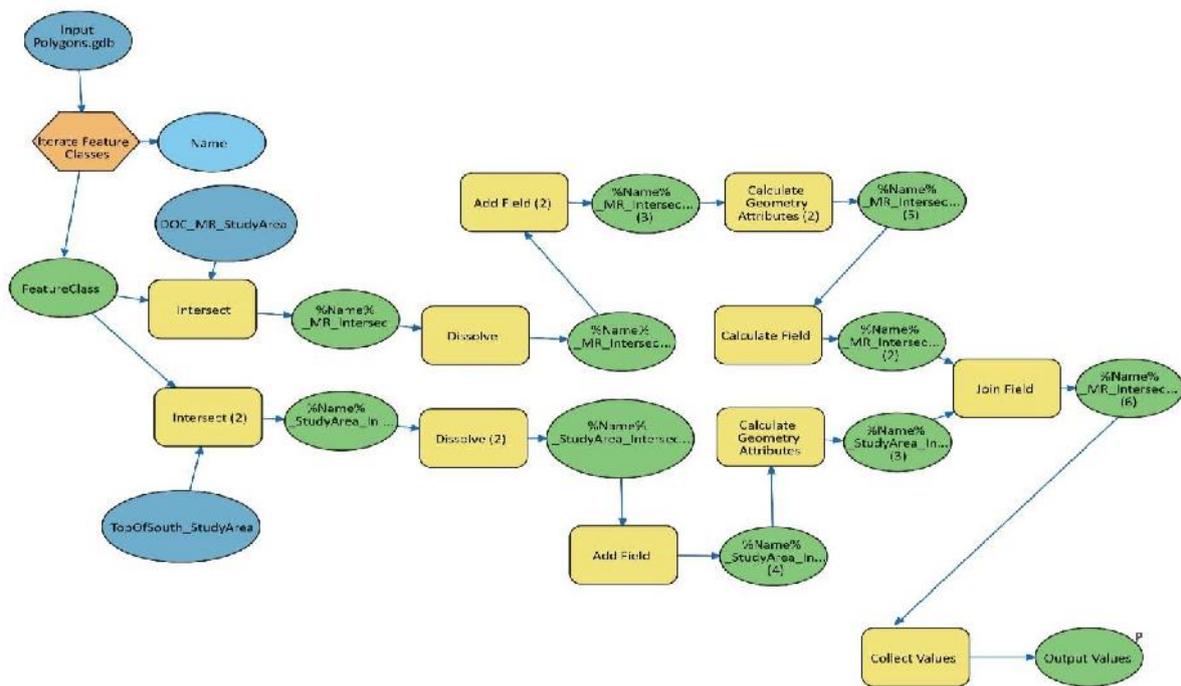


Figure 3-7: Analysis pathway for representativity design element. ModelBuilder analysis pathway used to calculate an evaluation metric the representativity design element using feature class datasets.

3.3.1 Representativity performance standards

The performance standard for the representativity metric is based on the proportion of each habitat class that is found within the MPA/MPA network. Poor representativity is defined as less than 0.05 of a habitat's distribution is protected within an MPA, adequate representativity is between 0.05 and 0.2 of a habitat distribution is protected, and good representativity is greater than 0.2. The settings of these performance standards were based on the commonly reported levels for representativeness in the literature review (column 3 Table 2-1), however their applicability to a wide range of evaluation projects remains

3.3.2 Representativity decision points

- The minimum size of habitat classes represented by polygons derived from gridded raster datasets (e.g., numerical classifications). This minimum size may need to be different for various habitats that are naturally variable in their spatial extent (e.g., seagrass vs deep fine sand)

3.4 Replication

The replication design element is represented by a metric that reports the number of times unique features representing a particular species, habitat or ecological process (e.g., ecosystem function, high productivity) occurs within the MPA network. Replication is applied to all features that are deemed to represent the ecological characteristics of the planning area – i.e., those that would be included in the evaluation of elements of viability, adequacy, representativeness and areas of importance. Replication is calculated in this study following the 2019 MPA gaps analysis (DOC 2019a), where the “the number of times habitats are represented in MPAs” is counted within a network. However, in this study, individual replicates (i.e., unique polygon or point features) are only considered replicates of a particular class if they are further than a minimum distance apart and are above a minimum size. Further, while some features may span more than one MPA within a network, a contiguous individual feature may only constitute a single replicate in a planning area. It is expected that the minimum distance between replicates will be different for particular taxa or habitat class and will require expert input during assessment (see section 3.4.2). Further, the distribution of threats may limit the number of viable replicates if stressor footprints interact with several features, negating the safeguarding/security utility of replicates. As with the viability element, replication may also be summarised hierarchically, with replication counted at the individual taxa or habitat grouping, or higher order classes of taxa or habitats (e.g., blue cod → demersal fish → species hotspots). It is assumed that replicates will generally be represented as polygon and point datasets (noting that raster datasets can be converted to polygons if needed, i.e., see section 3.3); we have developed different evaluation methods for each format.

Polygon datasets

The model pathway for replication using polygons begins with a *feature class iterator* that iterates through each polygon dataset in a defined geodatabase (Figure 3-8). The *intersect* tool is then used to extract the features that overlap with the MPA network. The *dissolve* tool then merges polygon features that overlap multiple MPAs, so that they count as a single replicate. Next, the *aggregate polygons* tool is applied which combines replicates of features within a prescribed distance and provides an option for a minimum replicate size. A field describing the value of the replicate (all with individual values of 1) is then added using *add field* and *calculate field*, and a final *dissolve* is used

across all features which sums the replicate values. The results from each polygon feature are then collated for export (Figure 3-8). As per viability and adequacy, an optional buffer tool can be used to represent the home-range size of species specific replicates when polygon features represents species presences (and not range).

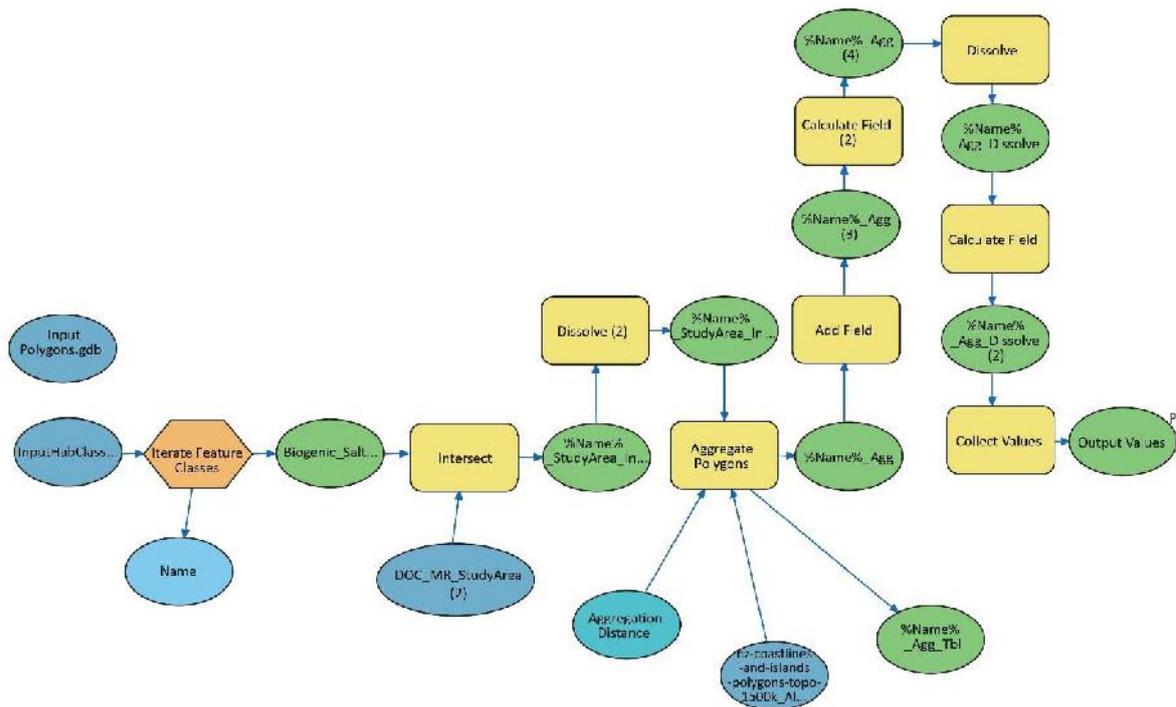


Figure 3-8: Analysis pathway for replication design element - polygon data. ModelBuilder analysis pathway used to calculate an evaluation metric for replication using polygon datasets.

Point datasets

The model pathway for replication using point datasets begins with a *feature class iterator* that iterates through each point dataset in a defined geodatabase (Figure 3-9). Point datasets are intersected with the MPA network to extract points that overlay the MPA or MPA network to represent ‘replicates’ – points outside the network are discarded. Next, the *buffer* tool is used to build polygons around each point to identify replicate features closer than a minimum distance to each other and the *dissolve* tool is used to merge replicates within the minimum distance into single features (i.e., multi-part polygons). Replicates can only occur once in a given MPA. A replicate value (1) is then added to the attribute table for each unique feature replicate using the *add field* and *calculate field* tools. The final replicates are then *dissolved* by a unique MPA network (or individual MPA code) to calculate the total number of feature replicates. The true number of replicates is the number of feature occurrences minus one (as a single occurrence is 0 replication). The name of the point dataset is added to the attribute tables with *calculate field* and the results are collated for export. As per viability and adequacy, an optional buffer tool can be used to represent the home-

range size of species specific replicates when point data represents species presences (and not range).

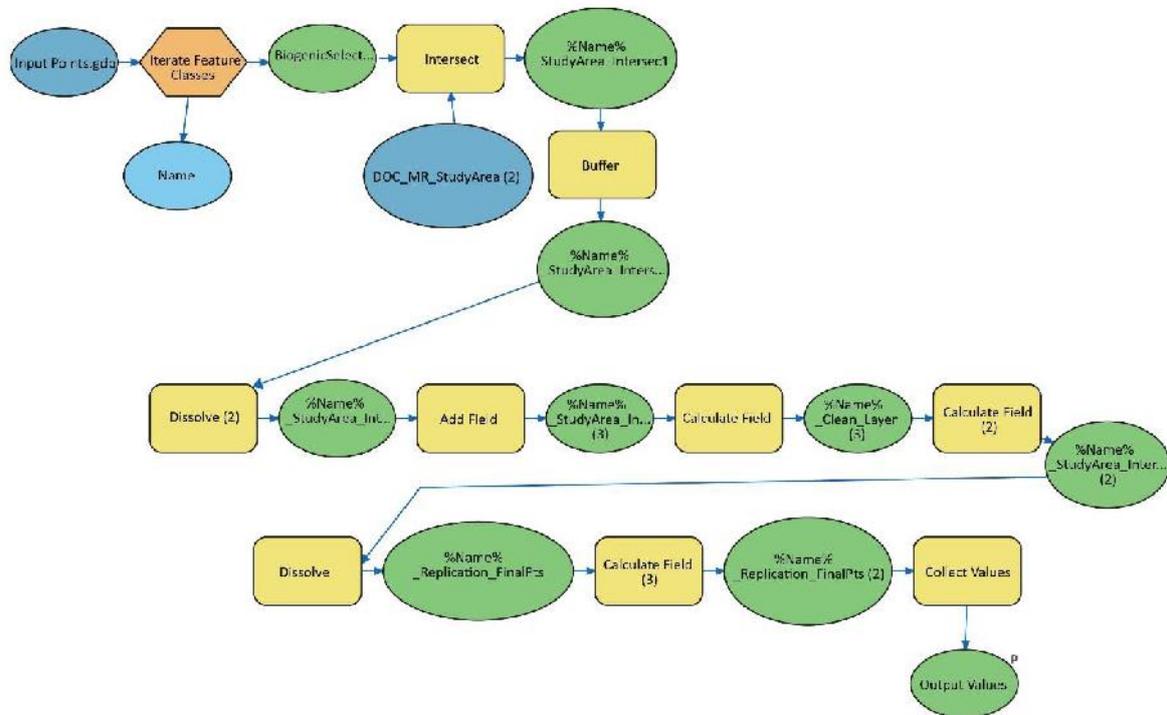


Figure 3-9: Analysis pathway for replication design element - point data. ModelBuilder analysis pathway used to calculate an evaluation metric for the replication element using point datasets.

3.4.1 Replication performance standards

The performance standards for the replication element are based on the total number of replicates for each ecological feature within the MPA network. Note that a replicate is defined as multiple occurrences of an ecological feature, so features with a single occurrence in the network represents zero replication. Zero replication is categorised as poor, a single replicate is adequate and more than two is considered good replication. As per the previous design elements, results for replication are plotted as boxplots against the performance standards and can be summarised at the level of individual taxa or habitat classes, taxa or habitat groupings or replication across all features.

3.4.2 Replication decision points

The calculation of replication metrics and subsequent comparison against the performance standards will be strongly influenced by the minimum size and distance apart values as well as the quality/distribution of data used for evaluation. Thus, careful consideration should be given to these settings and expert input should be sought to develop the best values for a particular evaluation. Specific decision points are:

- For ecological features represented as polygons, should replicates only be considered if they are above a minimum size and if so, what should that minimum size be?
- What is the minimum distance apart for ecological features within the same class to be counted as individual replicates for polygons and points features?

3.5 Areas of Importance

The areas of importance design element is evaluated by a metric that calculates the proportion of the area of defined ‘important areas’ occurring within a MPA or MPA network out of the total area within the planning area. Areas of importance are recognised features that have a high conservation priority as identified by the Key Ecological Area criteria (e.g., hotspots for key species, rare habitats, threatened taxa records). The areas of importance metric is calculated similar to the adequacy design element, though the input layers reflect important areas rather than biodiversity more generally. The areas of importance metric is hierarchical and can be summarised at the level of individual taxa or habitats, taxa or habitat groupings, or across all input features. It is assumed that important areas will be generally represented as polygons where their extents are well defined, though point features for discrete areas with poorly defined or small extents may also be used (e.g., seabird colonies). We provide evaluation metrics for both data formats as in previous design elements.

Polygon datasets

For polygon datasets, the analysis pathway begins with a *feature class iterator* that iterates through each dataset in a defined geodatabase (Figure 3-10). The pathway then splits into two parallel processes where the polygons are *Intersected* with either the MPA network (top pathway) or with the planning area (e.g., TopOfSouth_StudyArea). New fields are then added to calculate the area (m²) of each important area found within MPAs (top process) or within the planning area (bottom process) using the *add field* and *calculate geometry* tools. The pathways are then rejoined (*join field*) based on the network ID, a further *dissolve* is applied to sum the area of features that occur across multiple MPAs in a network and the feature layer name is added to the attributes tables. The results for each polygon dataset are then collated for export and the proportion of the area found within the network calculated.

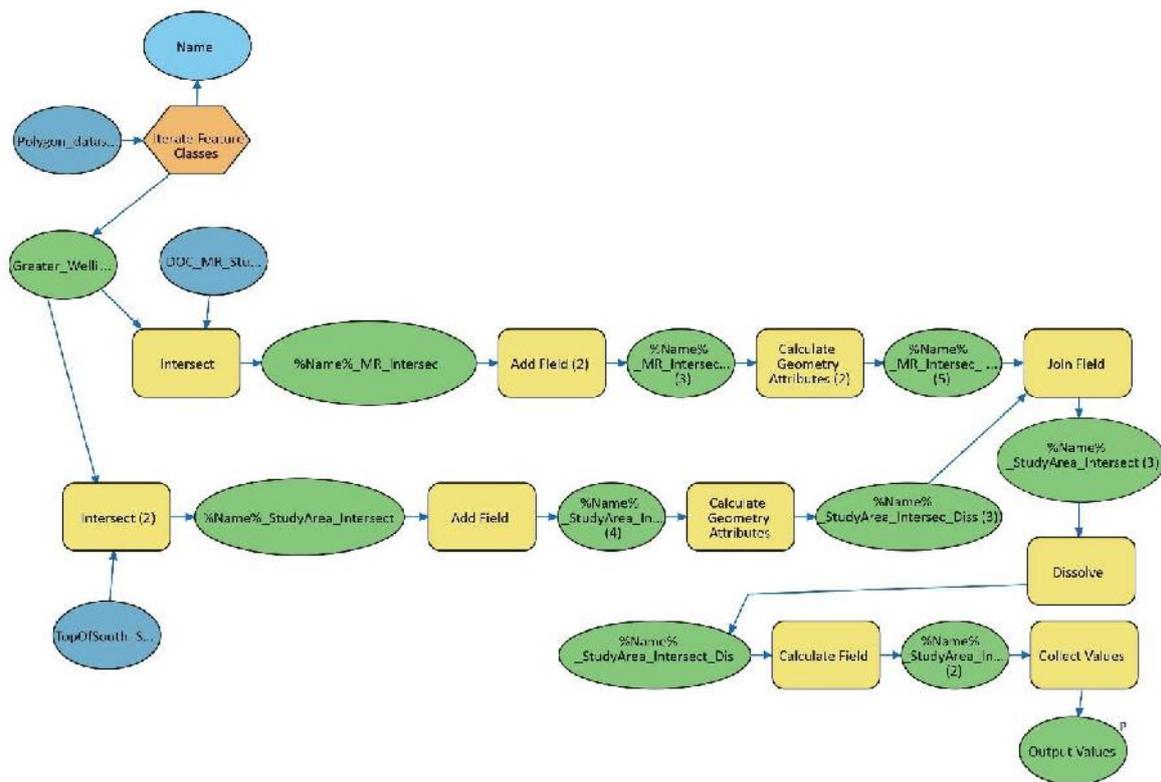


Figure 3-10: Analysis pathway for areas of importance design element - polygon data. ModelBuilder analysis pathway used to calculate an evaluation metric for the areas of importance element using polygon datasets..

Point datasets

The analysis pathway for point datasets under the areas of importance element similarly begins with a *feature class iterator* which iterates through each point dataset in a defined geodatabase (Figure 3-11). The pathway then splits into two parallel processes, where the top process determines the points that are found within the MPA or MPA network and the bottom process identifies all point features found within the planning area (via the Spatial join) tool. The MPA network pathway then sums all the point features found within the network with a *dissolve* tool and adds the feature dataset's name to the attribute table with *calculate field*. The field within the planning area dataset that holds the sum of all points is altered to 'sum_StudyArea' using the *alter field* tool and the two processes are joined (*join field*) allowing the calculation of the proportion of point features found within the network. The results of each iteration are then collated for export. As per viability and adequacy, an optional buffer tool can be used to represent the home-range size of species specific areas of importance when point data represents species presences (and not range).

