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Design Strategies for the Northern Shelf Bioregional Marine Protected Area Network

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Canada has committed to establishing a well-connected system of Marine Protected Areas (MPAs) that protect at least 10% of coastal and marine areas by 2020. To advance that goal in the Pacific region, the Government of Canada, Government of British Columbia (BC), and 16 member First Nations are collaborating on marine planning in the Northern Shelf Bioregion (NSB). A set of goals, objectives, principles, and design guidelines informed the development of conservation priorities, which are the ecological and cultural features to be prioritized for protection within the MPA network, and design strategies, which describe how to spatially incorporate ecological conservation priorities into the network. This paper focuses exclusively on Goal 1 of the Canada – BC MPA Network Strategy (2014), which specifies the protection and maintenance of marine biodiversity, ecological representation and special natural features. We developed ecological design strategies for the MPA network in the NSB. These include spatial ecological conservation targets specifying how much of each ecological conservation priority (or feature) an MPA network aims to protect, and approaches for determining the size, shape, and protection levels of MPAs, as well as the connectivity, representation, and replication of ecological conservation priorities. Specifically we: (1) set the context for developing ecological design strategies for the MPA network in the NSB by reviewing the components of MPA network planning processes in BC, best practices from these and other planning processes, and guidance from the scientific literature; (2) developed a method for setting coarse-filter and fine-filter ecological conservation targets and a flow diagram to determine which ecological conservation priority features and associated ecological conservation targets are appropriate for inclusion in site-selection analyses in the next phase of planning; (3) provided recommendations on design strategies for size, spacing, and replication by adapting best practices and guidance from the literature to the NSB; and (4) developed an iterative approach for adjusting ecological conservation targets in site-selection analyses based on protection levels that are linked to MPA effectiveness research. Together with the conservation priorities, the design strategies will inform site selection analyses conducted during the design scenarios phase of MPA network planning to identify priority areas for conservation and options for possible MPA network configurations in the NSB.

ACRONYMS

BC	British Columbia
BCMCA	British Columbia Marine Conservation Analysis
BCMEC	British Columbia Marine Ecological Classification
BCR	Bird Conservation Region
CBD	Convention on Biological Diversity
CDFG	California Department of Fish and Game
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CP	Conservation Priority
DFO	Fisheries and Oceans Canada (formerly Department of Fisheries and Oceans)
EBSA	Ecologically and Biologically Significant Areas
EBM	Ecosystem-based Management
ECCC	Environment and Climate Change Canada (formerly Environment Canada)
E-CP	Ecological Conservation Priority
IA	Important Areas (DFO)
IUCN	International Union for Conservation of Nature
MAPP	Marine Plan Partnership
MLPA	Marine Life Protection Act (California)
MPA	Marine Protected Area
MPATT	Marine Protected Area Technical Team
NMCA	National Marine Conservation Area
NSB	Northern Shelf Bioregion
PLD	Pelagic Larval Duration
PMECS	Pacific Marine Ecological Classification System
PNCIMA	Pacific North Coast Integrated Management Area
PNW	Pacific Northwest
SARA	Species At Risk Act
TNC	The Nature Conservancy
UNEP	United Nations Environment Programme
WCPA	World Commission on Protected Areas (IUCN)

1. INTRODUCTION/BACKGROUND

1.1. CONTEXT – DESIGN STRATEGIES FOR THE MPA NETWORK DEVELOPMENT PROCESS IN THE NSB

Marine protected area (MPA) network development is underway in five priority bioregions in Canada's oceans. Canada's Oceans Act (Government of Canada 1996), Oceans Strategy (DFO 2002), the National Framework for Canada's Network of MPAs (Government of Canada 2011), and the mandates of Fisheries and Oceans Canada (DFO) and Environment and Climate Change Canada (ECCC)[1] guide MPA network planning through collaboration with federal and provincial departments and First Nations. In the Pacific Region, MPA network planning was identified as a near-term implementation priority of the Pacific North Coast Integrated Management Area (PNCIMA), a marine spatial planning initiative driven by ecosystem-based management (EBM) objectives and principles (PNCIMA Initiative 2017). The MPA network is one of several management tools identified for achieving EBM goals in the area. This work is proceeding based on a 2004 Memorandum of Understanding with the Government of British Columbia (BC)[2] and agreements signed with Coastal First Nations and the North Coast-Skeena First Nations Stewardship Society in 2008[3] and 2012[4], as well as Na̲nwak̲olas Council in an amendment to the former Letter of Intent, that direct marine planning and conservation efforts in the Northern Shelf Bioregion (NSB) (Figure 1). In addition, the Government of BC and 17 partner First Nations recently collaborated on the Marine Plan Partnership for the North Pacific Coast (MaPP) and completed Marine Use Plans for subregions within the NSB that include candidate protected areas identified through an ecosystem-based management framework (e.g., Marine Plan Partnership Initiative 2015). Building on these commitments, the Government of Canada (represented by DFO, ECCC, Parks Canada, Transport Canada, and Natural Resources Canada), the Government of BC, and 16 member First Nations (represented by the Central Coast Indigenous Resource Alliance, Council of the Haida Nation, North Coast-Skeena First Nations Stewardship Society, Coastal First Nations - Great Bear Initiative, and Na̲nwak̲olas) have formed the Marine Protected Area Technical Team (MPATT) to coordinate MPA network design and implementation in the NSB.

The NSB is one of 13 ecologically distinct bioregions that have been delineated in Canada's oceans and the Great Lakes and provides the spatial framework for MPA network planning (Government of Canada 2011) and marine spatial planning. The NSB covers the same footprint as the MaPP and PNCIMA planning areas and covers an area of roughly 102,000 km^2, including two-thirds of the BC coastline, extending from Quadra Island/Bute Inlet north to the Canada-Alaska border and out to the base of the continental slope (Figure 1). The NSB includes a wide range of land- and seascapes ranging from narrow glacial-fed inlets, shallow intertidal zones, and current-swept passages to broad shelf waters, gyres, and upwelling areas. The relatively isolated nature and highly complex shape of the coastline with its many inlets and islands provides some unique challenges for MPA network planning, particularly around issues of scale and uncertainty.

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[1] 2015 Mandate Letters

[2] Memorandum of Understanding Respecting Implementation of Canada's Oceans Strategy, 2004

[3] Memorandum of Understanding on Pacific North Coast Integrated Management Plan (PNCIMA) Collaborative Oceans Governance, 2008

[4] Letter of Intent to Collaborate on Marine Planning and other Fisheries Related Issues in the Pacific North Coast, 2012

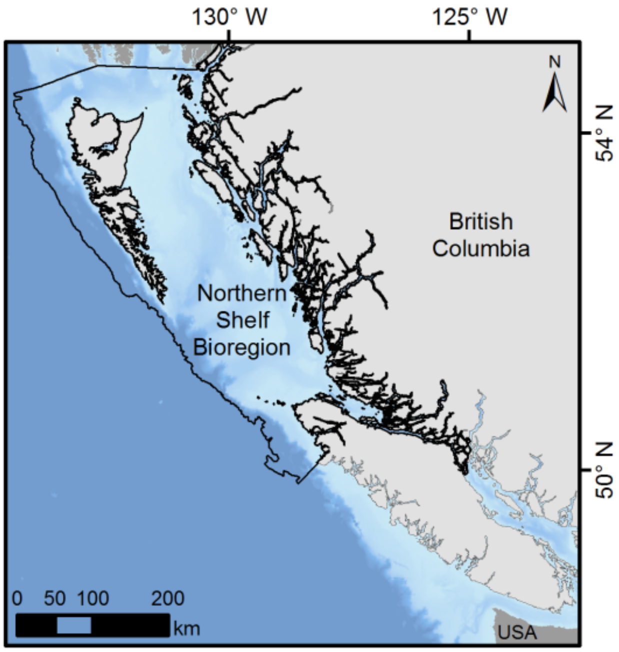

Figure 1. Map of the Northern Shelf Bioregion (NSB), which has the same footprint as the Pacific North Coast Integrated Management Area (PNCIMA).

The Canada – British Columbia Marine Protected Area Network Strategy (2014) ("the Strategy"), informed by the 2011 National Framework for Canada's Network of MPAs (Government of Canada 2011), serves as a basis for guiding the design, development, and implementation of MPA networks in the Pacific Region. The Strategy outlines six ecological, social, cultural, and economic goals to be achieved by the development of a network of MPAs. Goal 1 of the strategy is of primary importance and specifies the protection and maintenance of marine biodiversity, ecological representation and special natural features. Goal 2 focuses on the conservation and protection of fishery resources and their habitats. The remaining four goals relate to the protection and promotion of recreational, social, economic, cultural, and educational resources and opportunities. These goals and their related objectives[5] form the foundation of the MPA network planning process specific to the NSB and will be used as benchmarks to evaluate the effectiveness of the NSB MPA network for conserving marine biodiversity and other ecological, socio-economic and cultural priorities. The Strategy also describes 16 network design principles (including ecological, social, economic, cultural, and general implementation aspects) that are based on best practices for systematic conservation planning and inform the process by which the MPA network will be designed and implemented (Table 1). Principle 14 of the Strategy states that MPA network planning should build on existing MPAs, other management measures, and existing MSP initiatives. This principle ensures meaningful linkages across processes (e.g., PNCIMA, MaPP) and with other tools in the MSP toolbox. While sites that are identified through the MPA network planning process may contribute to the national and international goal to protect 10% of marine and coastal areas by 2020[6] (Aichi Target 11 in CBD 2011; DFO 2016), MPA network planning in the NSB does not have a footprint target and is an objective-driven and science-based process.

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[5] MPATT Network Objectives

[6] 2020 Biodiversity Goals and Targets for Canada

Table 1. Ecological network design principles and related guideline concepts relevant to design strategies for the MPA network in the NSB (Canada – British Columbia Marine Protected Area Network Strategy 2014). Details for each principle are found in Appendix 1.

Ecological Network Design Principle	Guideline Concept Relevant to Ecological Design Strategies
Principle 1. Include the full range of biodiversity present in Pacific Canada	Representation
	Replication
Principle 2. Ensure ecologically or biologically significant areas (EBSAs) are incorporated	Protection of unique or vulnerable habitats
	Protection of foraging or breeding grounds
	Protection of source populations
Principle 3. Ensure ecological linkages	Connectivity
Principle 4. Maintain long-term protection	MPA protection level
Principle 5. Ensure maximum contribution of individual MPAs	Size
	Shape
	Spacing

To guide the application of the broad network design principles in the NSB, MPATT solicited expert advice (see Lieberknecht et al. 2016) and consulted with stakeholders to deconstruct the principles into a suite of more specific design guidelines (Section 2; Appendix 2). The goals, objectives, principles, and design guidelines inform the development of ecological conservation priorities, which are the ecological features that will be prioritized when identifying sites to include in the MPA network, and design strategies that describe how the conservation priorities will be spatially incorporated into the network (Figure 2). Ecological conservation priorities for the NSB (DFO 2017b; Gale et al. 2019) include species considered vulnerable, ecologically important, or of conservation concern, as well as areas of climate resilience, degraded areas, representative habitats, and Ecologically and Biologically Significant Areas (EBSAs). Design strategies include spatial targets, referred to as ecological conservation targets, that are quantitative estimates for how much of each ecological conservation priority should be included in the MPA network, as well as other key variables (i.e., size, shape, spacing, and protection levels of MPAs, connectivity, and the representation and replication of ecological conservation priorities).

Together the ecological conservation priorities and design strategies will inform site selection analyses conducted during the design scenarios phase of MPA network planning in the NSB to identify priority areas for conservation (Figure 2). The spatial features (i.e., spatial datasets) identified to represent the conversation priorities will be inputs into site selection analyses using the Marxan decision support tool (Ball et al. 2009), along with the ecological conservation target ranges and guidance on MPA size and spacing (Appendix 3). As such, the ecological conservation target ranges are intended as an ecological starting point but not as species-specific management recommendations. A separate process is being undertaken by First Nations MPATT partners to identify cultural conservation priorities. Marxan analyses will be undertaken to incorporate the ecological and cultural conservation priorities, as well as socioeconomic considerations, to identify spatially efficient areas of high conservation value, explore tradeoffs, and minimize socioeconomic impacts. Together with the objectives, principles, design guidelines and design strategies, these analyses will inform the development of possible MPA network configurations in the NSB (Figure 2).

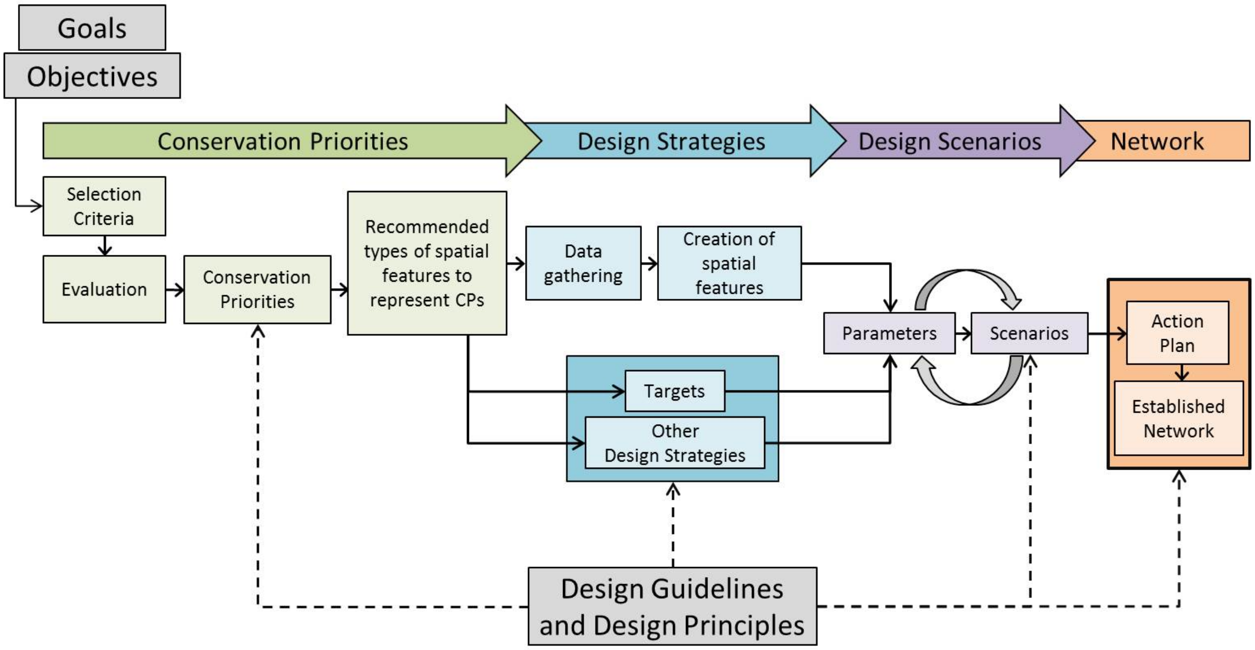

Figure 2. Conceptual diagram showing how design strategies fit within the NSB MPA planning process developed by MPATT in the Pacific Region.

1.2. SCOPE

This document identifies design strategies specifically for MPA network planning in the NSB. The purpose of this document is to:

1. Develop a systematic method for identifying the amount of each ecological conservation priority that should be protected within the network of MPAs (i.e., ecological conservation targets).
2. Apply the method to the list of ecological conservation priorities to create a suite of ecological conservation targets that can be used in site selection analyses.
3. Identify the ecological conservation priorities and associated features appropriate for spatial management in the NSB.
4. Identify the types of spatial features that are available and appropriate to represent the ecological conservation priorities for the NSB.
5. Recommend how to incorporate other design strategies, such as size, spacing, replication, connectivity, and protection levels, into MPA network design in the NSB.
6. Discuss uncertainties, gaps, research needs, and limitations.

This work

- Identifies design strategies at the scale of the NSB.
- Focuses on ecological conservation priorities, which are those prioritized under Goal 1 of the Strategy. The ecological conservation priorities may also have cultural, socioeconomic, or recreational values, which are being considered separately.
- Does not address site selection analyses specific to any particular design scenarios.

We first review the design principles and guidelines that relate to the ecological design strategies, including representation targets for the ecological conservation priorities. We then review methods and past applications of target-setting in marine spatial planning exercises in BC and the northeast Pacific. Next, we describe our approach and set ecological conservation targets applicable to the ecological conservation priorities identified for the NSB. From there, we detail our recommendations for other design strategies, including replication, size, spacing, and protection levels. Lastly, we summarize recommendations for future research and summarize considerations important for next steps in the MPA network planning process.

2. ECOLOGICAL NETWORK DESIGN PRINCIPLES, DESIGN GUIDELINES, AND DESIGN STRATEGIES

This section describes the background concepts for MPA network design, including key ecological principles and guidelines, and their relevance for development of the design strategies for the NSB MPA network. The first and primary goal of the Canada-BC MPA Network Strategy (2014) is “to protect and maintain marine biodiversity, ecological representation and special natural features.” Directly linked to this primary goal and its objectives are a set of ecological network design principles (Table 1), which are informed by, and not isolated from, the social, economic, and cultural network design principles and general operating principles and the regional context in which they will be applied. The principles are broad in order to be inclusive of a range of implementation possibilities. Their regional application requires further technical guidance and stakeholder input. General guidance for implementation of the principles has been developed based on past MPA network design processes from within British Columbia and other national and international jurisdictions (e.g., Natural England 2009; Government of Canada and Council of the Haida Nation 2010; Ban et al. 2013; DFO 2018b) as well as empirical evidence (e.g., Airamé et al. 2003; Halpern 2003), theory (e.g., Botsford et al. 2003; Shanks et al. 2003), working groups, and reviews (e.g., McLeod et al. 2009; Foley et al. 2010; Burt et al. 2014; Ardron et al. 2015; Lieberknecht et al. 2016). Building on this body of work, MPATT has developed design guidelines for the NSB MPA network planning process (Appendix 2, Figure 3).

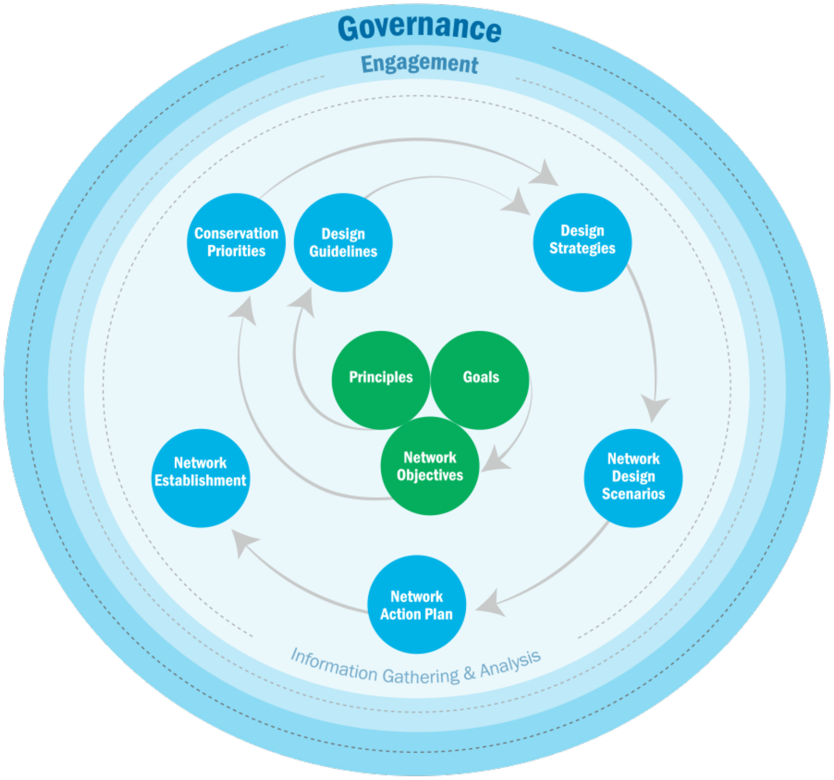

Figure 3. Conceptual diagram of Northern Shelf Bioregion Marine Protected Area planning process developed by the Marine Protected Area Technical Team (MPATT) in the Pacific Region.

Design guidelines (Lieberknecht et al. 2016) were developed to provide MPATT with a set of best practices that could be used to guide the design of the MPA network and to address the ecological design principles. Specifically, the design guidelines recommend that the configuration (size, shape, and spacing) of individual MPAs maximizes their contributions to the network, that the benefits of the MPA network are protected over the long term, and that MPA siting (a) includes the full range of biodiversity; (b) incorporates ecologically and biologically significant areas; and (c) considers ecological linkages (Table 1). These overarching guidelines (Appendix 2) informed the design strategies presented here, which will be used to inform the overall configuration of the network in the design scenarios phase (Figure 3). By applying these design strategies, the MPA network aims to represent the diversity of BC's marine ecosystems across their natural range of variation, maintain viable populations of native species, sustain ecological and evolutionary processes within an acceptable range of variability, and build a network resilient to environmental change.

2.1. PRINCIPLE 1: INCLUDE THE FULL RANGE OF BIODIVERSITY

One of the key ecological principles for MPA network design is to include the full range of biodiversity present within the study area (Burt et al. 2014). This principle can be addressed in part by representing and replicating the NSB's different marine habitat types, species, and unique areas that occur in the MPA network. Several of the MPATT design guidelines address the concept of representation and replication (Appendix 2), including (a) identifying a list of conservation priorities, including EBSAs and one or more broad-scale ecological classification systems; (b) developing spatial targets for conservation priorities that vary based on ecological criteria such as rarity, vulnerability, and importance; and (c) protecting replicates of conservation priorities across classes in the chosen classification system(s) at multiple scales.

2.1.1. Guideline Concept: Representation

Identifying ecological conservation priorities —the ecological features that the MPA network will aim to protect—is a key step in conservation planning (Margules and Pressey 2000; Rondinini and Chiozza 2010). Ecological conservation priorities can be individual populations or species, groups of species, habitats, communities, ecological processes, or other ecological features and areas. Conservation priorities can be considered at a coarse or broad scale, such as habitat classifications that span the entire region, or at a fine scale, such as priority species or spatially discrete natural features. Given that ecological communities vary along ecological gradients, habitats (i.e., coarse-filter features) alone might not be sufficient surrogates for biodiversity in site selection analyses and network design (e.g., Virtanen et al. 2018). Therefore, MPA design guidance recommends that comprehensive MPA networks capture representative examples of both coarse- and fine-filter conservation priorities (Lieberknecht et al. 2010).

The presence of individual species varies across latitudes, depths, and biogeographical areas. Because distinct species assemblages exist in different marine habitat types and habitat requirements within a species may vary with life stage, MPA networks that protect all habitat types and their affiliated ecological communities have a greater chance of conserving regional biodiversity across multiple levels, including genetic, species, habitat, and ecosystem diversity (Airamé et al. 2003; Roberts et al. 2003b; Roff et al. 2003; Palumbi 2004; IUCN-WCPA 2008; Gaines et al. 2010). To achieve representation in an MPA network, it is recommended to (a) incorporate at least one comprehensive classification system for a full range of habitat types, including information on their spatial distribution; (b) set targets to guide how much of each habitat type or feature should be protected; and (c) define spatial scales within which to address representation (Airamé et al. 2003; Fernandes et al. 2005; Burt et al. 2014; Ardron et al. 2015; Lieberknecht et al. 2016).

To protect biodiversity and build resilience of the overall network to environmental change, representation and replication targets should address conservation priorities across classes in the chosen classification system(s) at multiple scales. Protecting large areas of high-quality habitats is important for designing MPA networks that meet their ecological objectives (Gaines et al. 2010; Cabral et al. 2016; Krueck et al. 2017). In addressing representation, the Strategy (2014) states that the planning process "[r]epresent each habitat in the overall MPA network. For example, rocky reef habitat, eelgrass meadow, intertidal mudflat, persistent gyres or eddies, or representation within a hierarchy of ecological scales (e.g., representation of rocky reefs within a broader biogeographic classification)."

The MPATT design guidelines and guidance from other processes indicate that to fulfill the ecological network design principles, representation targets should be set for biodiversity proxies (i.e., habitats and features) and priority features and that these targets should vary based on characteristics of the conservation priority, such as rarity, vulnerability, importance, level of data uncertainty, and MPA protection levels applied (Appendix 2). For example, broad and widespread habitat classes should have lower proportional representation targets than less widespread and more narrowly defined ones (Lieberknecht et al. 2016). Conservation status and rarity should also be considered when setting representation targets (Lieberknecht et al. 2010). Rare, threatened, and endangered features should have higher representation targets and, where possible, more replicates than more common or less threatened features.

2.1.2. Guideline Concept: Replication

The network design principles recommend including spatially separated replicates of representative habitats and special or vulnerable features within MPA sites. Protecting multiple replicates of representative habitat types and other conservation priority features (e.g., vulnerable sites, EBSAs) (a) provides insurance against local disturbances or environmental disasters; (b) encapsulates natural variation among representative habitats and features in the MPA network; and (c) mitigates some of the uncertainty associated with identifying and capturing representative habitats and features in each area (Airamé et al. 2003; Roberts et al. 2003b; Gaines et al. 2010; Burt et al. 2014; Lieberknecht et al. 2016).

While there is no agreement on the number of replicates required by the network to meet ecological objectives, most processes and scientific studies recommend at least three spatial replicates (e.g., Fernandes et al. 2005; CDFG 2008; IUCN-WCPA 2008; Fernandes et al. 2012; Saarman et al. 2013).

To be adequate, replication should occur at a variety of nested scales. The Strategy (2014) states that, “The degree of replication should be assessed at a bioregional (or finer) scale(s) in an effort to safeguard against catastrophic events or disturbances and to build resilience in the overall MPA network.” Implementation of MPAs under the California Marine Life Protection Act Initiative (MLPA) (CDFG 2008, 2016) provides guidance on what constitutes a representative replicate that will contribute to the biodiversity protection objectives. In that process, a given MPA was considered to include a specific habitat if the MPA captured a critical extent of the habitat, defined as an area sufficient to encompass (a) a high proportion (90%) of the species known to use the habitat; and (b) sufficient abundance of such species to be resilient to movement and environmental perturbation (CDFG 2008; Saarman et al. 2013). The area of habitat required to count as a representative replicate was determined using accumulation functions applied to species-habitat data and general rules of thumb for habitats where data weren’t available (CDFG 2008).

2.2. PRINCIPLE 2: ENSURE ECOLOGICALLY AND BIOLOGICALLY SIGNIFICANT AREAS ARE INCORPORATED

4.2 (EBSAs) are a key input for MPA networks (DFO 2010; Canada – BC MPA Network Strategy 2014). Specific areas or features that can be considered EBSAs include:

- Areas of high biological diversity and productivity;
- Areas that are unique or rare;
- Features that represent habitats or species that are threatened, vulnerable or declining; and
- Areas of special importance to certain life history stages, including breeding grounds, spawning sites, and nursery areas.

Protecting areas characterized by high biological diversity is important because evidence suggests there is a strong relationship between biological diversity and ecosystem resilience, defined as the capacity of an ecosystem to respond to perturbation based on its ability to resist change and its rate of recovery after disturbance (Oliver et al. 2015). Furthermore, by protecting areas of high biological diversity, the network can achieve multiple objectives more efficiently. Areas with comparatively high productivity are also important for maintaining populations and promoting ecosystem resilience. Areas and features that are unique or rare are valuable because they are irreplaceable. Similarly, species or habitats that are threatened, vulnerable, or declining are important to protect because their loss may be permanent due to their restricted distribution, dependence on limited habitat, or sensitivity to environmental disturbance. Many species utilize regular areas for foraging, reproduction, or migration stopovers. Including these areas in the network protects sites that species depend on to complete their lifecycles.

To address these principles and guidelines, the list of ecological conservation priorities includes EBSAs and Important Areas (IAs) (DFO 2017a, DFO 2020). These areas were originally delineated based on expert advice (Clarke and Jamieson 2006a, 2006b) and the EBSAs were re-evaluated with empirical data (DFO 2018a; Rubidge et al. 2018). EBSAs, IAs, and other areas of importance will be incorporated into the network as spatial features with recommended ecological conservation targets (see Section 5).

2.3. PRINCIPLE 3: ENSURE ECOLOGICAL LINKAGES

2.3.1. Guideline Concept: Connectivity

Ecological spatial connectivity refers to processes by which genes, species, populations, nutrients, and/or energy move among spatially distinct populations, communities, or ecosystems (MPA Federal Advisory Committee Marine Protected Area Federal Advisory Committee 2017) (Section 9.3.1). In marine ecosystems, there are several mechanisms by which connectivity occurs. Many organisms (individuals or their propagules) are passively carried over a variety of distances by ocean currents, and many species are adapted to live in the marine environment through morphological and/or behavioral traits, allowing for routine movement across and among habitats. Populations within MPAs often rely on the delivery of individuals or their offspring from areas outside of the MPA. Similarly, chemical or physical materials are readily transported among MPAs or between areas outside of MPAs into MPAs. For example, nutrients derived from macroalgal drift from nearshore kelp forests may be delivered to deep water continental-shelf benthic communities or intertidal sandy beaches, subsidizing food webs (Harrold et al. 1998; Liebowitz et al. 2016).

Ecological spatial connectivity can be separated into four types or scales – genetic connectivity, population or demographic connectivity, community connectivity, and ecosystem connectivity – each of which acts at multiple scales in relation to the MPAs in the network (within MPAs, among MPAs, and between MPAs and areas outside MPAs) (Section 9.3.1). Addressing these four types of ecological connectivity in an MPA network is important because connectivity affects the species within an ecosystem as well as that ecosystem’s productivity, dynamics, resilience, and capacity to benefit humans. In short, connectivity influences whether MPAs can meet their ecological objectives (Green et al. 2014). For example, connectivity can maintain genetic diversity by reducing harvest-induced genetic selection, if MPA networks capture a set of genetically diverse populations and some level of larval retention occurs (Allendorf and Hard 2009; Baskett and Barnett 2015). Outside of MPAs, the spillover effect can supplement fisheries harvest by providing exports of target species from MPAs into adjacent areas (Christie et al. 2010; Gaines et al. 2010; Baskett and Barnett 2015; Le Port et al. 2017; Baetscher et al. 2019).

There are few examples of connectivity being explicitly incorporated into MPA design. Representation (Section 2.1.1), replication (Section 2.1.2), size (Section 2.5.1), and, in particular, spacing (Section 2.5.3) considerations all address connectivity implicitly. To date, they have been the primary means by which connectivity has been addressed in MPA network design (Green et al. 2014). For example, many MPA networks aim to protect breeding and/or nursery habitats, and set the size of MPAs and the spacing between MPAs within the dispersal distances of focal species so that larvae or juveniles can replenish populations within and among the MPAs (Marine Protected Area Federal Advisory Committee 2017). Ongoing developments in oceanographic modeling, genetics, and biophysical modeling may provide an opportunity to more directly include connectivity in MPA design, where adult movements and larval sources that are important for maintaining populations can be identified and incorporated as features in the network.

2.4. PRINCIPLE 4: MAINTAIN LONG-TERM PROTECTION

MPAs can prevent further degradation of marine and coastal environments, restore areas that have been degraded, and provide resilience in the face of potential changes in environmental conditions or human impacts (Halpern and Warner 2002; Stewart et al. 2009; Sciberras et al. 2013; Edgar et al. 2014). However, MPAs are implemented to meet diverse objectives, including biodiversity conservation, food security, adaptive capacity for climate change, and fisheries management (Green et al. 2014). As such, management restrictions within MPAs can range from strict no-take areas, where all extractive activities are prohibited and visitation may even be restricted, to areas that allow the sustainable use of natural resources (Day et al. 2012; Ban et al. 2014). The level and duration of protection that MPAs provide, the extent to which they limit human activities, their location, and the effectiveness of their enforcement influence their ability to mitigate human disturbances and provide resilience against future change (Sciberras et al. 2013; Edgar et al. 2014; Baskett and Barnett 2015; Gill et al. 2017). A number of guidelines have been developed to address these challenges (Appendix 2).

2.4.1. Guideline Concept: MPA level of protection

MPA designations can vary widely among jurisdictions and geographies. To provide a standardized approach for setting and assessing levels of protection and to allow for comparisons among protected areas around the globe, the IUCN developed a system to classify protected areas (IUCN-WCPA 1994). The IUCN categories have since been applied specifically to MPAs (Day et al. 2012), and are widely used in reporting progress on protected areas to international bodies such as the CBD.

In marine systems, the IUCN categories are based on the “primary stated objective(s)” of each MPA and its natural characteristics (Day et al. 2012) and describe allowable activities. As such, the categories reflect the management intent of MPAs but may not match current regulations (Robb et al. 2011; Horta e Costa et al. 2016). The categories range from strict protected areas that are commonly no-go/no-take areas (Category Ia), to areas that protect biodiversity and ecological processes by prohibiting extractive activities other than Indigenous use (Categories Ib, II, III), to areas that allow some limited extraction (Category IV, V), to those that intend sustainable use (Category VI) (Day et al. 2012) (Appendix 4).

The level of protection afforded to MPAs can influence the ecological effectiveness of MPA networks. There is evidence that managing a proportion of the MPA network in no-take reserves is critical to maintain ecological processes and meet biodiversity goals (Halpern 2003; Roberts et al. 2003a; Lester and Halpern 2008; Lester et al. 2009; Stewart et al. 2009; Edgar et al. 2014). Recent meta-analyses of multiple MPAs has shown that partially protected areas (i.e., IUCN Categories IV,VI) are less effective in meeting their ecological objective than fully protected areas (Sciberras et al. 2013; Ban et al. 2014). Several reports detailing science-based MPA guidelines specifically recommend that a proportion of the marine space or MPA network should be zoned as no-take reserves (30-50% of representative habitats - Airamé et al. 2003; 33% of study area - Fernandes et al. 2005; 21% of study area - Airamé and Ugoretz 2008; 30% of each bioregion - Jessen et al. 2011; 20-35% of each habitat - Fernandes et al. 2012; 30-35% of marine space - O'Leary et al. 2016). The design guidelines provide similar recommendations and suggest that the level of protection afforded to the MPAs be taken into consideration when providing size, shape, and spacing recommendations and applying ecological conservation targets for conservation priorities in the network (Appendix 2).

2.5. PRINCIPLE 5: ENSURE MAXIMUM CONTRIBUTION OF INDIVIDUAL MPAS

2.5.1. Guideline Concept: Size

MPAs need to be an adequate size to protect viable populations, habitats, and ecological processes within their boundaries (Butler et al. 1996; Palumbi 2004; Baskett et al. 2007; Fox et al. 2012). MPA networks aim to protect a variety of species with variable life history characteristics, movements, interactions, and habitat associations and there is no one ideal MPA size that will address all ecological objectives (Palumbi 2004; Baskett et al. 2007; Fernandes et al. 2012). Despite this challenge, several studies provide guidelines based on the best available science. These guidelines incorporate species movements and larval characteristics that affect the persistence of populations within an MPA and aim to protect species that move across MPA boundaries (Botsford et al. 2003; Shanks et al. 2003; Palumbi 2004; Botsford et al. 2009; Gaines et al. 2010; Pelc et al. 2010). For species whose adults and larvae only travel short distances, smaller MPAs (e.g., 4–6 km diameter, Shanks et al. 2003) can protect these populations within their boundaries (Gaines et al. 2010; Green et al. 2014). However, species with greater mobility or species whose larvae have longer-dispersal distances require larger MPAs (10–100 km in the smallest dimension; Botsford et al. 2009; Gaines et al. 2010). Species with adult home ranges larger than a reserve's size will be protected for only part of the time (Botsford et al. 2003; Palumbi 2004).

Many species undertake movements beyond the scale that MPAs typically encompass. In general, MPAs are thought to diminish in efficiency as the migratory potential of organisms increases (Carr and Reed 1993; DeMartini 1993; Micheli et al. 2004; Le Quesne and Codling 2009). However, MPAs and carefully designed networks of MPAs can contribute to the protection of more mobile species. More mobile species will benefit from MPAs if fishing mortality and other impacts are reduced within their boundaries and/or if the MPAs protect areas important for critical or vulnerable life stages or aggregations (e.g., foraging or breeding areas; migration bottlenecks; staging areas) (Hooker and Gerber 2004; Hooker et al. 2011).

Several planning processes and scientific studies provide specific recommendations for MPA size (Table 2); for a review, see Burt et al. 2014), but these vary depending on the particular species of interest and the planning process. For example, the California MLPA Science Advisory Team recommended that MPAs should have a minimum alongshore span of 5–10 km and preferably 10–20 km and a minimum size range of 23–47 km^2 and preferred size range of 47–93 km^2 (Saarman et al. 2013). Other work (IUCN-WCPA 2008; Jessen et al. 2011; Fernandes et al. 2012; Edgar et al. 2014) indicates that very large MPAs (i.e., 100s–1000s of km^2) are most appropriate to achieve overall network resilience and biodiversity conservation. For some planning processes focused on coral reef habitats, a network with a combination of larger (4–20 km diameter) and smaller (0.4 km^2) protected areas are considered beneficial as smaller MPAs can encompass an entire reef (Fernandes et al. 2012).

Table 2. MPA size recommendations and case examples from the literature (Adapted from Burt et al. 2014)

Examples	Recommendations	Reference
Rules of thumb (peer-reviewed literature)	The neighbourhood size of a species should be less than about twice the size of the marine reserve.	Botsford et al. (2001); Botsford et al. (2003); Palumbi (2004)
Modelling studies (peer-reviewed literature)	The size of the MPA should be at least as large as the average dispersal distance of the larvae (and home range of adults) to ensure viable populations can persist within its boundaries	Hastings and Botsford (2006)
Rules of thumb (peer-reviewed literature)	MPAs should have a diameter greater than the average dispersal distance of the species of interest.	Botsford et al. (2009); Gaines et al. (2010)
California nearshore (peer-reviewed literature)	Modelling based on observed larval characteristics in nearshore temperate environments suggests that a reserve 4–6 km in diameter should be large enough to contain the larvae of short-distance (<1 km) dispersers.	Shanks et al. (2003)
California, Marine Life Protection Act MPAs	MPAs should have a minimum alongshore span of 5–10 km and preferably 10–20 km and a minimum size range of 23–47 km^2 and preferred size range of 47–93 km^2.	CDFG (2008); Saarman et al. (2013)

Several studies provide rules of thumb for setting the size of MPAs. For example, an MPA should have a diameter greater than the home range of the adults of the species of interest to ensure viable populations can persist within its boundaries (Hastings and Botsford 2006; Botsford et al. 2009; Gaines et al. 2010). Also, MPAs should be at least twice the target species' average dispersal distance to ensure larval retention (Gaines et al. 2010; Pelc et al. 2010). However, this can become very complicated when there are many species to be protected in an MPA network. Ultimately the appropriate size for individual MPAs should be determined by the MPA management objectives, which will be influenced by the level of protection of the MPA and the species or features of interest (Burt et al. 2014).