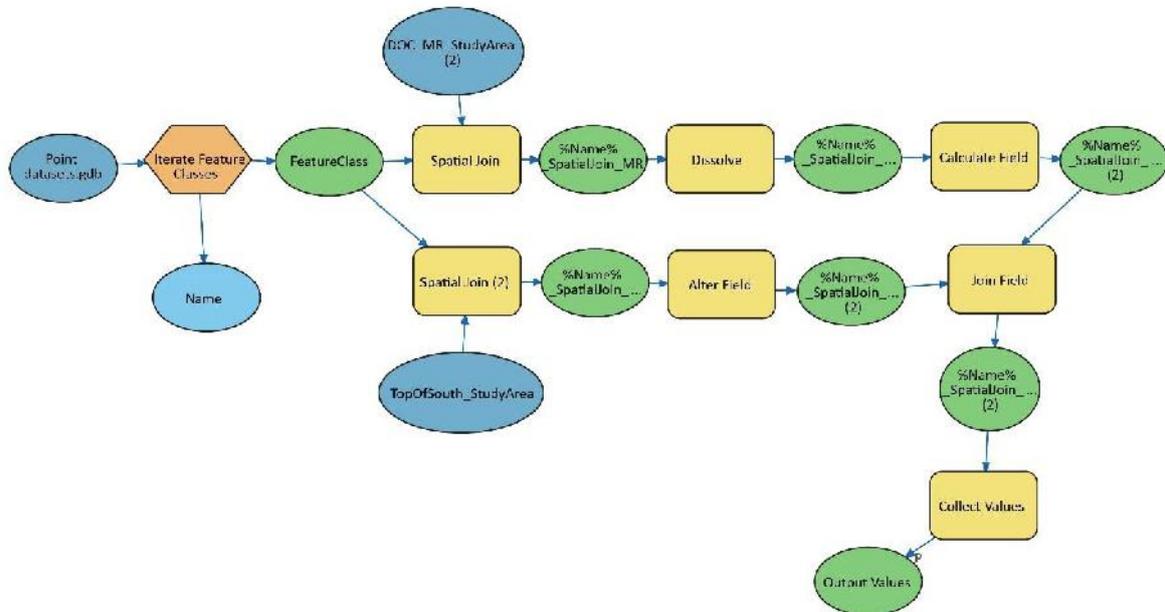


Figure 3-11: Analysis pathway for the areas of importance element - point data. ModelBuilder analysis pathway used to calculate an evaluation metric for the areas of importance element using point datasets.

3.5.1 Performance standards

The performance standard for the areas of importance metric is based on the proportion of the areal overlap between areas of importance and the MPA or MPA network, with values of 0 to 0.1 being deemed as not poor, 0.1 to 0.3 being satisfactory, and above 0.3 being good. The results for areas of importance are plotted as boxplots against the performance standards and can be summarised at the level of individual taxa or habitat classes, taxa or habitat groupings or replication across all features.

3.5.2 Areas of importance decision points

- The majority of the decision points around the areas of importance metric centre on the data layers to be used to represent such areas, and how they are to be formatted. Ideally these would be developed through using the Key Ecological Area criteria through the DOC KEA work programme.
- How should land-based areas of importance be incorporated (e.g., seabird and pinniped colonies)? It is simple to extend a search area for the *spatial join* tool to count point features that occur on land adjacent to MPAs, but there is a decision point on the maximum search distance.

3.6 Connectivity

The extent of ecological connectivity among MPAs in a network is complex, with a myriad contributing factors including species-specific adult, juvenile and larval dispersal distances, variable current flow direction, migratory corridors, etc. For most species and habitats there is limited information on the factors which could be used to develop accurate metrics for connectivity. Thus, in the absence of such information, we calculate connectivity based on the simple assumption that closer MPAs will have greater connectivity than those further apart. The distance between each MPA in a network is calculated using a minimum cost-path analysis based on Euclidean distance within ArcGIS Pro. Due to there being few datasets involved, and no need to automate the analysis, there is no ModelBuilder toolbox developed for the connectivity design element. Instead, we provide instructions on the calculation of the connectivity metrics using an analysis routine in ArcGIS Pro.

First, a barrier to prevent the cost path analysis from calculating distances over terrestrial habitat must be generated. This can be achieved by converting a *feature class* 'basemap' that denotes the presence of land (e.g., the NZ Coastlines and Islands Polygon from the LINZ data service) to a raster by using the *polygon to raster* tool. Data cells in this raster act as 'barriers' to the cost-path analysis. Ensure the *value* field in this tool identifies a field with a single value for each feature; such a field can be added to the attributes table using *Calculate field* if necessary.

Next, use the *Euclidean distance* tool to calculate raster surfaces that represent the increasing distance between MPAs on a cell by cell basis, include the 'barriers' raster dataset in this analysis to prevent distances being calculated over land. This tool also generates a 'back-direction' raster for each MPA that points to the shortest path as it passes through individual cells. Following this, the *cost path as polyline* tool is employed, using the 'Euclidian distance' and 'back-direction' rasters for each MPA, to calculate the distance between each combination of MPAs within the network. The output of this cost-path analysis is a poly-line feature class with the path of minimum distance between MPAs, for each MPA. These features can be exported as tables for further analysis and plotting of results.

Proposed metrics to evaluate the connectivity design element are: 1) the minimum distance between MPAs and their nearest neighbour (*min_distance*); and 2) a metric of the number of neighbours within 100 km for each MPA (*n_neighbours*). The metrics are hierarchical, with 2) being a sub-metric that reports in more detail which MPAs that have higher connectivity. Both metrics can be summarised at the level of the individual MPA or across an entire MPA network.

3.6.1 Connectivity performance standards

The performance standards for the connectivity design element are based on recommendations for a minimum distance between MPAs to ensure ecological connectivity (see column 5, Table 2-1). For metric 1 (min_distance), an MPA is considered to have poor connectivity if the distance to its nearest neighbour is greater than 150 km, marginal connectivity if the nearest neighbour is within 100 - 150 km, and good connectivity if the nearest neighbour is less than 100 km.

For metric 2 (n_neighbours) an MPA has poor connectivity if there are no MPAs within 100 km, has marginal connectivity if there are 1 – 2 MPA neighbours within 100 km, and good connectivity if there are >2 MPA neighbours within 100 km. However, these performance standards are subjective and intended for illustrative purposes.

3.6.2 Connectivity decision points

- When available, whether to use current flow direction as a cost path or not. Using this is primarily relevant for larval connectivity, while connectivity should also incorporate movement of adults and juveniles (including large mobile species) where current flow is less relevant. See Section 6.1 for additional explanation.
- The selection of minimum distance values within the performance standards (e.g., 100 km). Minimum distance values should differ depending on marine settings (estuarine – oceanic), and could be tailored to evaluate connectivity for specific species and habitat.

3.7 Integration

The integration design element calculates the degree of overlap between a MPA and other forms of spatial management and conditions of naturalness that may have an influence on the biodiversity values of the MPA. Three metrics are calculated under integration that describe the degree of overlap between a MPA and: 1) marine-based management; 2) land-based management; and 3) with areas of high/low naturalness. For marine-based management, polygons for existing management classes must intersect or be within a set distance of an MPA (e.g., 1 km). Marine-based management is diverse, so only features that directly complement an MPA's objectives should be included within the evaluation. For land-based management, the catchment area of each MPA will be generated using spatial watershed data (see Appendix A). The overlap between an MPA's catchment and polygons for land-based management that enhance MPA benefits (e.g., by reducing sedimentation) will be considered as integration. Integration with areas of high/low naturalness (depending on whether MPA objectives are conservation or restoration) will be assessed by generating areas of high/low naturalness from spatial footprints of marine stressors. These areas will be obtained from raster footprints by thresholding the top or bottom percent (e.g., 10%) of the values and converting these areas to polygons. Occurrence of these high/low naturalness zones within a set distance (1km in this example) of an MPA will count as integration with naturalness.

Marine integration

The analysis pathway for the calculation of metrics to evaluate the integration of MPAs with existing marine management begins with a *feature class iterator* that iterates through a defined geodatabase containing polygon features for different marine management classes (Figure 3-12). The pathway then splits, where the top path calculates the proportion of each MPA that overlaps the various management classes. The bottom path determines the MPAs that are adjacent to management. The

overlap pathway performs an *intersect* analysis using the MPA feature class dataset as an intersect feature. The intersection is then *dissolved* based on MPA ID to combine results for each MPA and calculate the proportion of the MPA area that overlaps with management. The results are then exported.

The bottom pathway uses a *spatial join* to determine the management polygons that are within a set distance and joins their attributes to the MPA feature class. *Dissolve* is then used to count the number of adjacent management features by MPA ID and *calculate field* adds the name of the management class to the attributes table. The metric for integration is the number of management polygons within a set distance (1km in this case) of each MPA. The results of each management class iteration are then collected for export.

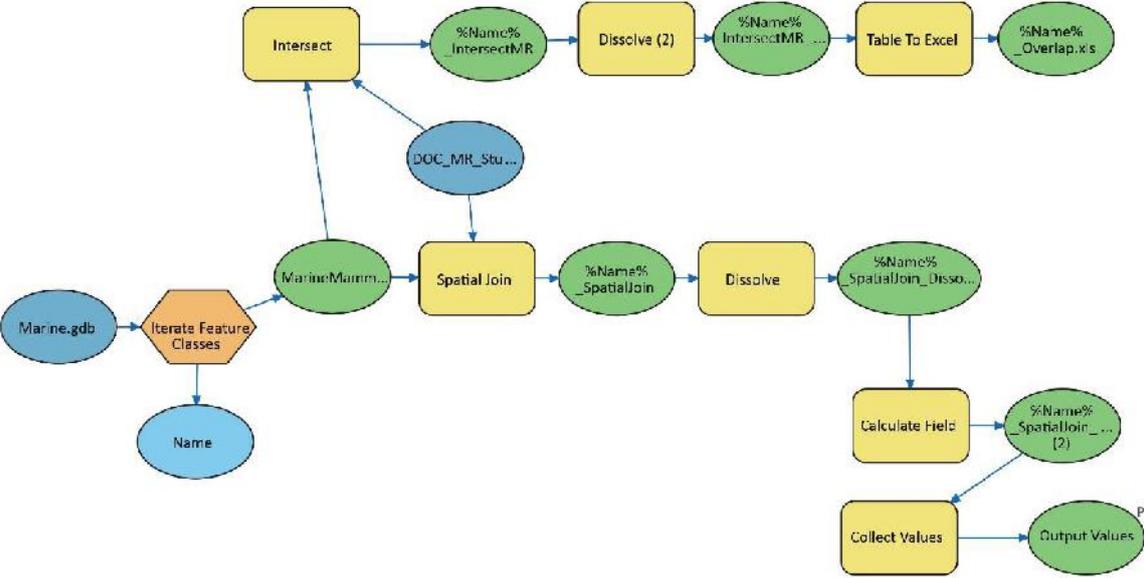


Figure 3-12: Analysis pathway for the connectivity element - marine. ModelBuilder analysis pathway used to calculate an evaluation metric for marine management for the integration element.

Terrestrial integration

The analysis pathway for terrestrial integration begins with a *feature class iterator* that iterates through a defined geodatabase containing separate polygon feature datasets for each terrestrial management class (Figure 3-13). The analysis then performs an *intersect* between each management class dataset at the catchment area for each MPA (predefined see Appendix A). The total area of the catchment that overlaps the terrestrial management class is added to the attribute table using *add field* and *calculate field* tools. The results are then *dissolved* by MPA ID to sum the total overlap area by MPA and the name of the management class is added to the attributes table with *calculate field*. An optional step can further use the *dissolve* tool to sum the cumulative proportion of an MPA’s catchment that is protected across all terrestrial management classes. The results of each iteration are then collated for export.

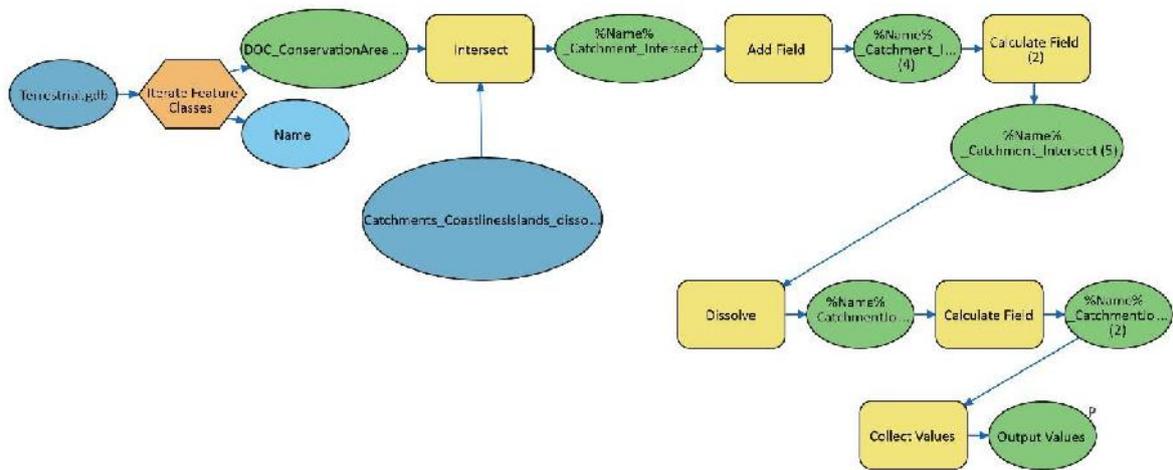


Figure 3-13: Analysis pathway for the integration element - terrestrial. ModelBuilder analysis pathway used to calculate an evaluation metric for terrestrial management for the integration element.

Naturalness

The analysis pathway to determine the integration of the MPA/MPA network with areas of high or low naturalness begins with a *feature class iterator* that iterates through a defined geodatabase that contains feature class polygons (defined from raster stressor footprints, see above) that describe the extent of the naturalness areas (Figure 3-14). A *spatial join* determines the naturalness polygons that are within a set distance of each MPA and joins their attributes to the MPA feature class. *Dissolve* is then used to count the number of adjacent naturalness features by MPA ID and *calculate field* adds the name of the management class to the attributes table. The metric for naturalness integration is the number of naturalness polygons within a set distance (1km in this case) of each MPA. The results of each management class iteration are then collected for export.

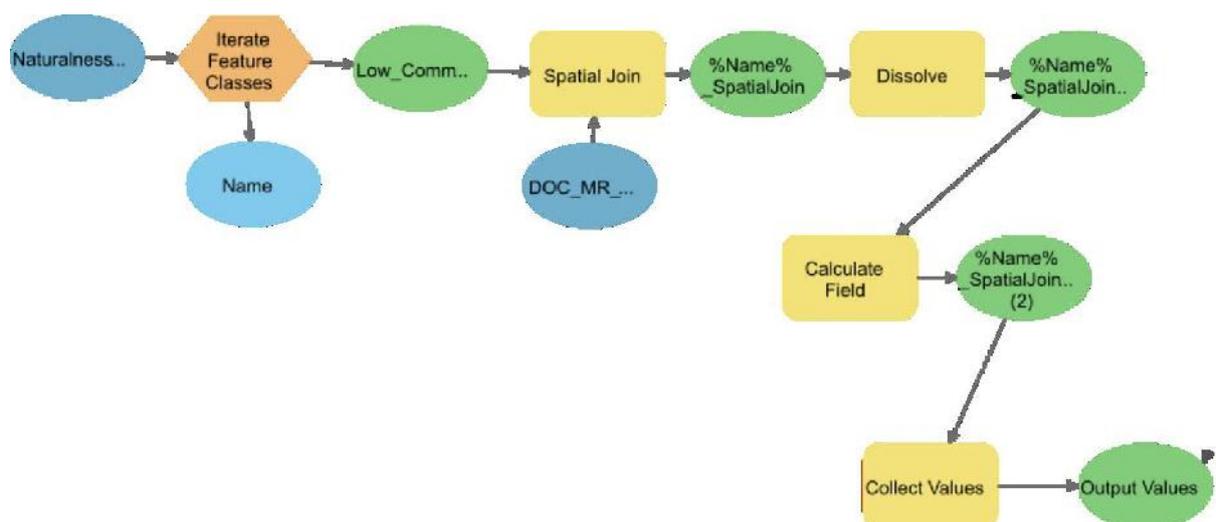


Figure 3-14: Analysis pathway for the integration element - naturalness. ModelBuilder analysis pathway used to calculate an evaluation metric for naturalness areas for the integration element.

3.7.1 Integration performance standards

Performance standards for the marine management and naturalness metrics of the integration element are based on the number of zones (either alternative management or naturalness areas) within a set distance from each MPA. This distance may need to be refined by the characteristics of MPAs (e.g., size) or to account for variability in the distance over which influences from various types of zone may persist. For the examples presented here, we consider MPAs with zero management or naturalness zones within 1km as poorly integration, a single zone as marginal integration and with more than two zones as good integration.

As performance standards for the terrestrial integration metric, poor integration is categorised as <0.1 of an MPA's catchment area overlapping with terrestrial management likely to mitigate terrestrial impacts on the nearshore environment, <0.5 of a catchment is categorised as marginal integration, and >0.5 of a catchment is categorised as good integration.

As with the performance standards for the previous elements, the settings for integration are subjective and intended for illustrative purposes. While the current settings were developed in consultation with the MSAG, further research should strive to develop performance standards that are meaningful for biodiversity protection (see Section 6-1).

The results of the three integration metrics will be provided at the level of individual MPAs within a network, however they can be merged to provide an indication of integration across an entire network. Additionally, the individual metrics can be reported at the level of individual management types (e.g., marine mammal sanctuaries, customary management areas for marine management) or combined across all management types.

3.7.2 Integration decision points

- Determination of the maximum distance for the identification of 'adjacent' marine management or naturalness areas for the calculation of the integration – marine and integration – naturalness metrics. This distance may vary by MPA or management/naturalness characteristics.
- Terrestrial management may not be relevant for some networks/MPAs (i.e., those that are far from shore and have no defined catchment).
- For both marine and terrestrial integration, there should be careful consideration of the management classes that benefit biodiversity within nearshore marine environments. There is limited evidence of benefits for marine biodiversity for most management classes.

4 Case study 1: Wider Cook Strait - Regional MPA Network

The wider Cook Strait was selected as a case study to represent a regional MPA network and illustrate how the design elements could be used at a regional scale. In this area there are several marine reserves already in existence; however, they were not originally designed as a network and the 'planning area' is purely hypothetical (Figure 4-1). It is important to acknowledge that changes in the extent of this planning area may significantly influence the calculation of the metrics. Additionally, the datasets used to calculate each metric are illustrative only and decisions about which datasets to include in the analysis substantially alter the calculation of each metric.

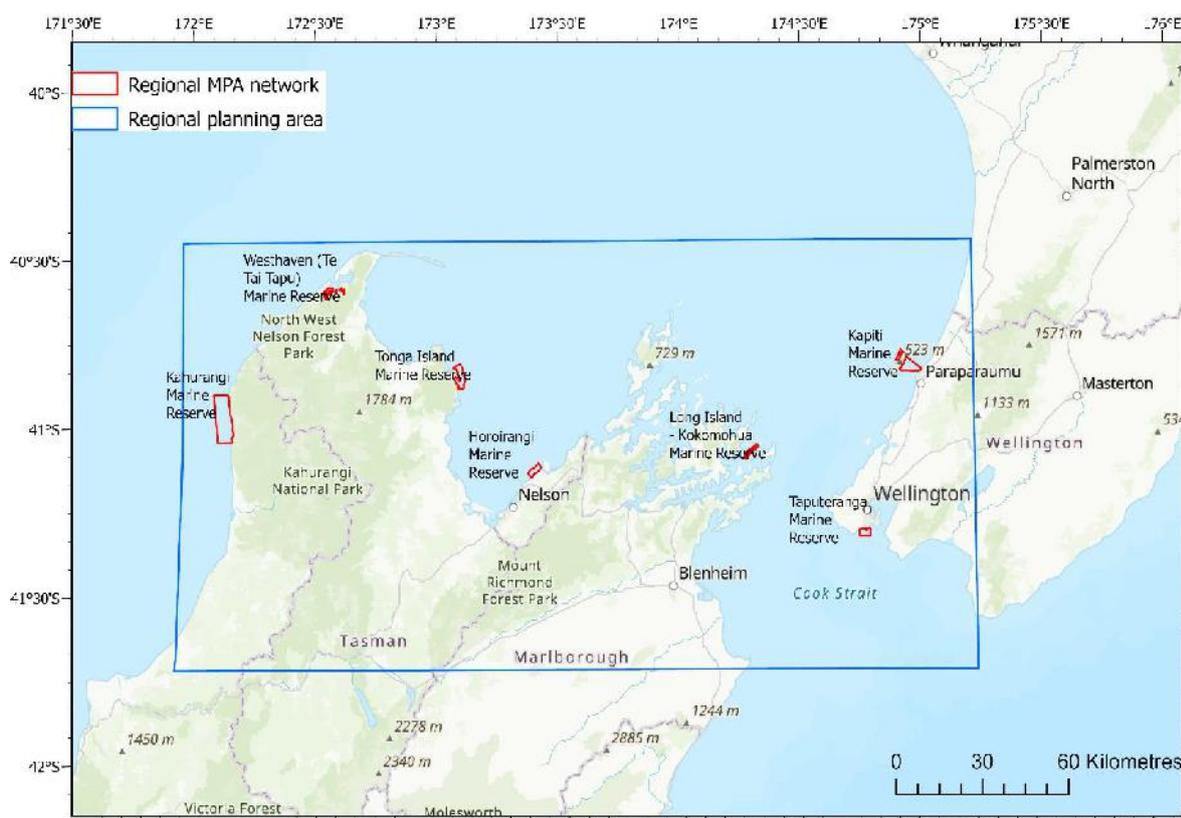


Figure 4-1: Wider Cook Strait Regional Case study. The planning area is outlined in blue. Existing marine reserves areas are outlined in red.

4.1 Viability

4.1.1 Datasets

The evaluation of viability for the regional marine reserve network case study included the use of datasets representing species and habitat of cultural, recreational and commercial value that occur within the planning area, and within the marine reserves in the network (Table 4-1). Key ecological features were selected representing species (e.g., demersal fish, macroalgae) and habitat classes (e.g., biogenic, physical). We also chose to represent ecological features in different data formats to showcase how viability can be evaluated using different input datasets.

For datasets available in gridded raster formats (e.g., predictions from habitat suitability models), we used the process illustrated in Figure 3-3 to classify rasters into suitable habitat based on ROC thresholds, with the rasters subsequently being converted to polygons in order to represent discrete ecological features.

Table 4-1: Datasets for viability-size for the wider Cook Strait region. A summary of the datasets used to calculate the size component of the viability design element for the regional marine reserve network case study.

Metric	Dataset	Data format	Species/habitat class	No. layers in dataset	Comment
Viability - size	Key biogenic habitats	Point	Biogenic	3	Rhodoliths, algal meadows
Viability - size	DOC MPA habitat classification	Polygon	Biogenic/physical	60	Multiple habitat types
Viability - size	Blue cod - HSI model	Raster/Polygon	Demersal Fish	1	
Viability - size	Gurnard - HSI model	Raster/Polygon	Demersal Fish	1	
Viability - size	Endemic invertebrates	Point	Invertebrates	>1000 sp	
Viability - size	Celleporina (bryozoan) - HSI model	Raster/Polygon	Invertebrates	1	
Viability - size	Scallop - HSI model	Raster/Polygon	Invertebrates	1	
Viability - size	Carpophyllum - HSI model	Raster/Polygon	Macroalgae	1	
Viability - size	Macrocystis - HSI model	Raster/Polygon	Macroalgae	1	
Viability - size	Blue moki - HSI model	Raster/Polygon	Reef Fish	1	
Viability - size	Butterfish - HSI model	Raster/Polygon	Reef Fish	1	
Viability - size	Rock lobster - HSI model	Raster/Polygon	Invertebrates	1	
Viability - size	Regional council listed seabird sites	Point	Seabirds	41 sp	

The shape metric of the viability design element was calculated using a feature class dataset of the polygon extents for each MPA within the network. Information used to calculate the protection level metric of the viability element is summarised in Section 3.1.3, and was used to create a matrix of ecological features vs protection scores.

4.1.2 Metrics

The evaluation metric for the size component of viability demonstrated marine reserves in the regional case study were variable in terms of the proportion of key features that occurred within them (Figure 4-2). Other than for the Kokomohua Marine Reserve, the median viability metric was considered 'good' by our performance standards for all MPAs in the network. However, the lower quantile of the metrics extended into poor viability for Kapiti Marine Reserve, and each reserve was non-viable for at least one of the ecological features assessed.

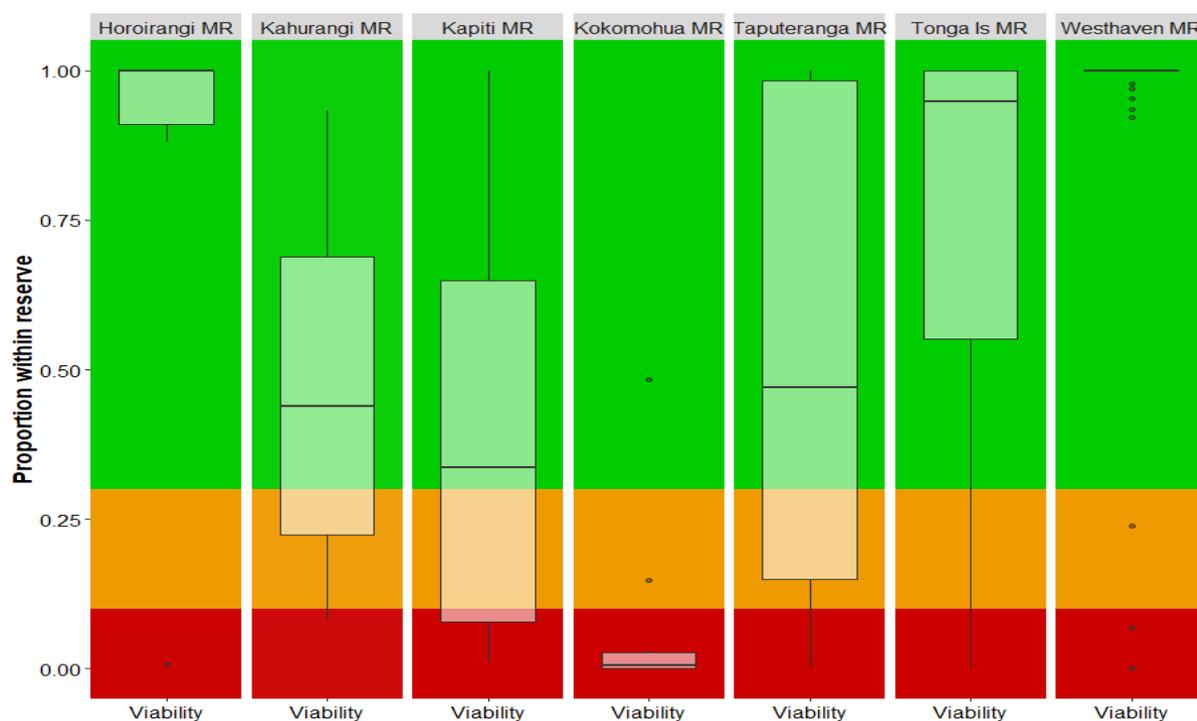


Figure 4-2: Viability-size for the wider Cook Strait region. An assessment of viability for the size metric for individual marine reserves in the regional network including all ecological features. The background colouring of the plot indicates the range of the performance standard associated with the viability – size metrics; where red is poor viability, orange is marginal viability and green is viable.

Grouping the viability-size metrics into either species or habitat classes illustrate variability among MPAs in terms of their viability for features that represent habitats or species (Figure 4-3). Viability-size metrics are lower for species features at Kapiti, Westhaven and Tonga Island Marine Reserves and is likely a function of the larger home range sizes required by the species present relative to the size of the reserves. Viability was low for both species and habitat groups at Kokomohua Marine Reserve. Note, the habitats assessed had no occurrence at either Horoirangi or Kahurangi Marine Reserves.

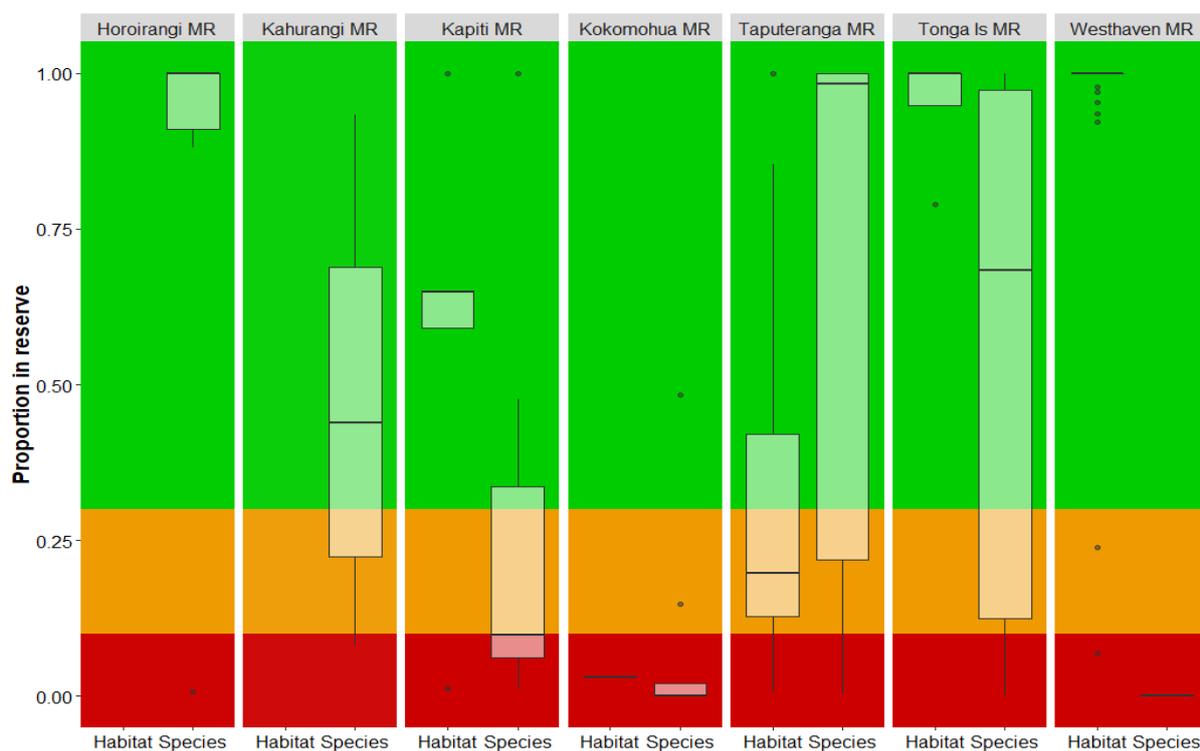


Figure 4-3: Viability-size for the wider Cook Strait region by species and habitat. Evaluation of the size metric for the viability element across all ecological feature grouped into either species or habitat classes, for each MPA in the regional network. The background colouring of the plot indicates the range of the performance standard associated with the viability – size metrics; where red is poor viability, orange is marginal viability and green is viable.

The viability-size metric can be further partitioned to evaluate performance across individual taxa or habitat classes which may be useful in determining where gains need to be made in terms of protecting species features (Figure 4-4). As an example, the Taputeranga Marine Reserve is viable for invertebrates (with the exception of rock lobster), marginally viable for fish and macroalgae and is not viable for seabirds.

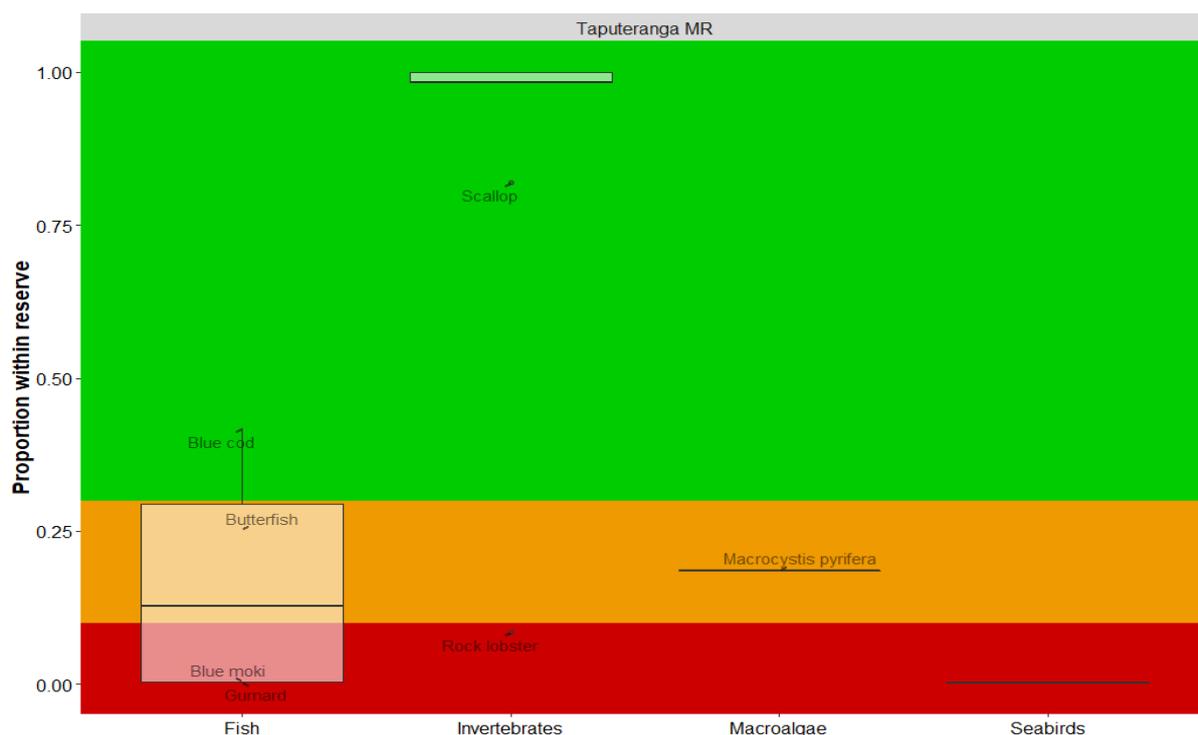


Figure 4-4: Viability-size for the Taputeranga Marine Reserve by taxa groups. Summary of the evaluation of the size metric of the viability element showing a subset of data for Taputeranga Marine Reserve and grouped by individual taxa classes. The background colouring of the plot indicates the range of the performance standard associated with the viability – size metrics; where red is poor viability, orange is marginal viability and green is viable. The position viability of Taputeranga for six key species within the broader taxonomic groups is given for illustrative purposes.

The shape component for the viability element shows some variability among the marine reserves in the regional network (Figure 4-5). Two MPAs have area to boundary ratios that indicate a viable shape, four marine reserves are marginally viable and one marine reserve (Kokomohua) has a non-viable shape.

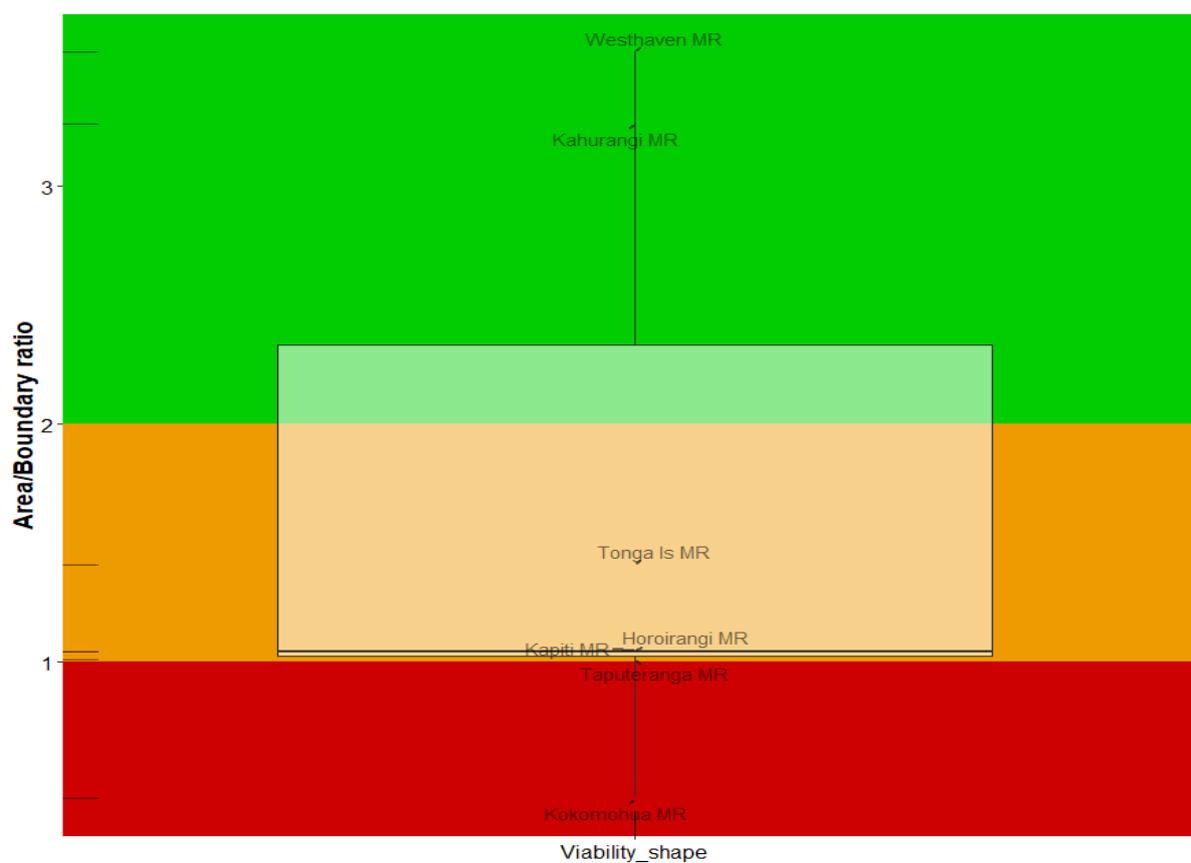


Figure 4-5: Viability-shape for the wider Cook Strait region. Summary of the evaluation of the shape component of the viability element for each marine reserve within the regional network. The background colouring of the plot indicates the range of the performance standard associated with the viability – shape metric; where red is poor viability, orange is marginal viability and green is viable. The distribution of each MPA according to this metric is also overlaid.