While these guidelines provide a starting point, each potential MPA network configuration should be assessed for adequacy based on whether the configuration can sustain viable target populations or communities (OSPAR 2007; Botsford et al. 2014). This will depend on the species of interest's life-history and population structure, habitat quality, management outside of the MPA, and the connectivity of the MPA to other sites (OSPAR 2007; Botsford et al. 2014; Burt et al. 2014). However, these types of data are typically not available for all features of interest.

Several NSB MPA network design guidelines address the size of MPAs in the network (Appendix 2). These include minimum size ranges, suggestions for minimum areas and recommendations on how size should vary with protection levels and replication.

2.5.2. Guideline Concept: Shape

Shape is another key feature of individual MPAs (Table 3), particularly the ratio of edge to volume. Shape affects the degree of species retention vs. species spillover; specifically, the more perimeter edge a reserve has, the more it will export larvae and adults to the surrounding area (Roberts et al. 2003b). This factor leads to tradeoffs among MPA network objectives, where minimized edges and higher volumes lead to improved biodiversity outcomes while greater edges and lower volumes may improve fisheries benefits (IUCN-WCPA 2008; McLeod et al. 2009; Gaines et al. 2010; Fernandes et al. 2012). In addition, shape influences the ease of compliance and enforcement; boundaries should be identifiable, navigable, and easily communicated (Burt et al. 2014).

Table 3. MPA shape recommendations and case examples from the literature (Adapted from Burt et al. 2014).

Examples	Recommendations	Reference
California, Marine Life Protection Act MPAs	To accommodate the movements of individuals across depth zones, MPAs should extend from the intertidal zone to the offshore limit of the state jurisdiction (5.56 km)	CDFG (2008); Saarman et al. (2013); Botsford et al. (2014)

2.5.3. Guideline Concept: Spacing

Spacing is the primary tool used to date for addressing ecological connectivity within an MPA network (see Section 2.3.1). Spacing guidelines vary in the literature and in practice (Table 4; see Burt et al. 2014 for a review). Like size, spacing guidelines are influenced by larval and nutrient transport and the movements of adults and juveniles. Estimates of larval dispersal distances vary widely among species and depend on local and regional oceanographic patterns, as well as the characteristics and behavior of larvae (Shanks 2009). Despite this variability and the difficulty in measuring connectivity, rules of thumb for incorporating these metrics into spacing guidelines have been developed based on average dispersal distances (e.g., Shanks et al. 2003; Palumbi 2004; CDFG 2008; Gaines et al. 2010; Gleason et al. 2010; Moffitt et al. 2011; Fernandes et al. 2012). For example, the California MPA network guidelines recommended having MPAs within 50–100 km of each other, based on estimates of invertebrate and seaweed larval movements of 1–100 km and estimates of fish larval movements of 50–200 km (Kinlan and Gaines 2003; Shanks et al. 2003). Generally, MPAs should be spaced far enough apart to maximize the area outside of MPAs replenished by larvae produced within MPAs, but close enough that larvae have the potential to be exported from one MPA to another (Palumbi 2004; Gaines et al. 2010). However, the types and distribution of habitats will also influence spacing of MPAs and acts as a source of uncertainty associated with using rules of thumb.

Table 4. MPA spacing recommendations and case examples from the literature (Adapted from Burt et al. 2014).

Examples	Recommendations	Reference
Science-Based MPA Guideline Reports	The spacing between individual sites should range from 10–20 km up to 50–100 km (depending on the habitat type and region); When specific data [on larval dispersal] is lacking, nearshore MPA sites should be spaced not further than 50 km apart to maintain connectivity of most short to moderate larval dispersing species.	OSPAR (2007); IUCN-WCPA (2008)
Science-Based MPA Guideline Report for BC	All MPAs should generally be within 20 to 200 km of the nearest MPA in the network.	Jessen et al. (2011)
California nearshore MPAs (peer-reviewed literature)	Reserves spaced 10–20 km apart should be close enough to capture propagules released from adjacent reserves; The spacing of reserves should reflect larval neighborhood scales, which range from 10 to 200 km; Distances between reserves ranging from 10 to 100 km enhance both conservation and fishery benefits because they approach mean larval dispersal distances estimated for many fished coastal marine species.	Shanks et al. (2003); (Palumbi 2004); Gaines et al. (2010)
California, Marine Life Protection Act MPAs	Based on currently known scales of larval dispersal for species in temperate climates, MPAs should be placed within 50 to 100 km of each other.	CDFG (2008)

3. REVIEW OF METHODS FOR SETTING REPRESENTATION AND REPLICATION TARGETS FOR ECOLOGICAL CONSERVATION PRIORITIES

3.1. DESCRIPTION OF APPROACHES

Setting targets is a core aspect of systematic conservation planning (Margules and Pressey 2000). Ecological conservation targets specify how much of each ecological conservation priority (and associated spatial feature(s)) an MPA network aims to protect (Carwardine et al. 2009; Ardron et al. 2010), provide a clear basis for conservation decisions, and are guidelines by which to measure success during the design scenario and implementation phases of the MPA network (Rondinini 2010; Lieberknecht et al. 2016). Targets are often expressed as a range to facilitate the development of a suite of potential network designs for consideration (Lieberknecht et al. 2010; Levin et al. 2015); hereafter we use “target” to refer to “target range”. For example, target ranges could include 20-40% of the spatial distribution of eelgrass beds or 40–60% of known tufted puffin colonies in the study area. Although cultural conservation priorities and economic and social activities may also be ecologically based and will inform the design of the network, the target-setting described here for ecological conservation priorities is independent of socio-cultural and economic considerations.

Ecological conservation targets can be set using approaches that are policy-driven, expert-based, and/or quantitative. Regardless of the chosen approach, targets should be informed by the conditions needed for biodiversity persistence and ecosystem functioning (i.e., ecological thresholds - Rondinini and Chiozza 2010). Because there can be considerable uncertainty in their development and application, targets should be revised and adapted regularly as new information becomes available (Carwardine et al. 2009). Below we elaborate on the different approaches to setting targets and describe how they have been used in planning processes relevant to the NSB.

3.1.1. Policy-driven approaches

Policy-driven approaches are generally fixed ecological conservation targets agreed upon in a political process but not necessarily based on the ecological requirements of the conservation features (Carwardine et al. 2009). Thus, achieving policy-driven targets will not necessarily ensure biodiversity protection and persistence. A well-known example of this type of policy-driven target is the CBD target of protecting 10% of coastal and marine areas by 2020 (CBD 2011). Policy-driven targets can provide a starting point for MPA network planning processes but should not be applied broadly to a range of conservation priorities (Lieberknecht et al. 2010). Nonetheless, coarse-filter features are sometimes assigned a fixed minimum target when more rigorous methods are not feasible (Lieberknecht et al. 2010; DFO 2018b).

3.1.2. Expert opinion and heuristic approaches

In many marine planning regions, expert opinion is used as a basis for setting ecological conservation targets (e.g., Cowling et al. 2003; Smith et al. 2006; Smith et al. 2009; Ban et al. 2013). Often this approach is used when data is not available for the species and features of interest. However, expert judgment can be challenging to justify and implement as experts may be biased toward their research interests and underlying principles influencing responses may not be transparent or consistent (Ardron et al. 2010; Burgman et al. 2011; Drescher et al. 2013).

Heuristic approaches (e.g., science-based “rules of thumb” – Moffitt et al. 2011; transforming ordinal data into quantitative targets – Saarman et al. 2013), similarly rely on a number of assumptions and on expert input and are also applied when more rigorous quantitative methods or data are not available (Rondinini and Chiozza 2010). These semi-quantitative or qualitative approaches are usually rooted in ecological theory, generalize from biodiversity data of variable quality and quantity, and can be complemented by expert judgment and traditional and local knowledge. Heuristic approaches, therefore, are more transparent and repeatable than expert judgment approaches and can be adapted to situations of variable data quantity and quality. However, it is important that rules of thumb be applied using as much specificity to the study system as possible and the limitations and assumptions noted.

Due to a common lack of data for strictly quantitative approaches—including species-habitat curves and population viability analyses—evidence-based heuristic scoring systems are often more feasible for conservation planning that targets multiple ecological features and objectives. The benefits of following an explicit, repeatable method for ecological conservation target development are widely documented (e.g., Pressey et al. 2003; Svancara et al. 2005; Carwardine et al. 2009; Ardron et al. 2010; Rondinini and Chiozza 2010; Ban et al. 2013; Metcalfe et al. 2013b). They include accountability, ecological credibility, scientific defensibility, and transparency, all of which improve stakeholder support and facilitate trade-off analyses (Carwardine et al. 2009; Metcalfe et al. 2013b). Expert opinion provides important supplementary criteria for target development (Miller et al. 2006; Smith et al. 2006; Carwardine et al. 2009; DFO 2018b).

3.1.3. Quantitative analytical approaches

Other evidence-based approaches for setting ecological conservation targets are more quantitative and more scientifically defensible, but can also be data-intensive and may involve similar uncertainties (Lieberknecht et al. 2010; Rondinini and Chiozza 2010). Some examples include estimating species-area relationships for minimum viable populations and developing habitat-specific species-area curves to set targets for specific species and habitats. These approaches estimate the amount of area or habitat required to conserve a species using demographic and habitat data (Rondinini 2010; Rondinini and Chiozza 2010). Although scientifically sound, quantitative methods are usually difficult to apply when conservation planning focuses on multiple conservation features, particularly if data are scarce.

3.2. REVIEW OF APPROACHES APPLIED IN CANADA AND THE NORTHEAST PACIFIC

There have been a number of planning processes that have been undertaken in marine areas of Canada and the Northeast Pacific. These processes and their ecological conservation targets are described below and summarized in Table 5.

3.2.1. British Columbia Marine Conservation Analysis

The British Columbia Marine Conservation Analysis (BCMCA) was initiated in 2006 by representatives from the Government of Canada, Government of BC, First Nations, academia, environmental non-government organizations, and marine user groups. Working collaboratively, the project team developed tools to advance marine spatial planning in the Canadian Pacific, including an atlas of the best available spatial data and a suite of example Marxan analyses that identified areas of high conservation value and areas important for human uses (Ban et al. 2013). The analyses were informed by conservation priorities, spatial features, and ecological conservation targets identified through a series of expert workshops. Targets identified by experts ranged up to 100%. The project team subsequently used a heuristic approach to create a standardized set of target ranges. Features of conservation concern, features that had been assigned a target of 75% or higher by the expert community, and distinctive or unique physical features were classified as special and assigned a target range of 20-60% (Table 5). A lower target range of 10-30% was used for all other features, which were termed representational or normal features.

The ecological conservation target ranges developed by the BCMCA project team have been adopted in Marxan analyses performed by planning processes in the Canadian Pacific. For example, the MaPP Science Advisory Committee recommended applying BCMCA target ranges to Marxan analyses designed to inform subregional marine use plans and identify candidate MPAs (Marine Plan Partnership Initiative 2016).

3.2.2. Gwaii Haanas

Gwaii Haanas National Park Reserve, National Marine Conservation Area (NMCA) Reserve, and Haida Heritage Site (hereafter, Gwaii Haanas) is a 5,000 km^2 land-and-sea protected area in southern Haida Gwaii, off the north Pacific coast. The area is cooperatively managed by the Council of the Haida Nation and the Government of Canada (Parks Canada, Fisheries and Oceans Canada) by the Archipelago Management Board (AMB).

Prior to establishment of Gwaii Haanas, an interim management plan (IMP) for the area was developed. The IMP included a zoning plan that described zones of strict protection (3% of the total area) and zones of sustainable use (Government of Canada and Council of the Haida Nation 2010). In developing the IMP zoning, Marxan was used as a tool to analyze the available ecological data. Following advice from experts of the NMCA Science Network, ecological conservation targets were established separately for coarser representation areas and finer biological features and distinctive areas (Government of Canada and Council of the Haida Nation 2010). Coarse-filter features were given targets ranging from 20-45%, and areas that were under-represented in the area compared with their representation in natural marine regions were assigned higher targets. Targets of 30% were assigned to biological features and distinctive areas, with higher targets of 60% given to features of conservation concern, features of particular ecological significance, or features that were rare in Gwaii Haanas (Table 5). The IMP Marxan analyses also used an overall protection target of 30% of the marine space.

In 2018, after the original regional peer review of this research document, the AMB finalized the Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan (Government of Canada and Council of the Haida Nation 2018), which replaces the 2010 IMP for the marine area and includes a revised zoning plan. During this process, Marxan was used to identify hotspots of high ecological and economic value that were combined with spatial information about cultural values. To identify ecological hotspots, key ecological features, species and habitats were defined, mapped, and assigned a 30% target. Areas of high biophysical diversity, special, rare and "sensitive" ecosystem elements were identified and assigned a 60% target. The final approved zoning plan includes 40% of the area in strict protection zones, which prohibit commercial and recreational fishing, and 60% of the area in multiple use zones.

3.2.3. Scotian Shelf Bioregion

In the Maritimes, DFO is leading MPA network planning within the Scotian Shelf Bioregion. Due to data constraints, planning has been separated into coastal and offshore components. In the coastal area, where data are scarce, expert advice will determine the spatial extent of each conservation priority. In the offshore component, where more spatial data are available, Marxan analyses will be performed to identify potential MPAs and explicit ecological conservation target ranges have been identified for a suite of conservation priorities based on expert advice and logic-based rules (DFO 2018b). To begin, a minimum target of 10% was set for all conservation priorities to ensure all are represented in the network. Coarse-filter features were revised based on area so that smaller features were assigned higher targets, a common practice in conservation planning (Carwardine et al. 2009; Lieberknecht et al. 2010). Fine-filter features were separated into areas of high species richness, biogenic habitats, and depleted species. Areas of high species richness were all targeted at 20–40% due to a lack of information necessary to differentiate among them. Targets for biogenic habitats were adjusted based on vulnerability and uniqueness or rarity and targets for depleted species were based on vulnerability and conservation status. A scoring system was used systematically so that higher targets were assigned to conservation priorities which were more vulnerable and unique/rare (biogenic habitats) or more vulnerable and more highly threatened (depleted species) (DFO 2018b)(Table 5).

3.2.4. Pacific Northwest Marine Ecoregional Assessment

The Pacific Northwest (PNW) Marine Ecoregional Assessment was an initiative led by the Nature Conservancy (TNC) "to identify priority areas for conserving representative biodiversity" along the west coast of Oregon, USA (Vander Schaaf et al. 2013). Similar in scope to the BCMCA, the PNW Ecoregional Assessment was designed to guide future marine spatial planning efforts by assembling the best available ecological data and using the compiled datasets in example Marxan analyses. The project focused on ecological data, with the caveat that any planning derived from this work would incorporate social and economic information. Marxan was used to identify priority areas for protecting representative features. Ecological conservation targets were set at 30%. Fine-filter targets were increased to 50% for species with declining distributions or fish species considered "overfished" (Table 5). Exceptions were made for Steller sea lion rookeries (targeted at 100%), Steller sea lion critical habitat (90%), and Orca critical habitat (20%) based on federal Endangered Species Act recovery goals (Vander Schaaf et al. 2013).

Table 5. Objectives and design strategies developed for past marine planning exercises.

Process	Objectives	Ecological Conservation Targets
British Columbia Marine Conservation Analysis (BCMCA)	• Represent the diversity of BC's marine ecosystems across their natural range of variation. • Maintain viable populations of native species. • Sustain ecological and evolutionary processes within an acceptable range of variability. • Build a conservation network that is resilient to environmental change.	• Normal or representational features: 10–30% • Special features: 20–60% *Special: features of conservation concern, features with high expert recommended targets (>75%), or unique or distinctive physical features*
Gwaii Haanas National Marine Conservation Area Reserve – Interim Management Plan	• Represent, conserve, and maintain the biophysical and ecological diversity of the study area and the region's special elements	• Representational features: 20–45% • Biological features and distinctive areas: ○ General: 30% ○ Special: 60% *Special: Listed, ecologically significant, or special features that are not widely distributed throughout the NMCAR*
Scotian Shelf Bioregional Marine Protected Area Network (offshore) *(Nearshore component did not use Marxan)*	• Protect unique, rare, or sensitive ecological features in the bioregion • Protect representative examples of identified ecosystem and habitat types in the bioregion • Help maintain ecosystem structure, functioning and resilience within the bioregion • Contribute to the recovery and conservation of depleted species • Help maintain healthy populations of species of commercial, recreational and/or Aboriginal importance	• Minimum target of 10%, adjusted based on: ○ Coarse-filter features: size ○ Biogenic habitats: vulnerability, uniqueness/rarity ○ Depleted species: vulnerability, current status • Areas of high species richness: 20–40%
Pacific Northwest Marine Ecoregional Assessment	• Identify priority areas in the Oregon territorial sea (out to 3 nm) that had the potential to be designated as a network of marine reserves.	• Coarse-filter features: 30% • Fine-filter features (regular): 30% • Fine-filter features (special): 50% *Special: kelp, seabird colonies, ESA listed species, overfished species, coastal upwelling zones, most marine mammals*

4. SETTING ECOLOGICAL CONSERVATION TARGETS IN THE NSB

In this section, we describe our method for setting ecological conservation targets for ecological conservation priorities in the NSB to meet design guidelines (see Section 2.1.1; Appendix 2).

Interactions within ecosystems operate at multiple spatial scales and not all interactions have been identified or quantified. Accordingly, peer-reviewed analyses and best practices for site selection analyses recommend the use of multiple types of data across different scales to represent a variety of ecosystem features. These approaches often divide conservation priorities into representative coarse-filter and spatially discrete fine-filter features to ensure that the proposed MPA network captures all ecosystem components (Wiersma et al. 2005; Lieberknecht et al. 2010; DFO 2018b). In the context of Marxan analyses, the term “feature” refers to the spatial representation of a conservation priority that will be targeted for inclusion in an MPA network (Ardron et al. 2010).

Experts often recommend that coarse-filter features are assigned ecological conservation targets as a function of the square-root of the feature’s spatial extent within the study region to ensure that smaller, rarer features are assigned higher targets than larger and more common features (BCMCA and PacMara 2010; Lieberknecht et al. 2010). This approach has been used in a variety of jurisdictions (e.g., Wiersma et al. 2005; Government of Canada and Council of the Haida Nation 2010; Vander Schaaf et al. 2013; DFO 2018b). Following this advice, we assessed feature size to develop ecological conservation targets for coarse-filter conservation priorities.

As described in Section 3, a variety of methodologies have been employed to set ecological conservation targets for fine-filter conservation priorities depending on the objectives of the proposed MPA network, the suite of conservation priorities, and the available spatial data (Svancara et al. 2005; Metcalfe et al. 2013a; Metcalfe et al. 2013b). Based on the available data and following approaches used in other planning processes within the region and nationally, we developed a heuristic approach for setting ecological conservation targets for fine-filter conservation priorities that integrates conservation priority-specific criteria derived from the ecological network objectives for the NSB (Gale et al. 2019). We adapted a scoring system originally developed for the Scotian Shelf bioregion (DFO 2018b) to calculate target scores relevant to the conservation priorities in the NSB. In addition, we used the results of the BCMCA project in Pacific Canada (Ban et al. 2013) and an updated expert survey to ensure that expert opinion was incorporated in a transparent and systematic fashion. The BCMCA’s expert-driven targets have been used widely in the Canadian Pacific to develop proposed protected areas (e.g., Marine Plan Partnership Initiative 2015) and are directly relevant to NSB conservation priorities and spatial datasets available for the NSB.

4.1. ECOLOGICAL CONSERVATION PRIORITIES FOR THE NSB

A systematic framework for identifying ecological conservation priorities in the NSB was developed and applied by (DFO 2017b; Gale et al. 2019).The framework included criteria for identifying species-based and area-based conservation priorities, based on global best practices and the ecological objectives associated with Goal 1 of the Canada – BC MPA Network Strategy (2014) (Table 6, Figure 4). Each conservation priority was evaluated using literature and further vetted and augmented by expert opinion and was assigned a score for each criterion ranging from 0 (low) to 2 (high). Species-based ecological conservation priorities included species considered vulnerable, of conservation concern, or ecologically significant (upper-level predators, key forage species, nutrient-transporting species, and habitat-forming species). Only these ecological criteria were assessed, although the resulting list of species may also be of cultural and/or socioeconomic importance. There were 195 species-based conservation priorities identified in the NSB, including 65 bony fishes and elasmobranchs, 23 marine mammals, one sea turtle, 46 invertebrates, five plants and algae, and 55 marine birds. These conservation priorities are all considered fine-filter features.

Ecosystem features and habitats, including areas of climate resilience, degraded areas, representative habitats, and EBSAs such as high current areas, were recommended as area-based ecological conservation priorities (Gale et al. 2019). The area-based conservation priorities are further subdivided into coarse- and fine-filter features based on their spatial scale.

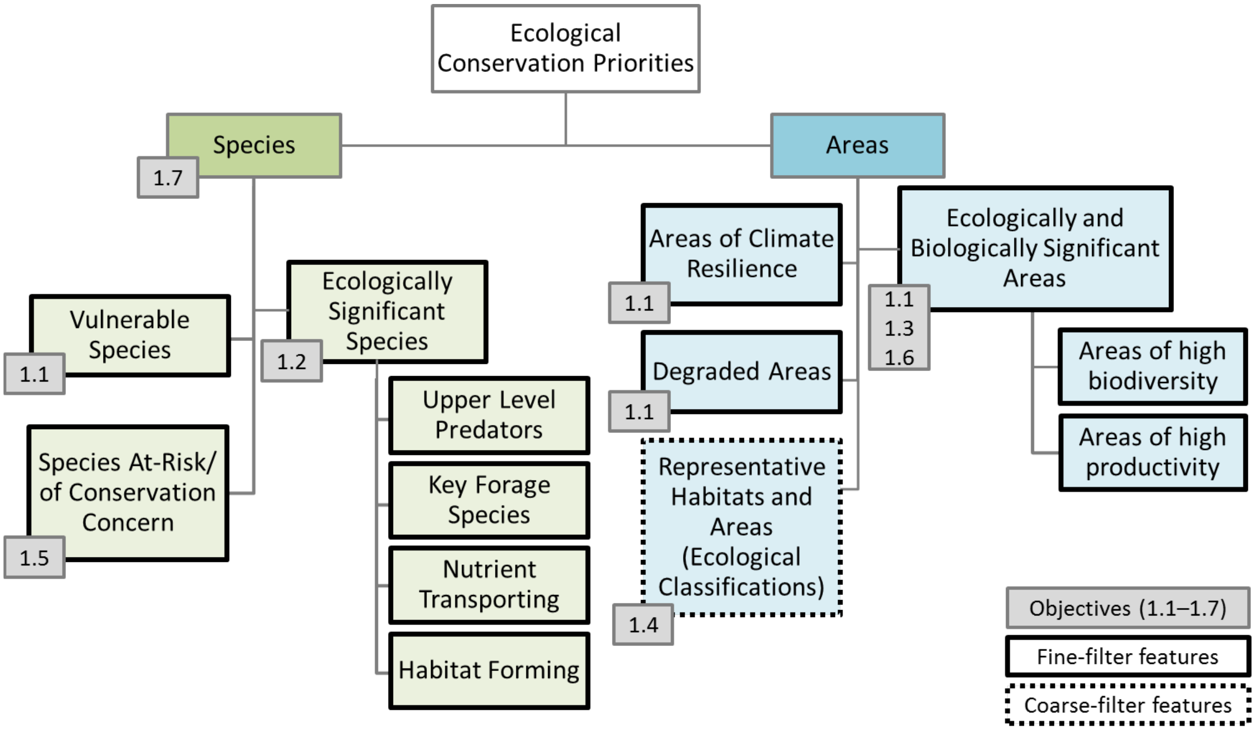

Figure 4. Ecological conservation priority framework (Gale et al. 2019). Numbers in grey boxes refer to network objectives in Table 3, and indicate the objectives met by identification of each conservation priority.

Table 6. Ecological objectives associated with Goal 1 of the Canada – BC MPA Network Strategy (2014).

Goal	Objective
Goal 1: To protect and maintain marine biodiversity, ecological representation and special natural features.	1.1. Contribute to the conservation of the diversity of species, populations, and ecological communities, and their viability in changing environments.
	1.2. Protect natural trophic structures and food webs, including populations of upper-level predators, key forage species, nutrient importing and exporting species, and structure-providing species.
	1.3. Conserve areas of high biological diversity (species, habitat and genetic diversity).
	1.4. Protect representative areas of every marine habitat in the bioregion.
	1.5. Contribute to protection of rare, unique, threatened, and/or endangered species and their habitats.
	1.6. Conserve ecologically significant areas associated with geological features and enduring/recurring oceanographic features.
	1.7. Contribute to conservation of areas important for the life history of resident and migratory species.

4.2. SETTING ECOLOGICAL CONSERVATION TARGETS FOR COARSE-FILTER CONSERVATION PRIORITIES

Coarse-filter features are included in site selection analyses to ensure that natural areas characteristic of the study area are represented in MPA network configurations. This is done to protect a broad suite of species, habitats, and ecological processes, even when detailed spatial information for some features is not available (Lieberknecht et al. 2010). Protecting representative areas within the NSB is consistent with ecological objective 1.4 (Table 6). Coarse-filter features are typically assigned lower ecological conservation targets to ensure that the fine-filter features – which are usually smaller yet of high ecological importance and meet multiple ecological objectives – drive the site-selection analyses (Lieberknecht et al. 2010; DFO 2018b). This approach meshes with the design guidelines (Appendix 2), which suggest low targets for broad and widespread habitat classes and higher ecological conservation targets for more constrained classes.

Several ecological classifications have been developed and the features derived from them have been identified as ecological conservation priorities in the NSB. Most recently, the Pacific Marine Ecological Classification System (PMECS; Rubidge et al. 2016) differentiates the benthic realm of the NSB into a hierarchical suite of layers, ranging from broad scale biophysical units, to finer geomorphological units, and finer still biotopes. The biotope layer is informed by bottom patches, which include information on substrate and depth for the nearshore environment (Gregr et al. 2013). The BC Marine Ecological Classification System (BCMEC; BC Ministry of Sustainable Resource Management 2002) is another hierarchical system that includes information on both the benthic and pelagic realms. Two layers from the BCMEC were identified as conservation priorities (Gale et al. 2019), including the broad-scale benthic ecosections and the finer-scale pelagic eco-units. The benthic ecosections were also used to inform broad representation in the Marxan analyses performed for the BCMCA (Ban et al. 2013) and MaPP (e.g., Marine Plan Partnership Initiative 2015). Another classification system used in previous Marxan analyses (e.g., Ban et al. 2013; Ban et al. 2014; Marine Plan Partnership Initiative 2015) was developed by Parks Canada and focuses on the pelagic realm, using oceanographic processes to identify a suite of upper ocean subregions BCMCA Project Team British Columbia Marine Conservation Analysis (BCMCA) Project Team (2011). In the coastal zone, the Shorezone dataset (Howes et al. 1994) includes a linear depiction of the coastline, classified based on biological (e.g., kelp or eelgrass biobands) or physical information (e.g., rocky slope or sandy beach coastal classes). The physical coastal classes were identified as a conservation priority and have also been used in past analyses (e.g., Ban et al. 2013; Ban et al. 2014; Marine Plan Partnership Initiative 2015). Appendix 5 displays maps of the conservation priorities suggested as coarse-filter features based on the work of Gale et al. (2019).

The design guidelines (Appendix 2, Lieberknecht et al. 2016) recommend that multiple classification systems at a variety of scales are targeted as coarse-filter features in the design scenarios and several have been identified as conservation priorities (Gale et al. 2019). Within each classification system, the literature recommends assigning higher ecological conservation targets to smaller, rarer habitat classes because they are likely more susceptible to disturbance while common, widespread classes, which are generally less threatened, are assigned lower targets to optimize conservation resources (BCMCA and PacMara 2010; Lieberknecht et al. 2010; DFO 2018b). Following the equation developed by Lieberknecht et al. (2010) (Equation 1) and used in MPA network development in the Scotian Shelf (DFO 2018b), Newfoundland and Labrador Shelves (DFO 2017a), and Gulf of St. Lawrence[7] bioregions, ecological conservation targets were calculated for coarse-filter features such that the area protected for each habitat class within a classification system is proportional to the square root of the class' total area within the region divided by the smallest habitat class, resulting in smaller classes with proportionally higher targets:

Equation 1. $$(Xp/Yp) \sim (Xt/Yt)^{0.5}$$

Equation 1. X and Y are habitat classes. Y is the smallest habitat class by area within the classification system. Subscript "p" denotes the area of the feature protected within the network of MPAs, while subscript "t" denotes the total area of the feature found throughout the study area.

This method generates a range of ecological conservation targets for the habitat classes within each classification system. To ensure the representation of target classes throughout the NSB, the habitat classes within the finer scale classification systems (i.e., the geomorphic units, bottom patches, and coastal classes) should be targeted separately within each of the ecosections or subregions within the NSB, once those boundaries have been finalized. Because these features vary in species and genetic composition across the NSB, this stratification will help meet representation goals as well as goals related to replication.

4.3. SETTING ECOLOGICAL CONSERVATION TARGETS FOR FINE-FILTER CONSERVATION PRIORITIES

The conservation priorities identified as fine-filter features (Gale et al. 2019) include marine taxa such as invertebrates, fishes, plants, algae, mammals, sea turtles, and marine birds. Other fine-filter conservation priorities are area-based and delineate discrete physical or oceanographic features such as submarine canyons and upwelling areas. Spatial data from a variety of source datasets, including scientific surveys, local and traditional knowledge, and observations, will be used to create spatial features that may be used represent fine-filter conservation priorities in site selection analyses, including:

- Areas of known or predicted high abundance/high habitat suitability/large extent
- Areas important for spawning/breeding

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[7] Faille, G., Dorion, D., and Pereira, S. unpublished. Methodology for the Development of the Marine Protected Area Network. Draft Document November 2014 for the Technical Committee on the Marine Protected Area Network.

- Areas important for rearing/nursery
- Areas important for feeding
- Areas important for migrating
- Areas important for other aggregations
- Critical habitat
- Areas of high/distinct genetics
- Habitat proxies.

While all ecological conservation priorities are amenable to spatial management at an appropriate spatial scale, the planning process should aim to set ecological conservation targets for those priority features that can benefit from spatial protection measures at the scale of the planning region (Appendix 2; Lieberknecht et al. 2016). For example, highly mobile species may be difficult to protect in static MPAs, unless the species aggregates in predictable geographic locations or utilizes particular habitat types at key lifecycle stages or times of year. In such cases, it is most appropriate to set ecological conservation targets for spatial features such as seasonal breeding, feeding, and resting areas for birds, seal haul-outs, or key staging areas along a migration route of a migratory species (Ardron et al. 2010).

To develop the ecological conservation target method for fine-filter conservation priorities, we reviewed and built upon approaches taken by past marine spatial planning exercises around the world (Appendix 6). Planning efforts often begin with a base target for all conservation priorities and then select conservation priorities that warrant higher targets based on a decision tree (e.g., Ban et al. 2013) or scoring system (e.g., DFO 2018b). Experts recommend using a systematic evidence-based approach to set fine-filter targets based on ecological factors, where the data are available (Helvey 2004; Svancara et al. 2005; Carwardine et al. 2009; Ardron et al. 2010), because of the limitations of policy-based approaches noted in Section 3.

Past work in the NSB has considered conservation status and expert opinion (Ban et al. 2013) or conservation status and rarity (Government of Canada and Council of the Haida Nation 2010) when assigning higher targets to conservation priorities. To standardize the inclusion of a broader suite of ecological factors and incorporate expert review in an explicit and systematic fashion, we have expanded upon past approaches by integrating expert feedback with the ecological criteria and scores developed to identify conservation priorities for the NSB (DFO 2017b). To determine ecological conservation target classes relevant to conservation priorities of the NSB, we adapted the ecological criteria scoring system applied to each conservation priority in the Scotian Shelf bioregion (DFO 2018b).

4.3.1. Calculation of fine-filter ecological conservation target scores

We assigned each ecological conservation priority a target score based on the scores from Gale et al. (2019) for the criteria relevant to the ecological objectives and expert review (see Sections 4.3.2 – 4.3.5; Figure 5, Figure 6, Figure 7). Ecological conservation priorities meeting multiple objectives received higher overall target scores. Following best practices (BCMCA and PacMara 2010; Gale et al. 2019) and advice from other bioregions (e.g., DFO 2017b, 2018b), each criterion was given equal weight and the scores for the criteria were combined using the square root of the sum of squares, as follows:

Equation 2. $((\mathrm{Obj1})^2 + (\mathrm{Obj2})^2 + (\mathrm{Obj3})^2 + (\mathrm{ExpRev})^2)^{0.5}$

Equation 2. Obj1-3 denote the criteria representing the relevant MPATT ecological objectives for each conservation priority type. ExpRev denotes the score assigned based on expert feedback.

Because the ecological criteria used to develop conservation priorities varied slightly among taxa, we developed separate scoring systems for 1) fish, invertebrate, marine mammal, plant, and alga species-based conservation priorities, 2) marine bird species-based conservation priorities, and 3) the area-based conservation priorities. Below we describe the criteria and scoring system for each.

4.3.2. Species-based conservation priorities (excluding marine birds)

Conservation Concern and Vulnerability

To support ecological objectives 1.5 and 1.1 (Table 6), conservation concern and vulnerability were assessed during the selection of species-based conservation priorities within the NSB (DFO 2017b; Gale et al. 2019). Conservation status is commonly used to identify conservation priorities that warrant a higher ecological conservation target level (Pressey et al. 2003; Ban et al. 2013; Levin et al. 2015; DFO 2018b) and its incorporation is considered good practice (Lieberknecht et al. 2010). Vulnerability has been explicitly incorporated in fewer analyses (though see DFO 2018b).

Conservation concern scores in Gale et al. (2019) were assigned to each conservation priority based on its conservation status at a global, national, or provincial scale, with a higher value assigned to species deemed highly threatened at any scale. Vulnerability refers to the ability of species to persist through and recover from disturbance (i.e., resilience or adaptive capacity), and was assessed on life history characteristics: species that are large, long-lived and have low reproductive rates have lower potential rates of population growth and recovery (higher vulnerability) than small, fast-growing species with high reproductive output (lower vulnerability). Vulnerability scores were assigned based on an approach developed by Cheung et al. (2005), for fishes, which was modified to incorporate expert knowledge for invertebrates, with higher values assigned to species with greater intrinsic vulnerability.

Conservation concern and vulnerability are intertwined and, when considered together, can complement and offset the limitations of each. More vulnerable species often are formally recognized as having unfavourable conservation status; in the scoring assigned in Gale et al. (2019), all but one of the conservation priorities of concern in the NSB were also classified as vulnerable. However, not all species recognized as vulnerable have had their conservation status formally evaluated (e.g., under the IUCN Red List [IUCN 2012] or Canada Species at Risk Act (SARA) [Environment and Climate Change Canada 2016]). Lists of conservation status often focus on larger, better-known species (McClenachan et al. 2012) and may not reflect the true status of some of the smaller, less-studied algae and invertebrates or commercially-exploited species (Mooers et al. 2007; Findlay et al. 2009; Hutchings and Festa-Bianchet 2009; Schultz et al. 2013). Furthermore, the peer-reviewed approach used to assess conservation priority vulnerability (Cheung et al. 2005) was more appropriate for fish and marine mammal species and vulnerability scores for other taxa were supplemented by expert opinion (Gale et al. 2019), potentially biasing some species over others. For these reasons, we incorporated conservation status and vulnerability scores developed by Gale et al. (2019) into a single criterion in the target scoring matrix.

We adapted these values to develop a range of scores for this criterion, ranging between 1 and 3, as shown in Figure 5. For example, yelloweye rockfish scored 1 for conservation concern and 2 for vulnerability in the framework of Gale et al. (2019) and therefore score a 3 for this criterion in the target score calculation.