The protection level component for the viability element shows that each marine reserve in the regional network is a fully no-take, type 1 MPA and is viable in terms of the level of protection afforded to its ecological features.

4.2 Adequacy

4.2.1 Datasets

The evaluation of adequacy for the regional marine reserve network case study included the use of datasets representing key species (e.g., demersal fish, macroalgae) and habitats (e.g., biogenic, physical) of cultural, recreational and commercial value that occur within the planning area, but not necessarily within the marine reserves (as was assessed with the viability metric) (Table 4-2). We also chose to represent key species and habitats in different data formats to showcase how adequacy can be evaluated using different input datasets. For datasets available in gridded raster formats (e.g., predictions from habitat suitability models), there is no need to distinguish discrete ecological features from the continuous surfaces as we are not solely concerned with features that overlap with MPAs (as per the viability metric). However, it is recommended that predictions from habitat suitability receive some thresholding (see section 2.1) before being applied in this design element.

Table 4-2: Datasets for adequacy-size for the wider Cook Strait region. A summary of the datasets used to calculate the size component of the adequacy design element for the regional marine reserve network case study.

Metric	Dataset	Data format	Species/habitat class	No. layers in dataset	Comment
Adequacy - size	Key biogenic habitats	Point	Biogenic Habitats	3	Rhodoliths, algal meadows
Adequacy - size	DOC MPA habitat classification	Polygon	Biogenic/physical	3	Subset of biogenic habitats
Adequacy - size	Gurnard spawning habitat	Polygon	Demersal Fish	1	
Adequacy - size	Blue cod - HSI model	Raster	Demersal Fish	1	
Adequacy - size	Gurnard - HSI model	Raster	Demersal Fish	1	
Adequacy - size	Endemic Invertebrates	Point	Invertebrates	>1000 sp.	
Adequacy - size	Scallop - HSI model	Raster	Invertebrates	1	
Adequacy - size	<i>Carpophyllum</i> - HSI model	Raster	Macroalgae	1	
Adequacy - size	<i>Macrocystis</i> - HSI model	Raster	Macroalgae	1	
Adequacy - size	Blue moki - HSI model	Raster	Reef Fish	1	
Adequacy - size	Butterfish- HSI model	Raster	Reef Fish	1	
Adequacy - size	Regional council listed seabird sites	Point	Seabirds	41 sp	
Adequacy - size	Rock lobster – HSI	Raster	Invertebrate	1	

The shape metric of the adequacy design element was calculated using a feature class dataset of the polygon extents for each MPA within the network.

Information used to calculate the protection level metric of the adequacy element is summarised in Section 3.2 and was used to create a list of ecological features vs protection scores.

4.2.2 Metrics

The evaluation of the size metric of adequacy for the regional case study demonstrates that the network is largely inadequate to protect the features found within the planning area (Figure 4-6). With the exception of one ecological feature (biogenic habitat), the proportions of all features found within the MPA network were less than 0.1.

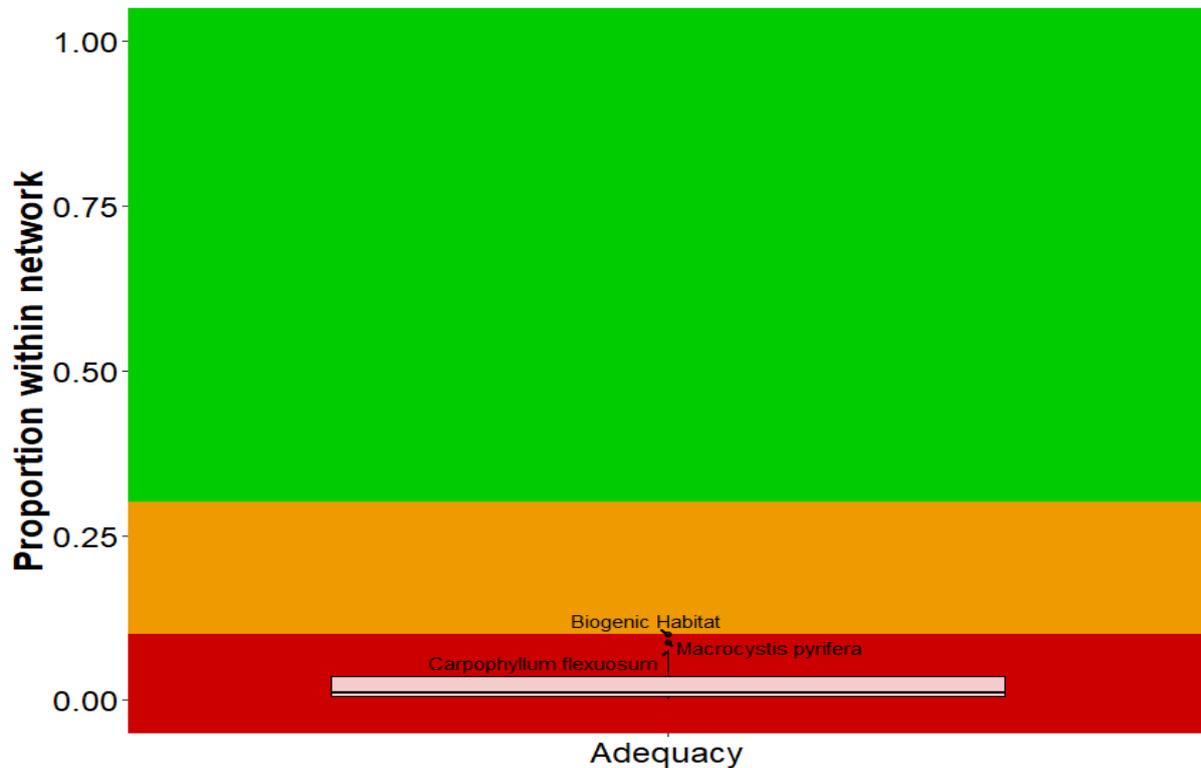


Figure 4-6: Adequacy-size for the wider Cook Strait region. Evaluation of the size component of the adequacy element with data pooled across all ecological features and the entire regional marine reserve network. The background colouring of the plot indicates the range of the performance standard associated with the adequacy – size metric; where red is not adequate, orange is marginal adequacy and green is adequate. Key habitat/species are overlaid for illustrative purposes only.

The metrics used to evaluate the spatial distribution of the regional network suggest the reserves are generally equally distributed within the study area, with no reserves being highly dispersed (dispersion ratio > 1.5 (Figure 4-7)). Two reserves (Tonga Island and Horoirangi) are relatively clustered around the mean centre of the distribution indicating that these reserves could be more equally distributed within the study area.

The metrics that summarise the level of protection component of the adequacy element show that the network provides an adequate level of protection to promote the conservation of its ecological features. This protection level is due to each marine reserve within the network being a Type 1 Marine Reserve, the highest level of protection. A single feature has a score of 1 (marginally adequate protection); this score is for a wide-ranging seabird species that would spend limited time in a static Marine Reserve (Figure 4-7).

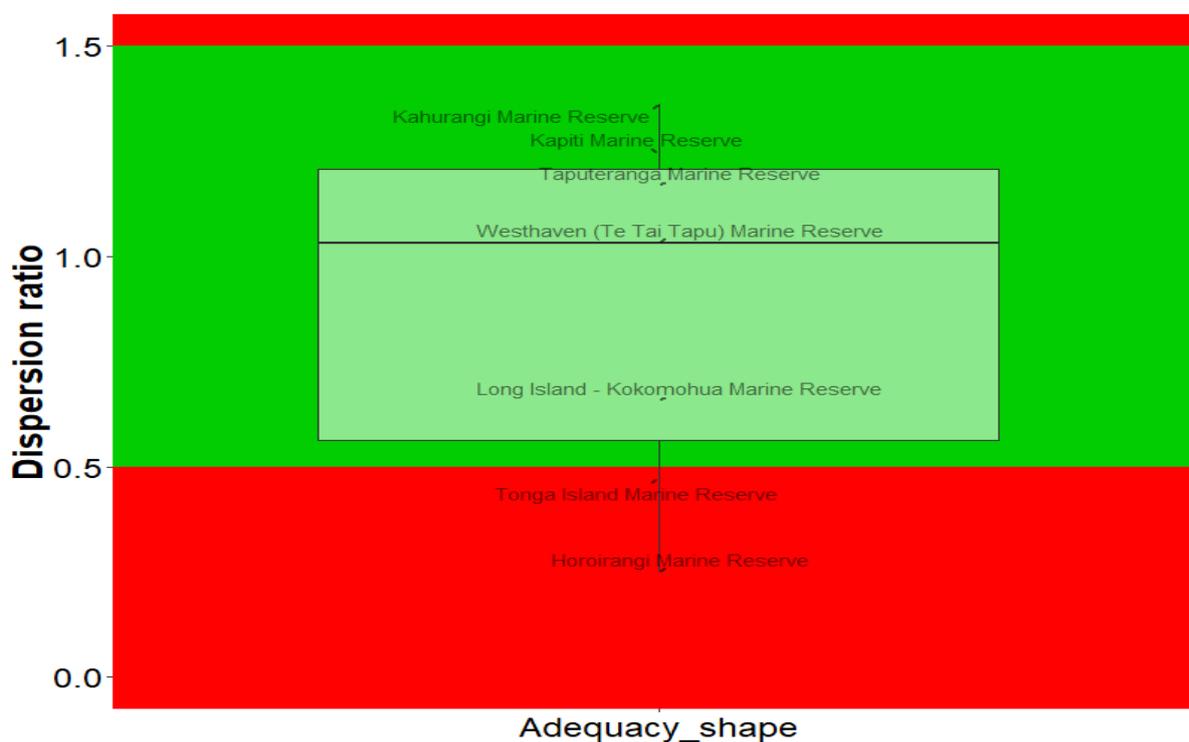


Figure 4-7: Adequacy-spatial distribution metrics for the wider Cook Strait region. Evaluation of the spatial distribution components of the adequacy element with data pooled across all MPAs in the regional case study network. The background colouring of the plot indicates the range of the performance standard associated with the adequacy – spatial distribution metric; where red is not adequate and green is adequate.

4.3 Representativity

4.3.1 Datasets

The representativity design element is calculated using defined and agreed habitat classifications that describe the distribution of habitat classes within the planning area (Table 4-3). More than one habitat classification can be used, particularly if the classifications summarise habitat groupings that reflect different bioregional scales (e.g., bioregional, national, or regional habitat classifications).

Table 4-3: Datasets for representativity for the wider Cook Strait region. A summary of the datasets used to calculate the representativity design element for the regional MPA network case study.

Metric	Dataset	Data format	Classification type	Comment
Representativity	DOC MPA Policy Habitat Classification	Polygon	Thematic	Includes fine-scale habitat types
Representativity	Seafloor Community Classification_75 Groups	Polygon	Numeric	National scale classification

4.3.2 Metrics

The metrics used to assess representativity for the regional case study report a poor level of representativity across the network for both habitat classifications. Under the MPA Policy Habitat Classification, five of the forty-five habitat types within the planning area were found to have moderate representation in the network, with the remaining habitats being poorly represented. All Seafloor Community Classification groups were poorly represented within the network with none having greater than 10% inclusion (Figure 4-8).

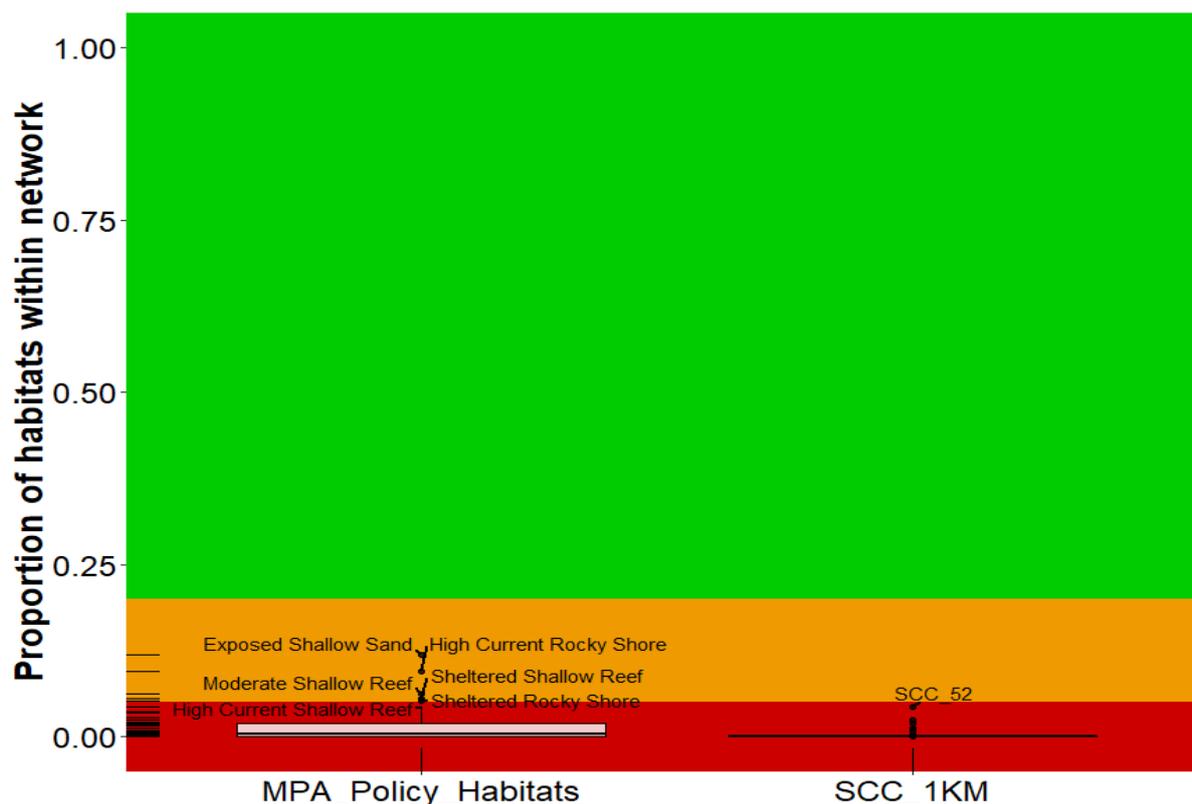


Figure 4-8: Representativity for the wider Cook Strait region. Evaluation of the representativity element by calculating metrics across the MPA Policy Habitat Classification and the New Zealand Seafloor Community Classification (SCC) for the regional MPA network. The background colouring of the plot indicates the range of the performance standard associated with the representativity metric; where red is poor representativity, orange is marginal representativity and green is good representativity. A selection of habitat types are shown with the best representativity for each classification.

4.4 Replication

4.4.1 Datasets

In order to evaluate the replication design element for the regional marine reserve network case study, we included datasets similar to those for viability and adequacy, reflecting species or habitats that have some occurrence within the planning area (Table 4-4). However, as per those design elements, the datasets used here are to illustrate the method across various taxa/habitats and data formats – they are not necessarily what may be used in an evaluation of this study area in real terms. As we are considering replication of defined ecological features, for raster datasets we use the same approach as viability to distinguish discrete patches of species presence from the continuous raster surfaces. We use a combination of polygons (both native and transformed rasters) and point datasets

to evaluate replication to illustrate the approaches with different data formats. Further, for features represented by discrete presences (i.e., not full extents) we use information on species home range to reflect the distribution of features (as per viability/adequacy).

Metric	Dataset	Data format	Species/habitat class	No. layers in dataset	Comment
Replication	Key biogenic habitats	Point	Biogenic Habitats	3	Rhodoliths, algal meadows
Replication	DOC MPA habitat classification	Polygon	Biogenic/physical	60	Subset of biogenic habitats
Replication	Gurnard spawning habitat	Polygon	Demersal Fish	1	
Replication	Blue cod - HSI model	Polygon	Demersal Fish	1	
Replication	Gurnard - HSI model	Polygon	Demersal Fish	1	
Replication	Endemic Invertebrates	Point	Invertebrates	>1000 sp.	Numerous species
Replication	Celleporina – bryozoan	Polygon	Invertebrates	1	
Replication	Scallop - HSI model	Polygon	Invertebrates	1	
Replication	<i>Carpophyllum</i> - HSI model	Polygon	Macroalgae	1	
Replication	<i>Macrocystis</i> - HSI model	Polygon	Macroalgae	1	
Replication	Blue moki - HSI model	Polygon	Reef Fish	1	
Replication	Butterfish- HSI model	Polygon	Reef Fish	1	
Replication	Regional council listed seabird sites	Point	Seabirds	41 sp	
Replication	Rock lobster – HSI	Polygon	Invertebrate	1	
Replication	Rocky reef habitat	Polygon	Physical	1	

Table 4-4: Datasets for replication for the wider Cook Strait region. A summary of the datasets used to calculate the replication design element for the regional marine reserve network case study. Note the Raster/polygon data format indicates raster layers that have been transformed to polygons.

4.4.2 Metrics

Across the network, there was generally marginal to poor replication of key ecological features within marine reserves, with the majority of features having either no replication or a single replicate. Three key features had levels of replication that are considered ‘good’ by our performance standard (Figure 4-9).

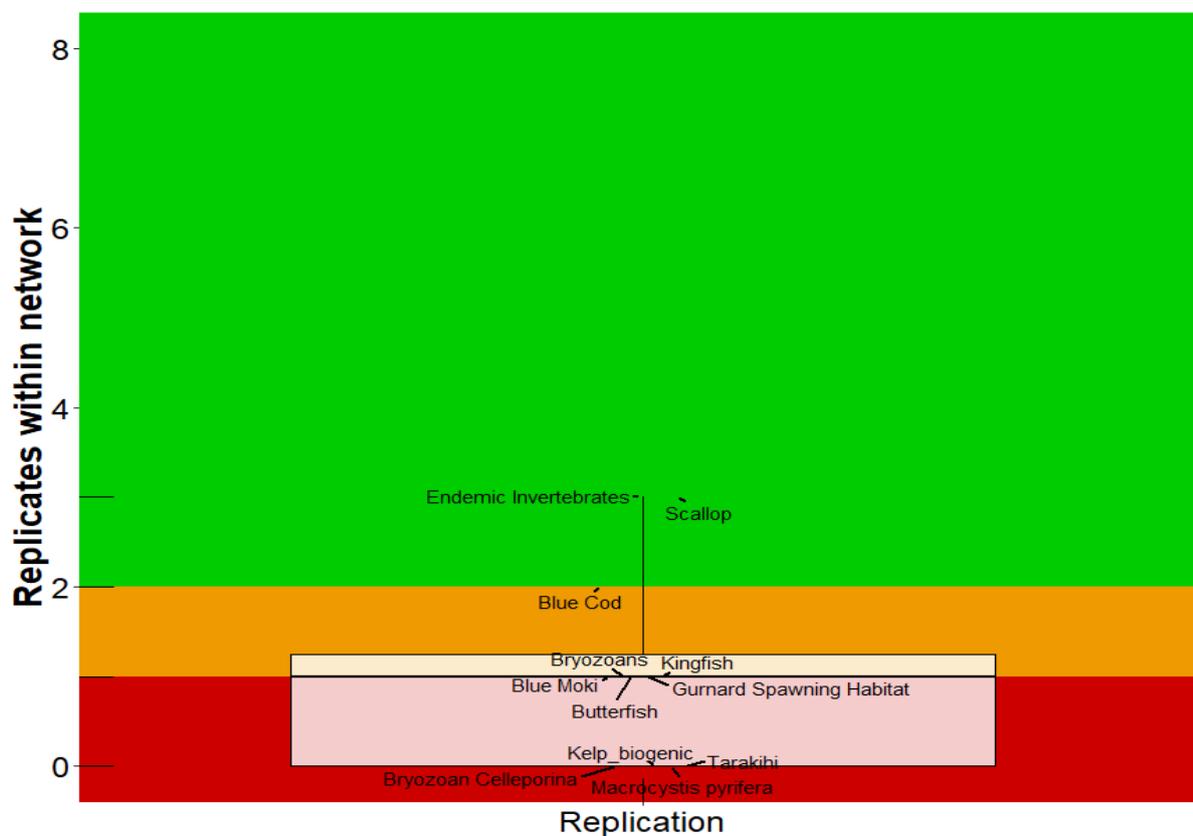


Figure 4-9: Replication for the wider Cook Strait region. Evaluation of the replication element across all ecological features within the regional marine reserve network. The background colouring of the plot indicates the range of the performance standard associated with the replication metric; where red is poor replication, orange is marginal replication and green is good replication. The metrics for each of the key features are provided for illustrative purposes.

When the replication metric is summarised by taxa and habitat groups, we can determine the groups that are the most poorly replicated (Figure 4-10). Ecological features under fish, invertebrate and physical habitat type groupings have marginal replication across the network, while biogenic habitat types and macroalgae have poor replication.

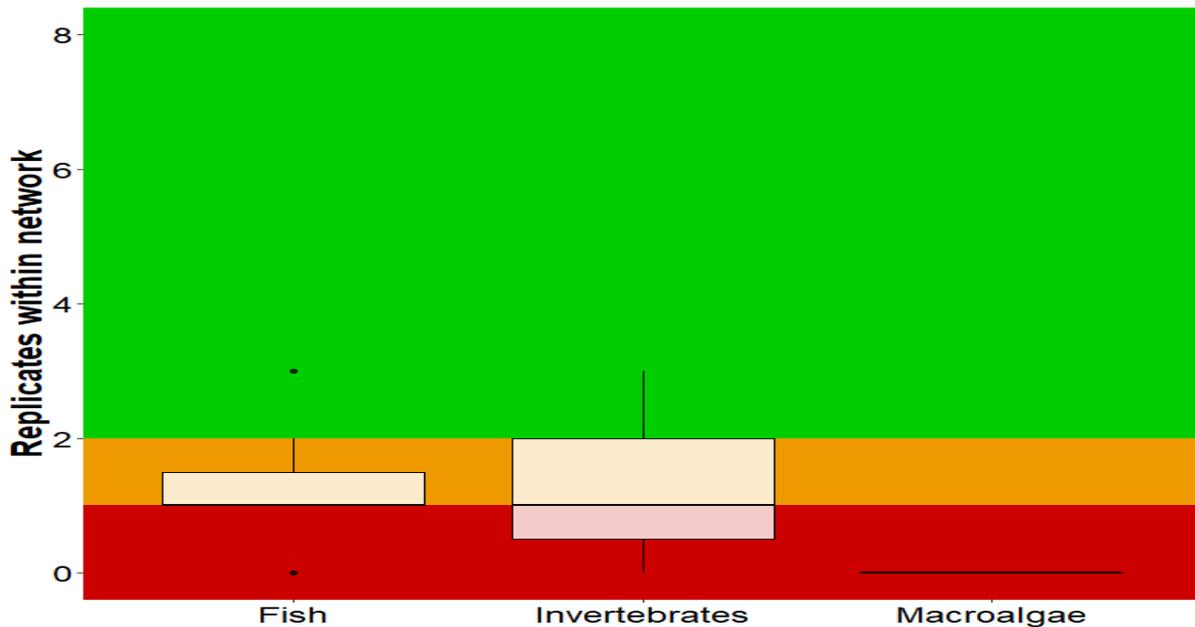


Figure 4-10: Replication by taxa/habitats for the wider Cook Strait region. Evaluation of the replication element across all ecological feature in the network and grouped into species (fish, invertebrate, macroalgae) and habitat (biogenic, physical) groupings for the regional marine reserve network. The background colouring of the plot indicates the range of the performance standard associated with the replication metric; where red is poor replication, orange is marginal replication and green is good replication.

4.5 Areas of Importance

4.5.1 Datasets

The assessment of the areas of importance design element for the regional marine reserve network used a combination of datasets of recognised important areas for the planning area, and ‘hotspots’ in the distribution of key threatened and important species (Table 4-5). Regional councils often have datasets available that summarise the locations and nature of significant marine ecological areas under a range of key ecological criteria. In the evaluation of areas of importance, we included datasets on key biodiversity areas and significant marine sites from Greater Wellington Regional Council and Marlborough Council, respectively. In addition, we calculated hotspots for some of the key species used in the evaluation of viability and adequacy by calculating the mean habitat suitability value for the presence polygons used in the evaluation of viability (using the *zonal statistics* tool). The top 10 polygons from each species were defined as ‘areas of importance’ and were included in the evaluation of the design element. Point records that represented the presences of threatened taxa were included under the assumption that each point represented an important location for a particular threatened taxa. Finally, areas of importance for conservation planning can also be represented by the outputs of decision support tool analyses as described in the recently developed cookbook for marine spatial planning in Aotearoa (Lundquist et al. 2021). To showcase how decision support tools can be incorporated into the MPA evaluation process, we extracted the top 10% of priority areas from a Zonation output of an analysis to determine important areas for reef fish conservation. The extent of the 10% priority area was represented by a polygon feature class dataset.

Table 4-5: Datasets for areas of importance for the wider Cook Strait region. A summary of the datasets used to calculate the areas of importance design element for the regional MPA network case study.

Metric	Dataset	Data format	Species/Habitat class	No. layers in dataset	Comment
Areas of importance	GWRC_BiodiversityArea	Polygon	Various	1	Physical, biogenic and estuary
Areas of importance	Marlborough_SigMarineSites	Polygon	Various	1	Contains all species and habitat classes
Areas of importance	Rocky Reef_Significant	Polygon	Physical	1	
Areas of importance	GWRC_ImportantBirdAreas	Polygon	Seabirds	1	
Areas of importance	Blue Cod_AreaofImportance	Polygon	Fish	1	
Areas of importance	Bryozoan (<i>Celleporina</i>)_AreaOfImportance	Polygon	Invertebrates	1	
Areas of importance	Scallop_AreasOfImportance	Polygon	Invertebrates	1	
Areas of importance	Butterfish_AreasOfImportance	Polygon	Fish	1	
Areas of importance	Zonation ReefFishDiversity_AreasOfImportance	Polygon	Fish	1	Output of zonation prioritisation
Areas of importance	All Council_AEA_Seabirds	Point	Seabirds	1	
Areas of importance	Elasmobranchs_threatened	Point	Fish	1	
Areas of importance	Invertebrates_threatened	Point	Invertebrates	1	
Areas of importance	Macroalgae_threatened	Point	Macroalgae	1	

4.5.2 Metrics

The metric used to evaluate the areas of importance element for the regional network suggests generally poor protection of areas of importance within the network with the median metric being close to 0 (Figure 4-11). Eleven areas of importance were considered well protected by the network, though these are considered outliers when considering areas of importance across all classes of ecological feature.

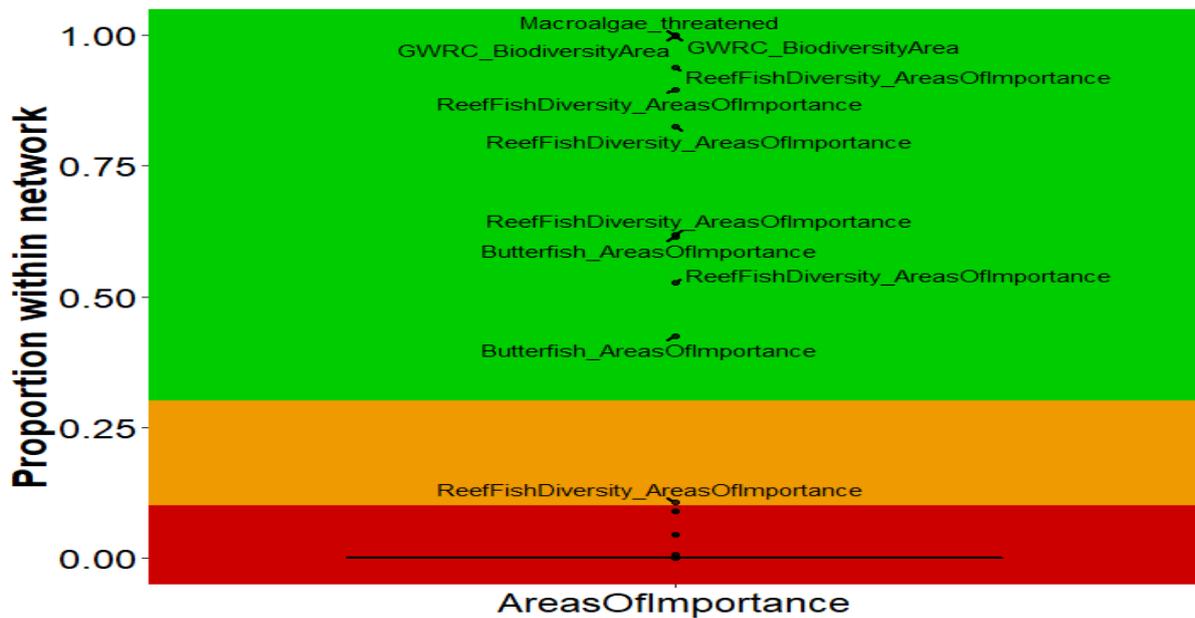


Figure 4-11: Areas of importance for the wider Cook Strait region. Evaluation of the areas of importance element across all important areas within the regional MPA network. The background colouring of the plot indicates the range of the performance standard associated with the areas of importance metric; where red is poor, orange is marginal and green is good protection for areas of importance. A selection of features with good and marginal inclusion within the network are plotted for illustrative purposes.

When the areas of importance metric is summarised according to unique classes of taxa and habitat we can determine whether important areas for certain classes are particularly poorly represented within the network. In the regional network case study, the metric reports poor protection for areas of importance across each taxon and habitat class (Figure 4-12), though fish, macroalgae and physical habitat classes have several areas of importance that are considered well protected.

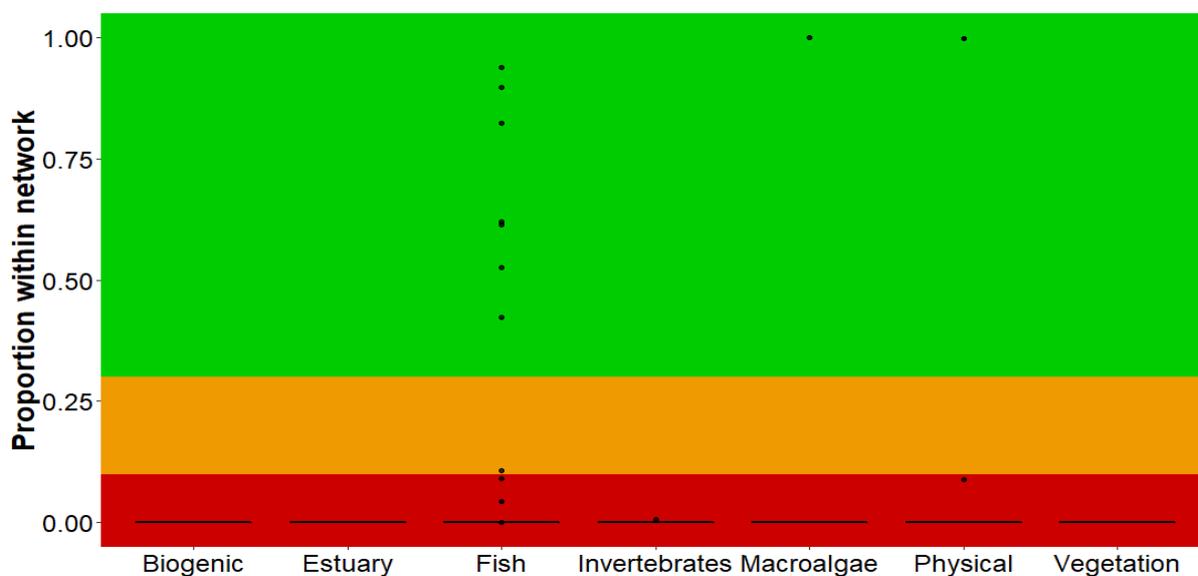


Figure 4-12: Areas of importance by species/habitats for the wider Cook Strait region. Evaluation of the areas of importance element across all important areas within the regional MPA network and grouped into taxa and habitat classes. The background colouring of the plot indicates the range of the performance standard associated with the areas of importance metric; where red is poor, orange is marginal and green is good protection for areas of importance.

4.6 Connectivity

4.6.1 Datasets

The calculation of the ecological connectivity design element for the regional marine reserve network requires only the input of a feature class dataset accurately denoting the extent of each marine reserve in the network. Further datasets calculated from this feature class to calculate the distances between MPAs are described in Section 3.6.

4.6.2 Metrics

The two metrics used to summarise connectivity among marine reserve within the network report generally good levels of connectivity. Each marine reserve has at least one neighbour within 100 km, the cut-off for the performance standard for 'good connectivity'. The sub-metric 'n_neighbours' has a median of 2 (indicating adequate connectivity). The majority of MPAs share this median, with one marine reserve having three neighbours within 100 km, while marine reserve had one neighbour within 100 km (Figure 4-13).

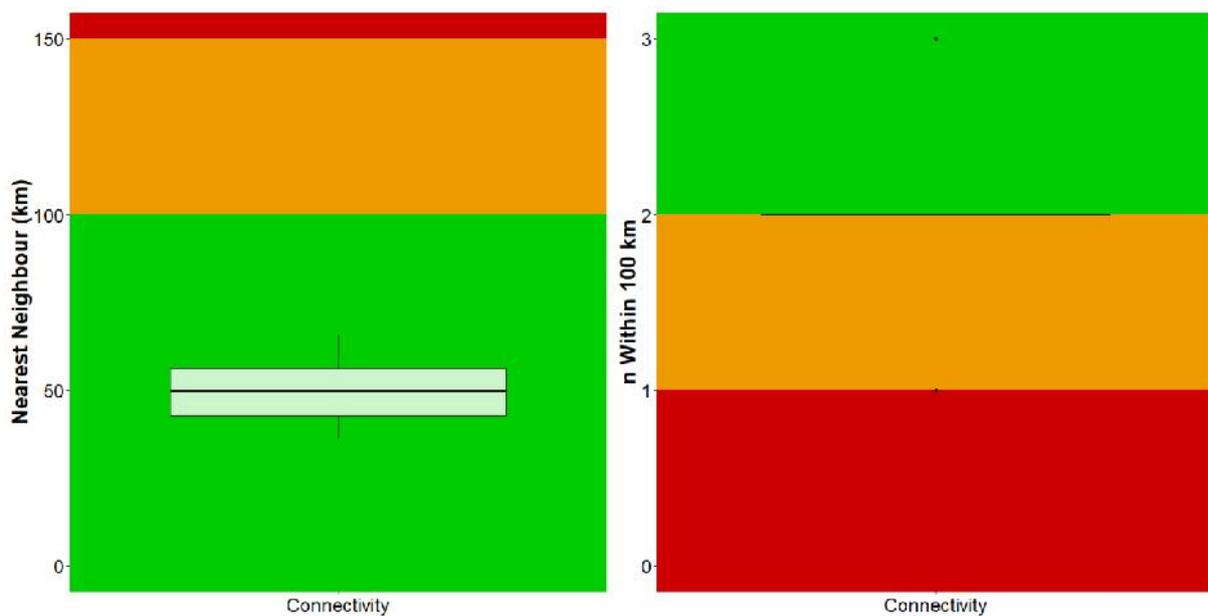


Figure 4-13: Connectivity for the wider Cook Strait region. Evaluation of the connectivity element using two metrics: 1) the minimum distance to the nearest neighbour, and 2) the number of neighbouring MPAs within 100km for the regional MPA network. The background colouring of the plot indicates the range of the performance standard associated with the connectivity metrics; where red is poor connectivity, orange is marginal connectivity and green is good connectivity.

4.7 Integration

4.7.1 Datasets

The evaluation of the integration design element for the regional MPA network case study pooled datasets on terrestrial and marine management that may afford some complementarity to the biodiversity protection designated by the MPAs within the network (Table 4-6). For the terrestrial metric these included polygons representing the extent of the DOC Conservation Estate, and protected areas of indigenous vegetation on private land established under Queen Elizabeth the Second Covenants (QEII Covenants). Marine datasets included customary management areas, Type 2 MPAs administered by DOC, marine mammal sanctuaries and commercial fishing restrictions. For the latter dataset, only restrictions that included an outright ban on destructive fishing practises (e.g., bottom trawling, set netting) were included.