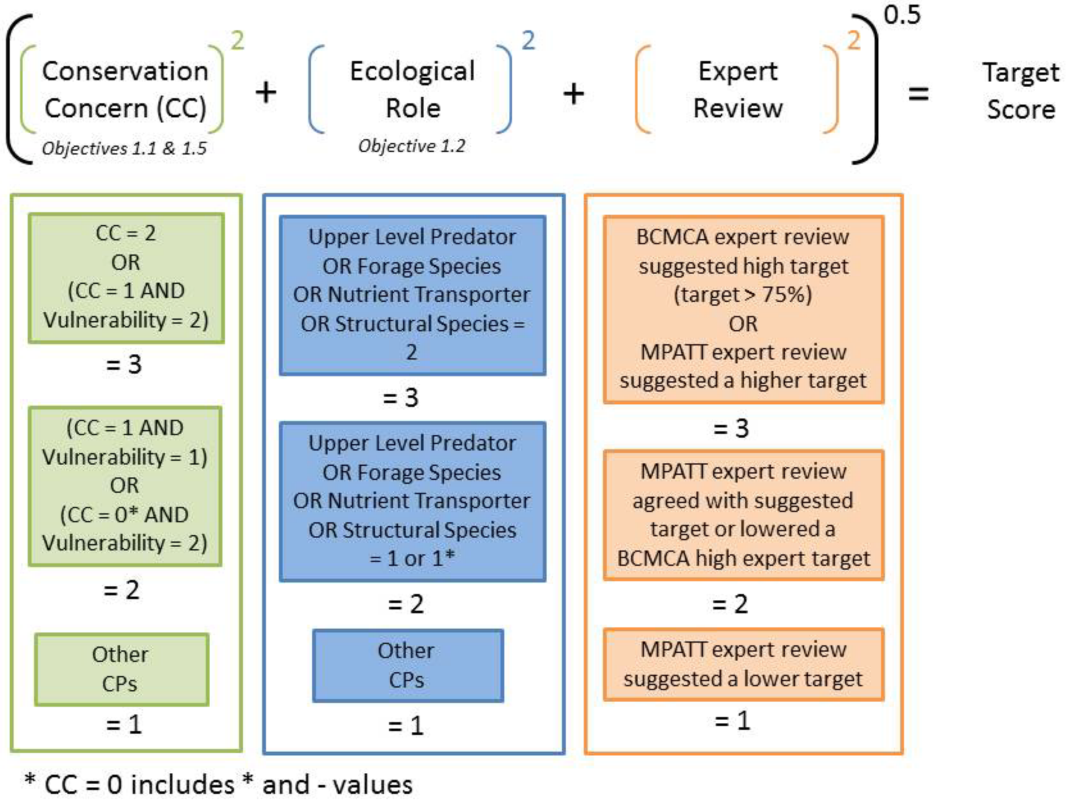


*Figure 5. Framework for assigning target scores to the species-based conservation priorities (CPs), excluding marine birds. * indicates there was insufficient information to assign a score, and 0 and – indicate the criterion was not applicable for that species (Gale et al. 2019).*

Ecological Role

Four ecological roles were assessed to support ecological objective 1.2 (Table 6) for the species-based conservation priorities. As part of the development of the conservation priority list (Gale et al. 2019), species that could be identified fully or partially as predators, forage species, nutrient transporters, and structural species were assigned a value between 1 and 2, with a higher value denoting a higher level of importance for each role. We assessed the values for each ecological role independently and not additively to ensure that species of importance in any ecological role were considered (BCMCA and PacMara 2010). Our approach assumes that species that have been assigned a higher level of importance for more than one role are equal to those that have been assigned a higher level of importance for only one role, which may be a limitation. Based on the values assigned to each conservation priority (Gale et al. 2019), we calculated scores for ecological role in the target scores as shown in Figure 5. For example, we assigned a value of 3 to species given a 2 for any of the assessed ecological roles. Species that had been given a 1 or 1*, but not a 2, in any role were assigned a value of 2. For example, eulachon were assigned a 3 because they were assessed as 2 for forage species and nutrient transport while petrale sole were assigned a 2 because they were assessed as 1 for their role as a predator species.

4.3.3. Species-based conservation priorities (for marine birds)

Conservation Concern and Vulnerability

Identification of marine bird conservation priorities was based on a different set of criteria than for the other species-based conservation priorities (Gale et al. 2019) and conservation status was considered, but vulnerability was not assessed explicitly. Therefore, to support objective 1.5 (Table 6), we used the conservation status scores alone as the conservation concern criterion for calculating target scores. The conservation status score across global, national, and/or provincial scales was assigned to each marine bird conservation priority (Gale et al. 2019). We rescaled the values to match the other criteria, as shown in Figure 6. For example, ancient murrelet were assigned a value of 2 in the conservation priority scoring and that scored was adjusted to 3 for this work.

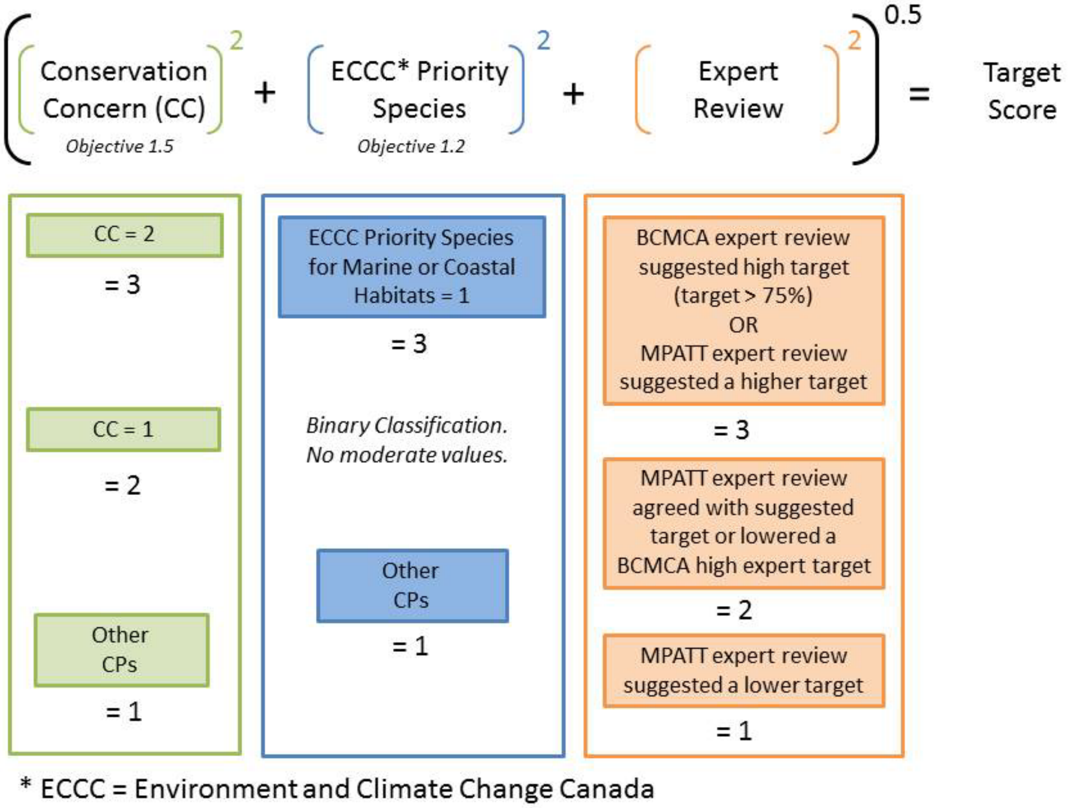


Figure 6. Framework for assigning target scores to the marine bird species-based conservation priorities (CPs).

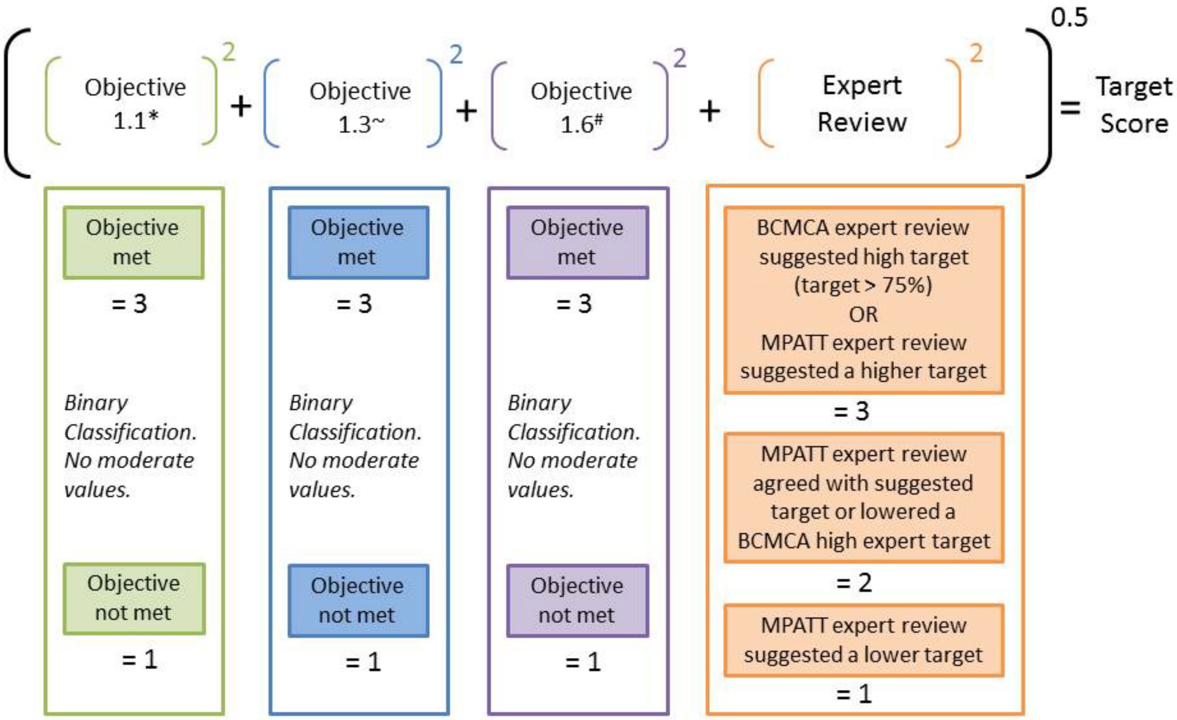
ECCC Priority Species

Information on the ecological role filled by each marine bird was not scored during the development of the conservation priority list (Gale et al. 2019). Instead, Gale et al. (2019) incorporated the Environment and Climate Change Canada (ECCC) Priority Species classification from the ECCC Bird Conservation Strategy for Bird Conservation Region 5: Northern Pacific Rainforest (Environment Canada 2013). ECCC Priority Species are those considered vulnerable or of conservation or management concern, as well as widely distributed and abundant “stewardship” species. Most, but not all, of the bird species identified as NSB ecological conservation priorities are also ECCC Priority Species (Gale et al. 2019).

Here, we use the ECCC Priority Species scores to inform ecological objective 1.2 (Table 6). We rescaled the values from the binary ECCC Priority Species classification to the same scale as the other criteria to ensure all criteria would be weighted equally in their contribution to the overall score, and to allow us to compare the overall scores of marine birds and other species. Marine bird conservation priorities identified as ECCC Priority Species solely because of their conservation status were assigned a value of 1 to avoid over-weighting the contribution of conservation concern in the final target scores. The final values for the ECCC Priority Species criterion are shown in Figure 6. For example, Brandt's cormorant were considered an ECCC Priority Species and assigned a value of 3 while double-crested cormorant are not an ECCC Priority Species and were assigned a value of 1.

4.3.4. Area-based conservation priorities

The work to identify conservation priorities (Gale et al. 2019) assessed the relevance of each area-based conservation priority to ecological objectives 1.1, 1.3, and 1.6 (Table 6). We scored each conservation priority based on whether it met each objective (Figure 7). Scoring was binary with values of 1 or 3, which matches the scale of the expert review criterion (see section 4.3.5 for further explanation) and ensures that all criteria had the same influence on final target scores. As an example, areas of high habitat heterogeneity contribute to objectives 1.3 and 1.6 but not objective 1.1. Because the area-based conservation priorities were assessed against a slightly different and larger suite of ecological objectives than the species-based conservation priorities, we analyzed area-based conservation priorities separately when assigning the conservation priorities into an ecological conservation target range category.



* *Objective 1.1* - Contribute to the conservation of the diversity of species, populations, and ecological communities, and their viability in changing environments.

~ *Objective 1.3* - Conserve areas of high biological diversity (species, habitat and genetic diversity).

\# *Objective 1.6* - Conserve ecologically significant geological features and enduring/recurring oceanographic features.

Figure 7. Framework for assigning target scores to the area-based conservation priorities.

4.3.5. Expert review

We incorporated expert feedback explicitly as a criterion in the scoring system for species-based and area-based conservation priorities, incorporating prior expert engagement completed during the BCMCA process (Ban et al. 2013) and an updated expert review tailored to the NSB ecological conservation priorities and design strategies. As part of the BCMCA process, workshops were held with individuals with expertise in various marine taxa. Workshop participants provided recommendations on species and habitats for conservation planning, including the spatial datasets appropriate to represent those features and ecological conservation targets for each feature that ranged from minimum to preferred amounts (Ban et al. 2013). We calculated an initial score for expert review based on the BCMCA review, assigning a value of 3 to conservation priorities that experts had recommended for high targets in excess of 75%. We assigned a value of 2 to all other conservation priorities and calculated an initial target score and class following the calculation described in section 4.3.6.

To ensure that expert opinions were current and available for the entire suite of conservation priorities, we solicited a new round of expert feedback between March and October, 2017. Experts were identified from the Government of Canada, the Government of BC, and First Nations (Appendix 7). Efforts were made to contact experts that had not previously provided advice to the BCMCA to avoid over-weighting any one person's opinion. Experts were asked to review the suggested ecological conservation targets for each conservation priority based on the initial target classes and to confirm their support or provide a rationale for alternatives. When a lower target class was suggested, we lowered the expert review score by 1 (Figure 5, Figure 6, Figure 7). Conversely, if a higher target class was suggested, the score was increased by 1. Scores were compiled for each expert, or group of experts, that was consulted (Appendix 8). We used the average of the expert review scores to calculate the final target scores, as described in Section 4.3.1. For the marine bird expert review, several experts reviewed the scores as a group and their feedback is reflected as the advice of two individuals when calculating the average expert review scores for the species reviewed by the group. As part of the 2017 expert review, we also asked experts to identify the types of spatial features important for each conservation priority and assess the spatial datasets currently available for use in site-selection analyses. This information is being compiled in a technical report[8].

4.3.6. Fine-filter ecological conservation target ranges

The literature recommends that ecological conservation targets should be developed individually for conservation priorities based on their characteristics because ecological features have different distribution patterns and vulnerabilities to human activities (Svancara et al. 2005; Lieberknecht et al. 2016). The design guidelines state that a wide range of targets should be considered for the conservation priorities, ranging from 5-100% (Appendix 2) (Lieberknecht et al. 2016). Experts also agree the ecological conservation target for each conservation priority should be represented as a range to facilitate the use of site selection analyses to create a suite of solutions to guide decision making (Lieberknecht et al. 2010; Levin et al. 2015).

The NSB benefits from a history of site-selection analyses that have incorporated a similar suite of conservation priorities and spatial data. Therefore, the selection of target ranges was informed by previous analyses in the NSB as well as scientific literature and best practices for Marxan analyses (Figure 8, Appendix 6). To determine the number of target range classes

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[8] Gale K.S.P., Robb C.K., MacMillan A., & Rubidge E. (in prep). An inventory of ecological spatial data used to support marine protected area network planning in the Northern Shelf Bioregion. Can. Tech. Rep. Fish. Aquat.

appropriate for the species-based conservation priorities, we combined target scores for all of the species-based conservation priorities and analyzed the frequency distribution of target scores. We split the distribution and assigned a target range to each of the resulting groups. To determine the most appropriate way to split the distribution, we carried out a sensitivity analysis by splitting both by quartiles and by thirds and comparing. Because the target scores for area-based conservation priorities incorporated more ecological objectives, they were assessed separately and split based on the median of the frequency distribution of target scores.

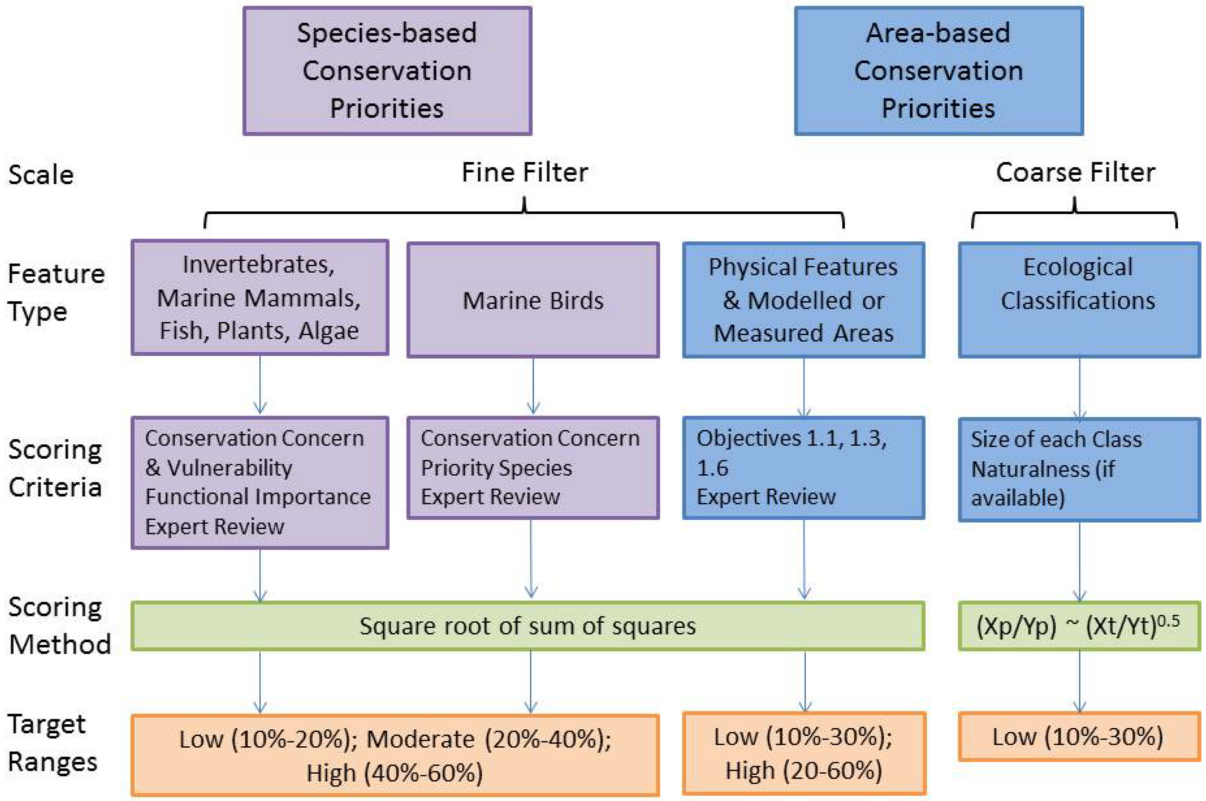

Figure 8. Framework for developing ecological conservation target ranges for coarse- and fine-filter ecological conservation priorities in the NSB.

5. DETERMINING THE CONSERVATION PRIORITIES APPROPRIATE FOR INCLUSION IN DESIGN SCENARIOS

As described above, ecological conservation target ranges were developed for all ecological conservation priorities. However, some conservation priorities such as highly mobile species may have ecological characteristics that make them less amenable to protection through spatial management measures at the scale of the NSB. Further, some ecological conservation priorities may be represented by spatial features that are not appropriate for site selection analyses or, depending on the known areas of importance, it may be possible to represent a conservation priority with multiple spatial features (Ardron et al. 2010). For example, breeding colonies and over-wintering areas could be used together to ensure all seasonal areas of importance for ancient murrelets are considered during site selection analyses. Areas of importance and the spatial datasets currently available to inform those areas were collated and reviewed by subject matter experts and will be published in a technical report[9]. Using this information we developed a flow diagram to help determine which conservation priorities and spatial features are appropriate for inclusion in site selection analyses using the Marxan decision support tool (Figure 9, Appendix 3).

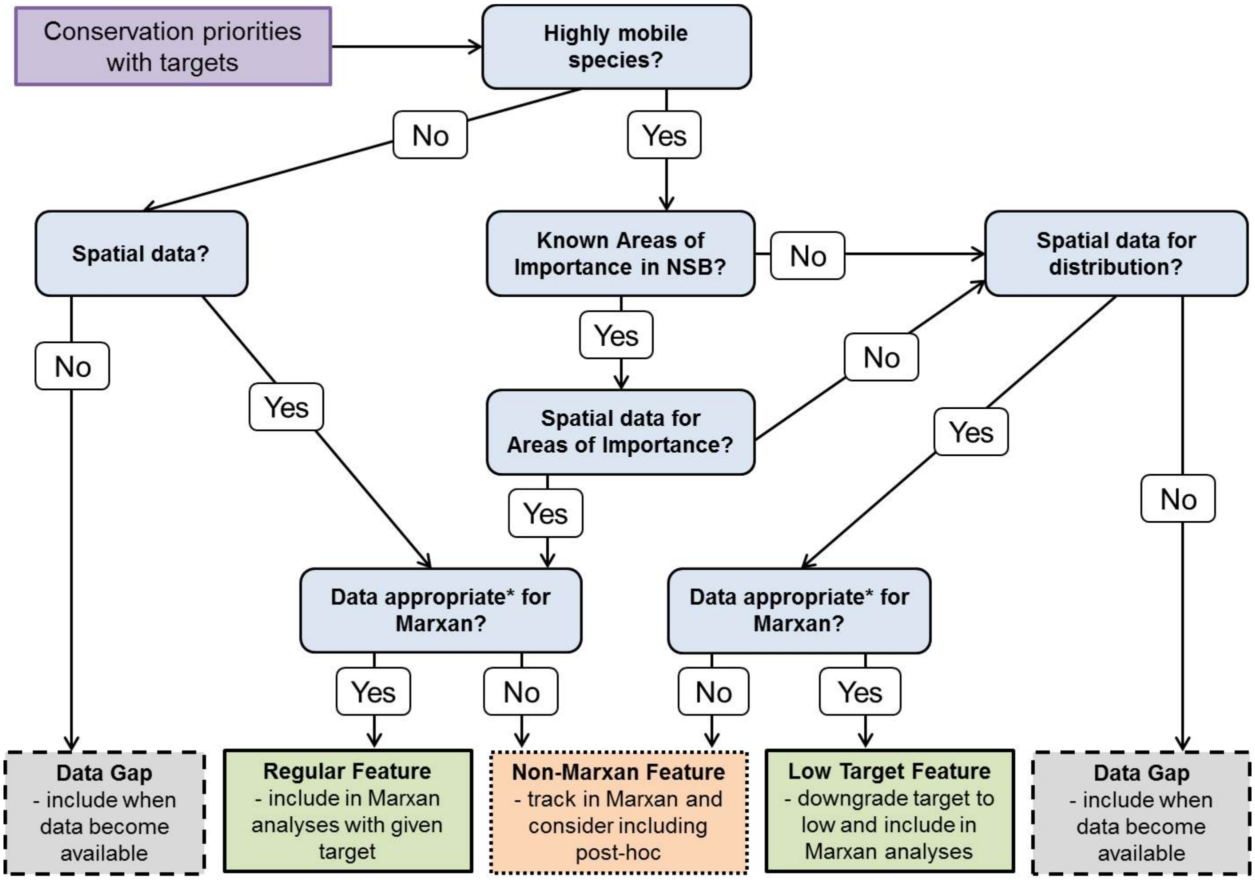

*Figure 9. Flow diagram to guide the identification of conservation priorities appropriate for inclusion in design scenarios. * Data should be high quality, at an appropriate scale, and comprehensive for the NSB or subregion. Preference will be given to data that have been groundtruthed.*

The flow diagram guides the user to determine whether appropriate spatial data exist to represent the conservation priorities. If no spatial data are available, the conservation priority should be clearly distinguished as a ‘data gap’ and flagged for inclusion in future iterations of the analyses if data become available (Figure 9). If spatial data are available, these should be evaluated for their appropriateness for Marxan, as described below.

To begin, each conservation priority should be assessed to determine if it is a highly mobile species based on juvenile and adult movement classes collated by Burt et al. (2014) and supplemented by a literature review and expert opinion (Appendix 10). We define highly mobile species as those in movement classes 50–1000 km and >1000 km. For these species, spatial features delineating areas of importance should be prioritized. Areas of importance may include DFO IAs (Clarke and Jamieson 2006a), critical habitat for SARA-listed species, or other areas important for particular life history stages, or hotspots generated from distribution data. If

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[9] Gale K.S.P., Robb C.K., MacMillan A., & Rubidge E. (in prep). An inventory of ecological spatial data used to support marine protected area network planning in the Northern Shelf Bioregion. Can. Tech. Rep. Fish. Aquat.

information on important areas is lacking for a highly mobile conservation priority, density distributions or abundance estimates should be identified. General range maps may skew conservation prioritization towards marginal habitats (Williams et al. 2014) and should be avoided.

Once the relevant spatial features have been identified for each conservation priority, the data should be reviewed for appropriateness for site-selection analyses using Marxan. Only datasets that are high quality, at an appropriate scale, and comprehensive for the NSB or subregion within the NSB, should be included in Marxan analyses as a 'regular feature' (Figure 9). Data that are science-based or informed by traditional knowledge should be prioritized. Conservation priorities that lack detailed and appropriate spatial information should be excluded from site selection analyses (Ardron et al. 2010). These 'non-Marxan features' can be tracked in Marxan (i.e., assigned a target of zero) so that they do not influence the analyses but their representation in potential network configurations can be calculated. Distribution datasets appropriate for highly mobile conservation priorities should be incorporated as 'low target features' so that they do not bias the analyses due to their broad spatial extents. Unjustifiably high ecological conservation targets for broad features may confer few conservation benefits but add high costs for development and stakeholder activities (Metcalfe et al. 2013a).

6. RESULTS: ECOLOGICAL CONSERVATION TARGETS FOR COARSE-FILTER FEATURES

Based on the suite of conservation priorities, the available spatial features, and expert opinion, we suggest including targets for six feature types from four different classification systems as coarse-filter features in the Marxan analyses (Table 7, Appendix 5).

Table 7. Classification systems and associated spatial datasets appropriate as coarse-filter features for Marxan analyses in the NSB.

Realm	Classification System	Spatial Dataset (Source)
Benthic	Pacific Marine Ecological Classification System (PMECS)	PMECS Biophysical Units (DFO) PMECS Geomorphological Units (DFO) Bottom Patches (nearshore only) (Gregr et al. 2013)
Pelagic	BC Marine Ecological Classification (BCMEC)	Ecosections (Province of BC)
Pelagic	Upper Ocean Subregions	Upper Ocean Subregions (Parks Canada via BCMCA)
Coastal	Shoreline Ecological Units	Shorezone Coastal Classes (Province of BC)

The size of the habitat classes within each recommended classification system was assessed separately to determine the appropriate ecological conservation target range. Following the Lieberknecht et al. (2010) approach, we assigned the coarse-filter features a range of ecological conservation targets by assigning the smallest habitat class within each classification a top starting target of 10%, 20%, or 30% and calculating the relative targets for the rest of the habitat classes. These targets were selected based on coarse-filter target ranges found in the literature and those used in past analyses in the NSB (e.g., IUCN 2003; Fraschetti et al. 2009; Natural England 2009; Government of Canada and Council of the Haida Nation 2010; Ban et al. 2013; Vander Schaaf et al. 2013; MaPP 2016; DFO 2018b) (Appendix 6). However, following this method some of the larger habitat classes were assigned very low ecological conservation targets because of the range of habitat class sizes found within each classification system. These targets could be adjusted so that the lowest target assigned to any class is 10% corresponding to the 10% CBD target (CBD 2011); this would be consistent with the MPA network process in the Scotian Shelf (DFO 2018b), and with advice in the literature regarding minimum levels of habitat protection in areas with lower fishing pressure (e.g., Botsford et al. 2001; Green et al. 2014). It is recommended that sensitivity analyses be performed to assess the using a minimum 10% threshold for ecological conservation targets.

Based on the size calculations, three ecological conservation target ranges of up to 10%, 20%, and 30% were assigned to the PMECS biophysical units (Table 8), PMECS geomorphological units (Table 9), ecosections (Table 10), Upper Ocean Subregions (Table 11), Shorezone Coastal Classes (Table 12), and bottom patches (Table 13). We included only those habitat classes that represent ecologically distinct features in the target calculations. We therefore assigned a score of 0 to the “manmade” Shorezone coastal classes (Table 12). The NSB covers small sections (“slivers”) of the northern Strait of Georgia Upper Ocean Subregion and the Strait of Georgia, transitional Pacific, and offshore Pacific Ecosections; these slivers were not included when calculating the target scores as to not bias the distribution of scores. Instead, we assigned these habitat classes the top target value after calculating the other target values (Table 10, Table 11).

Table 8. Ecological conservation target ranges assigned to the PMECS biophysical units. Targets vary inversely based on the relative area of each habitat class.

Biophysical Units (4b)	Area (km^2)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
OtherBank	2,272	10.0	20.0	30.0
DogfishBank	7,888	5.4	10.7	16.1
Slope	16,704	3.7	7.4	11.1
Trough	19,381	3.4	6.8	10.3
Shelf	35,207	2.5	5.1	7.6

Table 9. Ecological conservation target ranges assigned to the PMECS geomorphological units. Targets vary inversely based on the relative area of each habitat class.

Geomorphic Units	Area (km^2)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
Fjord, Depression floor	1,206	10.0	20.0	30.0
Fjord, Crest	1,247	9.8	19.7	29.5
Slope, Wall, sloping	1,272	9.7	19.5	29.2
Fjord, Mound	1,832	8.1	16.2	24.3
Fjord, Wall, steeply sloping	3,133	6.2	12.4	18.6
Slope, Ridge	3,318	6.0	12.1	18.1
Fjord, Depression	3,785	5.6	11.3	16.9
Slope, Canyon floor	3,802	5.6	11.3	16.9
Shelf, Depression floor	5,830	4.5	9.1	13.6
Shelf, Crest	7,582	4.0	8.0	12.0
Slope, Wall, steeply sloping	11,061	3.3	6.6	9.9
Shelf, Wall, sloping	11,833	3.2	6.4	9.6
Shelf, Depression	19,176	2.5	5.0	7.5
Shelf, Mound	23,720	2.3	4.5	6.8

Table 10. Ecological conservation target ranges assigned to the BCMEC Ecosections. Targets vary inversely based on the relative area of each habitat class.

Marine Ecosections	Area (km^2)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
Strait of Georgia	117	10.0	20.0	30.0
Transitional Pacific	1,643	10.0	20.0	30.0
Subarctic Pacific	2,209	10.0	20.0	30.0
Queen Charlotte Strait	2,871	10.0	20.0	30.0
Johnstone Strait	3,220	9.4	18.9	28.3
Vancouver Island Shelf	3,335	9.3	18.6	27.8
Dixon Entrance	11,309	5.0	10.1	15.1
Hecate Strait	13,571	4.6	9.2	13.8
North Coast Fjords	16,465	4.2	8.4	12.5
Continental Slope	21,750	3.6	7.3	10.9
Queen Charlotte Sound	36,626	2.8	5.6	8.4

Table 11. Ecological conservation target ranges assigned to the Upper Ocean Subregions. Targets vary inversely based on the relative area of each habitat class.

Upper Ocean Subregions	Area (km^2)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
Northern Strait of Georgia	280	10.0	20.0	30.0
Rose Spit Eddy	1,994	10.0	20.0	30.0
Cape St. James Tidal Mixing	2,345	9.2	18.4	27.7
Dogfish Bank Frontal Region	2,368	9.2	18.4	27.5
Johnstone Strait	2,565	8.8	17.6	26.5
Low Flow Nearshore	3,042	8.1	16.2	24.3
West Coast QCI Upwelling Region	5,237	6.2	12.3	18.5
Aristazabal Banks Upwelling	5,832	5.8	11.7	17.5
Eastern Queen Charlotte Sound	6,348	5.6	11.2	16.8
Southeast Alaska Mixing Region	6,750	5.4	10.9	16.3
Dixon Entrance Coastal Flow Region	6,853	5.4	10.8	16.2
Mainland Fjords	9,466	4.6	9.2	13.8
Cape Scott Tidal Mixing	10,506	4.4	8.7	13.1
Hecate Strait	12,032	4.1	8.1	12.2
Coastal Mixing Region	26,050	2.8	5.5	8.3

Table 12. Ecological conservation target ranges assigned to the Shorezone Coastal Classes. Targets vary inversely based on the relative area of each habitat class.

Coastal Classes (grouped)	Length (km)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
Channel	45	10.0	20.0	30.0
Mud Flat	111	6.4	12.7	19.1
Gravel Flat	159	5.3	10.6	15.9
Sand Beach	313	3.8	7.6	11.4
Undefined	1,021	2.1	4.2	6.3
Gravel Beach	1,047	2.1	4.1	6.2
Estuary (Organics/Fines)	1,105	2.0	4.0	6.0
Sand and Gravel Beach	1,143	2.0	4.0	5.9
Sand Flat	1,412	1.8	3.6	5.3
Sand and Gravel Flat or Fan	1,757	1.6	3.2	4.8
Rock Platform	2,976	1.2	2.5	3.7
Rock Cliff	6,000	0.9	1.7	2.6
Rock Ramp	10,389	0.7	1.3	2.0
Man made	138	0	0	0

Table 13. Ecological conservation target ranges assigned to the PMECS bottom patches. Targets vary inversely based on the relative area of each habitat class.

Bottom Patches	Area (km^2)	Low Target Range (%)	Medium Target Range (%)	High Target Range (%)
Hard	5,870	10.0	20.0	30.0
Mixed	8,941	8.1	16.2	24.3
Soft	10,927	7.3	14.7	22.0

7. RESULTS: ECOLOGICAL CONSERVATION TARGETS FOR FINE-FILTER FEATURES

7.1. SPECIES-BASED CONSERVATION PRIORITIES

The scores for the ecological criteria were rescaled directly from the scores assigned during the identification of conservation priorities (Gale et al. 2019). The ECCC Priority Species criterion for marine birds was an exception; it was revised for Priority Species identified solely on conservation status. That revision resulted in a lower value for the ECCC Priority Species criterion for eight marine bird species: Buller’s shearwater, double-crested cormorant, great blue heron, horned grebe, northern fulmar, red-necked phalarope, and wandering tattler (Appendix 8).

We calculated an initial suite of target classes for the conservation priorities prior to seeking expert review. The updated expert review resulted in changes to the target classes for 41 species-based conservation priorities: six marine birds, 21 fishes, eight invertebrates, five marine mammals, and one plant (Appendix 8). Of those, 10 conservation priorities, including all of the marine mammals, were revised to lower targets. The other 31 conservation priorities were revised to higher targets, including the majority of the revised fish, invertebrate, and seabird conservation priorities. An example of the ecological conservation target score calculation for humpback whales is shown in Figure 10.

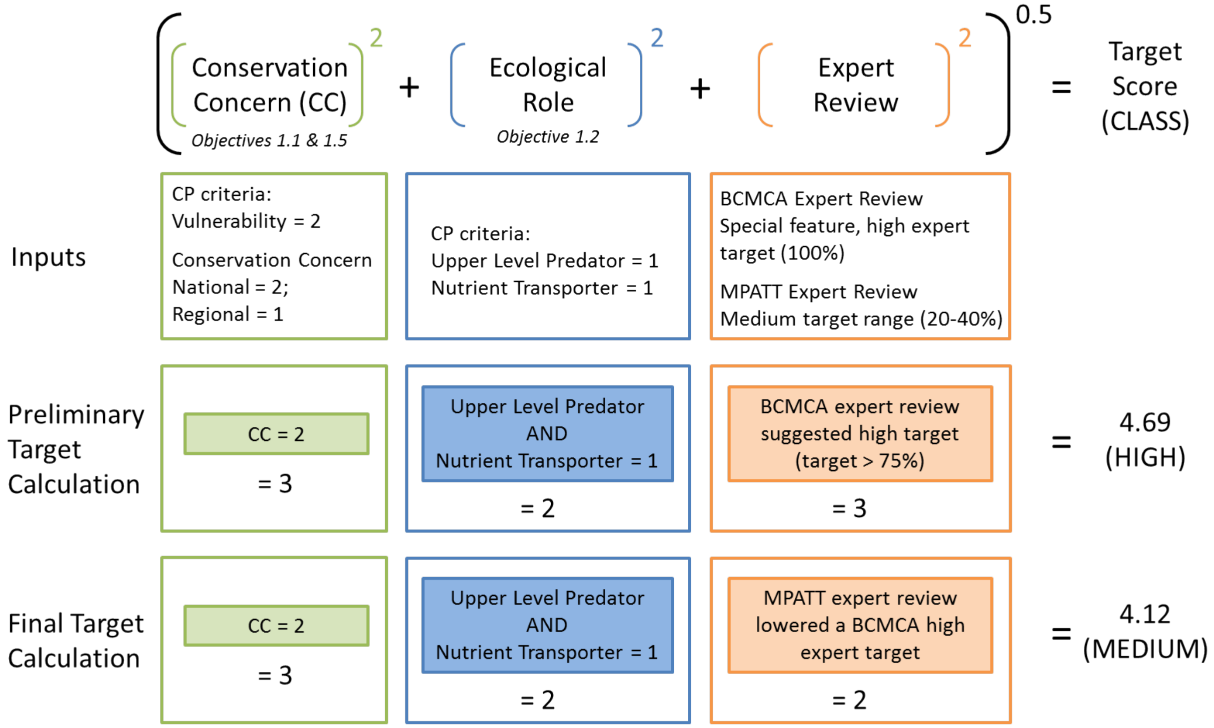

Figure 10. An example calculation of the ecological conservation target score and class for humpback whale, an ecological conservation priority (CP). The preliminary target calculation shows the target class that was reviewed during the 2017 MPATT expert review. The resulting feedback was incorporated into the expert review score for the final target calculation.

Based on the frequency distribution of the resulting target scores (Figure 11), we determined three ecological conservation target classes to be the most appropriate for the current suite of species-based conservation priorities. This is different from previous analyses in the NSB (Government of Canada and Council of the Haida Nation 2010; Ban et al. 2013; Marine Plan Partnership Initiative 2015) that have assigned conservation priorities to two target classes. We tested the assignment of target classes using both quartiles and thirds to split the frequency distribution of target scores (Appendix 9). Using quartiles assigned most conservation priorities to the medium target class and specified the high target class for those species of particular ecological importance. The quartile approach also aligned slightly better with the advice received during the expert review. Based on the results of the sensitivity analysis, and to simplify the presentation of results, in this paper we use quartiles to assign the conservation priorities to high (>75% of distribution of target scores), medium (>25% and ≤75% of distribution of target scores), and low (≤25% of distribution of target scores) target classes (Table 14, Appendix 8). Based on quartiles, we assigned 43 conservation priorities high targets, including marine birds, mammals, fishes, and sponge species of high functional importance and high conservation concern (Figure 12, Appendix 8). We assigned 104 conservation priorities medium targets, including the rest of the marine mammals, most of the invertebrates and fishes, all of the plants and algae, and 19 marine birds. We assigned low targets to 50 conservation priorities from all taxa except marine plants, algae, and mammals.