The metric to evaluate integration with naturalness used a polygon dataset on the distribution of areas with high naturalness due to low historical commercial fishing activity. This dataset was developed by extracting the areas with the lowest 10% of values from a raster dataset reporting cumulative commercial fishing intensity (discussed in Lundquist et al. 2020).

Table 4-6: Datasets for integration for the wider Cook Strait region. Datasets used in the evaluation of the integration design element for the regional MPA network.

Metric	Dataset	Data format	Comment
Integration - Marine	Customary management areas	Polygon	
Integration - Marine	Commercial fishing restrictions	Polygon	
Integration - Marine	Type 2 MPAs	Polygon	

Metric	Dataset	Data format	Comment
Integration - Marine	Marine Mammal Sanctuaries	Polygon	
Integration - Terrestrial	DOC Conservation Estates	Polygon	
Integration - Terrestrial	QEII Covenants	Polygon	
Integration - Naturalness	Low commercial fishing zones	Polygon	Calculated from raster surface

4.7.2 Metrics

Assessment of the integration of MPAs with additional marine management shows generally poor integration for most management types, with the exception of commercial fishing regulations (Figure 4-14). Each MPA except the Kahurangi Marine Reserve has either overlap or is adjacent to commercial fishing restrictions that are likely to complement MPA protection. Note that these restrictions are those administered under the Fisheries Act 1996, and are spatial measures in addition to the Marine Reserve status afforded these MPAs under the Marine Reserves Act 1971. Horoirangi Marine Reserve is the only reserve with some integration with customary management areas.

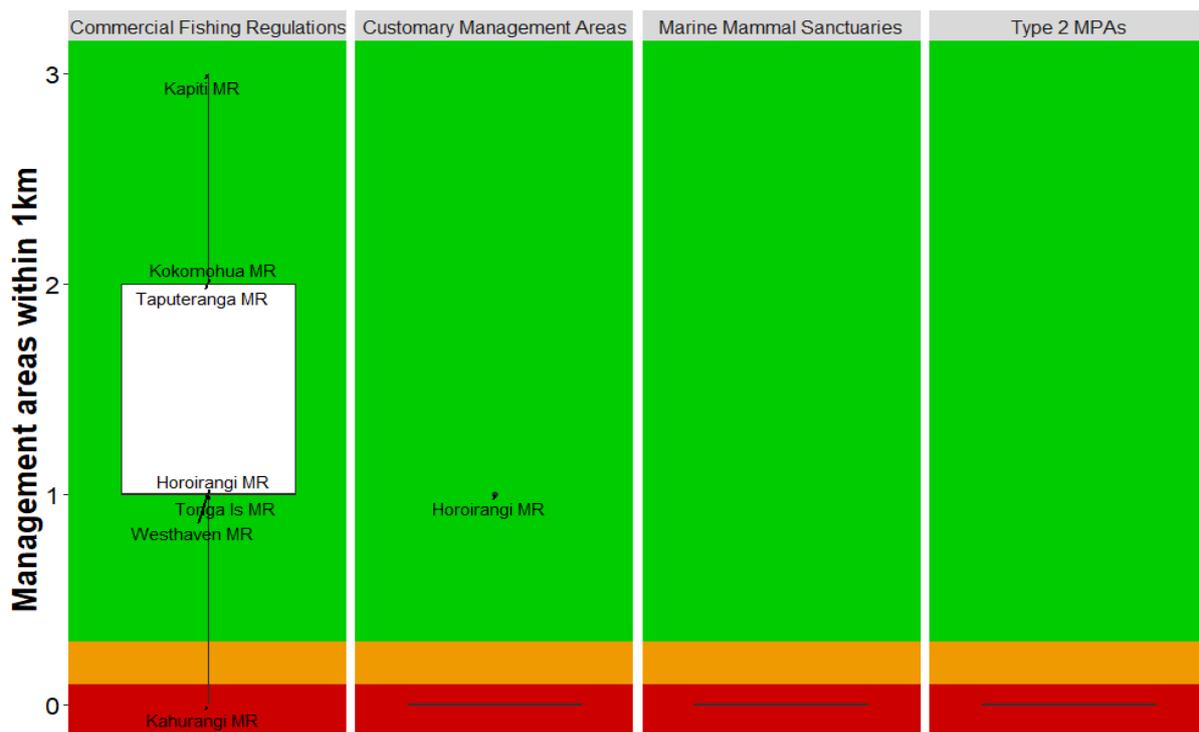


Figure 4-14: Integration – Marine for the wider Cook Strait region. Evaluation of the marine component of the design element integration using datasets on existing marine management for the regional marine reserve network. The background colouring of the plot indicates the range of the performance standard associated with the integration metrics where red is poor integration, orange is marginal integration and green is good integration.

The MPAs in the regional network have variable integration with existing terrestrial spatial management. The catchments that are adjacent to Kahurangi, Kokomohua, Tonga Island and Westhaven Marine Reserves each have over 80% overlap with terrestrial management that is likely complementary with marine protection (Figure 4-15). Horoirangi and Taputeranga Marine Reserves are poorly integrated with both beneficial terrestrial management types, whereas Kapiti Marine Reserve has marginal integration with the DOC conservation estate only (Figure 4-15).

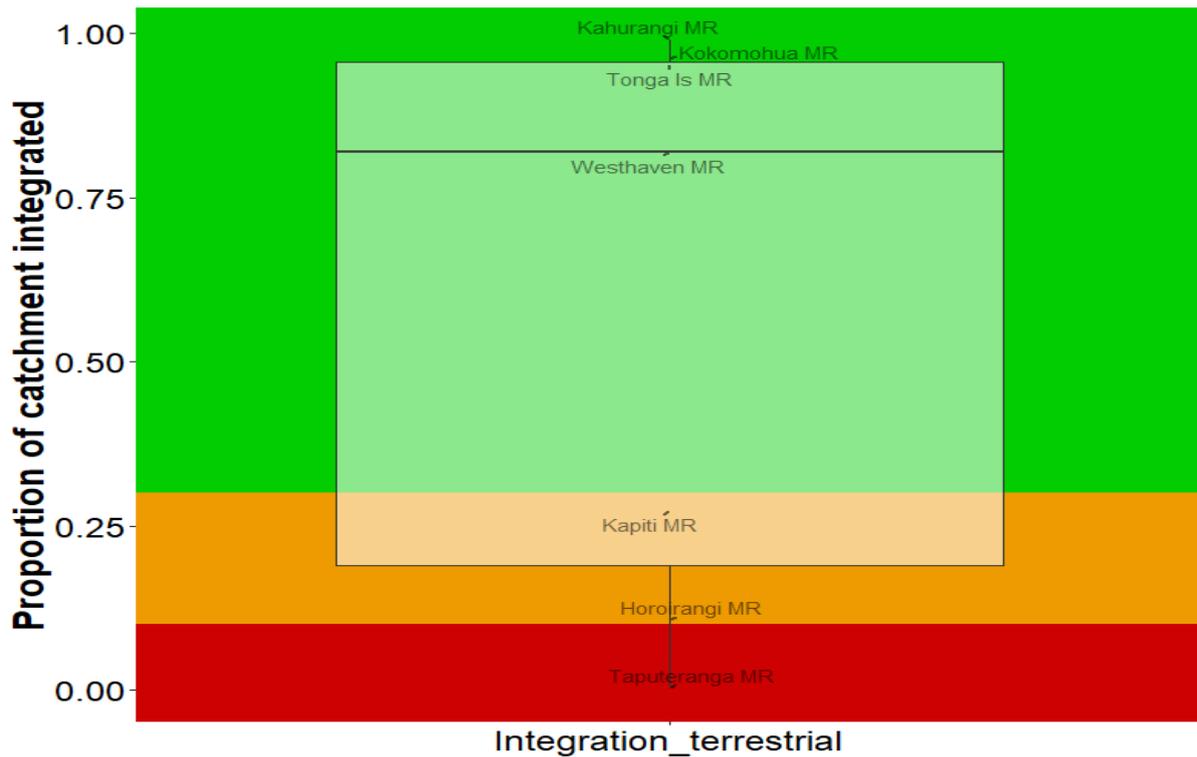


Figure 4-15: Integration-terrestrial for the wider Cook Strait region. Evaluation of the terrestrial component for the design element integration using datasets on existing terrestrial management for the regional MPA network. The background colouring of the plot indicates the range of the performance standard associated with the integration metrics where red is poor integration, orange is marginal integration and green is good integration

The reserves in the regional network have high variability in terms of their integration with areas of high naturalness defined by low commercial fishing effort (Figure 4-16). The Kapiti and Kahurangi marine reserves are adjacent to two areas of high naturalness (i.e., good integration), while the remaining reserves are either marginally (Westhaven) or poorly integrated with high naturalness areas. As per the previous elements, the decision points associated with this metric (e.g., how naturalness is represented) may substantially alter these calculations.

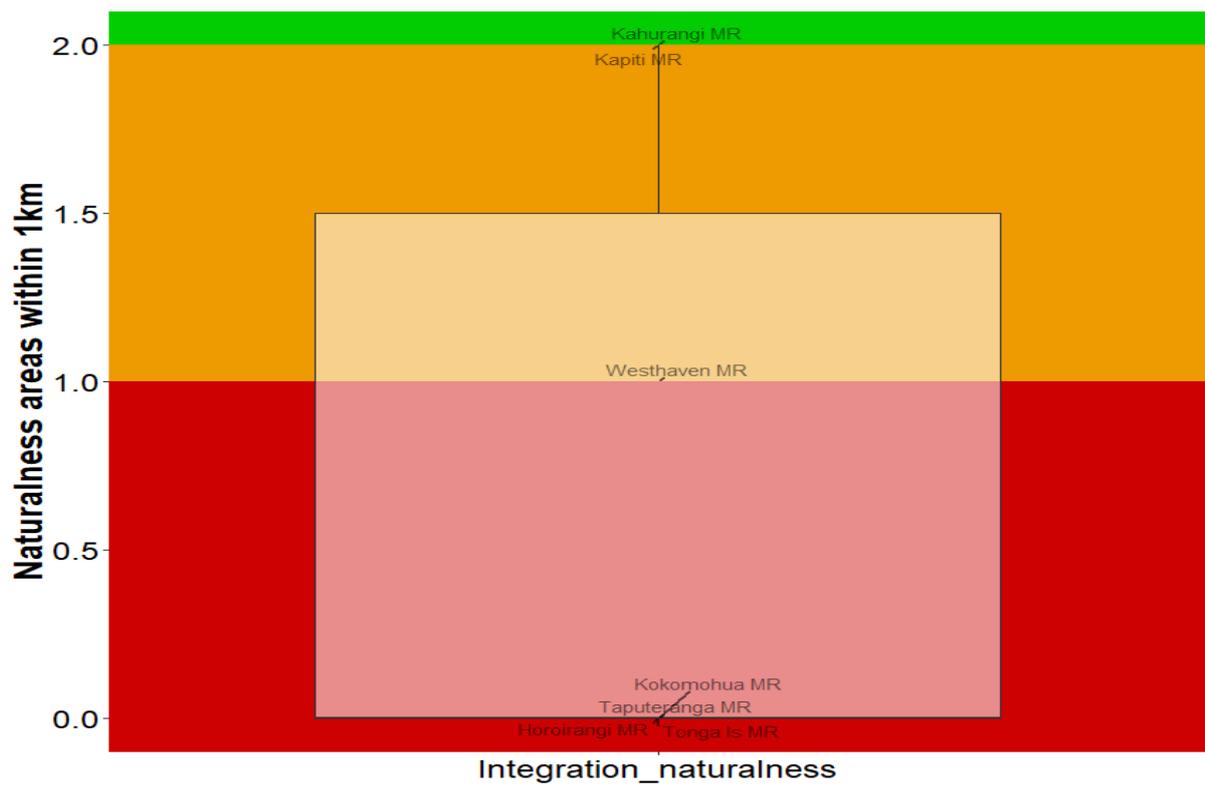


Figure 4-16: Integration-naturalness for the wider Cook Strait region. Evaluation of the naturalness component of the design element integration using datasets to represent high naturalness areas for the regional MPA network. The background colouring of the plot indicates the range of the performance standard associated with the integration metrics where red is poor integration, orange is marginal integration and green is good integration

5 Case study 2 – Kapiti Marine Reserve – Single MPA

The Kapiti Marine Reserve was selected as an illustration of the evaluation process for a single MPA (Figure 5-1). Similar to the previous case study, the planning area for this illustration is purely hypothetical, and doesn't necessarily reflect the area under consideration when the MPA was first proposed. Likewise, the datasets used for this case study and the way they are formatted and used are illustrative – the calculation of the metrics associated with this case study may change substantially relative to the decision points.

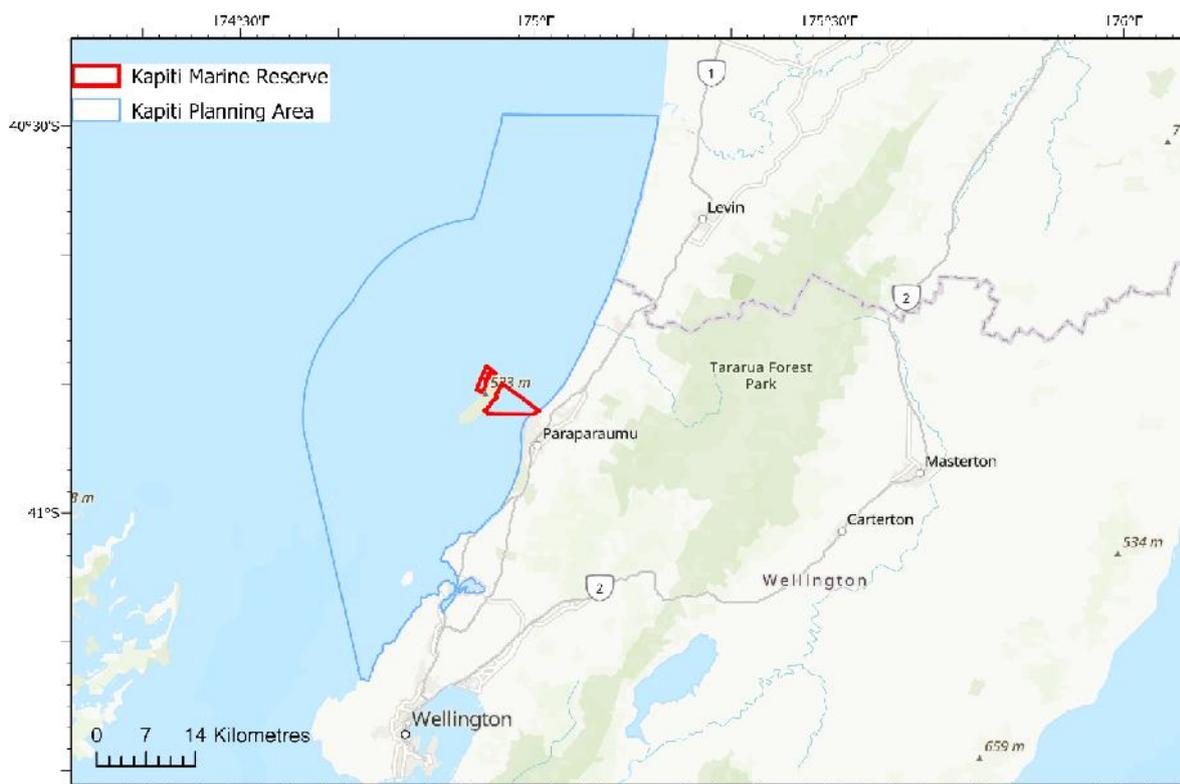


Figure 5-1: Kapiti Marine Reserve case study. The location of the Kapiti Marine Reserve case study used as an illustration of the evaluation process for a single MPA.

5.1 Viability

5.1.1 Datasets

The evaluation of viability for the Kapiti Marine Reserve case study included the use of datasets representing key species (e.g., demersal fish, macroalgae) and habitats (e.g., biogenic, physical) of cultural, recreational and commercial value that have some occurrence within the planning area, and within the marine reserve itself (Table 5-1), with some overlap with the features used to evaluate viability in the regional network case study. As per the regional case study, we chose to use a single classification to evaluate viability (DOC MPA habitat classification). We also chose to represent ecological features in different data formats to showcase how viability can be evaluated using different input datasets.

For datasets available in gridded raster formats (e.g., predictions from habitat suitability models), we used the process illustrated in Figure 3-3, to classify rasters into suitable habitat based on the ROC threshold, with the rasters subsequently being converted to polygons in order to represent the presence of ecological features. Information on home range was then used to represent the full extent of these features as per section 2.1.

Table 5-1: Datasets for viability-size for Kapiti Marine Reserve. A summary of the datasets used to calculate the size component of the viability design element for the Kapiti Marine Reserve case study.

Metric	Dataset	Data format	Species/habitat class	No. layers in dataset	Comment
Viability - size	Key biogenic habitats	Point	Biogenic	3	Rhodoliths, bryozoan
Viability - size	DOC MPA habitat classification	Polygon	Biogenic/physical	60	Multiple habitat types
Viability - size	Blue cod - HSI model	Raster/Polygon	Demersal Fish	1	
Viability - size	Gurnard - HSI model	Raster/Polygon	Demersal Fish	1	
Viability - size	Endemic invertebrates	Point	Invertebrates	>1000 sp	
Viability - size	Carpophyllum - HSI model	Raster/Polygon	Macroalgae	1	
Viability - size	Tarakihi - HSI model	Raster/Polygon	Demersal Fish	1	
Viability - size	Butterfish - HSI model	Raster/Polygon	Reef Fish	1	
Viability - size	Rock lobster - HSI model	Raster/Polygon	Invertebrates	1	
Viability - size	Regional council listed seabird sites	Point	Seabirds	5 sp	

The dataset used to evaluate the shape of the viability design element was a feature class dataset of the polygon extents for each MPA within the network. Information used to calculate the protection level metric of the viability element is summarised in Section 3.1.3.

5.1.2 Metrics

The evaluation of the size component of the viability element for Kapiti Marine Reserve suggests the reserve has variable viability for the ecological features it contains (Figure 5-2). The median viability-size metric is low and thus the reserve is not viable for most of the features assessed – particularly species with large ranges (i.e., seabirds, several fish). The reserve is viable, however, for species/habitats with smaller ranges/patch sizes including; bryozoans, endemic invertebrate species, rhodoliths and blue cod. Kapiti is considered marginally viable for butterfish and rock lobster.