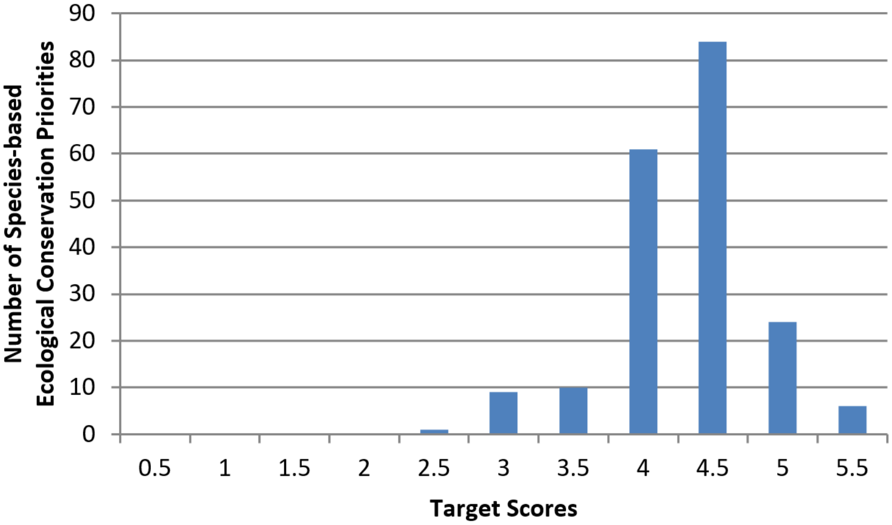

Figure 11. Frequency distribution of target scores for the species-based conservation priorities.

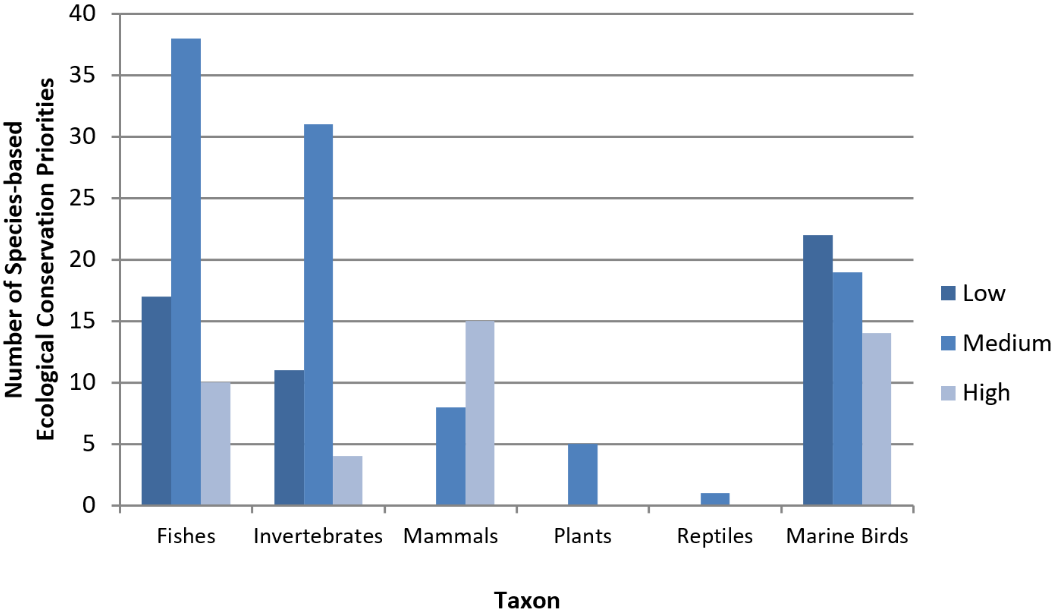

Figure 12. Target classes assigned to species-based ecological conservation priorities based on quartiles.

Building on targets used in the literature and in past analyses (Appendix 6), an ecological conservation target range was assigned to each of the three target classes. The low target class was assigned a target range of 10–20%, representing species of lower vulnerability, lower priority, and/or lower conservation concern. The medium target class was assigned a target range of 20–40%, which corresponds to studies that show that protecting 30–40% of species' important areas in no-take marine reserves improves outcomes for both conservation and fisheries productivity (Gaines et al. 2010; Pelc et al. 2010; Fernandes et al. 2012; Foster et al. 2013; Green et al. 2013) as well as international recommendations to include 30% of marine habitats in highly protected MPAs (IUCN-WCPA 2018). Some studies have suggested that for regions with lower fishing pressure or effective fisheries management that the lower end of the target range (i.e., 20%) is warranted (Fernandes et al. 2012; Green et al. 2013). The high target class was assigned targets of 40-60% in keeping with average of the highest targets assigned in the reviewed literature (Appendix 6). Targets of 40% and above may provide insurance against severe disturbances (Green et al. 2013), accommodate species that are vulnerable due to low reproductive rates (Fogarty and Botsford 2007), or conserve highly important and wide-ranging species that are currently over-exploited and may require the protection of 40–85% of their area to allow biomass recovery (Guénette et al. 2000; Le Quesne and Codling 2009). While targets higher than 60% have been recommended by experts in other planning processes in the NSB (e.g., Ban et al. 2013) and used in other bioregions (e.g., DFO 2018b), targets nearing 100% are can skew site selection analysis results for species with larger spatial footprints and limit Marxan's ability to achieve multiple solutions (Ardron et al. 2010; Ban et al. 2013). The final target class and target range assigned to each species-based conservation priority is shown in Appendix 8.

Table 14. Target classes and ranges assigned to species-based conservation priorities.

Target Class	Target Range	Quantile (Target Scores)	Count of Conservation Priorities (% of total)
Low	10-20%	≤25% (≤3.74)	50 (26%)
Medium	20-40%	>25% and ≤75% (3.75–4.36)	102 (52%)
High	40-60%	>75% (4.36–5.20)	43 (22%)

7.2. AREA-BASED CONSERVATION PRIORITIES

We used an assessment of the relevant ecological objectives and scores from the expert review to calculate target scores for the 11 fine-filter area-based conservation priorities. The updated expert review increased the score for one conservation priority, areas of upwelling (Appendix 8). Using the median value from the frequency distribution of the target scores (Figure 13), we assigned the area-based conservation priorities to two target classes (Table 15) based on the low and high target ranges used by the BCMCA (Ban et al. 2013), which correspond to ranges found in the literature (Appendix 6) and provide higher protection for areas particularly vulnerable to disturbance or climate change impacts (Allison et al. 2003; Fogarty and Botsford 2007).

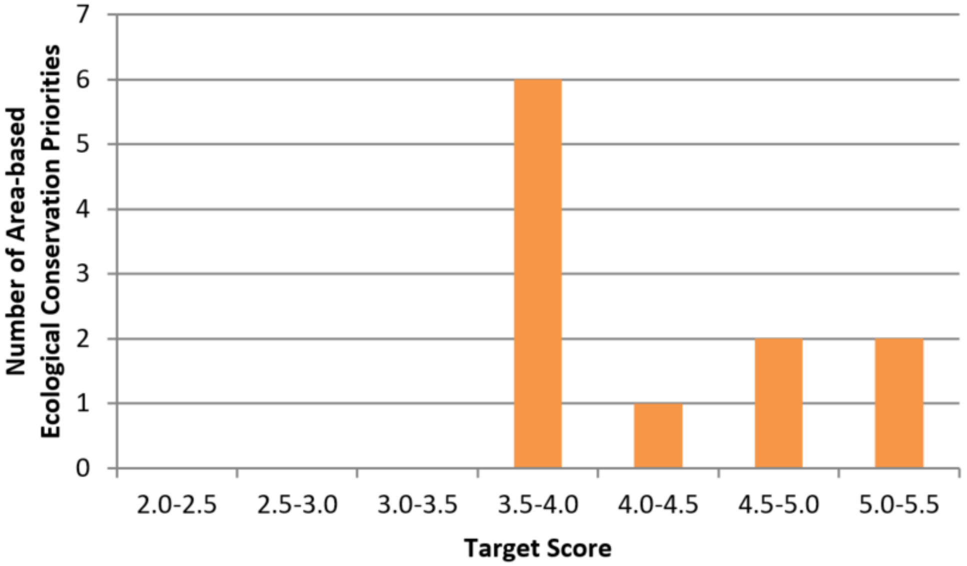

Figure 13. Frequency distribution of target scores for the area-based conservation priorities.

Table 15. Ecological conservation target classes and ranges assigned to area-based conservation priorities.

Target Class	Target Range	Target Scores	Count of Conservation Priorities (% of total)
Low	10–30%	≤3.87	6 (55%)
High	20–60%	>3.87	5 (45%)

The high ecological conservation target range was assigned to five conservation priorities, including areas of high habitat heterogeneity, frontal zones, submarine canyons, tidal passes and currents, and upwelling areas. The low target range was assigned to six conservation priorities. The final ecological conservation target ranges assigned to each area-based conservation priority is shown in Appendix 8.

8. RESULTS FOR OTHER DESIGN STRATEGIES

8.1. REPLICATION

To operationalize the design guidelines on replication (Appendix 2), we provide more specific recommendations for addressing replication across different scales in the NSB and an approach for varying the number of replicates based on patch size.

8.1.1. Replication across scales

To ensure replication across scales and to identify spatially separate replicates, we recommend that, where possible, replicates are selected within ecosections and/or the NSB subregions. Ecosections are a classification based on broad-scale oceanographic and physiographic variations in the Canadian Pacific, with units 100–1000s of km in extent (Figure 14) (Rubidge et al. 2016). The NSB subregions (i.e., Haida Gwaii, Central Coast, North Coast, and North Vancouver Island) are planning units demarcated with a combination of First Nation territorial and local government administrative boundaries and similar ecological characteristics. The subregions partition the larger ecosections north to south and east to west, and can help ensure replicates are spatially dispersed. By selecting multiple replicates of features in ecosections and/or subregions, the MPA network will provide some insurance against local disturbances, climate change, or environmental disasters. It also will ensure that natural variation among representative habitats and features are captured within the network, mitigate some of the uncertainty associated with identifying and capturing representative habitats and features, and ensure that MPAs are distributed more evenly among regions and communities.

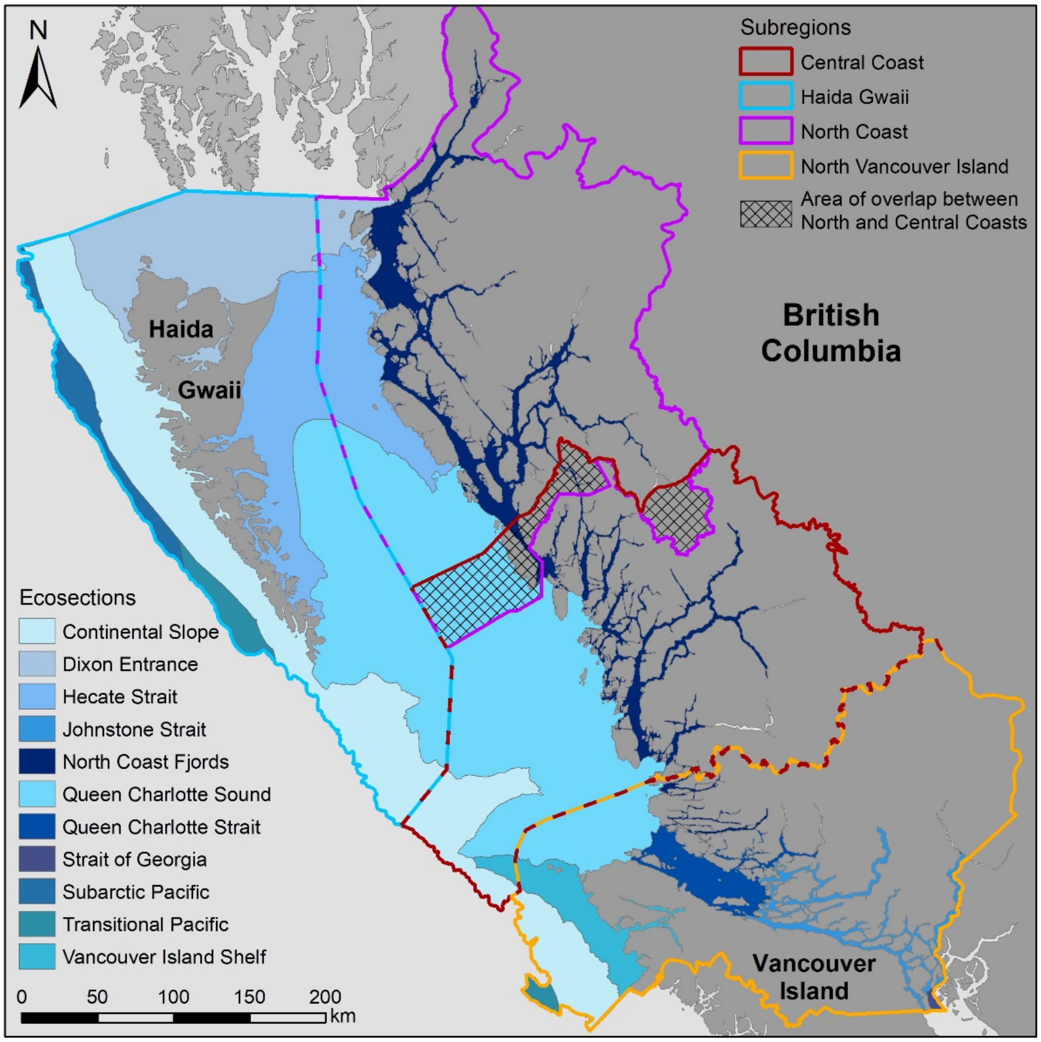

Figure 14. Map of the ecosections and subregions within the NSB that are recommended for use when addressing replication. Note overlap of Central and North Coast regions.

8.1.2. Varying the number of replicates by patch size and rarity

In addition to considerations of scale, the design guidelines recommend that rarer features and those with smaller patch sizes should have more replicates (Appendix 2; Lieberknecht et al. 2016). To address this, the distribution and patch sizes of conservation priorities should be evaluated across the study region. Conservation priorities can then be grouped based on type (e.g., marine birds) and spatial features used to represent them (e.g., nesting colonies). Each conservation priority should be assigned a patch size class based on the median size of habitat patches. The number of replicates should then be assigned to each feature, weighted by the total area of the features, such that the features with the smallest area get the highest number of replicates (Table 16). Rarity here is defined as species or habitats with low abundance and/or small range sizes, but can also include species that are highly specialized (Gaston 1997). The recommended minimum number of replicates will vary depending on the rarity and patch size of the feature, but should be at least 2–3 per ecosection or subregion, where possible, based on recommendations in the scientific literature (Table 16). For example, for eelgrass beds have patch sizes that typically range from 1 m^2 – 1 km^2 and are broadly distributed throughout the NSB. This feature would therefore be assigned 4–5 replicates per ecosection or subregion. Conversely, patches of seabird colonies are typically 10–80 km^2 but may be rarer and limited to a few sites so could be assigned 3-4 replicates per ecosection or subregion. A single MPA may contribute to the replicates for a variety of species and/or habitats that are found within its boundaries.

Table 16. Minimum number of replicates associated with a set of patch size and rarity classes for features in the NSB, stratified by ecosection or subregion where possible.

Replicate classes, based on rarity and median patch size	Minimum number of replicates, stratified by ecosection or subregion
Rare; median patch size ≤ 25%	5–6
Common; median patch size ≤ 25%	4–5
Rare; median patch size 25-75%	4–5
Common; median patch size 25-75%	3–4
Rare; Median patch size ≥75%	3–4
Common; Median patch size ≥75%	2–3

8.2. MPA SIZE AND SPACING

The NSB design guidelines provide a starting point for addressing MPA size and spacing in the network, suggesting that MPA size should (a) vary widely (minimum sizes between 5 and >600 km^2) based on specific conservation objectives; and, (b) should be larger offshore than nearshore (Appendix 2). However, these guidelines lack operational specificity. Here, we provide more specific guidance on size recommendations for MPAs in the NSB MPA network. Preferably, an understanding of species-specific movements, dispersal patterns, and population parameters provide the basis for size-related recommendations (Kinlan and Gaines 2003; Shanks et al. 2003; Shanks 2009; Gaines et al. 2010; Pelc et al. 2010; Grüss et al. 2011; Saarman et al. 2013). However, models and empirical estimates of adult movements and larval dispersal are lacking for many species along the BC coast, particularly in relation to the complex topography of the nearshore environment and interactions with ocean currents and eddies. Therefore, to devise more specific MPA size and spacing recommendations, we use rules of thumb established in the peer-reviewed literature, which are based on known, relevant species' movement and ranges of larval pelagic duration and dispersal distance.

8.2.1. MPA Size

While there is no ideal size applicable to all MPAs, it is suggested that MPA sizes should encompass the adult or juvenile home range or neighbourhood sizes (i.e., the area that an individual animal uses for its routine activities – Moffitt et al. 2009) of the species targeted for protection (Botsford et al. 2001; Botsford et al. 2003; Shanks et al. 2003; Palumbi 2004;

Hastings and Botsford 2006; Botsford et al. 2009; Moffitt et al. 2009; Gaines et al. 2010; Pelc et al. 2010; Moffitt et al. 2011). Larger MPAs often are recommended to protect species with larger movements (Green et al. 2014), although highly mobile species may spend large proportions of their time outside MPAs, limiting the protection afforded within their boundaries, unless the MPA is designed to protect areas that are used at particular life history stages (Kaplan et al. 2009; Moffitt et al. 2009; Green et al. 2014; Carr et al. 2017). Species with medium adult movement distances have been identified as the best focus for MPA sizes because species with short movement ranges (e.g., less than 1 km) will likely benefit from MPAs designed for medium movement distances.

To determine MPA spacing guidelines appropriate for marine species in BC, we built on work by Burt et al. (2014), who reviewed and summarized adult movements for a subset of marine fish, invertebrate, and algal species in BC. Using information assembled from the scientific and grey literature on adult home range size (mean and maximum ranges of individuals), general movement patterns, and depth distribution, Burt et al. (2014) assigned species to one of seven movement categories: 0, <0.05 km, <1 km, 1–10 km, 10–50 km, 50–1000 km, >1000 km. Here, we consider movement classes 0 and <0.05 km to be “restricted”, those between 1–50 km to be “moderate”, and those >50 km to be “highly mobile”.

We built on this synthesis by assigning species into nearshore and shelf/slope categories, with the understanding that these regions likely support different suites of species, and that the adult mobility of the predominant species in these regions may vary. For species-based conservation priorities that had not been reviewed by Burt and coauthors (2014), we filled in gaps where feasible from the literature (Appendix 10). We then determined the mean, median, and frequency distribution of the home ranges for species that use the nearshore and the slope/shelf areas for at least part of their life history (Figure 15). Using these metrics for the species in the moderate home range categories, and adhering to the rule of thumb that MPAs should be at least twice as large as the home range of the species of conservation interest (Botsford et al. 2001; Botsford et al. 2003; Palumbi 2004), we generated recommendations for the size of MPAs.

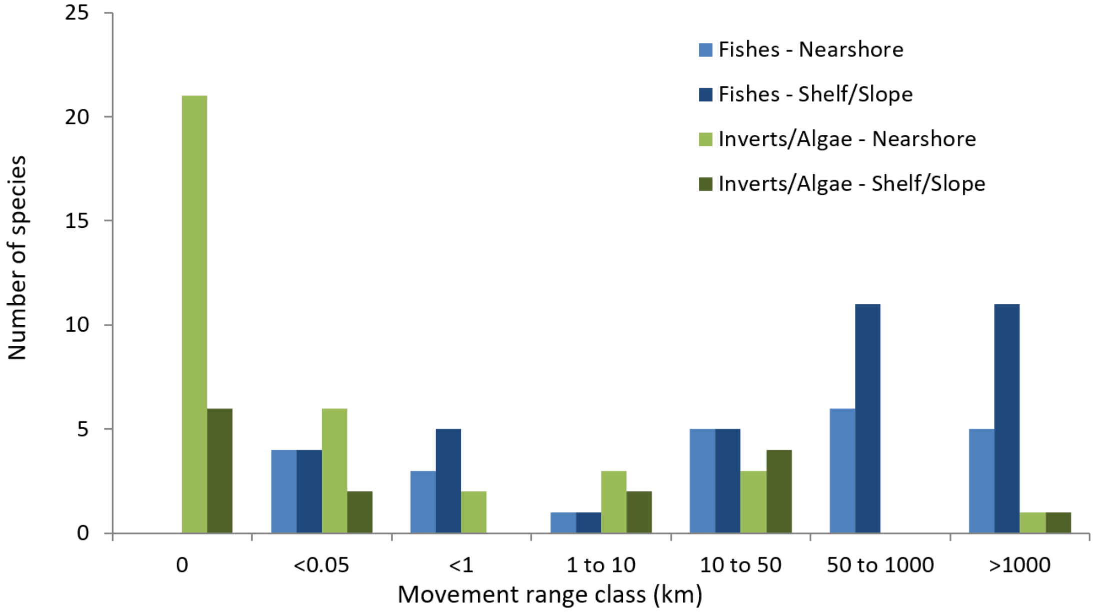

Figure 15. Frequency distribution of home range movement classes (km) for fish, invertebrate, and algae species in the NSB, split by groups that use the nearshore and shelf/slope. Based on data compiled from the literature reported in Appendix 10.

We found that more than half (62%) of the fish, invertebrate, and algal conservation priorities that spend at least part of their life history in the nearshore in BC, and for which movement information is known, move within a restricted range of less than 1 km (39/63 species) (Figure 15). About 19% of nearshore species for which movement information is known or inferred (12/63) were in the moderate movement range classes. On the shelf-slope, 36% of species (20/55) have restricted home ranges, and about 22% of species (12/55) were in the moderate range classes.

Based on the rules of thumb in Table 2, we calculated the area of a circle with a radius equal to ~4km and ~7km, based on the mean home range values for nearshore and shelf-slope species. For species in the restricted and moderate movement classes we recommend that MPAs are in the range of at least 50-150 km^2 (Table 17). For species with restricted home ranges (< 1 km), MPAs of at least 13 km^2 (based on a radius of 2 km) should be sufficient to protect adults, as long as the boundaries overlap with their habitats and/or areas of high densities. For highly mobile species, MPAs should target critical life stages or aggregations if they are spatially distinct, as the spatial scale of MPAs required to cover their distributions are likely prohibitively large (Hooker et al. 2011).

Table 17. Median and mean movement classes (km) for fish, invertebrate, and algae species in restricted and moderate movement classes (<0.5, <1, 1-10, and 10-50 kms) and minimum recommended size ranges for nearshore and shelf-slope regions. Data and sources used to estimate these values are reported in Appendix 10.

Region (number of species)	Median Home Range size (km)	Mean Home Range (km) ± SD	Recommended minimum MPA Size Ranges (km^2)
Nearshore (n = 20)	0.125	7.8 ±14.0	50–150 km^2
Shelf/Slope (n = 21)	0.75	9.5 ± 14.7	50–150 km^2

8.2.2. MPA Spacing

Data on ocean currents and larval dispersal patterns needed to inform the design of marine protected areas are lacking for British Columbia. One commonly used heuristic approach for determining MPA spacing is based on dispersal distance estimates. For example, the MLPA process based spacing guidelines on models of larval transport and syntheses of larval dispersal distances for marine fish, invertebrate and seaweed species (Kinlan and Gaines 2003; Shanks et al. 2003). Realized dispersal distance, the distance that the mean propagule disperses from an adult source population, is often unknown for many species, so pelagic larval duration (PLD: the time larvae spend as plankton in the water column) is often used as an indicator of dispersal potential (Shanks et al. 2003; Shanks 2009). However, realized larval dispersal distance is only partly explained by PLD and must be used with some caution (Shanks 2009).

To develop spacing guidelines for the NSB MPA network, we first updated a list of PLD values for a subset of fish, invertebrate, and algae conservation priorities compiled by Burt et al. (2014) adding values for species conservation priorities that had not been reviewed by that synthesis (Appendix 11). Species were grouped based on the spatial area in which they generally release their larvae/spores: intertidal, nearshore-subtidal (0–60 m depth), nearshore to shelf/slope (spawn across a broad spatial and/or depth range), or shelf/slope (larvae released offshore or at deeper depths (>60 m)).

We estimated dispersal distance for the conservation priorities for which PLD information was available using a regression analysis of PLD and dispersal distance developed by Shanks (2009), which was compiled from experiments and observations of a set of fishes, invertebrates, and algae:

Equation 3. $D_d = 0.0917*\mathrm{PLD}$

Equation 3. Estimated dispersal distance (D_d) in kilometres based on pelagic larval duration (PLD) in hours (Appendix 11).

For species for which PLDs were unavailable, we examined the literature for dispersal distance estimates and included this information where available (Appendix 12). For species where both PLD and estimated dispersal distances were available, dispersal distance information from the literature was used. While the data used to create the correlation between PLD and dispersal distance are based on species from different regions with different oceanographic conditions that may affect larval dispersal, and the relationship is relatively weak (Shanks 2009), it remains the most up-to-date and relevant information and approach currently available for B.C. While a majority of these are temperate species, they are from different regions, and may lead to over- or under-estimates of dispersal distance for species in BC.

Below we report the distribution of estimated dispersal distances for the subset of species-based conservation priorities for which we have data and provide MPA spacing guidance based on estimated dispersal distance of species with intermediate PLDs (1–3 months). For species with shorter PLDs, and thus shorter dispersal distances (<1 km), the minimum size recommendations allow for MPAs big enough to capture dispersal. For species with longer PLDs, and presumably longer dispersal distances, we assume that larvae will disperse far enough to settle into protected habitats throughout the network.

Estimated larval dispersal distance ranged broadly across the species-based conservation priorities for which information was available (Figure 16, Appendix 11). For the nearshore intertidal and subtidal areas, 48% of species (11/ 23) had estimated larval dispersal distances <50 km, and 65% of species (15/23) had larval dispersal distances <100 km. Most of these species were invertebrates, algae, or plants. The median estimated larval dispersal distances for species with intermediate PLDs in the nearshore intertidal and nearshore subtidal was 66.5 km (range 42–201 km; Table 18).

For species with intermediate PLDs that span the nearshore and shelf/slope (n = 26), the median estimated larval dispersal distance was 99.0 km (range 60.5–231 km; Table 18). Overall, 71% of species that span the nearshore and shelf/slope (24/34), including those that have more restricted or broader PLDs, had estimated larval dispersal distances smaller than 100 km. For species with intermediate PLDs that use the shelf-slope exclusively (n = 7), the median estimated larval dispersal distance was 198 km (range 44–264 km; Table 18). Given the ranges of estimated larval dispersal distance for intermediate dispersers, we recommend MPA spacing of 40–200 km in the NSB (Table 18). Within recommended size and spacing ranges, nearshore MPAs can be smaller, though spaced closer together, whereas shelf/slope MPA can be larger but spaced further apart to accommodate differing movement and dispersal distances (Burt et al. 2014).

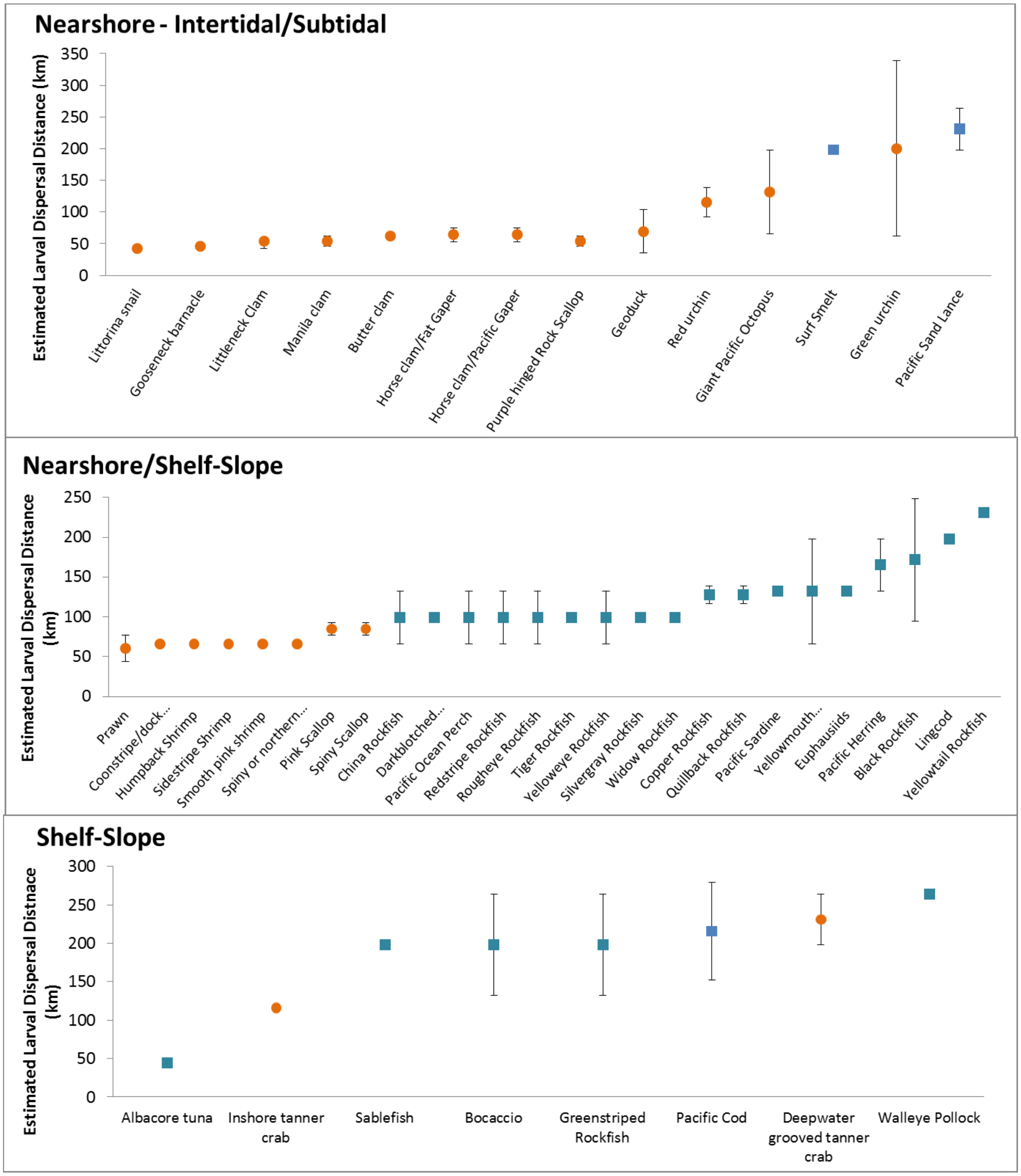

Figure 16. Estimated larval dispersal distance for species conservation priorities with intermediate PLD (1-3 months) in the NSB grouped by primary spatial areas used by species: (a) nearshore intertidal and subtidal; (b) nearshore/shelf-slope; (c) shelf-slope. Different colors and symbols correspond to different taxonomic groupings: orange circles = invertebrates; blue squares = fishes. Mean and lower and upper ranges of estimated dispersal distances (indicated by error bars) are reported if available.

Table 18. Median and ranges of estimated realized larval dispersal distance (km) for fish, invertebrate, and algae/plant species with intermediate PLDs and recommended spacing distance (km) for MPAs in the nearshore and shelf-slope regions. Data and sources used to estimate these values are reported in Shanks (2009).

Region	Median estimated realized larval dispersal distance (km)	Range of mean larval dispersal distance (km)	Recommended spacing of MPAs in network
Nearshore Intertidal and Subtidal (n = 14)	66.6	42.0–200.3	40–200 km
Nearshore-Shelf-Slope (n = 26)	99.0	60.5–231.1	
Shelf-Slope (n = 7)	198.1	44.0–264.1	

8.3. INCORPORATING MPA EFFECTIVENESS INTO THE APPLICATION OF ECOLOGICAL CONSERVATION TARGETS IN MPA SITE-SELECTION ANALYSES

Canada’s Oceans Act (Government of Canada 1996) allows for MPAs with a variety of protection levels. MPAs that allow human activities may fail to prevent some impacts to the populations, habitats or other physical features they are trying to protect, thus reducing their efficacy in meeting the ecological goals of the network. For example, a meta-analysis of multiple MPAs from around the world showed that partially protected areas that allow for different activities are less effective in protecting fish biomass and densities than fully-protected areas (Sciberras et al. 2013). Design guidelines indicate that the level of protection of an MPA should be considered when assessing how much it can contribute to meeting ecological conservation targets (Appendix 2; Lieberknecht et al. 2016). Therefore, we propose a method for integrating protection level with a risk-based assessment of conservation priority-specific impacts into assessments of the representation of the ecological conservation priorities in proposed MPA network designs. This method can be applied during the design scenarios phase in conjunction with Marxan or Marxan with Zones (Appendix 3).

8.3.1. Risk-based approach for assessing impacts to conservation priorities

A risk-based decision framework was developed to account for how individual ecological conservation priorities may be affected by allowable activities in an MPA (Figure 17). The underlying premise of the framework is that MPAs with allowed activities that impact ecological conservation priorities do not provide the same conservation benefit as MPAs that prohibit activities that could impact those same conservation priorities. The framework provides a mechanism to down-weight the contribution of a given MPA to the targets for certain ecological conservation priorities that may be influenced by cumulative effects of allowed activities within that MPA. It is intended to be used iteratively during the design scenarios phase to ensure that an appropriate amount of area is being targeted for ecological conservation priorities, given the range of activities that are proposed to occur. The method can be used to assess the levels of protection afforded by existing MPAs to individual ecological conservation priorities and evaluate management recommendations for proposed MPAs in the network, thereby highlighting ecological conservation targets that are not being met and guiding the identification of additional potential protected areas.

A number of risk assessment frameworks have been developed to evaluate the impacts of human activities on ecological components for integrated ecosystem-based ocean management (see Holsman et al. 2017 for a review). These frameworks are typically based on pathways of effects that determine how stressors from different activities impact ecosystem components (e.g., populations, habitats, species assemblages) and dynamics. Each activity-ecosystem component interaction is evaluated on a set of attributes that define how the activity and its associated stressor(s) may impact the ecosystem component. Scores are based on the scientific literature and/or expert opinion.

The decision framework presented here assigns levels of potential impact, incorporating any risk-based or impact-based scoring method (e.g., Teck et al. 2010; O et al. 2015) that can evaluate whether an activity has the potential to alter an ecological conservation priority (i.e., species, habitat, area) directly or indirectly. Using one or more of these risk assessment methods, each proposed activity-conservation priority interaction within an MPA is first evaluated to determine whether the activity has a high, moderate, or low impact. Using the resulting matrix of impact scores for each conservation priority-activity interaction, potential cumulative impacts of multiple activities can be assessed, and a level of potential impact can be assigned to each ecological conservation priority within a given MPA (Figure 17).

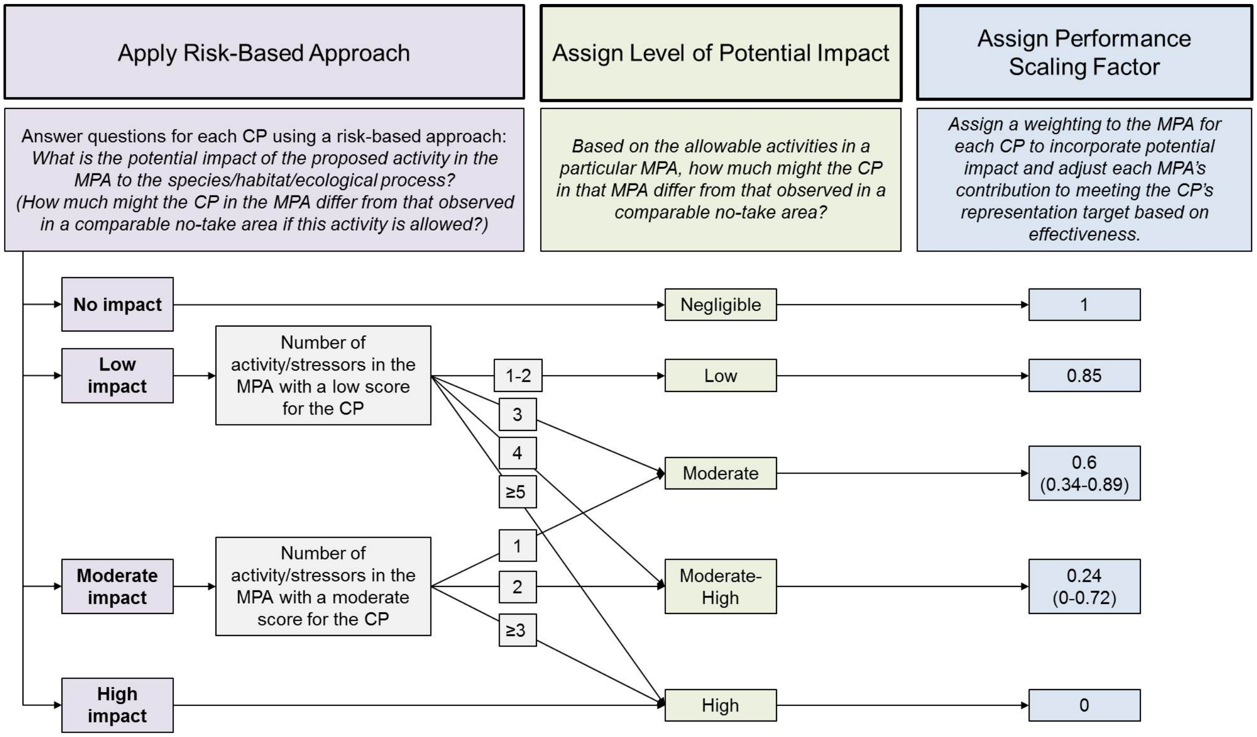

Figure 17. Decision framework for incorporating risk-based approaches to assign levels of potential impact and scale the contribution of each MPA to each ecological conservation priority (CP) when considering allowable activities in each MPA, following work from Ban et al. (2014).

If none of the proposed activities in an MPA have the potential to impact a given conservation priority, the level of potential impact for that conservation priority in that MPA is negligible. If any proposed activity in the MPA has a high potential impact on a conservation priority, the level of potential impact is considered to be high for that conservation priority in that MPA, even if other activities are low or moderate. If the MPA doesn't have activities with a high impact but does have one or more activities with a moderate potential impact, the level of potential impact depends on how many activities with moderate impact occur. A similar approach is followed if only low potential impact activities are proposed to occur.

8.3.2. MPA performance scaling factors to weight the achievement of ecological conservation targets

Following application of the framework (Figure 17), the contribution of MPAs to each ecological conservation priority's conservation targets can be adjusted, following a method that links MPA levels of protection to effectiveness estimates of fully and partially protected MPAs compared to open-fishing areas (Ban et al. 2014). Ban and co-authors (2014) developed a metric of ecological effectiveness for MPAs in BC based on a meta-analysis of MPAs from around the world (Sciberras et al. 2013). The meta-analysis provided mean response ratios of fish assemblages (density and biomass) for (a) no-take areas (IUCN Categories I-III) compared with partially protected areas (IUCN Categories IV and VI); and, (b) partially protected areas (IUCN categories IV and VI) compared with areas with no protection (Sciberras et al. 2013; Ban et al. 2014). A response ratio of 1 represents equal fish density or biomass inside the no-take areas and partially protected areas or partially protected areas and areas with no protection. A response ratio >1 means more and/or larger fishes inside the no-take area and <1 means fewer and/or smaller fishes inside the no-take area (Sciberras et al. 2013; Ban et al. 2014). The authors used a weighted meta-analytical approach and mixed effects linear models to quantify the response of fish assemblages to spatial protection. Analyzing response ratios of fish density and biomass together, they detected a significant difference between no-take areas and IUCN Categories IV and VI and between IUCN Categories IV and VI and areas open to fishing.

The authors then determined the relative ecological effectiveness of different levels of protection for biodiversity conservation by scaling the predicted estimate of response ratios between areas subject to conventional fisheries management (0% effective) and no-take areas (100% effective). They did this by using the outputs from the mixed effects linear model that included the response ratios of both fish assemblage density and biomass by IUCN Category. They rescaled the predicted estimate from the models and lower and upper 95% confidence intervals, such that areas open to fishing have a value of 0 and no-take areas had a value of 1, using the following formula:

Equation 4.

$$z_i = \frac{x_i - open\ fishing\ area}{no\ take\ area - open\ fishing\ area}$$

Equation 4. z_i is the rescaled score between 0-1 for areas with different protection levels (i.e., IUCN levels IV and VI), and x_i is the original data score (predicted estimate, upper and lower confidence intervals) (Ban et al. 2014).

The rescaled effectiveness scores for IUCN Category IV was 0.6 (lower and upper 95% CI = 0.34 and 0.89, respectively), and the effectiveness score for IUCN Category VI was 0.24 (95% lower and upper CI = -0.12 and 0.72, respectively). In addition, because IUCN categories Ib and II allow for Indigenous use, the authors assigned an effectiveness score of 0.85 derived from expert opinion about the likely effectiveness of MPAs with these IUCN categories compared to no-take areas (Ban et al. 2014) (Table 19).

Table 19. Effectiveness scores of IUCN Categories (adapted from Ban et al. 2014).

IUCN Categories	Effectiveness Scores
IUCN Ia, II	1.00
IUCN Ib and II, with Indigenous use	0.85
IUCN IV	0.60 (95% CI: 0.34–0.89)
IUCN VI	0.24 (95% CI: 0–0.72)
Fished areas	0.00

8.3.3. Combination of the risk-based approach and MPA performance scaling factors

During the design scenarios phase, for each conservation priority in each MPA, a risk-based or impact-based approach would first assign a level of potential impact. Next, the relative effectiveness of that MPA would be used to calculate an MPA performance scaling factor to be used when calculating how that MPA contributes to each ecological conservation target (Figure 17). If a negligible impact was assigned, the MPA performance scaling factor would be 1 (i.e., equivalent to a no-take MPA). For those MPAs where a low level of impact occurs, we assumed that the MPA would provide similar protection to the conservation priority as an MPA with low-level use such as an IUCN level Ib, II, or III. Where a moderate-level of impact occurs, we assumed that the effectiveness of the MPA would be similar to an MPA that allows some extractive human uses (i.e., IUCN Category IV, Appendix 4). These MPAs likely would be less effective than no-take MPAs in meeting the ecological objectives for the conservation priority. For conservation priorities in these MPAs, the contribution to ecological conservation targets would be down-weighted by 0.6 (i.e., IUCN Category IV effectiveness score range - Ban et al. 2014). For MPAs where moderate-high levels of impact occur, we assumed that the effectiveness of the MPA would decrease similar to a protected area with sustainable use of natural resources and non-industrial use of natural resources compatible with nature conservation (i.e., IUCN Category VI, Appendix 4). For conservation priorities in these MPAs, the contribution to ecological conservation targets would be down-weighted by 0.24 (i.e., IUCN Category VI effectiveness score range - Ban et al. 2014). Finally, where the level of potential impact is high for a conservation priority, we assumed that an MPA would not meet its ecological objectives and the MPA performance scaling factor would be 0 for that ecological conservation priority in that MPA and thus would not count toward its ecological conservation target (Figure 17). This method may lead to (a) a larger overall spatial footprint to meet ecological conservation targets for conservation priorities exposed to potential impacts within the MPA network; and/or, (b) a greater proportion of area in higher protection.

8.3.4. IUCN levels of protection

Although we have recommended a risk-based framework with MPA performance scaling factors to account for potential impacts of activities on conservation priorities and the ability of MPAs to contribute to ecological conservation targets, we emphasize that this does not preclude assigning IUCN categories to the MPAs within the network and identifying thresholds for the different categories in the network. IUCN categories have been assigned to existing and proposed MPAs within the NSB and across Canada and are a useful tool for assessing and comparing MPAs. There is strong support in the literature for ensuring a proportion of the marine space is managed as no-take reserves to maintain ecological processes and meet ecological recovery and biodiversity objectives (Halpern 2003; Roberts et al. 2003a; Lester and

Halpern 2008; Stewart et al. 2009; Edgar et al. 2014). Based on this literature, international recommendations for protecting 30% of the ocean in highly protected MPAs with no extractive activities (IUCN-WCPA 2018), work done in other marine jurisdictions (Airamé et al. 2003; Fernandes et al. 2005; Fogarty and Botsford 2007; Gaines et al. 2010; Jessen et al. 2011; Green et al. 2014; O'Leary et al. 2016), and the existing management measures in place in the NSB for many activities, we recommend that at least 20-50% of the footprint of the MPA network should be in no-take (generally thought to correspond to IUCN Level Ia) or at least limited-take (generally thought to correspond to IUCN Level Ib, II, III) reserves, with the appropriate range of protection levels determined through sensitivity analyses. This is a key design strategy for the overall effectiveness of the network and should be considered separate from the application of a risk-based approach to evaluate and adjust the contribution of the MPA network configurations to the specific ecological conservation targets.

9. DISCUSSION

In this paper we (1) set the context for developing design strategies for the NSB MPA network by reviewing the components of MPA network planning processes ongoing in BC, best practices from these and other planning processes, and guidance from the scientific literature; (2) developed a method for setting coarse-filter and fine-filter ecological conservation targets and provided a flow diagram for determining which features and associated targets are appropriate for inclusion in site-selection analyses in the next phase of planning; (3) provided recommendations on design strategies for size, spacing, and replication by adapting best practices and guidance from the literature to the NSB; and (4) developed an iterative approach linked to MPA effectiveness research for assessing how MPAs contribute to ecological conservation targets based on protection levels. Below we summarize the results and recommendations stemming from this report and discuss some of the implications and limitations of our work.

- We set spatial ecological conservation targets for coarse-filter ecological classification based on feature sizes and developed an approach for fine-filter area-based and species-based conservation priorities based on conservation concern, vulnerability, ecological role, and expert review. Ecological conservation target ranges can be used to develop initial site selection analyses that will identify potential areas that meet the ecological network objectives and ‘starting points’/’base case’ for possible MPA network configurations in the NSB. The ecological conservation target ranges are not intended as single species management recommendations.
- Application of the approach for calculating ecological conservation targets for fine-filter conservation priorities resulted in 55% of area-based conservation assigned low target ranges of 10–30% and 45% assigned high target ranges of 20–60%. Application of the approach to species-based conservation priorities using the quartile classification (Appendix 9) resulted in 26% assigned low target ranges of 10–20%, 52% assigned medium ranges of 20–40%, and 22% assigned high target ranges of 40–60%.
- We recommended a minimum MPA size of 50–150 km^2 for the nearshore and shelf/slope, though sessile species may benefit from smaller MPAs between 13–50 km^2.
- We recommended MPA network spacing of 40–200 km distance in the nearshore and shelf/slope.
- We provided an approach for determining the number of replicate areas needed to meet representation targets based on patch size or rarity, stratified at the scale of ecosections or subregions in the NSB.

- We developed a risk-based framework linked to MPA performance scaling factors derived from global meta-analysis of MPAs to assess and account for the potential ability of each MPA to contribute to the ecological conservation targets.
- We recommended that at least 20–50% of the MPA network should be in no-take (generally thought to correspond to IUCN Level Ia) or at least limited-take (generally thought to correspond to IUCN Level Ib, II, III) reserves and that the distribution of protection levels be assessed in sensitivity analyses.

9.1. ECOLOGICAL CONSERVATION TARGET-SETTING

9.1.1. Ecological conservation targets and MPA network coverage

Canada’s commitment to the CBD requires that 10% of marine and coastal habitats be protected with MPAs. The literature expands upon this recommendation and 30% is often used as an area-based target for MPA coverage, whether protected in a range of MPA types (Lieberknecht et al. 2016) or solely within no-take reserves (Gaines et al. 2010; Jessen et al. 2011). We have recommended ecological conservation target ranges between 10–60% but cannot yet determine explicitly how these targets will relate to the final total area of the proposed MPA network within the NSB when the design process is complete. Leveraging the optimization of Marxan can help inform efficient network design because Marxan analyses focus on areas of high feature richness and seek to maximize spatial efficiency while meeting the targets. As such, areas that can achieve the targets for multiple features simultaneously are often selected and the number of features incorporated into an analysis does not necessarily correlate with the spatial footprint of the analysis results. Similarly, areas that are selected may also capture replicates for multiple features. Once the spatial features have been finalized, sensitivity analyses can be performed using Marxan to determine the spatial extents of proposed MPA network configurations and investigate whether any of the spatial features unduly influence the analyses. Until then, we can look to past planning exercises to see the total area recommended for protection from analyses using similar ecological conservation target ranges with similar spatial features. In particular, regional-scale Marxan analyses performed for MaPP[10] are informative. The MaPP analyses used a lower target range (10–30%) for representative features and higher targets (20–60%) for species of conservation concern, species valued highly by experts, and unique or distinctive physical features. A range of Marxan scenarios was run, employing either the low end of each target range (i.e., 10% for representational features and 20% for special features) or the higher end of the target ranges (i.e., 30% and 60%). The scenarios were informed by additional parameters linked to size and shape, but the results show that the when the low targets were used, 12% of the NSB was suggested for protection while analyses using the high targets placed 37% of the NSB within a potential MPA network. The Marxan analyses did not consider the protection level that would be afforded to the resulting MPAs in the proposed network. Therefore, while the high target levels would protect a greater proportion of the NSB than suggested by some of the literature (Gaines et al. 2010; O'Leary et al. 2016), the results did not guarantee that the areas would be protected as no-take reserves as recommended by others (Airamé et al. 2003; Fernandes et al. 2005; Jessen et al. 2011; Fernandes et al. 2012).

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[10] BCMCA 2013. Marxan analyses for the Marine Planning Partnership (MaPP): Summary report of initial scenarios. Technical document prepared for the MaPP Science Advisory Committee. Unpublished.

9.1.2. Coarse-filter features and naturalness

The full spatial extent of each habitat class was used to establish the ecological conservation target ranges for each ecological classification system. Coarse-filter features are intended to represent the natural diversity of ecological units within the study area but habitat quality or ecosystem intactness will vary across space and highly impacted sites may not be truly ecologically representative. Protecting more pristine areas is recommended as a proactive approach for biodiversity conservation (DFO 2013) to protect areas that may be important sources for recolonization or may be at risk of future degradation. However, areas that overlap with human activity may also be important to include in an MPA network to facilitate the restoration of highly productive ecosystems and maximize the contribution of MPAs (Joppa and Pfaff 2009). Incorporating both approaches to biodiversity conservation can help ensure the protection of vulnerable or threatened species and areas (Brooks et al. 2006; DFO 2013; Robb 2014). Similar to work in other bioregions (e.g., DFO 2018b), a spatial assessment of naturalness within the NSB could be completed and sensitivity analyses performed to investigate the impact of incorporating naturalness into the coarse-filter features.

To determine naturalness, the spatial extents of human activities within the NSB can be overlaid using GIS to support assessment of cumulative impacts. Spatial datasets for many of marine and terrestrial activities relevant to the NSB have been compiled and assessed in past analyses (e.g., Ban et al. 2010; Murray et al. 2015). These analyses could be updated using newer and more detailed information, including updated datasets of catch and effort for commercial and recreational fisheries, to improve estimates and more accurately delineate areas of low or no impact. “Natural areas” in the ocean would need to be defined based on a low impact threshold for each habitat type, using a vulnerability or cumulative impact assessment (e.g., Halpern et al. 2009; Ban et al. 2010; Teck et al. 2010; Murray et al. 2015). Resulting natural areas can be overlaid with each targeted classification system to ascertain the areas within each habitat class that are relatively pristine.

9.1.3. Fine-scale conservation priority features

More information was available to score the ecological characteristics and conservation status of some species (Gale et al. 2019), which may have resulted in the application of higher ecological conservation targets for well-studied species. However, this may have been partially moderated by including expert reviews as a factor influencing the final target scores. To some extent, knowledge gaps were addressed through species expert feedback on the conservation priority scoring, especially for marine invertebrates and birds (Gale et al. 2019), as well as the expert reviews of the targets performed through this review. Future assessments of target scores using similar conservation priorities should incorporate updated information, where available.

Data availability and quality may influence the outcomes when applying ecological conservation targets in design scenarios. For example, setting targets for features with patchy coverage of spatial data may bias the selection of data-rich areas over data-poor areas. While data availability and coverage should not limit target-setting, it may influence the application of targets in the design scenarios phase (Ardron et al. 2010). Depending on the feature of interest and the data available, it may still be useful to include features with patchy data distribution when selecting the network (e.g., to ensure that known examples of particularly valuable features are protected). However, the influence of these data on the network and its ability to capture the broader range of biodiversity should be considered during the design scenarios phase, following the decision points suggested in Figure 9. Review of available spatial data as well as draft network designs by experts and stakeholders with local knowledge can also help to identify areas that may be data poor but ecologically important. For example, the spatial coverage of surveys that can be used to inform the representation of fish and invertebrate species may not extend into coastal fjords and inlets or areas currently closed to certain gear types, such as Rockfish Conservation Areas (RCAs). Local knowledge of species prevalence in those areas can help inform their potential contribution to MPA network objectives and ecological conservation targets.

9.1.4. Expert review

Initial ecological conservation target ranges were developed by incorporating expert feedback received at taxon-specific workshops held by the BCMCA (e.g., BCMCA Project Team 2008). These workshops provide the best available compilation of expert opinions for setting targets for conservation priorities in the NSB. Also, many of the species and areas assessed by the BCMCA are included in the list of conservation priorities for MPATT. However, the BCMCA noted challenges associated with using expert workshops to develop targets, including concerns from experts about working with limited data (Bodtker 2010), the variation between taxa in suggested targets, the technical difficulties of incorporating high expert-recommended targets in analyses (Ban et al. 2013), and the potential bias of group-think on target-setting (Nicolson 2010). Our process for updating the expert feedback with a new suite of reviews follows recommendations that resulted from the BCMCA process (Bodtker 2010; Nicolson 2010). Recommending an initial target range and providing information on spatial features that have been used successfully in prior Marxan analyses alleviated concerns among experts over limited data. Because Marxan has been used successfully in the study area several times since the original BCMCA workshops, the scientific community may also have become familiar with the software and the concept of targets. Further, meeting with individuals or small groups of taxon-specific experts allowed us to explain the MPA network planning process for the NSB and the role of the design strategies, facilitated a review of past target recommendations, gave experts equal opportunity to provide feedback, and reduced the potential for one expert's opinion to bias those of other scientists.

Some of the final ecological conservation target ranges do not match recommendations from all of the experts who participated in the BCMCA or MPATT reviews. In part, this was due to a difference of expert opinions on appropriate target ranges. For example, experts recommended both high and medium targets for coldwater coral conservation priorities. Taking the average of the export review scores (2.33) together with a moderate score for conservation concern and a high score for ecological role resulted in a medium target for coral conservation priorities (Appendix 8). Had all of the experts recommended a high target, the expert review score (3) would have resulted in a high target range for coral. Further, the scoring method treated all of the criteria equally when calculating the target scores, which moderated the influence of the experts on the final target ranges. A medium target was suggested by experts for sperm whales, for example, but because of their high functional importance and conservation concern, the target remained high (Appendix 8). However, because sperm whales are highly mobile and the spatial features available to represent sperm whales are based on density distributions and not known areas of importance, the target was downgraded to low following the flow diagram (Figure 9) for identifying the features appropriate for site selection analyses.

Some experts also suggested changes to the scores for the ecological criteria (e.g., Northern Lampfish) but because those scores have been reviewed previously (Gale et al. 2019), we made no alterations but documented the comments (Appendix 8). Future analyses may benefit from combining the development of the list of conservation priorities, and the scoring of the ecological criteria, with the development of appropriate targets. Where discrepancies existed in the resulting targets, we have documented the expert recommendations and the final ecological conservation target ranges assigned to the conservation priority (Appendix 8). During sensitivity analyses performed as part of the design scenarios, alternate target ranges suggested by experts can be tested to determine their applicability and their influence on the results and the overall configurations of the proposed MPA networks.

9.1.5. Limitations

Few studies are available to help identify appropriate ecological conservation target ranges relevant to the species and geography of the NSB, in part because measuring the efficacy of conservation measures requires a long time series of data from MPAs pre- and post-implementation (Appendix 6). In such cases, sensitivity analyses of the proposed suite of conservation priorities and targets is considered best practice in Marxan analyses (Ardron et al. 2010). Sensitivity tests should be performed as part of the initial Marxan calibration in the design scenarios phase of MPA network planning and can include analyses to test: (a) the ecological conservation target ranges; (b) the appropriate proportion of no-take MPAs within the network; (c) the use of a minimum target threshold for coarse-filter features; (d) the impact of focusing on habitat features alone or of separating the nearshore and offshore environments because of differences in data availability and resolution; and (e) the incorporation of naturalness in coase-filter features.

The results of past Marxan analyses in the NSB can help to determine the applicability of the recommended ecological conservation target ranges. Our heuristic approach recommends higher targets for species conservation priorities with higher vulnerability and conservation concern that have important ecological roles as well as area-based conservation priorities that meet multiple objectives. Thresholds or empirical data were not used. As a result, the targets may differ from those that would be assigned using more quantitative analyses, such as Population Viability Analyses (Svancara et al. 2005). Because data are limited for many of the conservation priorities, these analytical methods are not available to guide site-selection analyses, especially for a large number of species and features. However, future updates to these analyses should reassess the available information to determine whether a quantitative approach to target-setting is possible.

We systematically assigned three ecological conservation target ranges to a diverse suite of species and areas based on the ecological criteria relevant to each conservation priority. It is possible that this number of target ranges is not diverse enough to be appropriate for all species. For example, protecting 60% of one species may not be sufficient to increase population size. Furthermore, the persistence of some conservation priorities may be influenced by the targets set for other conservation priorities. Therefore, the targets do not necessarily ensure that ecological functions will be protected or recover. Despite this uncertainty, our recommended targets are based on ecological studies that suggest protecting a certain amount of habitat and/or distribution of ecological conservation priorities should help protect biodiversity and promote population protection or recovery. It is therefore recommended that the ecological conservation target ranges be used to develop initial site selection analyses that will identify potential areas that meet the ecological network objectives. These analyses can serve as a starting point for possible MPA network configurations in the NSB. The ecological conservation target ranges are not intended as single species management recommendations but the targets set for MPA network planning can work together with other conservation objectives and spatial and non-spatial management measures, such as recovery strategies developed for endangered species.

9.2. OTHER DESIGN STRATEGIES

9.2.1. Replication

Our recommendations are consistent with the literature that replication of coarse-scale and fine-scale features should occur at the bioregional scale (at least 3 replicate MPAs per habitat type or feature) (e.g., Fernandes et al. 2005; IUCN-WCPA 2008; McLeod et al. 2009 ; Fernandes et al. 2012; Burt et al. 2014), as well as within smaller ecologically-defined classifications and coastal planning regions. This will allow representation objectives to be met at finer-spatial scales at which marine planning in BC is typically conducted, address uncertainty, provide insurance against potential disturbances, and facilitate evaluations of the efficacy of MPAs as the network is implemented.

We also provide a method for using patch size and rarity to vary the number of replicates for different conservation priorities at the ecosection or NSB subregion scales. As the data are not yet available for all of the conservation priorities to do the analyses, we were not able to provide results for this approach. Furthermore, more information is needed on size thresholds required for a replicate to be considered viable in meeting biodiversity protection objectives. Work has been done in California to identify thresholds for some habitat features using accumulation functions applied to species-habitat data (CDFG 2008), but the data necessary for this work is not currently available for the NSB. Thus, there is uncertainty as to the outcomes associated with applying this method.

9.2.2. Size, spacing, and shape

No one MPA size fits all species. To address size ranges of MPAs that protect multiple species in the NSB, we used species with moderate home ranges to recommend a range of minimum MPA sizes in the nearshore and shelf/slope regions. Our results suggest that species that are sessile or exhibit limited movements, including a wide range of algae, invertebrates, and some fishes, should benefit from MPAs in these size ranges as long as the allowable activities are not detrimental to those species. Our recommended size ranges in the nearshore are similar to those recommended by other processes, including the California MLPA process, which recommended minimum sizes of 23–47 km^2 and preferred sizes of at least 47–93 km^2 (CDFG 2008). While we recognize that smaller MPAs (13–50 km^2) could benefit species with more limited movements and may be more feasible in more confined geographies such as the coastal inlets and fjords, we recommend a wider range of MPA minimum sizes in the nearshore and shelf-slope regions (50–150 km^2), as they cover a diverse set of ecosystem types and conservation priorities with larger ranges. The MPA network can benefit species with larger movement patterns if individuals spend part of their life history in MPAs that limit harmful activities. Given that ecological conservation targets for more mobile species will be set on features where individuals aggregate–such as key habitats or areas important to breeding, feeding, or nursery areas– the MPA network could benefit these species even if MPA size is smaller than the species' home ranges.

While MPA size should be scaled to match the home ranges of adults (Carr et al. 2017), the magnitude and spatial extent to which larvae produced by protected populations within MPAs replenish populations outside of MPAs is also determined by the size and spacing of MPAs (Botsford et al. 2001; Botsford et al. 2003; Botsford et al. 2009; Shanks 2009). Thus, MPA size recommendations should also be informed by larval dispersal. Modelling studies of larval stages of nearshore species in California indicated that a reserve size of 4–6 km in diameter should be large enough to contain the larvae of short-distance (i.e., <1 km) dispersers (Shanks et al. 2003). Our results suggest that many of the species in the nearshore in the NSB are short-distance dispersers. Thus, our minimum size recommendation of 13 km^2 should be adequate to capture the recruits of many of these species. However, there is a lot of uncertainty in the method we used to estimate dispersal distance (Shanks 2009), and the coastline of B.C. is influenced by different oceanographic currents than California, has many fjords and inlets, and has many islands and archipelagos characterized by high tidal activity. These factors can greatly influence the movement of particles among different areas of the B.C. coast, including the possibility of higher retention in some areas (Robinson et al. 2005). The complexity of current patterns within the nearshore waters of BC may limit the dispersal distances of species with longer-distance dispersal (Lotterhos et al. 2014; Sunday et al. 2014; Markel et al. 2017), thus the recommended size range is likely conservative for conservation goals across the spectrum of larval durations of nearshore BC species. This may occur to a lesser degree in more offshore species along the open coast, reinforcing the guideline that suggests placement of larger MPAs that are further apart in offshore waters.

MPAs should be spaced far enough apart to allow for recruitment and spillover of larvae to areas adjacent to MPAs, but close enough to allow larval transport among MPAs. MPA network guidelines for California recommend having MPAs within 50–100 km of each other based on models of larval transport and estimates of larval dispersal distance (1–100 km and 50–200 km; Kinlan and Gaines 2003), but other recommendations suggest that some reserves should be spaced only 10–20 km apart to capture propagules released from adjacent reserves for shorter distance dispersers (<1 km) (Shanks et al. 2003). The lower range of our spacing recommendations in the nearshore meshes with the recommendation in California's nearshore, and would accommodate shorter-distance dispersers, and the upper range also reflects the need to accommodate intermediate dispersers. Spacing MPAs based on the distance of intermediate dispersers is likely to increase the extent of coastline replenished by larvae produced within MPAs, including those areas that are fished (Carr et al. 2017).

We acknowledge that realized larval dispersal distance is only partially explained by larval duration (Shanks et al. 2003; Shanks 2009). Dispersal is a distribution of potential connections which will vary species to species and over different time scales. Larval behaviour, oceanographic currents, seasonal wind-patterns, upwelling, tidal influences, and other environmental conditions can influence dispersal distance. Furthermore, habitat is an important consideration, as recruitment is only realized if suitable habitats are available. Larval dispersal has not been examined extensively on the BC coast, although some studies provide insight into larval dispersal dynamics and highlight complex interactions. For example, models that integrate oceanographic particle dispersion and assumptions of typical larval durations and dispersal distances indicate that Gwaii Haanas NMCAR likely contributes particles to other northern MPA sites (~100 km away), receives particles from regions several 100s of km to the south, and likely can retain particles within its 100 km north to south boundary (Robinson et al. 2005). Genetic techniques that estimate the average dispersal distance for black rockfish in BC conclude that the distance between RCAs should be no greater than 100 km to facilitate connectivity (Lotterhos et al. 2014). Genetic data, coupled with an oceanographic circulation model, indicate passive larvae of nearshore species with a 6–10 week pelagic larval phase are often retained within 20–50 km of their parents along the complex coastline of BC (Sunday et al. 2014). Further modeling studies, particle tracking studies, and empirical estimates of larval dispersal and transport within BC would be useful to further inform recommendations for MPA size and spacing.

Our recommendations for size and spacing remain broad but provide more specific operational guidance for the MPATT design guidelines. Design guidelines indicate that size ranges should vary between the inshore and offshore, and with predominant geography, oceanography and landscape scale, as well as with protection level. Specifically, the design guidelines recommend that a minimum size range of 5–150 km^2 is applied for highly protected sites, while lower protection levels should have larger minimum size ranges (IUCN category IV: 10–300 km^2; IUCN category VI: 20–600 km^2). Our recommended approach for integrating potential impacts from human activities with ecological conservation targets should ensure that sizes will vary with protection level when applied in the MPA network design strategies phase. Our recommendations also mesh with design guidelines that refer to spacing, including the recommendation that inshore sites be smaller and closer together than offshore sites. While we don't provide more specific recommendations for MPA shape beyond the design guidelines, the shape of individual MPAs to the degree possible should follow ecological boundaries, reflect known species' behaviours such as aggregating, feeding, or breeding, avoid fragmenting cohesive habitats, and facilitate surveillance and enforcement. This is an important assessment that should be performed when evaluating potential MPA network configurations resulting from Marxan analyses and adapted iteratively through feedback from planning partners and stakeholders.

9.2.3. MPA level of protection

Risk-based framework: strengths and weaknesses

Design guidelines indicate the importance of considering levels of protection when assessing the potential effectiveness of the MPA network in meeting ecological conservation targets. To address this, we proposed a risk-based framework to assess and account for the potential ability of each MPA to contribute to ecological conservation targets. One alternative to the risk-based approach is to assign each MPA an IUCN level of protection and then use these levels to score the effectiveness of the MPA (Ban et al. 2014). Using IUCN categories is a simpler approach, though both approaches are transparent and have clear decision points. However, the risk-based approach allows for consideration of conservation priority-specific impacts from each activity, rather than assuming an equal level of impact across all conservation priorities in an MPA with a particular IUCN level. The risk-based approach also allows for consideration of potential cumulative impacts from multiple activities. However, there is uncertainty associated with assigning risk scores to interactions between activities and conservation priorities and there is a lack of knowledge of all impacts faced by each conservation priority. The risk-based framework is precautionary. It assumes that (a) compared to an MPA with two low impacts, an MPA with four low impacts reduces the effectiveness by a a factor of 3.5; (b) compared to an MPA with one moderate impact, an MPA with two moderate impacts reduces the effectiveness by a factor of 2.5; and, (c) five low or three moderate impacts are equal to one high impact.

Other science-based approaches outside the IUCN framework have been developed to determine how different MPA types with different allowable activities influence the ability of an MPA to contribute to the ecosystem protection goals. Under the California MLPA MPA network planning process, the Science Advisory Team devised a framework to determine how allowing different fishing activities within the MPAs would contribute to ecosystem protection goals (Saarman et al. 2013). Each proposed fishing activity was evaluated (e.g., rockfish hook-and-line, salmon trolling) and assigned a level of protection based on whether the activity altered community structure and therefore ecosystem functioning. Each MPA was then assigned a level of protection corresponding to the allowed activity with the greatest potential for ecosystem impacts. Although similar to the IUCN levels of protection approach, this method allows for ecosystem- and activity-specific assessment of impacts. However, it doesn't account for conservation priority-level impacts, and assigns the level of protection based on the activity with the highest impact rather than considering cumulative impacts.

One of the key challenges to the risk-based method is that it requires resources and time to implement, and the iterative application of Marxan analysis in the decision scenarios phase will be computationally intensive. However, one way to reduce complexity would be to apply the risk-based framework using an update of Marxan known as Marxan with Zones (Watts et al. 2009) (Appendix 3). This analytical tool can account for multiple MPAs or zone types and can incorporate multiple human activities. Each zone would be defined by the types of activities allowed, and each zone-conservation priority interaction would be assessed in the risk-framework. This would simplify the iterative calculation of MPA performance scaling factors and the ability of overall MPA configurations in each scenario to contribute to ecological conservation targets.

Flexibility is another strength of the risk-based approach, which can accommodate a variety of risk assessment methods. A number of risk assessment tools have been developed to evaluate the impacts of multiple stressors on multiple ecological components for integrated ecosystem-based ocean management (e.g., Teck et al. 2010; Samhouri and Levin 2012; O et al. 2015; Holsman et al. 2017). Typically, these approaches determine the potential consequences to the ecosystem components (i.e., species, habitats, communities) based on key attributes that reflect their vulnerability to a variety of stressors, such as life history or habitat characteristics, as well as the ability of the ecosystem component to resist or recover from exposure to the stressor. These attributes are usually scored using expert opinion or a literature review.

As part of the regional peer review for this paper, no specific recommendations were made as to which risk assessment method to incorporate into the risk-based approach to scaling ecological conservation targets. However, as part of the NSB MPA network planning process, an approach has been developed for evaluating potential effects of human activities on the ecological conservation priorities[11]. This approach uses the scientific literature to assign scores to each activity-conservation priority interaction. In this framework, activities can have effects on species or communities that are major positive, minor positive mixed, minor negative, major negative, or negligible (Table 20). Each scoring record has a confidence score and a rationale founded in the scientific literature. We suggest that the scores from this risk-based approach could be used to determine high, moderate, and low risk to a given conservation priority from a given activity (Table 17).

Although transparent with clear decision points, this approach and the scores have not been peer-reviewed. While the impact score rationale is provided and is founded in the literature, Tamburello et al. don’t provide a set of clearly defined attributes/criteria and thus the approach may not be applied consistently across activity-stressor-ecosystem components[10]. Moreover, the recent application of this approach does not reflect how much the conservation priority in an MPA might differ from that observed in a comparable no-take area if the activity were allowed. For example, in assessing risk to Pacific Halibut from long-line fisheries, the interaction was scored as negligible based on fisheries sustainability reports. However, in the context of MPAs, allowing halibut long-line fishing within the boundaries of an MPA would potentially influence the ability of that MPA to meet conservation objectives for halibut compared to a no-take area. To address this shortcoming, the scores would need to be reviewed and revised with this context in mind.

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[11] Tamburello, N., Cueva-Bueno, P., Olson, E., Grosbeck, A., and Porter, M. unpublished. Linking Human uses to Ecosystem Components and Ecosystem Goods and Services in Canada’s Northern Shelf Bioregion. Report prepared by ESSA Technologies Ltd. For Fisheries and Oceans Canada.

Table 20. Correspondence between Risk-Based Framework Impact Level and scoring schemes describing the direction and consequences of interactions between activities and populations or assemblages of species[11].

Risk Based Framework Impact Level	Effect Consequence Score (ESSA[9])	Criteria (ESSA[9])
High Potential Impact	Major Negative Effect (-2)	Negative interaction can occur and may cause substantial impacts to local population abundance and persistence due to extensive habitat damage, loss of food resources, and/or other factors.
Moderate Potential Impact	Minor Negative Effect (-1)	Negative interaction can occur and may impact populations to some extent through small, generally reversible changes in habitat quality and or/local population densities due to deterioration in habitat conditions, reduced food availability, and/or other factors. There appears to be little or no overall effect of this activity on the ecologically significant species or community.
Low Potential Impact or N/A	Negligible (0)	There appears to be little or no overall effect of this activity on the ecologically significant species or community.
Low Potential Impact or N/A	Mixed Effects (+/-)	A mix of potential negative and positive effects where insufficient information is available to determine whether there is an overall net positive or negative effect on habitat area, function, or population abundances.
N/A	Minor Positive Effect (+1)	Positive interaction can occur and may benefit populations to some extent through enhancement of existing habitat, increased food resources, and/or other factors that increase local population densities.
N/A	Major Positive Effect (+2)	Positive interaction can occur and may create substantial benefits to populations through creation of new habitat, long term increases in population size, and/or other factors that increase the range of a species or community.

MPA performance scaling factor strengths and weaknesses

We recommend using the ecological effectiveness scores developed by Ban and co-authors (2014) to incorporate potential impacts from allowable activities on conservation priorities in MPAs. While this method has been used to evaluate the ability of a set of established MPAs to contribute to ecological conservation targets, its application to MPA site-selection is novel. This method is based on global meta-analysis of empirical data on the effectiveness of MPAs on protecting fish density and biomass (Sciberras et al. 2013). That the scores are based on empirical data from MPA implementation is a strength, but the studies were done in tropical and temperate systems outside of BC, which introduces uncertainty. In addition, there is relatively high variability around the effectiveness scores (Ban et al. 2014) and uncertainty associated with applying the scores to a wide variety of conservation priorities in the NSB, as the meta-analysis that provides the foundation is fish-specific. However, a number of empirical studies, reviews, and meta-analyses of MPA effectiveness indicate that other taxonomic groups show positive responses to MPA protection (Lester and Halpern 2008; Lester et al. 2009; Micheli et al. 2012; Edgar et al. 2014) especially when well-enforced (Gill et al. 2017). Therefore, effectiveness scores remain an appropriate approach that is pragmatic and well-supported by theoretical and empirical evidence.

One proposed alternative to assigning effectiveness scores to protection levels is to identify a set of protection levels that can be "counted" as contributing to the MPA network. This threshold- based approach has been applied in the California MLPA planning process (Saarman et al. 2013). The Science Advisory Team identified the different activities associated with the different levels of protection in their framework and assigned each MPA a level of protection. The Science Advisory Team then worked with the Task Force (which included government, scientists, and stakeholders) to determine which levels of protection were considered sufficient to contribute towards the MLPA's conservation goals (e.g., very high, high, moderate-high). Only MPAs with these protection levels were included in the evaluation of how a proposed network configuration met the science-based design guidelines in the process (e.g., size, spacing, replication guidelines). This approach could be applied in the NSB as an alternative to the effectiveness scores, where only MPAs with sufficient protection levels would count towards meeting the ecological conservation targets. However, this threshold-based approach would be less inclusive and not all MPAs would count toward ecological conservation targets, whereas the risk-based approach allows the contribution of MPAs with lower levels of protection to still be counted.

9.3. ADDITIONAL CONSIDERATIONS

Many aspects of the effectiveness of the MPA network cannot be fully assessed until site selection analyses are completed and potential MPAs identified. Connectivity, climate change, and cumulative impacts will be key considerations as planning continues for the MPA network.

9.3.1. Connectivity

Ecological connectivity within MPA networks is important for maintaining biodiversity and resilience in marine ecosystems. Individual MPAs will benefit from one another if they are linked by a flow of dispersing eggs or larvae, migrating juveniles and adults, and/or nutrients and other materials, which will also depend on the management of areas outside of the MPA network. Ecological connectivity is often assessed in post-hoc analyses of MPA network scenarios due to a general lack of guidelines and methods for incorporating connectivity in initial phases of MPA network design. While the primary considerations in MPA design used to date to address connectivity are related to spacing and shape (Green et al. 2014; Carr et al. 2017), there are other approaches that could be used to address four aspects of connectivity that can influence the effectiveness of a network of MPAs. Here we describe these aspects of connectivity and potential ways to address them in future network design.