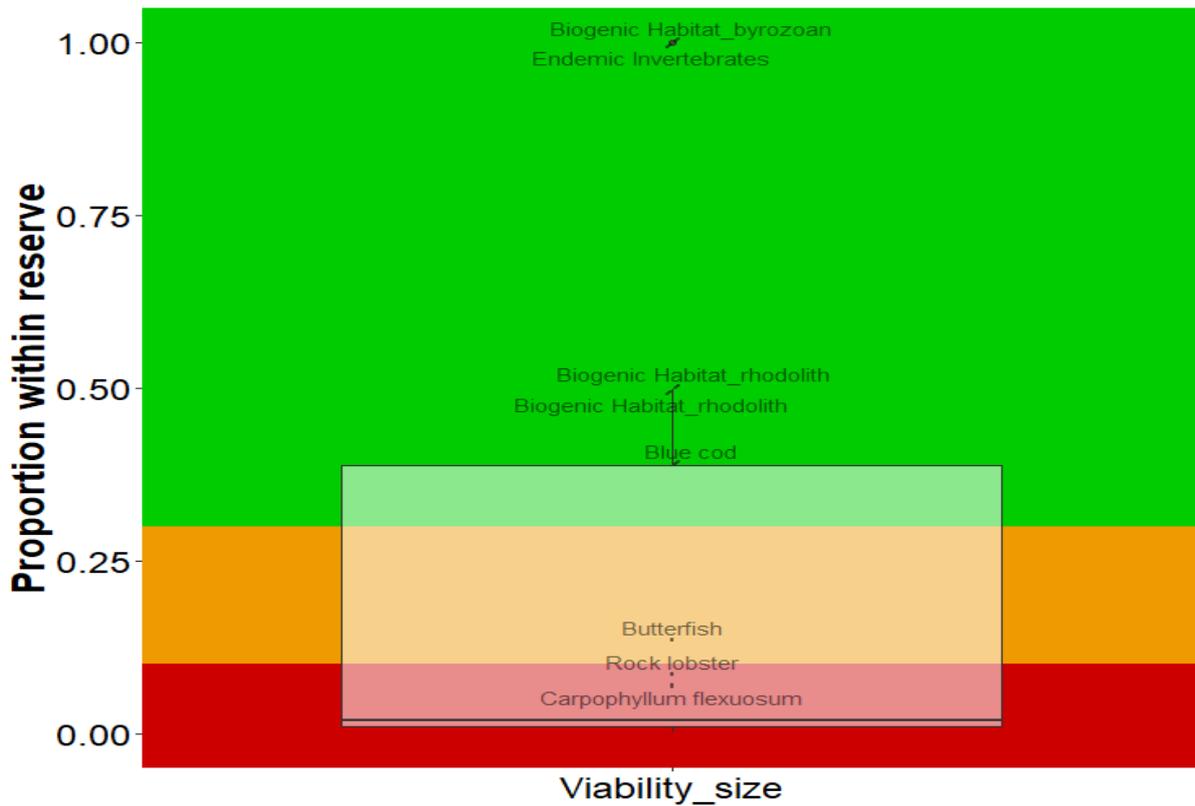


Figure 5-2: Viability-size for Kapiti Marine Reserve. Evaluation of the size component of the viability design element using all ecological features found within the Kapiti Marine Reserve. The background colouring of the plot indicates the range of the performance standard associated with the viability – size metrics; where red is poor viability, orange is marginal viability and green is viable

When the size component of viability is summarised into species or habitat classes, there is a clear distinction in the viability of Kapiti Marine Reserve between classes (Figure 5-3). For ecological features that represent certain species, the reserve is generally not viable or marginally viable. In contrast, the reserve is generally viable for ecological features that represent discrete habitat patches. This difference is likely due to the widespread occurrence of small, discrete patches of habitat that are mostly entirely contained within the boundaries of the reserve, in contrast to the wider range of certain species.

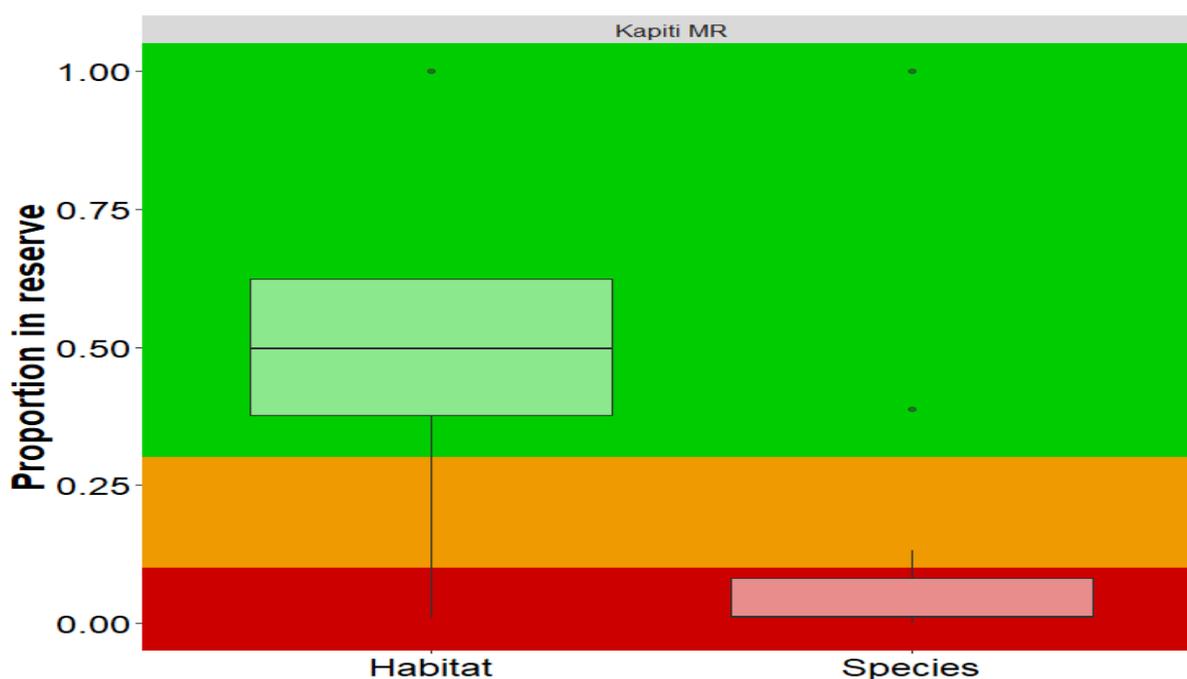


Figure 5-3: Viability-size by species/habitat for Kapiti Marine Reserve. Evaluation of the size component of the viability element using ecological features grouped in species or habitat classes for the Kapiti Marine Reserve. The background colouring of the plot indicates the range of the performance standard associated with the viability – size metrics; where red is poor viability, orange is marginal viability and green is viable

Evaluation of the shape component of the viability element for Kapiti Marine reserve suggests the reserve is marginally viable in terms of its shape with an area to boundary ratio of 1.05. As Kapiti Marine Reserve is a no-take, type 1 MPA, the protection level component is deemed viable for most ecological features the reserve contains, with the exception of wide-ranging seabird species.

5.2 Representativity

5.2.1 Datasets

The representativity design element is calculated using defined and agreed habitat classifications that describe the distribution of habitat classes within the planning area (Table 5-2). More than one habitat classification can be used, particularly if the classifications summarise habitat groupings that reflect different bioregional scales (e.g., bioregional, national, or regional habitat classifications).

Table 5-2: Datasets for representativity for Kapiti Marine Reserve. A summary of the datasets used to calculate the representativity design element for the Kapiti Marine Reserve study.

Metric	Dataset	Data format	Classification type	Comment
Representativity	DOC MPA Policy Habitat Classification	Polygon	Thematic	Includes fine-scale habitat types
Representativity	NZ Seafloor Community Classification_75 Groups	Polygon	Numeric	National scale classification

5.2.2 Metrics

The evaluation of the representativity design element for the Kapiti Marine Reserve suggests the reserve has poor to marginal representation of the habitat types found within the planning area (Figure 5-4). Two of the seven Seafloor Community Classification groups within the study area have marginal representation, while four of the twenty-seven MPA Habitat Classification habitats are marginally represented. All remaining habitats from both classifications are poorly represented within Kapiti Marine Reserve.

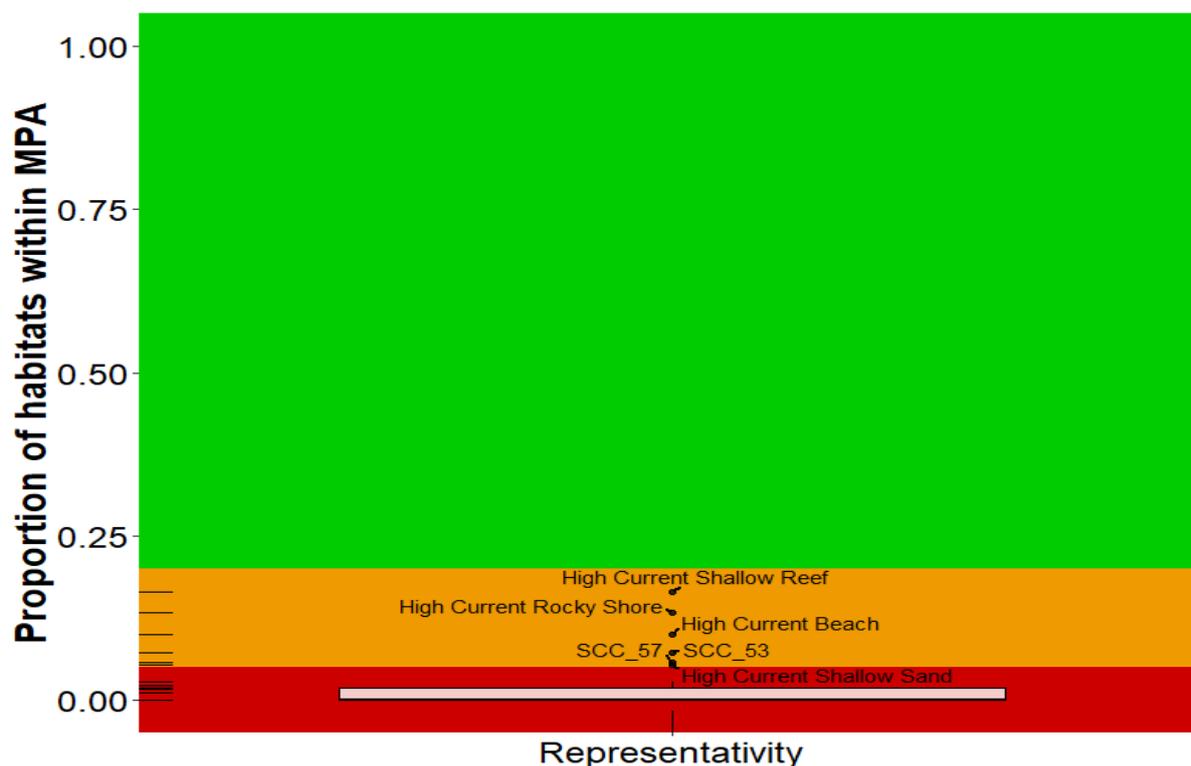


Figure 5-4: Representativity for Kapiti Marine Reserve. Evaluation of the representativity design element for the Kapiti Marine Reserve using two habitat classifications, the MPA Policy Habitat Classification (left) and the Seafloor Community Classification (right). The background colouring of the plot indicates the range of the performance standard associated with the representativity metric; where red is poor representativity, orange is marginal representativity and green is good representativity

5.3 Areas of Importance

5.3.1 Datasets

The assessment of the areas of importance design element for the Kapiti Marine Reserve case study used a combination of datasets describing important areas within the planning area (as per the regional network case study) and 'hotspots' in the distribution of key threatened and important species (

Table 5-3). Hotspots were defined by the mean habitat suitability value for the presence polygons used in the evaluation of viability (using the *zonal statistics* tool). The top 10 polygons from each

species were selected as ‘areas of importance’ and were included in the evaluation of the design element. Further we produced a layer denoting ‘significant’ areas of rocky reef habitat that was defined as all reef patches that were greater than 2 km² in size. Point records that represented the presences of threatened taxa were included under the assumption that each point represented an important location for a particular taxa. Finally, as per the regional network case study, we included a Zonation output to demonstrate the links between important areas designated using decision support tools and the evaluation of MPA effectiveness at the individual MPA scale.

Table 5-3: Datasets for areas of importance for Kapiti Marine Reserve. A summary of the datasets used to calculate the areas of importance design element for the Kapiti Marine Reserve case study.

Metric	Dataset	Data format	Species/Habitat class	Comment
Areas of importance	GWRC_BiodiversityArea	Polygon	Various	Physical, biogenic and estuary
Areas of importance	Blue Cod_AreaofImportance	Polygon	Fish	
Areas of importance	Bryozoan (<i>Celleporina</i>)_AreaOfImportance	Polygon	Invertebrates	
Areas of importance	Butterfish_AreasOfImportance	Polygon	Fish	
Areas of importance	Zonation - ReefFishDiversity_AreasOfImportance	Polygon	Fish	Output of zonation prioritisation
Areas of importance	Elasmobranchs_threatened	Point	Fish	
Areas of importance	Invertebrates_threatened	Point	Invertebrates	
Areas of importance	Macroalgae_threatened	Point	Macroalgae	
Areas of importance	Bivalve_AreasofImportance	Point	Invertebrates	

5.3.2 Metrics

The evaluation of the areas of importance design element for the Kapiti Marine Reserve suggest the reserve achieves poor protection of the areas of importance with its planning area, with the median proportion within the reserve being close to 0 (Figure 5-5). Five areas of importance have a good level of occurrence within the reserve and a single area has marginal occurrence.

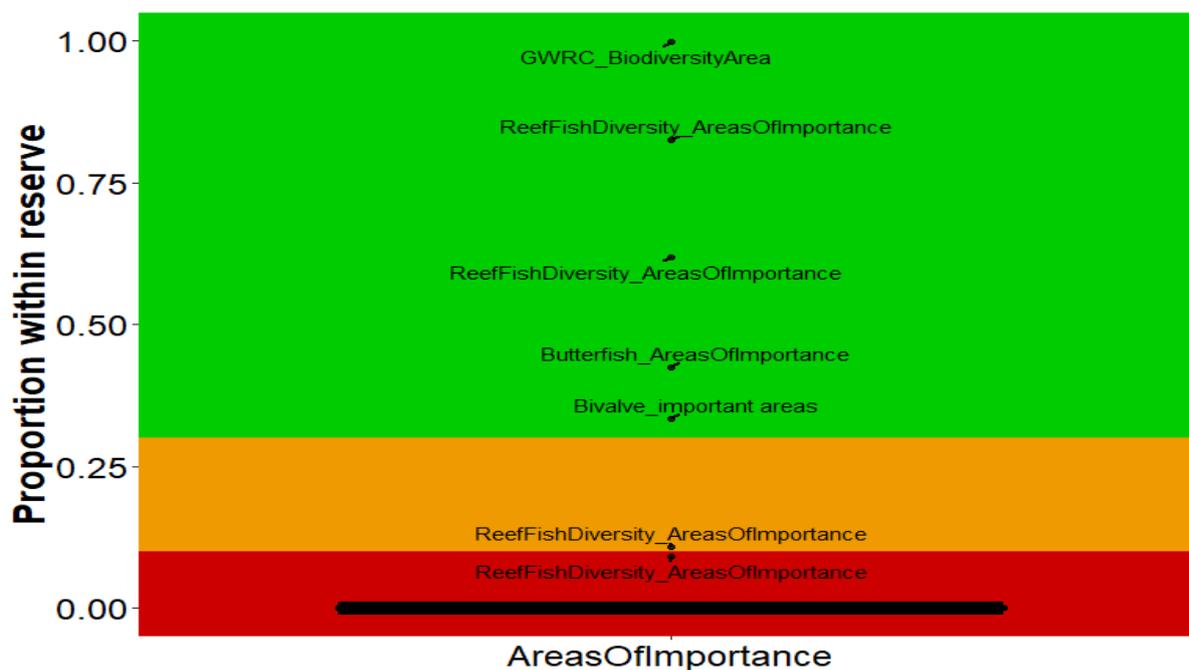


Figure 5-5: Areas of importance for the Kapiti Marine Reserve. Evaluation of the areas of importance design element for the Kapiti Marine Reserve summarised over all areas of importance within the planning area. The background colouring of the plot indicates the range of the performance standard associated with the areas of importance metric; where red is poor, orange is marginal and green is good protection for areas of importance. A selection of features with good and marginal inclusion within the network are plotted for illustrative purposes

When summarised according to species and habitat groups, the areas of importance metric for Kapiti Marine Reserve retains a generally low performance standard. The group ‘invertebrates’ is the sole class that meets the marginal performance standard for several features. Several outliers in the fish and physical habitat groups obtain a performance standard suggestive of good occurrence within the reserve (Figure 5-6).

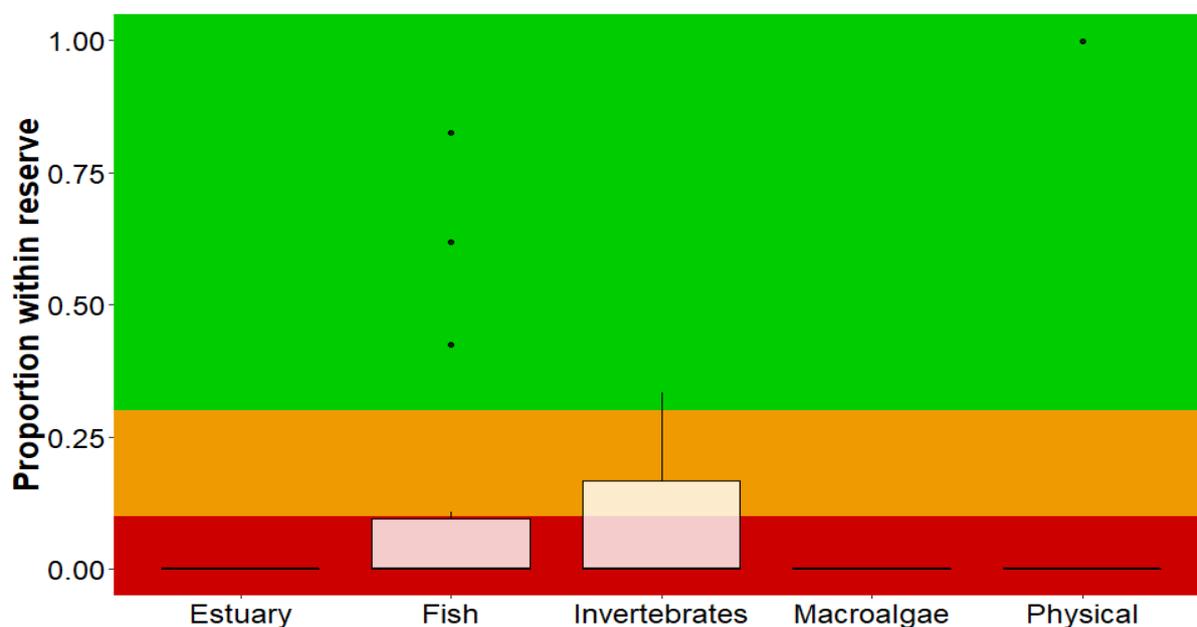


Figure 5-6: Areas of importance by species/habitat groups for the Kapiti Marine Reserve. Evaluation of the areas of importance design element for the Kapiti Marine Reserve summarised by individual species and habitat groups. The background colouring of the plot indicates the range of the performance standard associated with the areas of importance metric; where red is poor, orange is marginal and green is good protection for areas of importance.