Genetic connectivity

Genetic connectivity refers to the movement of genes among distinct populations of a single species. Genetic connectivity affects spatial patterns in the genetic composition and diversity of populations, and therefore influences the ability of species to adapt to environmental change. The degree of genetic connectivity in the marine environment depends upon numerous naturally occurring factors. These include ocean currents, larval behavior, habitat availability, and processes occurring at settlement and recruitment (Selkoe et al. 2016). However, human activities also impact marine genetic connectivity via habitat loss (e.g., van der Meer et al. 2012), fishing pressure (e.g., Munguía-Vega et al. 2015) and climate change (e.g., Gerber et al. 2014). A network of well-connected MPAs, reduces the loss of genetic connectivity across space, but also partially restores connectivity across a degraded system if stressors are addressed. Networks of MPAs can help protect genetic diversity of a species across its entire range. Genetic information for multiple species could be incorporated to protect areas of community-wide genetic diversity by setting targets for different levels of regional genetic variability, if data are available (Beger et al. 2014; Nielsen et al. 2017).

Population connectivity

Population (or demographic) connectivity results from the movement of individuals among patchily distributed “local” or “subpopulations” of a single species in space and time. The movement of individuals among these populations influences the size and structure of local populations and their demographic rates (e.g., birth, death, immigration, emigration), ultimately affecting the dynamics of individual populations. Persistent and productive local populations can act as “sources” within a metapopulation, exporting individuals to replenish less persistent and productive “sink” populations. These source-sink dynamics are important to consider in MPA design as they can influence the resilience of local populations and influence metapopulations. To date, most processes have addressed population connectivity on a post-hoc basis. However, if available, information on productivity, adult migration, ontogenetic migration, and larval dispersal could be used to identify areas important for connectivity and these areas could be incorporated into the network design scenarios (e.g., D'Aloia et al. 2017; Friesen et al. 2019).

Community connectivity

Community connectivity results from the movement of multiple species between distinct ecological communities (i.e., the assemblage of species that co-occur and interact with one another in a particular habitat). It influences the structure (i.e., the identity, relative abundance, and diversity of species and species groups) and function (e.g., productivity, resilience to anthropogenic disturbance) of these communities. Because different species move over different distances, MPA network design should consider size and spacing that can accommodate these differences to protect ecological communities and meet biodiversity objectives (Gaines et al. 2010).

Ecosystem connectivity

Ecosystem connectivity refers to the movement of multiple species among distinct ecological communities, as well as the movement of chemicals (e.g., nutrients, pollutants), energy (e.g., carbon-rich organic materials), and physical materials (e.g., sediments, debris). Protecting ecosystem connectivity implies maintaining ecologically important functional relationships among ecosystems in the design of MPA networks. One approach is to protect within a single MPA or a network of MPAs different types of ecosystems that function as nurseries for a given species or set of species and those ecosystems to which juveniles or adults migrate, including foraging and spawning habitats. Design guidelines suggest including MPAs that stretch from the nearshore to the offshore in order to incorporate multiple habitat types (Lieberknecht et al. 2016). Identifying and protecting ecosystems that are exporters of nutrients or other physical materials can also address ecosystem connectivity in the MPA network. Methods for evaluating and incorporating ecosystem connectivity into MPA network design are currently being developed for the NSB[12]. Using landscape ecology metrics (e.g., He et al. 2000; Turner et al. 2001) the degree of benthic structural connectivity among benthic habitat maps or ecological units (e.g., Rubidge et al. 2016) could be identified and maps of habitat linkages produced.

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[12] Optimization of MPA selection based on spatial connectivity and on metapopulation and metacommunity dynamics

These could then be integrated into network design scenarios that consider the spatial configuration, connectivity, and aggregation of habitat classes or ecological units.

9.3.2. Cumulative impacts

Although MPAs can decrease human impacts to marine ecosystems within their boundaries (Lester et al. 2009; Aburto-Oropeza et al. 2011), most MPAs remain exposed to other activities and their associated stressors (Hazen et al. 2013; Maxwell et al. 2013; Mach et al. 2017). This can lead to cumulative impacts from multiple stressors that arise from land- and ocean-based activities, or from climate change. For example, MPAs subject to land-based stressors such as nutrient runoff from agriculture or pollution from urban centres also may be exposed to global change stressors, such as ocean acidification or increased UV radiation (Mach et al. 2017). This can lead to synergistic impacts on coastal ecosystems (e.g., Peachey 2005; Russell et al. 2009) and potentially alter ecosystem function and resilience, thus compromising the ability of MPAs to meet their objectives (Gaines et al. 2010).

To meet the full ranges of objectives from MPA networks, managers must mitigate impacts from multiple stressors, both within the MPA and the surrounding ecosystems (Álvarez-Romero et al. 2011; Mach et al. 2017). To do this, managers will need to identify where cumulative impacts may occur and quantify cumulative impacts (or the risk to species from these impacts) across the MPA network, identify the greatest impacts to conservation priorities within MPAs, and specify which of these impacts co-occur within MPAs (Halpern et al. 2009; Teck et al. 2010; Álvarez-Romero et al. 2011; Mach et al. 2017). However, although cumulative impacts from multiple stressors may compromise the effectiveness of MPAs, MPA networks remain one of the few management tools available to address broad-scale environmental impacts, especially climate change (Micheli et al. 2012; Micheli and Niccolini 2013; Huijbers et al. 2015).

Our approach for calculating the potential effectiveness of MPA networks in meeting recommended ecological conservation targets considers cumulative impacts. However, additional work should be done to ensure that MPAs are located in areas that are not exposed to multiple stressors currently or where stressors will be reduced after the MPA is established. For example, MPAs in the nearshore could be established near terrestrial protected areas to minimize the impacts from land-based stressors. This may also contribute to resilience of ecosystems within MPAs to climate stressors, as land-based stressors often exacerbate the effects of climate stressors. For example, increasing freshwater runoff might increase ocean acidification rates (Strong et al. 2014). A more complete analysis of the potential impacts to MPAs from a suite of stressors could be done using cumulative impact mapping for BC (e.g., Clarke Murray et al. 2015), similar to what has been done in California (Mach et al. 2017).

9.3.3. Climate change

Climate change is a pervasive and increasing threat to marine ecosystems. A suite of stressors associated with a changing climate, including warming sea temperatures, ocean acidification, shifting oxygen minimum zones, and sea level rise, can act singly and cumulatively leading to complex and unprecedented impacts to local and regional marine communities (Kroeker et al. 2010; Doney et al. 2012; Kroeker et al. 2013; Pörtner et al. 2014). The ocean is not changing uniformly in response to these global scale stressors, and the changes will affect different species, habitats, and ecosystems in a variety of ways (Harley et al. 2006; Pörtner et al. 2014). For example, rising temperatures and changes in oxygenation may lead to shifts in species ranges. This could result in the range of some protected species shifting beyond the static boundaries of MPAs, undermining their efficacy (Maxwell et al. 2013). In addition to range shifts, climate change is expected to affect body sizes of fishes (Cheung et al. 2013), leading to shifts in species interactions and community structure. Ocean acidification and hypoxia may also lead to increased vulnerability and mortality of species (Strong et al. 2014). This provides both a challenge and an opportunity to identify species-habitat linkages and incorporate climate change considerations in MPA network planning.

While MPAs cannot prevent climate change from progressing, a coherent network of MPAs that protects biodiversity can protect important carbon sinks, buffer habitats and species from climate change and protect ecosystem resilience (Micheli et al. 2012; Green et al. 2014; Carr et al. 2017). As such, the establishment of MPAs is one of the few management tools available to address the effects of broad-scale environmental impacts (Gaines et al. 2010). In addition to protecting sufficient space and fostering MPA connectivity (Magris et al. 2014), climate change considerations can be addressed specifically in conservation planning by identifying areas in the ocean that are have more stable environmental conditions (i.e., climate refugia) (Keppel et al. 2012) and/or areas that will become important as species and communities in response to environmental change. Therefore, protecting some more isolated areas that contain locally adapted populations or potential sources of future adaptation may be an important consideration in MPA design (Edgar et al. 2014) as can protecting areas that experience extreme conditions or degradation as these areas may contain disturbance-tolerant species and habitats better able to adapt to future environmental conditions (Côté and Darling 2010; Green et al. 2014). Climate refugia, included with the area-based conservation priorities, refer to places that may be less susceptible to expected future climate change impacts, including extreme anomalous conditions (West and Salm 2003; Magris et al. 2015; Ban et al. 2016). For example, in temperate ecosystems seamounts may act as potential refugia from ocean acidification for stony corals (Tittensor et al. 2010). Because climate change is occurring faster than many species can adapt, protecting areas that are experiencing less extreme climactic change may promote species' persistence or recovery (Heller and Zavaleta 2009; Game et al. 2011). Furthermore, as sea level continues to rise, some areas may become important estuarine habitats for species. If modeling studies identify these areas, they could be incorporated into terrestrial and marine protected area planning. Areas of climate refugia are not yet well-known in Canada due to high levels of uncertainty (Ban et al. 2016), providing an opportunity for further research and modeling efforts.

10. NEXT STEPS

We have provided a number of recommendations for ecological design strategies that can inform the next phase of NSB MPA network planning. While these recommendations provide more specific operational guidance for implementing some of the MPA network ecological design guidelines, they are not meant to supersede them. Indeed, several of the ecological design guidelines have not been addressed here (Appendix 2). Thus, our recommendations should be taken together with the full suite of design guidelines to inform the design scenarios phase of MPA network planning in the NSB.

The design strategies, the features of importance for each ecological conservation priority, and the currently available spatial datasets are all important components of the design scenarios, which will identify priority areas for conservation and options for possible MPA network configurations in the NSB. The design scenarios will also be informed by the cultural conservation priorities and socioeconomic values and work is now underway to develop detailed spatial information for each feature type that the analyses will require.

Once the spatial features have been compiled for each conservation priority, they will be provided to stakeholders to review, groundtruth, and provide advice on newer or more complete datasets that may be available. Spatial features will also be incorporated into gap analyses to calculate how existing MPAs and other conservation areas may contribute to the ecological conservation targets.

Using the Marxan or Marxan with Zones decision support tool (Appendix 3), the design scenarios will use the spatial features and ecological conservation targets in site selection analyses to identify areas of high conservation value that maximize potential benefits and minimize potential costs. Sensitivity analyses will be performed as part of Marxan calibration to test the influence of spatial features and target ranges. Further analyses will be performed using ecological conservation priorities alone, ecological and cultural conservation priorities, socioeconomic values alone, as well as analyses incorporating the ecological and cultural conservation priorities while attempting to avoid areas of importance for socioeconomic values. These analyses will be used as one input into the identification of potential MPA network design scenarios. As they are developed, draft design scenarios will be evaluated with respect to representation, replication, size, spacing, shape, and protection level recommendations as well as social, economic, cultural, and management considerations. This stage of the process will be iterative and informed by engagement with experts and stakeholders, resulting in modification of the location of network sites, associated boundaries, proposed management measures, and protection levels.

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APPENDIX 1: MPA NETWORK DESIGN PRINCIPLES

Table 21. MPA network design principles for the NSB.

Ecological Network Design Principles	
Principle 1. Include the full range of biodiversity present in Pacific Canada	
Representation	Represent each habitat types in the overall MPA network. For example, rocky reef habitat, eelgrass meadow, intertidal mudflat, persistent gyres or eddies, or representation within a hierarchy of ecological scales (e.g., representation of rocky reefs within a broader biogeographic classification).
Replication	The degree of replication should be assessed at a bioregional (or finer) scale(s) in an effort to safeguard against catastrophic events or disturbances and to build resilience in the overall MPA network.
Principle 2. Ensure ecologically and biologically significant areas (EBSAs) are incorporated	
Protection of Unique or Vulnerable Habitats	Design networks to include biophysically special and unique places, and areas of high biodiversity and productivity.
Protection of Foraging or Breeding Grounds	Design networks to include important areas for breeding, feeding and high aggregation.
Protection of Source Populations	Design networks to include important sources of reproduction (e.g., nurseries, spawning areas, egg sources, etc.)
Principle 3. Ensure ecological linkages	
Connectivity	To the extent possible, consider the dispersal dynamics, the home range(s) of marine organisms, and the distribution of marine habitats, over space and time, especially when assessing replicates and when determining the spacing of individual MPA sites within the network.
Principle 4. Maintain long-term protection	
The benefits of MPA networks may be realized in a few seasons or it may take several decades. Therefore, management measures should be implemented on a permanent basis to better realize the benefits of protection.	
Principle 5. Ensure maximum contribution of individual MPAs	
Size	Design individual MPAs to include sufficient area to meet the related site objectives and effectively contribute to network goals and bioregional objectives over the long term.
Spacing	Design MPA networks to reflect the spacing of habitats, cover the geographic range of habitats, and facilitate ecological connectivity between sites. Spacing should be assessed at multiple scales (i.e., bioregionally and coast wide) to best facilitate connectivity.
Shape	Design the shape of individual MPAs to the degree possible to follow ecological boundaries, avoid fragmenting cohesive habitats and facilitate surveillance and enforcement.

Ecological Network Design Principles
Social, Economic and Cultural Network Design Principles
Principle 6. Recognize and consider the full range of uses, activities and values supported by marine environments.
Principle 7. Maximize the positive.
Principle 8. Minimize the negative.
Principle 9. Enhance management effectiveness and compliance to maximize benefits and minimize costs.
General Operating Principles
Principle 10. Work with people.
Principle 11. Respect First Nations' treaties, title, rights, aspirations, and world-view.
Principle 12. Foster ecosystem-based management.
Principle 13. Apply adaptive management.
Principle 14. Build on existing MPAs, other management tools and marine planning initiatives.
Principle 15. Include a full range of protection levels.
Principle 16. Take a precautionary approach.

APPENDIX 2: ECOLOGICAL DESIGN GUIDELINES

Table 22. Draft MPATT ecological design guidelines and related design strategies developed by MPATT using guidance provided by PacMara (Lieberknecht et al. 2016) and incorporating feedback from stakeholders and MPATT partners. CPs: conservation priorities; EBSAs: Ecologically and Biologically Significant Areas; IAs: Important Areas.

Primary Guideline	Secondary Guideline	Design Strategy
1. Represent and replicate targets for each class in at least one broad-scale comprehensive classification system across the planning area.	1.1. Use species-habitat classifications as biodiversity proxies, as appropriate.	Coarse-filter Targets
	1.2. Use more than one comprehensive classification system at the same time, if possible, integrating systems as necessary.	Coarse-filter Targets
2. Identify a list of CPs and set representation and replication targets using criteria that support the network goals and objectives.	2.1. Include best available spatial information for identified CPs that can be geographically demarcated in network design.	Spatial Features and Datasets
	2.2. Consider whether the important ecological qualities of CPs will benefit from, or be enhanced by, spatial protection measures in deciding whether or not to target individual CPs (in whole or in part) in the MPA network.	Fine-filter Targets, Spatial Features and Datasets
	2.3. Replicate CPs across classes in the chosen classification system(s), at multiple scales.	Replication
	2.4. Vary representation targets for CPs widely (<5–100%) based on rarity, vulnerability, importance, levels of data uncertainty and MPA protection levels applied.	Fine-filter Targets
	2.5. Apply lower representation targets for broad and widespread habitat classes, and higher targets for less widespread and more narrowly defined ones.	Coarse-filter Targets
	2.6. Apply higher representation targets for rare, threatened and endangered features and, where possible, apply a higher number of replicates than for common features.	Fine-filter Targets
	2.7. Increase representational targets when applying lower MPA protection levels as warranted and vice versa.	Protection Levels
	2.8. Consider patch size and level of protection in determining replication targets.	Replication
	2.9. Ensure inclusion (in whole or in part) of EBSAs that are CPs within the NSB MPA network.	Fine-filter Targets, Spatial Features and Datasets
3. Ensure MPAs with varying levels of protection are well-distributed throughout the planning region, and in both nearshore and offshore areas.	3.1. Apply size and spacing such that inshore sites can be smaller and closer together than offshore sites.	Size, Spacing
	3.2. Capture inshore-offshore gradients by orienting series of sites extending offshore from the shoreline/nearshore.	Not addressed explicitly here
	3.3. Measure distances between sites as the fish swims, not as the crow flies, when applying the spacing guidelines in confined fjords and passages.	Not addressed explicitly here
	3.4. Consider expected effects of climate change on habitats and species in determining replication and representation of CPs and distribution of MPAs to foster ecological resilience.	Not addressed explicitly here

Primary Guideline	Secondary Guideline	Design Strategy
4. Vary MPA size and shape based on site location, protection level, and conservation objectives.	4.1. Apply minimum size range of 5–150 km^2 for highly protected sites, with a preference for a minimum size of 50 km^2.	Size
	4.2. Ensure sites with lower protection levels are larger than highly protected sites, with minimum size range of 10–300 km^2 for IUCN category IV sites and minimum size range of 20–600 km^2 for IUCN category VI sites.	Protection Levels
	4.3. Surround areas of high protection with a buffer area of lower protection, where appropriate.	Not addressed explicitly here
	4.4. Consider differences in predominant geography, oceanography and landscape scale when determining MPA size and spacing.	Size, Spacing
	4.5. Apply a minimum patch size of 0.25 km^2 (25 ha) for inclusion of fine-scale habitats (median habitat size <250 km^2) in the MPA network.	Replication
	4.6. Apply a minimum patch size of 2.5 km^2 (250 ha) for inclusion of coarse-scale habitats (median habitat size > 250 km^2) in the MPA network.	Coarse-filter Targets
	4.7. Protect discrete features and habitats and locally dominant ecological processes in their entirety, and not fragmented.	Not addressed explicitly here
	4.8. Reflect known species' behaviours, such as aggregating, feeding or breeding, when determining MPA shape.	Spatial Features and Datasets
	4.9. Minimize edge-to-area ratio in MPA shape to maximize compactness, where practical.	Not addressed explicitly here

APPENDIX 2 REFERENCES

Lieberknecht, L.M., Ardron, J.A., Ban, N.C., Bennet, N.J., Eckert, L., Hooper, T.E.J., and Robinson, C.L.K. 2016. Recommended guidelines for applying Canada-BC Marine Protected Area Network Principles in Canada's Northern Shelf Bioregion: Principles 1,2,3,5,6,7,8,9,11,14 and 15. Report produced by PacMARA for the British Columbia Marine Protected Areas Technical Team (MPATT).

APPENDIX 3: MARXAN AND MARXAN WITH ZONES

OVERVIEW:

- Marxan is the most widely used decision support tool for systematic conservation planning.
- Marxan has supported marine spatial planning exercises across Canada: e.g. Northern Shelf Bioregion (MaPP[13]), West Coast Vancouver Island (WCA[14]), BC coast (BCMCA[15]), Scotian Shelf Bioregion (DFO).
- Marxan is used to identify areas that will meet conservation objectives while minimizing the impact on human interests in a transparent and repeatable way.
- Marxan facilitates stakeholder engagement and the evaluation of trade-offs by creating multiple possible MPA network configurations that meet ecological, cultural, and socioeconomic needs.

MARXAN PROCESS:

- Define goals and objectives for the network.
- Identify conservation features and corresponding spatial data.
- Set targets for each feature (e.g. 30% of eelgrass beds; 20% of salmon spawning streams).
- Divide study area into planning units (e.g. 1km x 1km polygons) and calculate the amount of each feature in each unit.
- Determine scenarios:
  - Identify the most spatially efficient solutions.
  - Identify solutions that minimize impacts to human users.
  - Assess the contribution of existing and proposed MPAs to the conservation objectives and identify additional areas that can help meet the targets.
- Run Marxan - using the input variables, Marxan tests millions of combinations of planning units to identify a suite of solutions that meet the targets with the lowest possible costs (Figure 18).

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[13] MaPP – Marine Plan Partnership for the North Pacific Coast

[14] WCA – West Coast Aquatic

[15] BCMCA – British Columbia Marine Conservation Analysis

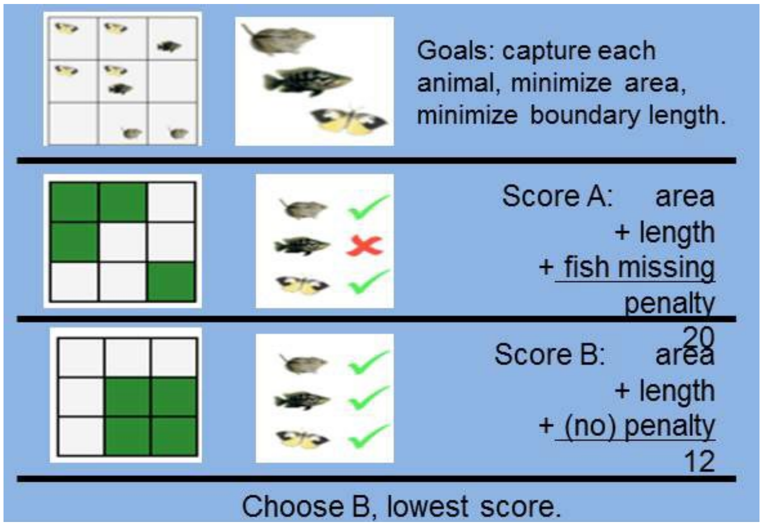

Figure 18. Example Marxan workflow (CLUZ website, adapted by the BCMCA).

- Marxan outputs (Figure 19):
  - A suite of example network configurations that meet targets with lowest possible costs.
  - Selection frequency - Marxan identifies how often each planning unit is chosen in the example solutions, helping users identify the importance of each area for meeting conservation objectives while minimizing economic, social, or cultural impacts.

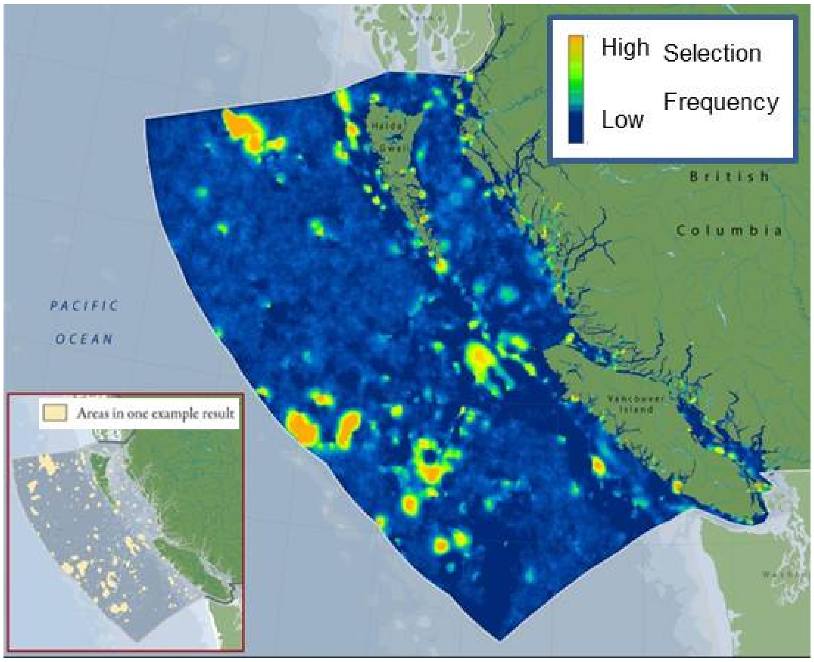

Figure 19. Marxan outputs from an example analysis, not intended for planning purposes (BCMCA).

MARXAN WITH ZONES:

- An update to the Marxan software that allows you to set zones and define the features desired, and activities allowed, within each zone.

HOW OUTPUTS WILL BE USED:

- Marxan analyses will be used to inform network design by MPATT (the software cannot incorporate all information needed to meet objectives)
- The heatmaps representing selection frequency will be combined with spatial information not suitable for Marxan (e.g., connectivity, temporal, or cultural data) and used to guide placement of MPAs.

FURTHER RESOURCES:

- Official Marxan site
- Marxan overview (PacMara)
- Marxan analyses for the Canadian Pacific (BCMCA)

APPENDIX 4: IUCN PROTECTION LEVELS

Table 23. Description of IUCN protected area categories (Ban et al. 2014; adapted from Day et al. 2012).

Category	Description	Primary Objective	Other relevant objectives or notes
Ia.	Strictly protected areas set aside to protect biodiversity or biodiversity proxies (e.g., geomorphological features, oceanographic processes), where human visitation, use and impacts are strictly controlled and limited to ensure protection of conservation values. These areas may serve as indispensable reference areas for scientific research and monitoring.	To conserve regionally, nationally, or globally outstanding ecosystems, species (occurrences or aggregations) and/or other biophysical features, formed mostly or entirely by non-human forces that will be degraded or destroyed when subjected to al but very light human impact	Conserve cultural and spiritual values associated with nature. Managed for relatively low visitation by humans. No resource extraction allowed.
Ib	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation; protected and managed to preserve their natural condition.	To protect the long-term ecological integrity of natural areas that are undisturbed by significant human activity, free of modern infrastructure and where natural forces and processes predominate, so that current and future generations have the opportunity to experience such areas.	Enable Indigenous communities to maintain their traditional wilderness-based lifestyle and customs. First Nations traditional harvesting and collection for scientific research allowed.
II	Large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational, and visitor opportunities	To protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation.	Take into account the needs of Indigenous people and local communities, including subsistence resource use, insofar as these will not adversely affect the primary management objective; support compatible economic development, mostly through recreation and tourism, that can contribute to local communities. Collection for scientific research allowed.
III	Protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.	To protect specific outstanding natural features and their associated biodiversity and habitats.	To conserve traditional spiritual and cultural values of the site. First Nations traditional harvesting and collection for scientific research allowed.

Category	Description	Primary Objective	Other relevant objectives or notes
IV	Aim to protect particular species or habitats and management reflects this priority. Many category IV protected areas need regular, active interventions to address this requirements of a particular species or to maintain habitats.	To maintain, conserve, and restore species and habitats.	Not strictly protected from human use. Some sustainable resource extraction allowed, as long as it is compatible with conservation objectives of the MPA.
V	Areas where the interaction of people and nature over time has produced distinct character with significant ecological, biological, cultural, and scenic value; safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.	To protect and sustain important landscapes/seascapes and the associated nature conservation and other values created by interactions with humans through traditional management practices.	To maintain a balanced interaction of nature and culture through the protection of landscape and/or seascape and associated traditional management approaches, societies, cultures, and spiritual values. Sustainable resource extraction allowed, as long as it is compatible with conservation objectives of the MPA.
VI	Conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. These areas are generally large, with most of the area in natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.	Protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial.	Promote sustainable use of natural resources, considering ecological, economic, and social dimensions; integrates other cultural approaches, belief systems and world-veiws within a range of social and economic approaches to nature conservation. Sustainable resource extraction allowed, as long as it is compatible with conservation objectives of the MPA.

APPENDIX 4 REFERENCES

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APPENDIX 5: MAPS OF COARSE-FILTER FEATURES

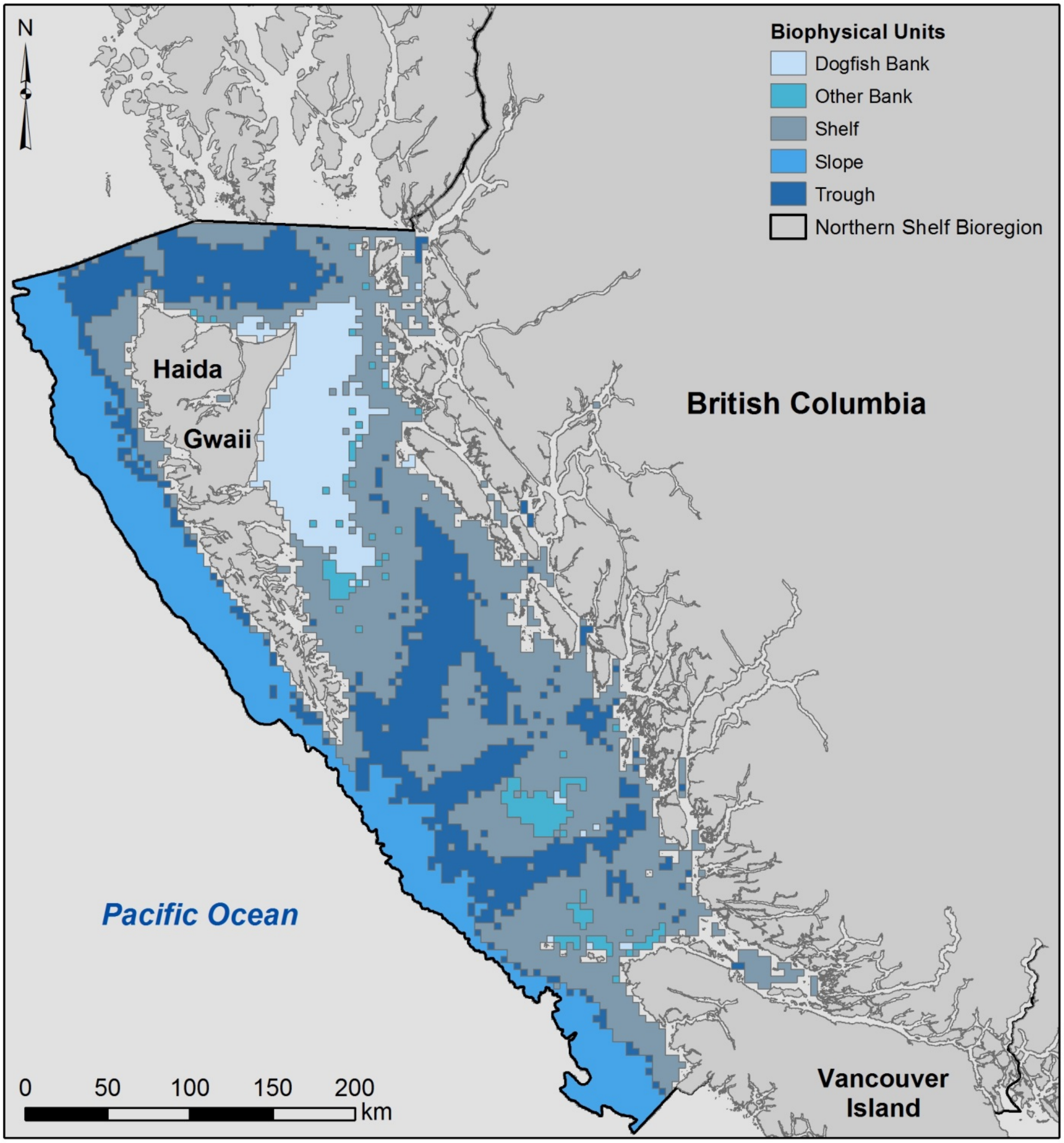

Figure 20. Biophysical units from the Pacific Marine Ecological Classification System (PMECS; Rubidge et al. 2016).

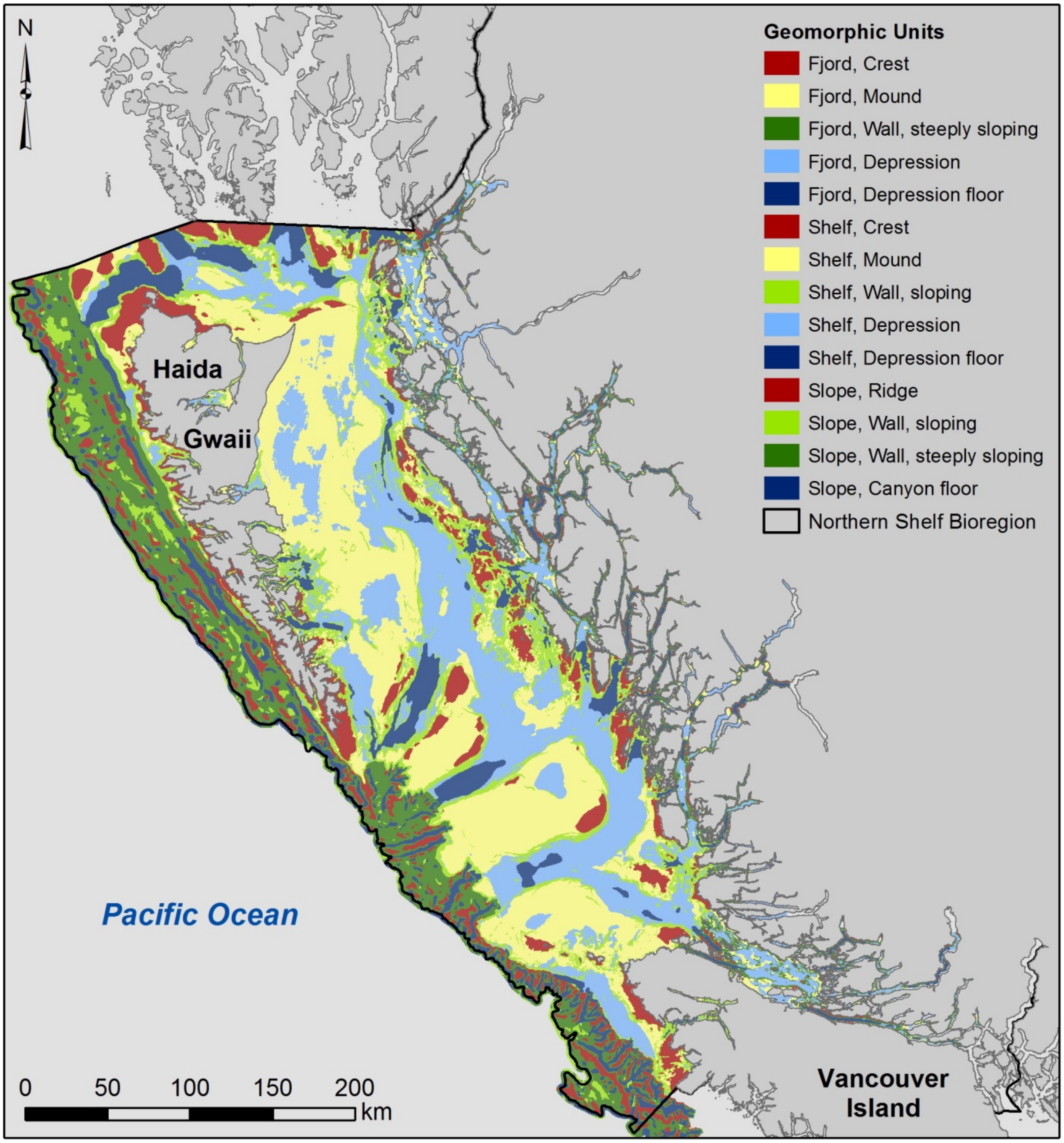

Figure 21. Geomorphic units from the Pacific Marine Ecological Classification System (PMECS; Rubidge et al. 2016).

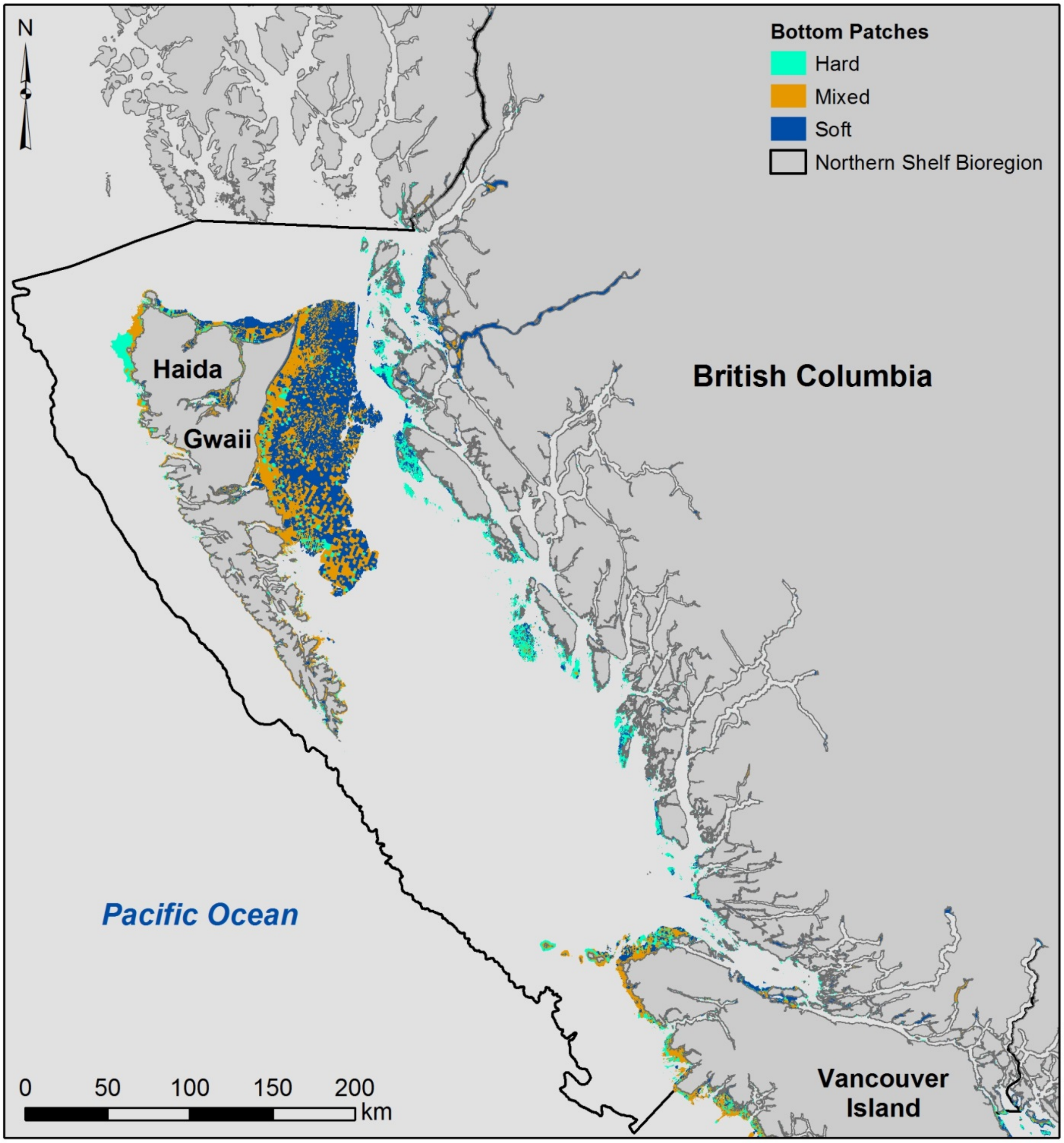

Figure 22. Bottom patches included in the Pacific Marine Ecological Classification System (PMECS; Rubidge et al. 2016) (Gregr et al. 2013).

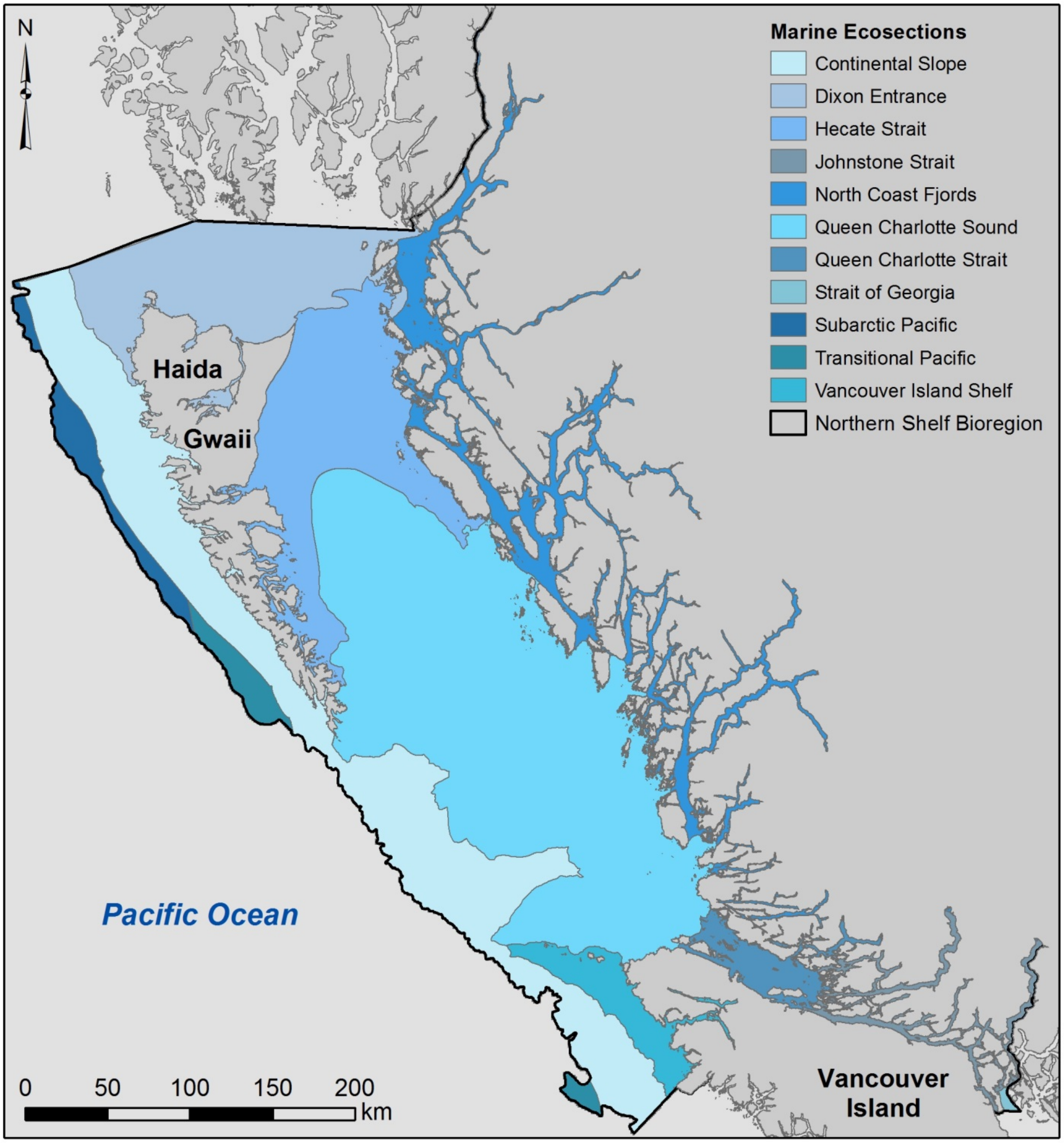

Figure 23. Marine ecosections from the British Columbia Marine Ecological Classification (BCMEC).

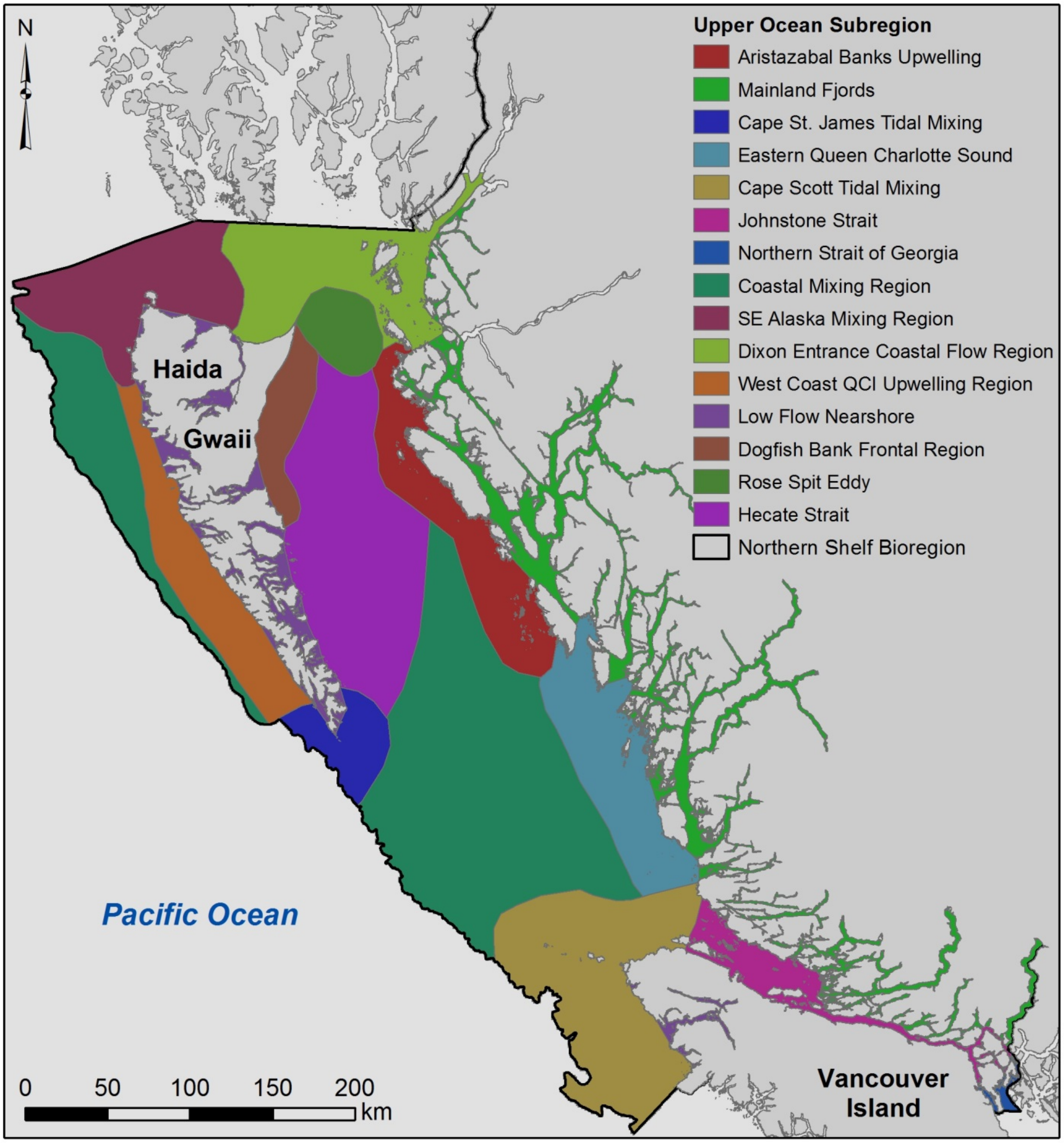

Figure 24. Upper Ocean Subregions developed by Parks Canada.

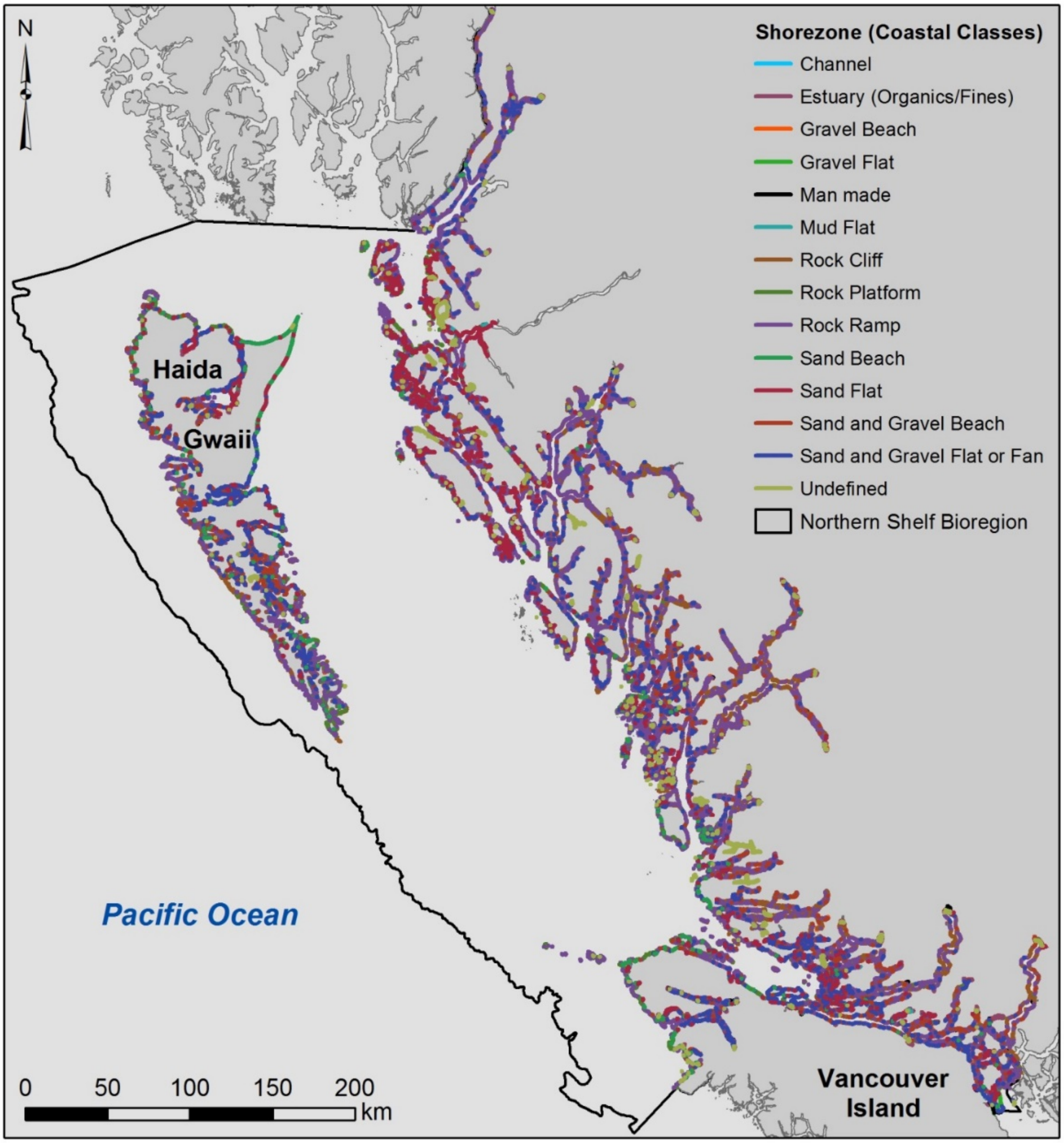

Figure 25. Shorezone coastal classes compiled by the Province of British Columbia.

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APPENDIX 6: ECOLOGICAL CONSERVATION TARGET RANGES USED IN THE LITERATURE

Table 24. Ecological conservation target ranges used in the literature to represent species and habitat features in Marxan analyses designed to identify potential MPA network configurations. As recommended by best practices (Lieberknecht et al. 2010), varying target ranges are often applied so we show the low and high end of the target ranges used in each study.

Reference	Location	Lowest Targets Used	Highest Targets Used	Features Targeted in Analysis	Approach Used to Set Targets
Ban et al. (2013)	BC (coastwide)	10–30%	20–60%	Marine and coastal species and habitats	Heuristic approach
MaPP[16]	BC (NSB)	10% 30%	20% 60%	Marine and coastal species and habitats	Heuristic approach
Government of Canada and Council of the Haida Nation (2010)	BC (Gwaii Haanas)	30%	60%	Marine and costal species and habitats	Expert opinion
Hazlitt et al. (2010)	BC (marine/ terrestrial)	30%	70%	Marbled Murrelet	Expert opinion; Qualitative analysis
DFO (2018)	Scotian Shelf	10–20%	80-100%	Marine and coastal species and habitats	Heuristic approach
Vander Schaaf et al. (2013)	Oregon Coast	30%	50%	Marine and coastal species and habitats	Expert opinion
McGowan et al. (2013)	California	10%	50%	Seabird foraging habitats	Expert opinion
Natural England (2009)	United Kingdom	10%	20%	Marine and coastal species and habitats	Policy-driven (OSPAR)
Giakoumi et al. (2012)	Mediterranean	20–60%	60–80%	Marine and coastal species and habitats	Policy-driven (EU directives); Expert opinion; Literature review
Fraschetti et al. (2009)	Mediterranean	10–30%	30–50%	Nearshore habitats	Expert opinion; Literature review
IUCN (2003)	Global	20%	30%	Marine and coastal habitats	Policy-driven (5th World Parks Congress)

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[16] BCMCA 2013. Marxan analyses for the Marine Planning Partnership (MaPP): Summary report of initial scenarios. Technical document prepared for the MaPP Science Advisory Committee. Unpublished.

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APPENDIX 7: DESIGN STRATEGIES EXPERT REVIEW PARTICIPANTS

Table 25. Scientists who provided expert feedback on the MPATT ecological conservation targets.

Conservation Priority Group	Expert Reviewers	Affiliation
Marine Birds	Louise Blight	Government of BC
	Doug Bertram	Environment Canada (Canadian Wildlife Service)
	Sean Boyd	
	Mark Drever	
	Mark Hipfner	
	Kathleen Moore	
	Ken Morgan	
	Patrick O’Hara	
	Laurie Wilson	
Marine and Anadromous Fishes	Doug Biffard	Government of BC
	Lais Chaves	Council of the Haida Nation
	Brendan Connors	Fisheries and Oceans Canada
	Dana Haggarty	
	Jim Irvine	
	Rob Kronlund	
	Lynn Lee	Parks Canada
Marine Invertebrates	Doug Biffard	Government of BC
	Anya Dunham	Fisheries and Oceans Canada
	Jason Dunham	
	Tammy Norgard	
	Lynn Lee	Parks Canada
Marine Zooplankton	Doug Biffard	Government of BC
	Moira Galbraith	Fisheries and Oceans Canada
	Ian Perry	
Marine Algae/Plants/ Phytoplankton	Doug Biffard	Government of BC
	Angelica Pena	Fisheries and Oceans Canada
	Lynn Lee	Parks Canada
Marine Mammals	Charlie Short	Government of BC
	Sheena Majewski	Fisheries and Oceans Canada
	Brianna Wright	
Area-based Features	Doug Biffard	Government of BC
	Charlie Short	
	Kim Conway	Natural Resources Canada

APPENDIX 8: ECOLOGICAL CONSERVATION TARGET SCORES AND EXPERT RECOMMENDATIONS FOR FINE-FILTER CONSERVATION PRIORITIES

Table 26. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the species-based conservation priorities (CPs; fishes and elasmobranchs).

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Flatfish	*Atheresthes stomias*	Arrowtooth	2	2	3	med	2	–	1	Low; Vulnerability score based only on body size; doesn't take into consideration that IFMP indicates low vulnerability and effective fisheries management.	1	Low or lower limit of medium; DFO (2015) - Arrowtooth flounder stock for the entire coast of B.C estimate of SB (2015) that was approximately 2.5 times greater than estimated SB (MSY). Fishing mortality also very low concern	2	–	1.5	3.91	med	20-40%
	Microstomus pacificus	Dover Sole	2	2	2	low	2	–	2	–	–	–	2	–	2.0	3.46	low	10-20%
	Hippoglossus stenolepis	Pacific Halibut	2	2	3	med	2	–	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Eopsetta jordani	Petrale Sole	2	2	2	low	2	–	2	–	–	–	2	–	2.0	3.46	low	10-20%
Flatfish	*Glyptocephalus zachirus*	Rex Sole	2	2	2	low	2	–	2	–	–	–	2	–	2.0	3.46	low	10-20%
	Lepidopsetta bilineata	Rock Sole	2	2	2	low	2	–	2	–	–	–	2	–	2.0	3.46	low	10-20%
Forage Fish	*Mallotus villosus*	Capelin	2	1	3	low	2	–	3	Increase targets if possible - seek to identify areas that are possible CC refugia and give high priority for protections. Capelin may be a CC transition species	–	–	2	–	2.3	3.93	med	20-40%

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[17] While the individual reviewers may vary for the different species assessed, no more than four species experts reviewed any species. Not all reviewers provided additional rationales to accompany their recommended target score.

[18] Target class and range were determined for the purposes of this report by splitting the target scores based on quartiles (see Appendix 10).

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Forage Fish	*Thaleichthys pacificus*	Eulachon	2	3	3	high	2	–	2	–	1	Medium	2	–	1.8	4.59	high	40-60%
	Clupea pallasii	Pacific Herring	2	1	3	low	2	–	3	Medium, at least; Although you are following a structured approach my main concern rests on the fact that stocks are not being replenished in Haida Gwaii after a decade of moratorium. And although research showed minimum impact on SOK by fishing, the HG stock, genetically isolated from other stocks, is therefore more vulnerable and should give it more weight	3	Medium; CC (in NSB) and ecological importance. Central Coast and HG stocks are declining. Look at stock assessments for locations - conservation zones.	3	Medium to High; very important forage fish for many species and of high cultural importance; some herring stocks such as Haida Gwaii's east coast are still at low abundances despite no fishery for over a decade; herring may be vulnerable to changing ocean conditions	2.8	4.19	med	20-40%
	Ammodytes hexapterus	Pacific Sand Lance	2	1	3	low	2	–	3	Increase targets - very likely a CC transition species. Will provide forage as other small fish decline due to changing ocean climate	–	–	3	Medium to High; very important forage fish for many species, however little known about important spawning and rearing areas; although targets should be high, not sure if we have sufficiently reliable spatial data to determine where important areas really are	2.7	4.14	med	20-40%
	Sardinops sagax	Pacific Sardine	2	1	2	low	2	Not sure why this species is on the list; they are not a regularly occurring species in the NSB.	2	–	–	–	1	No target; species presence in northern BC depending on warm water masses moving into the area; not a regularly occurring species and hard to define highly variable temporal and spatial habitat	1.7	2.79	low	10-20%
	Hypomesus pretiosus	Surf Smelt	2	1	3	low	2	–	3	Increase targets - another species that needs increased protection as CC;	–	–	2	–	2.3	3.93	med	20-40%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
										drives community re-structuring.								
Groundfish	*Ophiodon elongatus*	Lingcod	2	2	3	med	2	–	2	Rank Kelp Greenling about the same as Lingcod.	–	–	2	–	2.0	4.12	med	20-40%
	Anoplopoma fimbria	Sablefish[19]	2	2	3	med	2	Consider looking at stock assessments to see if they could be downgraded.	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Anarrhichthys ocellatus	Wolf-eel	2	2	2	low	2	–	2	I don't get why this species is considered - probably just because it shows up in the groundfish survey data.	–	–	2	–	2.0	3.46	low	10-20%
Mesopelagic fish	*Stenobrachius leucopsarus*	Northern Lampfish	2	1	3	low	2	I don't get why this species is considered.	2	I don't get why this species is considered - probably just because it shows up in the groundfish survey data. If these species then why not Pacific Saury or Mackerel	–	–	2	–	2.0	3.74	low	10-20%
	Leuroglossus schmidti	Northern Smoothtongue	2	1	3	low	2	I don't get why this species is considered.	2	I don't get why this species is considered - probably just because it shows up in the groundfish survey data.	–	–	2	–	2.0	3.74	low	10-20%
Native Salmonids	*Oncorhynchus tshawytscha*	Chinook Salmon	2	2	3	med	2	–	3	High; 3 different life histories; probably rate them fairly high; rely heavily on estuaries (high vulnerability and some cc)	–	–	3	High; Some chinook populations in more decline than others and many be some areas for killer whale feeding that are most important to protect	2.7	4.48	high	40-60%

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[19] In addition to the four experts that recommended targets for sablefish, as shown in this table, an additional expert review was completed for sablefish after the regional peer review meeting. No target range was suggested, but the feedback 1) highlighted the importance of the existing approach to managing the sablefish fishery in meeting sablefish conservation and fishery objectives and the regular evaluation of stock status via a Management Strategy Evaluation; 2) noted that the stock is considered to lie in the cautious zone under the DFO Fisheries Decision Making Framework Incorporating the Precautionary Approach (DFO 2009); 3) suggested a conservation criteria score of zero would be appropriate given that biomass appears to be increasing; and 4) indicated it was unclear whether spatial management measures at the scale of the NSB would yield detectable conservation outcomes given that sablefish are highly mobile with little genetic differentiation across their range.

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Native Salmonids	*Oncorhynchus keta*	Chum Salmon	2	1	3	low	2	–	3	Medium; least concern of the species; doing incredibly well across the N. Pacific; rely heavily on estuaries (High vulnerability based on estuaries)	–	–	3	Medium; Salmon generally are important with some populations of all species generally at lower abundances than in the past; should be medium to be precautionary	2.7	4.14	med	20-40%
	Oncorhynchus kisutch	Coho Salmon	2	1	3	low	2	–	3	High; highest concern; doing poorly (CC) (populations that migrate through the area)	–	–	3	Medium; Salmon generally are important with some populations of all species generally at lower abundances than in the past; should be medium to be precautionary	2.7	4.14	med	20-40%
	Oncorhynchus clarkii	Cutthroat Trout	2	1	3	low	2	–	3	Medium; small numbers overall and very local populations; don't have extended marine distributions	–	–	2	–	2.3	3.93	med	20-40%
	Salvelinus malma lordi	Dolly Varden	2	2	3	med	2	–	2	Medium; small numbers overall and very local populations; don't have extended marine distributions; vulnerability	–	–	2	–	2.0	4.12	med	20-40%
	Oncorhynchus gorbuscha	Pink Salmon	2	1	3	low	2	–	3	Medium; Depends on odd or even years; odd years are better adapted to warming; using the same habitats; exist in the same watersheds; interact in some ways but are genetically distinct; Haida Gwaii are in transition zone; medium	–	–	3	Medium; Salmon generally are important with some populations of all species generally at lower abundances than in the past; should be medium to be precautionary	2.7	4.14	med	20-40%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Native Salmonids	*Oncorhynchus nerka*	Sockeye Salmon	2	1	3	low	2	–	3	High; highest concern; doing poorly (CC) (populations that migrate through the area)	–	–	3	Medium; Salmon generally are important with some populations of all species generally at lower abundances than in the past; should be medium to be precautionary	2.7	4.14	med	20-40%
	Oncorhynchus mykiss	Steelhead	2	1	3	low	2	–	3	High; highest concern; doing poorly (CC); overall taxonomic species	–	–	2	–	2.3	3.93	med	20-40%
Pelagic Fish	*Thunnus alalunga*	Albacore	2	3	3	high	1	Not sure why this species is on the list; They are highly migratory and we don't know where important areas are so they are not amenable to spatial management.	1	This high target really skews the design offshore - need balance here!!!	–	–	1	No target; Albacore migratory through BC waters and not sure if spatial measures will be effectively particularly since their distribution is based location and duration of warm water masses	1.0	4.36	med	20-40%
	Mola mola	Ocean Sunfish	2	3	2	med	1	No target; migratory through BC waters and not sure if spatial measures will be effectively particularly since their distribution is based location and duration of warm water masses	1	This high target really skews the design offshore - need balance here!!!	–	–	1	No target; same as above	1.0	3.74	low	10-20%
Rockfish	*Sebastes melanops*	Black Rockfish	2	2	2	low	2	–	3	High; Again this low rating dismisses the real need for nearshore/ inshore/ estuary protection.	–	–	3	Medium; overall, likely is a reduced amount of kelp forest habitat, therefore should target higher proportion; potentially also declining even though not listed or assessed	2.7	3.89	med	20-40%
	Sebastes melanostictus	Blackspotted Rockfish	2	3	3	high	1	Medium	1	Low; This high target really skews the design offshore - need balance here!!!	2	–	2	–	1.5	4.50	high	40-60%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
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			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Rockfish	*Sebastes paucispinis*	Bocaccio	2	3	3	high	2	–	2	Agree but need to emphasize protection of the fjord populations as well as the shelf	1	–	2	–	1.8	4.59	high	40-60%
	Sebastes pinniger	Canary Rockfish	2	3	2	med	2	–	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Sebastes nebulosus	China Rockfish	2	2	2	low	3	Medium: Targets through the Rockfish conservation strategy for nearshore are 20% - need to make sure that the lower end of the target range meets this conservation need (Yamanaka and Logan 2010)	3	High: China RKF are nearly gone from the Salish Sea due to overharvest. Will this trend continue up the coast? Need a high target	3	Medium: bottom longline highly threats CP and other species, potentially CPs (Seafood Watch-avoid)	3	Medium: overall, likely is a reduced amount of kelp forest habitat, therefore should target higher proportion; potentially also declining even though not listed or assessed	3.0	4.12	med	20-40%
	Sebastes caurinus	Copper Rockfish	2	2	2	low	2	Medium: Targets through the Rockfish conservation strategy for nearshore are 20% - need to make sure that the lower end of the target range meets this conservation need (Yamanaka and Logan 2010)	3	–	3	Medium: There is no up-to-date stock assessment for copper rockfish. In light of this species' high inherent vulnerability, stock status is scored 'high' concern. Bottom longline highly threats CP and other species, potentially CPs (Seafood Watch-avoid).	3	Medium: overall, likely is a reduced amount of kelp forest habitat, therefore should target higher proportion; potentially also declining even though not listed or assessed	2.8	3.94	med	20-40%
	Sebastes crameri	Darkblotched Rockfish	2	3	2	med	2	No change but suggest that look at Stock assessment	2	if other shelf RKF are reranked lower	3	High: Darkblotched rockfish are listed as “Special Concern” by COSEWIC (Appendix D, COSEWIC 2009). While a recent summary of available information is available (Haigh and Starr 2008), there is no assessment of the status of the stock	2	–	2.3	4.25	med	20-40%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Rockfish	*Sebastes elongatus*	Greenstriped Rockfish	2	2	2	low	2	–	2	–	2	–	3	Medium: rockfish and thornyheads have inherently vulnerable life histories and for most species, there is little information available on their stock status and distribution, therefore they should all be at least medium to be precautionary	2.3	3.61	low	10-20%
	Sebastolobus altivelis	Longspine Thornyhead	2	3	2	med	2	Low: look at stock assessments which likely indicate not vulnerable; Important areas not known and widespread distribution suggests lower targets warranted	2	if other shelf species are reranked lower	1	–	2	–	1.8	4.01	med	20-40%
	Sebastes alutus	Pacific Ocean Perch	2	2	2	low	2	–	2	–	2	–	3	Medium: same as for greenstriped rockfish	2.3	3.61	low	10-20%
	Sebastes maliger	Quillback Rockfish	2	3	2	med	2	–	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Sebastes proriger	Redstripe Rockfish	2	2	2	low	2	–	2	–	3	Medium: bottom longline highly threats CP and other species, potentially CPs (Seafood Watch-avoid)	3	Medium: same as for greenstriped rockfish	2.5	3.77	med	20-40%
	Sebastes helvomaculatus	Rosethorn Rockfish	2	2	2	low	2	–	2	–	2	–	3	Medium: same as for greenstriped rockfish	2.3	3.61	low	10-20%
	Sebastes aleutianus	Rougheye Rockfish	2	3	3	high	1	Medium	1	Low: Another shelf/offshore species given too high a priority - skewing the design. Re-rank the target down	–	–	2	–	1.3	4.45	high	40-60%
	Sebastes borealis	Shortraker Rockfish	2	2	3	med	2	–	2	–	–	–	2	–	2.0	4.12	med	20-40%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Rockfish	*Sebastolobus alascanus*	Shortspine Thornyhead	2	3	2	med	1	Low: look at stock assessments which likely indicate not vulnerable; Important areas not known and widespread distribution suggests lower targets warranted	2	–	–	–	2	–	1.7	3.97	med	20-40%
	Sebastes brevispinis	Silvergray Rockfish	2	2	2	low	2	–	2	–	–	–	3	Medium: rockfish and thornyheads have inherently vulnerable life histories and for most species, there is little information available on their stock status and distribution, therefore they should all be at least medium to be precautionary	2.3	3.67	low	10-20%
	Sebastes nigrocinctus	Tiger Rockfish	2	2	2	low	3	Medium: Targets through the Rockfish conservation strategy for nearshore are 20% - need to make sure that the lower end of the target range meets this conservation need (Yamanaka and Logan 2010)	3	High; This is another inshore species that is very vulnerable to exploitation. But also dive surveys find that the Tiger RKF are found in areas of high biodiversity/ productivity. Pretty typical to find Tiger RKF at sites with 20+ other RKF species.	–	–	3	Medium: rockfish and thornyheads have inherently vulnerable life histories and for most species, there is little information available on their stock status and distribution, therefore they should all be at least medium to be precautionary	3.0	4.12	med	20-40%
	Sebastes miniatus	Vermilion Rockfish	2	2	2	low	2	–	2	–	–	–	3	Medium: rockfish and thornyheads have inherently vulnerable life histories and for most species, there is little information available on their stock status and distribution, therefore they should all be at least medium to be precautionary	2.3	3.67	low	10-20%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Rockfish	*Sebastes entomelas*	Widow Rockfish	2	2	2	low	3	Medium: Concerns about vulnerability; Look at stock assessments/ May be assessments from COSEWIC	2	–	–	–	3	Medium: rockfish and thornyheads have inherently vulnerable life histories and for most species, there is little information available on their stock status and distribution, therefore they should all be at least medium to be precautionary	2.7	3.89	med	20-40%
	Sebastes ruberrimus	Yelloweye Rockfish	2	3	3	high	1	Medium: Targets through the Rockfish conservation strategy for nearshore are 20% - need to make sure that the lower end of the target range meets this conservation need (Yamanaka and Logan 2010)	2	–	–	–	2	–	1.7	4.56	high	40-60%
	Sebastes reedi	Yellowmouth Rockfish	2	3	2	med	2	–	2	–	–	–	2	–	2.0	4.12	med	20-40%
	Sebastes flavidus	Yellowtail Rockfish	2	2	2	low	2	–	2	–	–	–	3	Medium; overall, likely is a reduced amount of kelp forest habitat, therefore should target higher proportion; potentially also declining even though not listed or assessed	2.3	3.67	low	10-20%
Roundfish	*Gadus macrocephalus*	Pacific Cod	2	1	3	low	2	–	2	–	–	–	3	Medium: current population quite a low percentage of former abundance even though not listed or assessed	2.3	3.93	med	20-40%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Roundfish	*Merluccius productus*	Pacific Hake	2	2	3	med	1	Low: Not vulnerable (look at stock assessment) - fluctuations in Hake stocks; Carefully managed internationally; Widespread and movements based on climate - dynamic movements from south to north	2	–	–	–	2	–	1.7	3.97	med	20-40%
	Theragra chalcogramma	Walleye Pollock	2	1	3	low	2	–	2	–	–	–	3	Medium: important forage fish that may be at reduced abundance compared to past so better to target higher proportion	2.3	3.93	med	20-40%
Other fishes	*Acipenser medirostris*	Green Sturgeon	2	3	2	med	1	Low: Disagree with functional importance	2	–	–	–	2	–	1.7	3.97	med	20-40%
	Embiotoca lateralis	Striped Seaperch	2	1	3	low	2	–	2	–	–	–	2	–	2.0	3.74	low	10-20%
Demersal sharks	*Hexanchus griseus*	Bluntnose Sixgill Shark	2	3	3	high	1	Medium	2	–		–	2	–	1.7	4.56	high	40-60%
	Somniosus pacificus	Pacific Sleeper Shark	2	2	3	med	1	Low; not really high conservation concern	2	–	–	–	2	–	1.7	3.97	med	20-40%
	Squalus suckleyi	Spiny Dogfish	2	3	3	high	1	Low: Not vulnerable	2	–	1	Low: It is categorized as a Low Concern species by IUCN; bottom longline represent low impact to BC stock, although harmful to other species (Seafood watch); still it is a long-lived and slow maturity species.	2	–	1.5	4.50	high	40-60%

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[17]								Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3		Expert #4					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class[18]	Target Range[1]
Pelagic Sharks	*Cetorhinus maximus*	Basking Shark	2	3	2	med	2	–	2	–	–	–	2	–	2.0	4.12	med	20-40%
	Prionace glauca	Blue Shark	2	3	3	high	1	No Target (or low): IAs unknown and too widespread for the NSB to protect (would have to protect 1/3 of Pacific ocean, Bonfil 1999)	1	Medium: Another shelf/offshore species given too high a priority - skewing the design. Re-rank the target down	2	–	2	–	1.5	4.50	high	40-60%
	Lamna ditropis	Salmon Shark	2	2	3	med	1	No Target (or low): IAs unknown and too widespread for the NSB to protect (would have to protect 1/3 of Pacific ocean, Bonfil 1999)	2	–	–	–	2	–	1.7	3.97	med	20-40%
Skates	*Raja binoculata*	Big Skate	2	3	3	high	1	Low: Not functionally important in NSB; Look at Stock assessment - not vulnerable in BC (King et al. 2015); highly fecund	2	–	–	–	2	–	1.7	4.56	high	40-60%
	Raja rhina	Longnose Skate	2	2	3	med	1	Low: Not functionally important in NSB; Look at Stock assessment - not vulnerable in BC (King et al. 2015)	2	–	3	High: both bottom longline and bottom trawl have major impact on populations and habitat CPs, also on other CP species by-catch	2	–	2.0	4.12	med	20-40%
	Bathyraja trachura	Roughtail Skate	2	2	3	med	1	Low: Not functionally important in NSB	2	–		–	2	–	1.7	3.97	med	20-40%
	Bathyraja interrupta	Sandpaper Skate	2	2	2	low	2	–	2	–		–	2	–	2.0	3.46	low	10-20%

Table 27. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the species-based conservation priorities (CPs; invertebrates).

Group	Species[20]	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Recommended Target Level	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Coldwater Corals	Antipatharia	Black Corals	2	2	3	med	3	High; FAO considers VMEs; habitat forming; some long-lived (proxy for naturalness?).	2	–	2	–	2.3	4.29	med	20-40%
	Scleractinia	Hard or Stony corals	2	2	3	med	3	High; FAO considers VMEs; habitat forming; some long-lived (proxy for naturalness?).	2	–	2	–	2.3	4.29	med	20-40%
	Pennatulacea	Sea Pens	2	2	3	med	3	High; FAO considers VMEs; habitat forming; some long-lived (proxy for naturalness?).	2	–	2	–	2.3	4.29	med	20-40%
	Alcyonacea	Soft Corals	2	2	3	med	3	High; FAO considers VMEs; habitat forming; some long-lived (proxy for naturalness?).	2	–	2	–	2.3	4.29	med	20-40%
Crust. - Barnacles	*Pollicipes polymerus*	Gooseneck Barnacle	2	1	3	low	3	Medium; structurally important; not widely distributed	2	–	2	–	2.3	3.93	med	20-40%
Crustaceans - Crabs	*Chionoecetes tanneri*	Deepwater grooved tanner crab	2	2	1	low	2	–	2	–	2	–	2.0	3.00	low	10-20%
	Metacarcinus magister	Dungeness Crab	2	2	2	low	2	–	2	–	2	–	2.0	3.46	low	10-20%
	Chionoecetes bairdi	Inshore tanner crab	2	2	1	low	2	–	2	–	2	–	2.0	3.00	low	10-20%
	Lopholithodes mandtii	Puget Sound King Crab	2	2	1	low	2	–	2	–	2	–	2.0	3.00	low	10-20%

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[20] After the regional peer review meeting, the original conservation priority scoring for select invertebrate species was updated in Gale et al. (2019). For clarity, the changes include: 1) coonstripe/dock shrimp, humpback shrimp, prawn, sidestride shrimp, smooth pink shrimp, and spiny/northern pink shrimp – vulnerability score changed from 2 to 0; 2) red urchin and green urchin – conservation concern score changed from 1 to *; 3) abalone – ecological role (forage species) score changed from 0 to 1; and 4) geoduck – ecological role (forage species) score changed from 2 to 0. Because the changes would have affected the original target scores reviewed by experts, the relevant experts who had not already provided explicit comments on recommended final target classes (i.e., low, medium, high) were contacted to review their original recommendations on target scoring. The updates did not change the final calculated target classes and ranges. The information shown in the invertebrate target calculations above reflects the current conservation priority scoring and expert recommendations.