5.4 Connectivity

5.4.1 Datasets

The calculation of the ecological connectivity design element for the Kapiti Marine Reserve required the input of a feature class dataset accurately denoting the extent of marine reserve within the wider area. The same selection of marine reserves was used in the Kapiti Marine Reserve case study as in the regional network case study. Further datasets calculated from this feature class to calculate the distances between MPAs are described in Section 3.6.

5.4.2 Metrics

The Kapiti Marine Reserve achieved a high level of connectivity when considering the two metrics proposed to evaluate the connectivity design element. The MPA nearest to Kapiti Marine Reserve is located 55 km away, and there are two MPAs within 100 km of the reserve

5.5 Integration

5.5.1 Datasets

The evaluation of the integration design element for the Kapiti Marine Reserve case study pooled datasets on terrestrial and marine management that may afford some complementarity to the biodiversity protection afforded by the marine reserve (Table 5-4). For the terrestrial metric, these included polygons representing the extent of the DOC Conservation Estate, and protected areas of indigenous vegetation on private land established under Queen Elizabeth the Second Covenants (QEII Covenants). Marine datasets included customary management areas, Type 2 MPAs administered by DOC, marine mammal sanctuaries and commercial fishing restrictions. For the latter dataset, only restrictions that included an outright ban on destructive fishing practises (e.g., bottom trawling, set netting) were included. The metric to evaluate integration with naturalness used a dataset on the distribution of areas with high naturalness due to low historical commercial fishing activity.

Table 5-4: Datasets for integration for Kapiti Marine Reserve. Datasets used in the evaluation of the integration design element for the Kapiti Marine Reserve case study.

Metric	Dataset	Data format	Comment
Integration - Marine	Customary management areas	Polygon	
Integration - Marine	Commercial fishing restrictions	Polygon	
Integration - Marine	Type 2 MPAs	Polygon	
Integration - Marine	Marine Mammal Sanctuaries	Polygon	
Integration - Terrestrial	DOC Conservation Estates	Polygon	
Integration - Terrestrial	QEII Covenants	Polygon	
Integration - Naturalness	Low commercial fishing zones	Polygon	Calculated from raster surface

5.5.2 Metrics

The evaluation of the integration design element for the Kapiti Marine Reserve revealed poor and marginal integration across the three metrics (Figure 5-7). In terms of marine management, Kapiti Marine Reserve was well integrated with commercial fishing regulations, but with no other forms of marine spatial management. The reserve was poorly integrated well integrated areas of high naturalness with two zones of historically low commercial fishing within 1km of the reserve. There was marginal integration of the reserve with terrestrial management, with just over 25% of the reserve's terrestrial catchment being integrated with the DOC Conservation Estate, but no integration with other terrestrial management.



Figure 5-7: Integration for the Kapiti Marine Reserve. Evaluation of the integration design element for the Kapiti Marine Reserve using metrics that summarise integration with marine management (left), areas of high naturalness (middle), and terrestrial management (right). The background colouring of the plot indicates the range of the performance standard associated with the integration metrics where red is poor integration, orange is marginal integration and green is good integration

6 Discussion

This study has developed an initial analysis framework that can be used to evaluate the effectiveness of MPAs and MPA networks according to seven design elements. The analyses are semi-automated, requiring limited user intervention (typically supplying specific planning area, MPA boundaries, and working geodatabases). While the framework is fully operational, there are important decision points associated with its use and we advise careful consideration of these when undertaking evaluations of MPA effectiveness. We have demonstrated how the evaluation methodology can be applied to examples including a regional MPA network and an individual MPA and such methods may be equally applicable at the design stage of a new MPA/network, or during a review of existing MPAs. Despite the utility of the methods, there are several caveats on their use that are important to consider. Caveats are often related to a lack of information on the settings of the performance standards used to categorise the evaluation metrics or on the appropriateness of datasets used to calculate such metrics.

6.1 Caveats on element evaluation

Viability

In many cases, there is limited information on the proportion of an ecological feature that needs to be incorporated within a protected area for the feature to respond positively to protection and therefore be viable. Information availability will be very different for various taxa and habitat classes and is an important research gap for New Zealand marine ecology. Currently, we developed performance standards based on consultation with the MSAG, though they are subjective and require refining for particular planning areas, species and habitats. Further targeted research could explore how discrete patches of habitat/species range with variable protection coverage respond to

MPA protection. Such research would establish ecologically meaningful performance standards to inform the viability – size metric for New Zealand habitats and taxa. Additionally, research to define the accurate home-range of habitat patch size characteristics would greatly increase our ability to represent the extent of ecological features that occur within MPAs.

The issue of information availability also occurs with the ‘shape’ design element; there is limited knowledge on how ‘non-compactness’ (measured by area to boundary ratio) influences the viability of a reserve in real terms. There are also likely differences among taxa and habitats due to the varying influence of edge effects on species with different mobility (for example, sessile benthic invertebrates vs. mobile predators that regularly interact with MPA boundaries or even cross them). Future research could investigate how various habitat/species classes respond to protection in MPAs with varying shape characteristics and would provide empirical information to inform the performance standards of this metric.

The ‘level of protection’ metric (Section 3.1.3) is also highly circumstantial. The matrix should be further developed to establish an agreed upon standard and encompass a broader range of habitats and threats, with realistic modifiers to qualify the circumstances where habitats are afforded meaningful protection by different types of MPA. This information should be prioritised as a critical element of the evaluation process. The use of expert judgement is recommended in situations where it is unclear whether an ecological feature may be appropriately protected given the level of protection. Alternatively, the marginal (1) score could be used. Similar to previous metrics, targeted research on how ecological features respond to protection

Adequacy

Adequacy has similar inputs as viability, and as a result has similar caveats. However, the size component of adequacy is concerned with the wider MPA Network rather than the individual MPA scale and would require different investigations in order to provide good estimates for the proportion of a feature in a planning area that is required to be included in a protected area for it to be adequate. The spatial distribution component of adequacy currently assesses the general dispersion/compactness of reserves within a network to check if reserves are distributed equally within a planning area. Further work may expand on this component to include the distribution of reserves within ecologically meaningful bioregions.

There is also the caveat of how the planning area is defined. If the planning areas has arbitrary boundaries or boundaries that are too small this may impact the calculation of the size component of adequacy. The use of ecologically relevant boundaries to planning areas (e.g., bioregions) may offer opportunities for calculations of adequacy to be more ecologically meaningful. While the designation of planning areas is typically a management decision, the boundaries of such areas should be ecological informed where possible.

Representativity

An important caveat around representativity is the proportion of a habitat that needs to be protected before it is considered represented. While we have followed national and international guidance to determine these proportions for the case studies shown here, these may need to be further refined based on the ecology of New Zealand habitats. Further, ensuring representativity requires consideration of the habitat classification(s) to use to get the best evaluation of representativity, and different habitat classifications may need to be selected to represent multiple scales of representativity. The recently developed New Zealand SCC (Stephenson et al. 2020)

provides good opportunities for the evaluation of representativity, potentially at several scales - though additional research is required to explore the optimum number of habitat classes at different spatial scales. New Zealand does not currently have a fit-for-purpose thematic classification that may add value for evaluation at finer scales (Rowden et al. 2018). Further, pelagic habitats are not currently well-represented within New Zealand classification schemes and requires additional research to incorporate their inclusion within new or existing classifications.

Replication

The current evaluation for replication counts the number of replicates for different ecological features within a network while considering the minimum distance apart and size of individual replicates. Two questions to ask when considering replication are: 'what is the minimum size for a replicate?' and 'how far apart should replicates be for each to count as a separate replicate?' There are limited examples to draw on to ground these values in empirical evidence. Replicates are based on the patch characteristics of features but also the distribution of stressors that may impact those features. In the absence of empirical evidence, it is recommended to use precaution, based on expert knowledge of stressors within the planning area. Future research could investigate the resilience of habitat/species patches of different sizes to stressors with varying spatial extents and thus build the knowledge base required to address the questions concerning the replication element.

Area of importance

A caveat exists around how to define an 'area of importance'. The issue is minimised when we can draw on published literature, or well-documented and designated important areas such as regional council areas of significance (e.g., McCartain et al. 2021). In other cases, such as when designating hotspots for spatial predictions or decision-support tool outputs, the decision points around what values to use to define an area of importance can impact on the evaluation of this metric. Future research may shed light on for example, how best to threshold habitat suitability/abundance models to generate 'areas of importance', which would enable a more robust designation of important areas using predictive models. 'Ground-truthing' using independent datasets for both predictive models and zonation outputs may also provide opportunities for empirical validation of any 'threshold value' for designating important areas. Previous work to pool and review datasets that can inform the distribution of Key Ecological Areas (Stephenson et al., 2018, Lundquist et al., 2020) and proposed future work to identify national Key Ecological Areas will significantly advance our ability to determine areas of importance across a range of taxa/habitats.

Connectivity

In this study, the calculations for connectivity are simplistic and could be improved by several interventions. Firstly, we recognise that performance standards for connectivity should distinguish between different habitats and species. Different performance standards for connectivity could be quantified for MPAs in different physical settings, such as by differentiating oceanic MPAs from coastal MPAs.

For larval connectivity, a more accurate method of calculation would incorporate a raster surface with the mean direction of current flow, which could then be used to calculate cost-paths, and then take into consideration the distance between MPAs given the average direction of current flow. However, incorporating current flow is only relevant for larvae, and possibly smaller, less mobile species that may be prone to advection. Connectivity should also incorporate adult and juvenile dispersal and movement of highly mobile animals. One option would be to include different metrics

for larval connectivity (that includes current flow), while retaining others based on Euclidian distance (as used in this work) for other life history stages.

A more sophisticated analysis could consider pelagic larval durations (PLDs) and dispersal characteristics of key species and the ratio between those characteristics and MPA distances. However, PLDs and dispersal characteristics are not available for most species. Research could be undertaken to provide mean PLDs, juvenile and adult dispersal distances for groups of taxa (with benthic invertebrates split into many classes for average taxa group values) to provide approximate values to work with.

Integration

The degree of benefits from integration of different types of management, terrestrial or marine, is poorly understood, although likely to be significant. There is no empirical information on the degree of overlap or proximity required between MPAs and other forms of management to enhance biodiversity. Without this, the performance standards used to categorise integration are arbitrary and should be based on expert judgement. Further research should investigate the degree of biodiversity enhancement realised from nested marine spatial management measures. For terrestrial management, it is known that land-based impacts/benefits extend much further than just the catchment within which they occur, with the direction of impact also depending on local oceanographic processes. However, there is currently inadequate information with which to model such variability. Future work could look at how highly protected terrestrial catchments benefit biodiversity along adjacent stretches of coastline. Further, evaluation of the biodiversity benefits afforded to existing MPAs along a gradient of overlap with terrestrial management may provide robust information on the proportion of a catchment required to be protected.

Similar caveats occur for integration with naturalness. Ideally, this type of analysis would incorporate knowledge of ecological responses to stressors, allowing for stressor layers to be divided into high or low naturalness zones that are known to influence biodiversity (either positively or negatively). While greater knowledge of ecological responses to stressors is emerging in Aotearoa New Zealand, there are still myriad relationships of taxa and stressor combinations that have not yet been quantified. Additionally, other than some key stressors (e.g., commercial fishing, sedimentation), stressor footprints are rarely available.

6.2 Conclusions

Despite several caveats on the use of the evaluation methodology for each design element, the current methods provide a useful approach to evaluating the effectiveness of MPA design. Over time, further research will allow the assumptions and caveats associated with each element to be addressed. Due to the simplicity of the analysis pathways, users may easily amend the methods as new information becomes available. Additional work could embed the code from each ModelBuilder model within python which would enable the development of standard ArcGIS system toolboxes. Currently, each ModelBuilder model is available in a geodatabase that accompanies this report and datasets used to apply the evaluation methods to the case study areas are available on the DOC online geoportal.

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Appendix A Model builder pathway for catchment area

To evaluate the terrestrial metric for the integration design element we constructed a model builder analysis pathway that can be used to calculate the catchment area that is adjacent to any MPA on the NZ coastline.

This simple model uses a spatial join tool to join the attributes of any polygon feature containing the MPA/network extents to a feature class with digitised spatial watershed polygons for the NZ mainland and major islands. The spatial join can incorporate watersheds within a user-defined distance from an MPA polygon. The pathway then dissolves the resultant feature class by MPA ID, to create a multipart polygon feature class of merged watersheds for each MPA. Individual or combined catchments can then be exported as required.

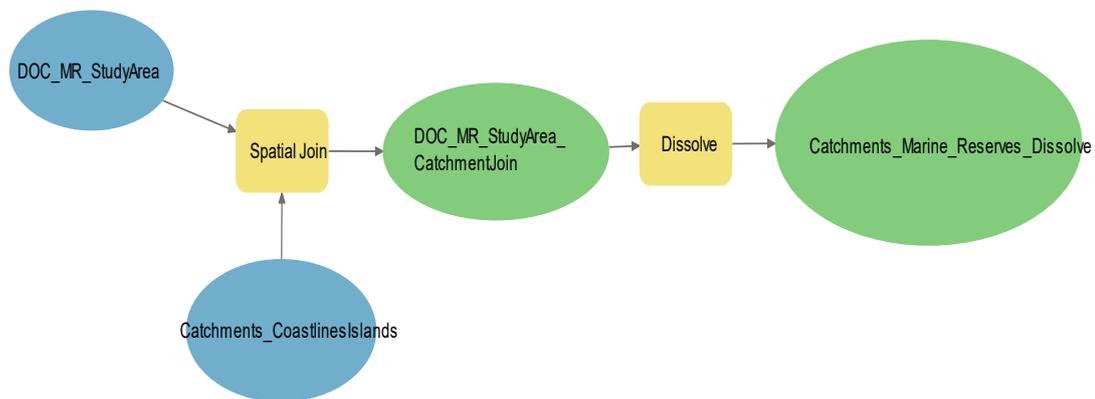
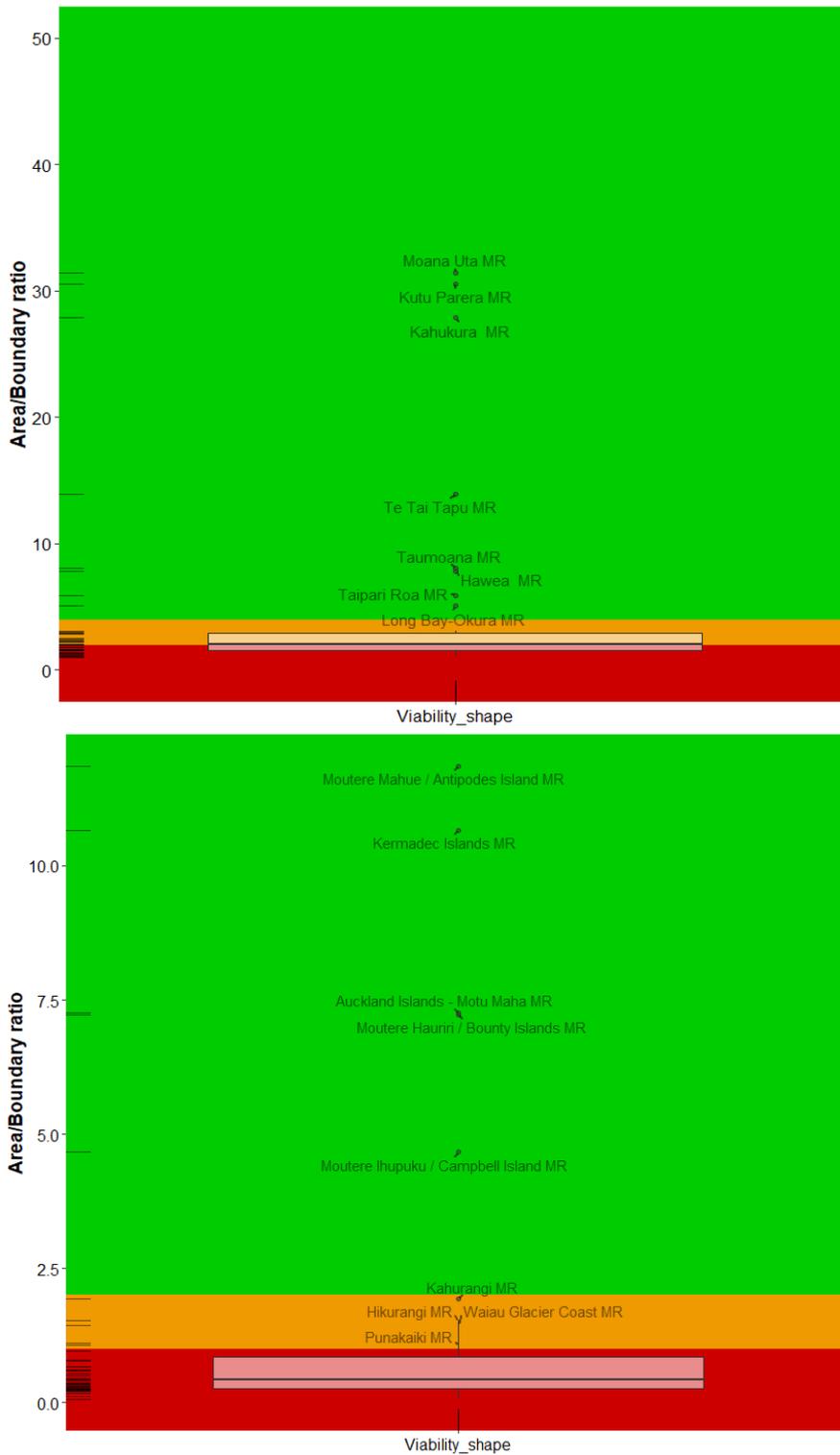


Figure A-1: Generate catchments model. Analysis pathway used to generate catchments for any MPA polygon on the NZ coast.

Appendix B Viability shape across all Type 1 MPAs

Viability-shape analyses for all type 1 analyses using marine boundaries (top) and all boundaries (bottom) for the calculation of the area to boundary ratio metric. Note, two outliers have been removed from the upper plot to aid visualisation; Te Tapuwae o Hua and Te Hapua Marine Reserves which had 184 and 180 area/boundary ratios respectively.



Appendix C Viability – size analysis routine for polygons datasets showing the mapped extent of habitats