Group	Species[20]	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Recommended Target Level	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Crustaceans - Shrimps	*Neotrypaea californiensis*	Bay Ghost Shrimp	2	1	3	low	2	–	2	–	2	–	2.0	3.74	low	10-20%
	Pandalus danae	Coonstripe/ Dock Shrimp	2	1	3	low	2	Low; widespread; populations are doing well; not terribly vulnerable	3	–	2	Aim for 20%	2.3	3.93	med	20-40%
	Pandalus hypsinotus	Humpback Shrimp	2	1	3	low	2	Low; widespread; populations are doing well; not terribly vulnerable	3	–	2	Aim for 20%	2.3	3.93	med	20-40%
	Pandalus platyceros	Prawn	2	1	3	low	3	–	3	–	2	Aim for 20%	2.7	4.14	med	20-40%
	Pandalopsis dispar	Sidestripe Shrimp	2	1	3	low	2	Low; widespread; populations are doing well; not terribly vulnerable	3	–	2	Aim for 20%	2.3	3.93	med	20-40%
	Pandalus jordani	Smooth pink shrimp	2	1	3	low	2	Low; widespread; populations are doing well; not terribly vulnerable	3	–	2	Aim for 20%	2.3	3.93	med	20-40%
	Pandalus borealis	Spiny/ northern pink shrimp	2	1	3	low	2	Low; widespread; populations are doing well; not terribly vulnerable	3	–	2	Aim for 20%	2.3	3.93	med	20-40%
Crustaceans - Zooplankton	Euphausiacea	Euphausiids	2	2	3	med		–	2	–	2	–	2.0	4.12	med	20-40%
	Neocalanus sp.	Neocalanus copepods	2	1	3	low		–	2	–	3	Medium: very important component of food web for many species in the NE Pacific; northern species may be more susceptible to changing distribution due to climate change	2.5	4.03	med	20-40%
	Crustacean Zooplankton	Crustacean Zooplankton	2	2	3	med		–	2	–	2	–	2.0	4.12	med	20-40%
Echinoderms	*Strongylocentrotus droebachiensis*	Green Sea Urchin	2	2	2	low	3	–	3	–	2	–	2.7	3.89	med	20-40%
	Mesocentrotus franciscanus	Red Sea Urchin	2	2	2	low	3	–	3	–	2	–	2.7	3.89	med	20-40%

Group	Species[20]	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Recommended Target Level	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Echinoderms	*Pisaster ochraceus*	Ochre Sea Star	2	3	3	high	1	Medium; keystone predator so stays medium but widespread and not conservation concern - recovering from sea star wasting disease	1	Low; Occur pretty much everywhere so basically the selection is basically the shoreline except pure mud or sand. Additionally, unless someone has a coast wide robust survey the selection would be biased to sites that have been surveyed. Another issue is the impact of disease - it is documented that seastars go through massive die-offs that are not understood at all. So even a robust survey would have disease status bias.	1	Medium; Although agreed that they are important predators in the rocky intertidal, data will be based on pre-sea star wasting disease when they were prevalent throughout rocky shores in BC; representational targets of 10-30% of rocky shores likely sufficient for MPA network	1.0	4.36	med	20-40%
	Pycnopodia helianthoides	Sunflower Sea Star	2	2	3	med	1	Low; widespread; important functionally but we don't know their important areas so downgrade due to distribution	1	Low; although again disease has had a massive impact on this species - in Saanich Inlet the population is at best 10% of prior to pandemic pop. With very poor signs of recovery; Question why just this particular species and not other seastars?	2	–	1.3	3.84	med	20-40%
Molluscs - Cephalopods	*Enteroctopus dofleini*	Giant Pacific Octopus	2	2	3	med	1	Low: intrinsic vulnerability low (only live 3 years); widespread	2	–	2	–	1.7	3.97	med	20-40%
	Doryteuthis opalescens	Opal squid	2	2	3	med	2	–	2	–	2	–	2.0	4.12	med	20-40%
Molluscs - Clams and Cockles	*Saxidomus gigantea*	Butter Clam	2	2	3	med	1	Low; wide-ranging distribution and abundant	2	–	2	–	1.7	3.97	med	20-40%
	Clinocardium nuttalli	Cockle	2	2	3	med	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Panopea generosa	Geoduck	2	2	2	low	3	–	3	–	3	Should be a 1 for forage species rather than 0 [in CP scoring of ecological role] because of importance to sea otter foraging	3.0	4.12	med	20-40%
	Tresus capax	Horse Clam/ Fat Gaper	2	2	3	med	1	Low; wide-ranging distribution	2	–	2	–	1.7	3.97	med	20-40%

Group	Species[20]	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Recommended Target Level	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Molluscs - Clams and Cockles	*Tresus nuttallii*	Horse Clam/ Pacific Gaper	2	2	3	med	1	Low; wide-ranging distribution	2	–	2	–	1.7	3.97	med	20-40%
	Leukoma staminea	Littleneck Clam	2	2	3	med	1	Low; wide-ranging distribution	2	–	2	–	1.7	3.97	med	20-40%
	Siliqua patula	Razor Clam	2	2	3	med	3	high; unique species in the region and the only location in the region for the clam is this IA	2	–	2	–	2.3	4.29	med	20-40%
Molluscs - Epibenthic Bivalves	*Mytilus californianus*	California mussel	2	2	3	med	2	–	2	–	2	–	2.0	4.12	med	20-40%
	Ostrea lurida	Olympia Oyster	2	3	2	med	3	High: Historically abundant and formed reefs - functionally very important in NSB; extremely low numbers in former habitat	2	–	2	–	2.3	4.29	med	20-40%
	Chlamys rubida	Pink Scallop	2	2	2	low	–	–	2	–	2	–	2.0	3.46	low	10-20%
Molluscs - Epibenthic Bivalves	*Crassadoma gigantea*	Purple-hinged Rock Scallop	2	2	1	low	–	–	2	–	2	–	2.0	3.00	low	10-20%
	Chlamys hastata	Spiny Scallop	2	2	2	low	–	–	2	–	2	–	2.0	3.46	low	10-20%
	Patinopecten caurinus	Weathervane Scallop	2	2	1	low	3	Medium; uncertainty around functional importance; unique feature in NSB - only in deep waters off North Beach; vulnerable to aquaculture (genetic impacts)	3	High; Species distribution cannot be explained by standard set of physical parameters	3	–	3.0	3.74	low	10-20%
Molluscs – Gastropods and Chitons	*Littorina sp.*	*Littorina* snail	2	1	3	low	2	–	2	–	2	–	2.0	3.74	low	10-20%
	Haliotis kamtschatkana	Northern Abalone	2	3	2	med	2	Medium; high conservation concern and vulnerable	1	–	2	Medium; Culturally important species that is likely to see further declines in abundance with sea otter population expansion along the coast; Aim for 40%	1.7	3.97	med	20-40%
Other	Non-Crustacean Zooplankton	Non-Crustacean Zooplankton	2	1	3	low	–	–	2	–	2	–	2.0	3.74	low	10-20%

Group	Species[20]	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Recommended Target Level	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Sponges	Demospongiae	Demosponges	2	2	3	med	2	–	2	–	3	high; ok with medium if these are for individuals or small colonies of these sponges; assuming that the sponge reef complexes themselves have been identified separately for high protection targets	2.3	4.29	med	20-40%
	Hexactinellida	Glass sponges	2	2	3	med	3	High; 1. I would think of this as a target specific to glass sponges in sponge reefs. 2. I would bring up to high for same reasons as above for coldwater corals and sponges + due to global uniqueness of the glass sponge reefs and their ecosystem function. Two of the largest known reef complexes - Hecate & Chatham - both occur within the NSB.	2	–	3	high; ok with medium if these are for individuals or small colonies of these sponges; assuming that the sponge reef complexes themselves have been identified separately for high protection targets	2.7	4.48	high	40-60%
	Aphrocallistes vastus	Cloud sponge	2	2	3	med	3	1. This is one of the 3 glass sponge species that forms reefs. It is also found in sponge grounds. I suggest this target to be specific to "non-reef forming *A. vastus*". 2. Consider changing target to high, same reasons as above for cold water corals.	2	–	3	high; ok with medium if these are for individuals or small colonies of these sponges; assuming that the sponge reef complexes themselves have been identified separately for high protection targets	2.7	4.48	high	40-60%
Sponges	*Farrea occa*	Glass sponge	2	2	3	med	3	High: 1. This is one of the 3 glass sponge species that forms reefs. It is also found in sponge grounds. I suggest this target to be specific to "non-reef forming *F. occa*". 2. Consider changing to high, same as above.	2	–	3	high; ok with medium if these are for individuals or small colonies of these sponges; assuming that the sponge reef complexes themselves have been identified separately for high protection targets	2.7	4.48	high	40-60%
	Heterochone calyx	Glass sponge	2	2	3	med	3	High: 1. This is one of the 3 glass sponge species that forms reefs. It is also found in sponge grounds. I suggest this target to be specific to "non-reef forming *H. calyx*". 2. Consider changing to high, same reasons as above.	2	–	3	high; ok with medium if these are for individuals or small colonies of these sponges; assuming that the sponge reef complexes themselves have been identified separately for high protection targets	2.7	4.48	high	40-60%

Table 28. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the species-based conservation priorities (CPs: marine mammals and reptiles).

Functional Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[21]				Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Dolphins and Porpoises	*Phocoenoides dalli*	Dall's Porpoise	3	2	3	high	3	–	2	Would have put at same target level as Humpback; Seen throughout NSB, often around Port Hardy and Gordon Channel.	2.5	4.39	high	40-60%
	Phocoena phocoena	Harbour Porpoise	3	3	3	high	3	secondary target herring, sandlance, squid	3	High; A little more vulnerable because often found nearer shore or in inlets.	3.0	5.20	high	40-60%
	Lissodelphis borealis	Northern Right Whale Dolphin	3	2	2	med	3	secondary target herring, anchovy, squid	3	Perhaps appropriate to have a similar target to Pacific White-sided Dolphin because they often co-occur, though there are fewer Northern Right Whale Dolphins.	3.0	4.12	med	20-40%
	Lagenorhynchus obliquidens	Pacific White-sided Dolphin	3	2	3	high	2	Medium; widespread coastal	2	–	2.0	4.12	med	20-40%
	Grampus griseus	Risso's Dolphin	3	2	3	high	2	Medium; widespread offshore accidental	2	–	2.0	4.12	med	20-40%
Orcas	*Orcinus orca*	Northern Resident Orca	3	3	3	high	3	Secondary target HIGH - prey species key habitats: Salmonid spp. (chinook)	3	–	3.0	5.20	high	40-60%
	Orcinus orca	Offshore Orca	3	3	3	high	2	Medium; widespread offshore; lack of info on pop #'s; Secondary target MED for known prey: elasmobranchs	3	–	2.5	4.92	high	40-60%
	Orcinus orca	Southern Resident Orca	3	3	3	high	3	Secondary target HIGH - prey species key habitats: Salmonid spp. (chinook)	3	–	3.0	5.20	high	40-60%
	Orcinus orca	West Coast Transient Orca	3	3	3	high	2	Medium; Widespread, Coastal; Secondary target HIGH - prey species key habitats: pinnipeds	3	–	2.5	4.92	high	40-60%
Pinnipeds	*Zalophus californianus*	California Sea Lion	3	2	3	high	3	–	2	Medium; Has become more widespread lately, perhaps due to warming waters.	2.5	4.39	high	40-60%
	Phoca vitulina	Harbour Seal	3	2	3	high	3	–	2	Medium; Not as vulnerable as other species because they are ubiquitous, eat a variety of prey, and make use of lots of habitats. However, they are also more heavily predated, which may be why their population is leveling off.	2.5	4.39	high	40-60%
	Mirounga angustirostris	Northern Elephant Seal	2	3	3	high	2	–	3	–	2.5	4.92	high	40-60%

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[21] 'Expert #1' reviewed the mammal features and targets prior to the RPR. An additional review ('Expert #2') was solicited and incorporated into the target scoring after the RPR based on the feedback of the participants.

Functional Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)[21]				Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2					
			Expert Review	CC/ Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Pinnipeds	*Callorhinus ursinus*	Northern Fur Seal	2	3	3	high	2	–	–	–	2.0	4.69	high	40-60%
	Eumetopias jubatus	Steller Sea Lion	2	3	3	high	2	–	3	High; COSEWIC reassessment kept population at Special Concern because Triangle Island rookery has most births and population is therefore vulnerable. Rookeries warrant high target but perhaps not all haulouts.	2.5	4.92	high	40-60%
Otters	*Enhydra lutris*	Sea Otter	2	3	3	high	2	–	3	–	2.5	4.92	high	40-60%
Whales	*Balaenoptera musculus*	Blue Whale	2	3	2	med	2	Medium; Widespread pelagic and coastal spp. ranges	2	Medium; Species is wide-ranging.	2.0	4.12	med	20-40%
	Balaenoptera acutorostrata	Common Minke Whale	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
	Balaenoptera physalus	Fin Whale	3	3	2	high	2	Medium; Widespread pelagic and coastal spp. ranges; Secondary target HIGH: prey. Euphausiid, herring, pilchard.	3	High; target should be higher than that for Humpbacks. Population increasing but hasn't fully bounced back and is not at levels of Humpbacks. Species is found in NSB year-round and eat krill only, so not as versatile as Humpbacks.	2.5	4.39	high	40-60%
Whales	*Eschrichtius robustus*	Grey Whale	3	3	2	high	2	Medium; Widespread pelagic and coastal spp. ranges; Secondary target HIGH: rocky reefs, sheltered sandy bottom bays WCVI, HG.	2	Medium; Population is doing well and species moves through the NSB, not spending as much time in the area.	2.0	4.12	med	20-40%
	Megaptera novaeangliae	Humpback Whale	3	3	2	high	2	Medium; Widespread pelagic and coastal spp. ranges; Secondary target HIGH: prey. Euphausiid, herring, pilchard.	2	Medium; Play a big role in the ecosystem but ubiquitous.	2.0	4.12	med	20-40%
	Eubalaena japonica	North Pacific Right Whale	3	3	2	high	2	Medium; Widespread pelagic and coastal spp. ranges	3	High; Highly endangered.	2.5	4.39	high	40-60%
	Balaenoptera borealis	Sei Whale	3	3	2	high	2	Medium: Widespread pelagic and coastal spp. ranges; Secondary target HIGH: prey. Euphausiid, herring, pilchard.	–	–	2.0	4.12	med	20-40%
	Physeter macrocephalus	Sperm Whale	3	3	3	high	2	Medium; Widespread pelagic; Secondary target HIGH - canyons, troughs, depth >500m	2	Medium; Would assign Blue Whale a high target before Sperm Whale. Only lone males in the NSB.	2.0	4.69	high	40-60%
Turtles	*Dermochelys coriacea*	Leatherback	2	3	2	med	–	–	2	–	2.0	4.12	med	20-40%

Table 29. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the species-based conservation priorities (CPs; plants, phytoplankton, algae).

Group	Species	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)						Average Expert Review Score	Final Calculated Targets		
							Expert #1		Expert #2		Expert #3					
			Expert Review	CC/Vulnerability	Funct. Importance	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Score	Target Class	Target Range
Phytoplankton	Phytoplankton	Phytoplankton	2	1	3	low	2	–	2	–	3	Medium; depending on how these are defined, it may be important to target a higher proportion of these if they are persistent areas of high phytoplankton productivity, since these will be areas of concentrated feeding activity higher up the food web; if a lot of area is defined as phytoplankton area, a 10-20% target may be okay if they capture persistent high productivity areas, but if these are pretty well-defined smaller areas, higher targets should be considered; also expect that these are spatially variable so may be difficult to address over time unless boundaries are somewhat movable	2.3	3.93	med	20-40%
Large algae	*Nereocystis leutkeana*	Bull kelp	3	1	3	med	–	–	3	–	3	High; special feature that is very important for many nearshore functions in addition to those identified for CPs including protection against coastal erosion, increasing nearshore productivity, and provision of wrack to shorelines; in areas without sea otters, kelp forest areal extent and depth is also likely to be in a reduced condition, therefore higher targets should be set for kelp in those areas; kelp also sensitive to increasing temperatures so important to protect from other human impacts to increase resilience	3.0	4.36	med	20-40%
	Macrocystis sp.	Giant Kelp	3	1	3	med	–	–	3	–	3	High; special feature that is very important for many nearshore functions in addition to those identified for CPs including protection against coastal erosion, increasing nearshore productivity, and provision of wrack to shorelines; in areas without sea otters, kelp forest areal extent and depth is also likely to be in a reduced condition, therefore higher targets should be set for kelp in those areas; kelp also sensitive to increasing temperatures so important to protect from other human impacts to increase resilience	3.0	4.36	med	20-40%
Seagrasses	*Zostera marina*	Eelgrass	3	1	3	med	–	–	3	High; species is vulnerable due to overlap with human high use areas	3	High; special feature that is important for additional nearshore functions including potential carbon storage, sediment control, and control on nutrient loading; worldwide, eelgrass is recognized as an important coastal habitat that is declining due to coastal development and climate change, therefore important to protect	3.0	4.36	med	20-40%
	Phyllospadix sp.	Surfgrass	3	1	3	med	–	–	2	low; basically the species occurs wherever there is surf - might as well select for exposure and substrate. No evidence that the species has or will decline due to local/regional human activities (except for a large spill event)	3	High; special feature that is important for additional nearshore functions including potential carbon storage, sediment control, and control on nutrient loading; worldwide, eelgrass is recognized as an important coastal habitat that is declining due to coastal development and climate change, therefore important to protect	2.5	4.03	med	20-40%

Table 30. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the species-based conservation priorities (CPs: marine birds).

Scientific Name	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)				Average Expert Review Score	Final Calculated Targets		
						Expert #1[22]		Expert #2					
		Expert Review (original)	Conservation Concern	ECCC Priority Species	Prelim. Targets (for expert review)	Expert Review #1	Expert #1 - Recommended Targets/Rationale	Expert Review #2	Expert #2 - Recommended Targets/Rationale		Target Scores	Target Class	Target Ranges
Synthliboramphus antiquus	Ancient Murrelet	3	3	3	high	3	Agree; high targets important for colonies; low targets appropriate for distribution	3	–	3.0	5.20	high	40-60%
Bucephala islandica	Barrow's Goldeneye	2	1	3	low	3	Medium; Vulnerable to oil spills; representative of nearshore; huge proportion of winter population globally; much remains unknown for sea ducks in NSB	–	–	3.0	4.36	med	20-40%
Haematopus bachmani	Black Oystercatcher	3	1	3	med	3	Agree; don't congregate in great numbers	–	–	3.0	4.36	med	20-40%
Melanitta americana	Black Scoter	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Arenaria melanocephala	Black Turnstone	2	1	3	low	2	–	–	–	2.0	3.74	low	10-20%
Phoebastria nigripes	Black-footed Albatross	2	2	3	med	2	–	2	–	2.0	4.12	med	20-40%
Phalacrocorax penicillatus	Brandt's Cormorant	3	3	3	high	1	Low; not breeding within NSB in great numbers; not a hotspot for the species; likely little data	3	–	1.7	4.56	high	40-60%
Puffinus bulleri	Buller's Shearwater	2	3	1	low	2	–	2	–	2.0	3.74	low	10-20%
Branta hutchinsii	Cackling Goose	2	1	3	low	2	Agree; not much of a wintering population	–	–	2.0	3.74	low	10-20%
Larus californicus	California Gull	2	3	3	high	1	Low; only listed at a provincial level; widely distributed; not breeding within NSB; not great proportion of global population	1	Medium?; Not clear why this species comes out as a high priority as it is wide-ranging, IUCN Least Concern and assessed as "expanding in range and numbers" by the CDC	1.0	4.36	med	20-40%
Branta canadensis	Canada Goose (Pacific, residents & migrants)	2	1	3	low	2	Agree; moult everywhere	–	–	2.0	3.74	low	10-20%
Ptychoramphus aleuticus	Cassin's Auklet	3	2	3	high	3	–	3	–	3.0	4.69	high	40-60%

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[22] 'Expert #1' for the marine bird expert review was comprised of a group of seabird biologists who provided recommendations and feedback on the marine bird ecological conservation targets as an ensemble. As such, the recommended score from 'Expert Review #1' was counted twice in the calculation of the 'Average Expert Review Score'. For example, for Brandt's cormorant, several experts through 'Expert Review #1' recommended lowering the target (expert review score = 1). Therefore the 'Average Expert Review Score' for Brandt's Cormorant was calculated as: (1 + 1 + 3)/3 = 1.7

Scientific Name	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)				Average Expert Review Score	Final Calculated Targets		
						Expert #1[22]		Expert #2					
		Expert Review (original)	Conservation Concern	ECCC Priority Species	Prelim. Targets (for expert review)	Expert Review #1	Expert #1 - Recommended Targets/Rationale	Expert Review #2	Expert #2 - Recommended Targets/Rationale		Target Scores	Target Class	Target Ranges
Bucephala clangula	Common Goldeneye	2	1	3	low	2	–	–	–	2.0	3.74	low	10-20%
Gavia immer	Common Loon	2	1	3	low	2	–	–	–	2.0	3.74	low	10-20%
Uria aalge	Common Murre	3	3	3	high	3	–	3	–	3.0	5.20	high	40-60%
Phalacrocorax auritus	Double-crested Cormorant	3	2	1	low	3	–	3	Medium?; A widespread species in North America, but numbers of nesting birds in BC have been declining at known sites.	3.0	3.74	low	10-20%
Calidris alpina	Dunlin	2	2	3	med	3	High; Use estuarine/muddy intertidal habtiats, which are good for a variety of species	–	–	3.0	4.69	high	40-60%
Oceanodroma furcata	Fork-tailed Storm-Petrel	3	1	1	low	3	Agree; Not know much about population; found everywhere	3	Medium; An increase should be discussed at least. Possible that factors affecting Leach's Storm-petrels at their BC colonies are also affecting Fork-tailed Storm-petrels	3.0	3.32	low	10-20%
Ardea herodias fannini	Great Blue Heron, Fannini Subspecies	2	3	1	low	2	Agree; Listed subspecies is primarily found on the South coast (not in the NSB)	–	–	2.0	3.74	low	10-20%
Histrionicus histrionicus	Harlequin Duck	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Podiceps auritus	Horned Grebe	2	3	1	low	2	–	–	–	2.0	3.74	low	10-20%
Fratercula corniculata	Horned Puffin	3	3	3	high	1	Low; Not breeding within NSB in great numbers	3	Agree; Consider protecting all known (active) colonies in any post-Marxan process, as there are very few individuals nesting in BC	1.7	4.56	high	40-60%
Phoebastria immutabilis	Laysan Albatross	2	2	3	med	2	Agree; Most numerous of albatrosses; population seems to be increasing	2	–	2.0	4.12	med	20-40%
Oceanodroma leucorhoa	Leach's Storm-Petrel	3	1	3	med	3	–	3	High; Uplisted by IUCN (2016) from LC to Vulnerable due to an apparent decline of > 30% over 3 generations. Data are primarily for Atlantic populations, but data for a limited number of BC colonies also suggest a decline (susp. river otter predation), e.g., see refs to Gillam Islands (in NSB) in Carter et al. (2012).	3.0	4.36	med	20-40%
Clangula hyemalis	Long-tailed Duck	2	3	1	low	2	–	–	–	2.0	3.74	low	10-20%

		BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)					Final Calculated Targets		
						Expert #1[22]		Expert #2					
Scientific Name	Common Name	Expert Review (original)	Conservation Concern	ECCC Priority Species	Prelim. Targets (for expert review)	Expert Review #1	Expert #1 - Recommended Targets/Rationale	Expert Review #2	Expert #2 - Recommended Targets/Rationale	Average Expert Review Score	Target Scores	Target Class	Target Ranges
Brachyramphus marmoratus	Marbled Murrelet	2	3	3	high	2	–	2	–	2.0	4.69	high	40-60%
Fulmarus glacialis	Northern Fulmar	2	3	1	low	2	Agree; Found everywhere; not breeding in BC in large numbers	2	–	2.0	3.74	low	10-20%
Gavia pacifica	Pacific Loon	2	2	1	low	2	–	–	–	2.0	3.00	low	10-20%
Phalacrocorax pelagicus resplendens	Pelagic Cormorant	2	1	3	low	2	–	3	Medium?; Declining in other parts of BC range; see Carter et al. 2007 and other cormorant refs above	2.3	3.93	med	20-40%
Phalacrocorax pelagicus pelagicus	Pelagic Cormorant, Pelagicus Subspecies	2	3	3	high	2	–	2	–	2.0	4.69	high	40-60%
Cepphus columba	Pigeon Guillemot	3	1	3	med	3	High; 30-50% of global population on small number of colonies (vulnerable); very representative of nearshore; good indicator	2	–	2.7	4.14	med	20-40%
Puffinus creatopus	Pink-footed Shearwater	2	3	3	high	2	Agree; Recently increased to endangered by COSEWIC	2	–	2.0	4.69	high	40-60%
Calidris canutus	Red Knot	2	3	3	high	1	Medium; Very little data (not in surveys, few sites in NSB); was rated high because of national status	–	–	1.0	4.36	med	20-40%
Phalaropus fulicarius	Red Phalarope	2	2	1	low	2	–	–	–	2.0	3.00	low	10-20%
Phalaropus lobatus	Red-necked Phalarope	2	2	1	low	2	–	–	–	2.0	3.00	low	10-20%
Cerorhinca monocerata	Rhinoceros Auklet	3	1	3	med	3	High; High proportion of global population on few colonies within breeding season (vulnerable); good flagship species (eat the same species as many others)	3	–	3.0	4.36	med	20-40%
Calidris ptilocnemis	Rock Sandpiper	2	1	3	low	2	–	–	–	2.0	3.74	low	10-20%
Arenaria interpres	Ruddy Turnstone	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Calidris alba	Sanderling	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Limnodromus griseus	Short-billed Dowitcher	2	3	3	high	2	–	–	–	2.0	4.69	high	40-60%

Scientific Name	Common Name	BCMCA expert review and original CP scores				Expert Score Review and Recommended Targets (2017)				Average Expert Review Score	Final Calculated Targets		
						Expert #1[22]		Expert #2					
		Expert Review (original)	Conservation Concern	ECCC Priority Species	Prelim. Targets (for expert review)	Expert Review #1	Expert #1 - Recommended Targets/Rationale	Expert Review #2	Expert #2 - Recommended Targets/Rationale		Target Scores	Target Class	Target Ranges
Phoebastria albatrus	Short-tailed Albatross	2	3	3	high	2	Agree; Juveniles primarily seen; concentrate in QCSo (outer); co-occur with fish boats	2	–	2.0	4.69	high	40-60%
Puffinus tenuirostris	Short-tailed Shearwater	2	1	1	low	2	–	–	–	2.0	2.45	low	10-20%
Puffinus griseus	Sooty Shearwater	2	2	1	low	2	–	–	–	2.0	3.00	low	10-20%
Melanitta perspicillata	Surf Scoter	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Aphriza virgata	Surfbird	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Larus thayeri	Thayer's Gull	2	2	3	med	2	Agree; Found everywhere	2	–	2.0	4.12	med	20-40%
Uria lomvia	Thick-billed Murre	3	3	3	high	1	Low; Primarily an Arctic bird; few breeding pairs in NSB (~20 in BC)	3	–	1.7	4.56	high	40-60%
Cygnus buccinator	Trumpeter Swan	2	1	3	low	2	Agree; More of an issue on the South Coast	–	–	2.0	3.74	low	10-20%
Fratercula cirrhata	Tufted Puffin	3	3	3	high	3	–	3	–	3.0	5.20	high	40-60%
Heteroscelus incanus	Wandering Tattler	2	2	1	low	3	Medium; Canada has moderate (20-50% of species) jurisdictional responsibility, species can nest right on the coast	–	–	3.0	3.74	low	10-20%
Aechmophorus occidentalis	Western Grebe	2	3	3	high	2	Agree; Distribution shift down to California has occurred	–	–	2.0	4.69	high	40-60%
Calidris mauri	Western Sandpiper	2	1	3	low	2	–	–	–	2.0	3.74	low	10-20%
Numenius phaeopus	Whimbrel	2	2	3	med	2	–	–	–	2.0	4.12	med	20-40%
Melanitta fusca	White-winged Scoter	2	1	3	low	3	Medium; Align with other scoters	–	–	3.0	4.36	med	20-40%
Gavia adamsii	Yellow-billed Loon	2	3	1	low	2	–	–	–	2.0	3.74	low	10-20%

Table 31. Ecological criteria and expert feedback used to calculate the final MPATT target ranges for the area-based conservation priorities (CPs).

Physical Feature or Measured/Modeled Area	BCMCA expert review and original CP scores					Expert Score Review and Recommended Targets (2017)						Average Expert Review Score	Final Calculated Targets		
						Expert #1		Expert #2		Expert #3					
	Expert Review	Obj. 1.1	Obj. 1.3	Obj. 1.6	Prelim. Targets (for expert review)	Recommended Target Score	Rationale	Recommended Target Score	Rationale	Recommended Target Score	Rationale		Target Scores	Target Class (2 classes)	Target Range
Areas of high habitat heterogeneity	3	1	3	3	high	3	–	3	–	3	–	3.0	5.29	high	20-60%
Frontal zones	2	1	3	3	high	2	–	2	–	2	–	2.0	4.80	high	20-60%
Submarine canyons (relative to surrounding slope) and steep walled troughs	2	1	3	3	high	2	–	2	–	2	–	2.0	4.80	high	20-60%
Areas of upwelling	2	1	1	3	low	3	–	–	No target; areas are variable over time with climate change and not appropriate to protect in network	2	Medium; critical for zooplankton, primary production and key prey spp. for listed cetacean spp.	2.5	4.15	high	20-60%
Tidal passes and currents	3	2	1	3	high	3	–	3	–	3	–	3.0	5.29	high	20-60%
Eddies and plumes	2	1	1	3	low	2	–	2	–	2	–	2.0	3.87	low	10-30%
Non-tidal currents	2	1	1	3	low	2	–	2	–	2	–	2.0	3.87	low	10-30%
Marine areas influenced by freshwater discharges with high oxygen levels (climate refugia)	2	3	1	1	low	2	–	–	No target; large uncertainty over time; other areas at least as relevant	2	–	2.0	3.87	low	10-30%
Underwater banks (climate refugia)	2	3	1	1	low	2	–	–	No target; large uncertainty over time; other areas at least as relevant	2	–	2.0	3.87	low	10-30%
Degraded areas	2	3	1	1	low	–	Unsure how this would be used. I think if it were more explicit around, say, degraded estuaries, tidal flats, etc. it would be more valuable.	–	Should be some effort to quantify 'degraded area'; many areas are considered degraded. Could move to representative habitat types?	2	–	2.0	3.87	low	10-30%
Areas of high species abundance, diversity or richness (for appropriate groups of species)	2	1	3	1	low	2	–	–	–	2	–	2.0	3.87	low	10-30%

APPENDIX 8 REFERENCES

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APPENDIX 9: SENSITIVITY ANALYSIS OF TARGET SCORE CLASSIFICATION

BACKGROUND:

In the initial development of the ecological conservation targets for the species-based conservation priorities, quartiles were used to classify target scores into three classes: high (>75% of distribution of target scores), medium (>25% and ≤75% of distribution of target scores), and low (≤25% of distribution of target scores). The quartile approach was chosen because it assigns most ecological conservation priorities a medium target and specifies the high target class for those species of particular ecological importance and conservation concern. During the Regional Peer Review meeting, participants recommended performing a sensitivity analysis to assess the impact of using quartiles to assign an ecological conservation target range when compared to an alternative approach differentiating the target scores based on thirds.

METHODS:

To assess the appropriateness of using quartiles and thirds to assign a target range to the species-based ecological conservation priorities, the distribution of target scores for the conservation priorities was calculated and classified based on thirds and quartiles. The resulting target ranges were compared to the feedback on targets received during the expert review.

RESULTS:

The approach to assigning ecological conservation target classes using thirds, resulted in a more even distribution of ecological conservation priorities in all three target classes. The classification changed for 37 (19%) ecological conservation priorities when shifting from quartiles to thirds (Table 32). Of these, 22 moved to a higher target range and 15 were downgraded to a lower target range. Expert feedback aligned with the target assigned using the quartiles approach for a slight majority (57%) of those ecological conservation priorities (Table 32).

CONCLUSION:

The quartile approach assigns the majority of ecological conservation priorities a medium target and specifies the high target class for those species of particular ecological importance and conservation concern. Further, ecological conservation targets assigned using the quartile classification align slightly better with expert feedback. Therefore, we recommend proceeding with the quartile classification.

Table 32. Species-based ecological conservation priorities for which the target changes when the target score values are classified based on quartiles vs. thirds and the alignment of the resulting target classes with feedback received during the expert review. A value of "-" indicates where there was no clear consensus from the experts on the appropriate target.

Group	Common Name	Target Class based on Quartiles	Target Class based on Thirds	Expert Review Feedback (# of experts - score recommended)	Classification Approach most Aligned with Expert Feedback
Fishes	Arrowtooth	Med.	Low	2 - Low; 2 - Med.	-
Fishes	Capelin	Med.	Low	2 - Low; 1 - Med.	Thirds
Fishes	Pacific Herring	Med.	High	1 - Low; 2 - Med.; 1 - Med./High	Quartiles
Fishes	Surf Smelt	Med.	Low	2 - Low; 1 - Med.	Thirds
Fishes	Cutthroat Trout	Med.	Low	2 - Low; 1 - Med.	Thirds
Fishes	Steelhead	Med.	Low	2 - Low; 1 - Med.	Thirds
Fishes	Albacore	Med.	High	3 - Low/Med.	Quartiles
Fishes	Black Rockfish	Med.	Low	1 - Low; 2 - Med.	Quartiles
Fishes	Copper Rockfish	Med.	Low	1 - Low; 3 - Med.	Quartiles
Fishes	Darkblotched Rockfish	Med.	High	3 - Med.; 1 - High	Quartiles
Fishes	Redstripe Rockfish	Med.	Low	2 - Low; 2 - Med.	-
Fishes	Widow Rockfish	Med.	Low	1 - Low; 2 - Med.	Quartiles
Fishes	Pacific Cod	Med.	Low	2 - Low; 1 - Med.	Thirds
Fishes	Walleye Pollock	Med.	Low	2 - Low; 1 - Med.	Thirds
Invertebrates	Black corals	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Hard or stony corals	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Sea pens	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Soft corals	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Gooseneck barnacle	Med.	Low	2 - Low; 1 - Med.	Thirds
Invertebrates	Neocalanus copepods	Med.	High	1 - Low; 1 - Med.	Quartiles
Invertebrates	Ochre star	Med.	High	1 - Low; 2 - Med.	Quartiles
Invertebrates	Sunflower sea star	Med.	Low	2 - Low; 1 - Med.	Thirds
Invertebrates	Olympia Oyster	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Razor clam	Med.	High	2 - Med.; 1 - High	Quartiles
Invertebrates	Demospongiae	Med.	High	2 - Med.; 1 - High	Quartiles
Plants	Phytoplankton	Med.	Low	2 - Low; 1 - Med.	Thirds
Plants	Bull kelp	Med.	High	2 - High	Thirds
Plants	Giant Kelp	Med.	High	2 - High	Thirds
Plants	Eelgrass	Med.	High	2 - High	Thirds
Marine Birds	Barrow's Goldeneye	Med.	High	2 - Med.	Quartiles
Marine Birds	Black Oystercatcher	Med.	High	2 - Med.	Quartiles
Marine Birds	California Gull	Med.	High	1 - Low; 2 - Med.	Quartiles
Marine Birds	Leach's Storm-Petrel	Med.	High	2 - High	Thirds
Marine Birds	Pelagic Cormorant	Med.	Low	2 - Low; 1 - Med.	Thirds
Marine Birds	Red Knot	Med.	High	2 - Med.	Quartiles
Marine Birds	Rhinoceros Auklet	Med.	High	3 - High	Thirds
Marine Birds	White-winged Scoter	Med.	High	2 - Med.	Quartiles

APPENDIX 10: DATA AND LITERATURE ON ADULT MOVEMENT RANGES TO INFORM MPA SIZE AND SPACING RECOMMENDATIONS

Table 33. Data and Literature on adult movement ranges.

(a) Nearshore

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Forage Fish	*Clupea pallasii*	Pacific Herring	–	50-1000	–	–	–	Seasonal migrations between offshore areas and nearshore spawning grounds. (Large movement category inferred).	11, 42
		Ammodytes hexapterus	Pacific Sand Lance	–	10-50	–	6-50	100	No spawning migrations have been observed; however, offshore-onshore movements occur before spawning in the fall. Exhibits high site fidelity to spawning locations, although eggs and larvae are subject to limited movement by water currents and tides. Adults feed in large schools, consuming mainly copepod zooplankton within relatively short distances of fish burrowing habitat. (Moderate movement category inferred).	41, 84, 88, 91
		Hypomesus pretiosus	Surf Smelt	–	U	–	0-20	–	Adults are suggested to remain within near-shore habitats, but no information on movement patterns is reported.	11, 104
	Groundfish	*Ophiodon elongatus*	Lingcod	3.3-498 (28.3)	10-50	28.3	10-100	400	The majority of individuals have movement less than 50 km (typically <30 km). Several studies document a small percentage (7-9%) of tagged individuals that migrate long distances (50-500 km). Individuals move to nearshore rocky reef habitats for spawning).	11, 46, 47, 68, 71, 98
		Anarrhichthys ocellatus	Wolf eel	–	<0.05	0.05	0-20	225	When in mating pairs, individuals reside in single den with restricted movement (very limited movement category inferred). However they will travel long distances in search of a mate.	11, 25, 64
	Surf-perches	*Cymatogaster aggregata*	Shiner Surfperch	–	50-1000	200	0-150	146	Make seasonal onshore-offshore migrations over 200 km. Often migrate to shallow water estuaries during the spring and summer to breed and bear young , and seasonal changes in their size distributions in various habitats often reflect these seasonal migrations.	4, 5, 110
InvInvertebrates	Crustaceans	*Neotrypaea californiensis*	Bay ghost shrimp	–	<0.05	0.01	0.76	–	Conduct their daily activities within a relatively small circumscribed area. Under experimental conditions, ghost shrimp spent over 25% of the time within 2 cm of the burrow entrance; furthermore, the shrimp were also observed to move from one burrow to another. Ghost shrimp territory is limited to a few cm within the vicinity of their own burrow, which they defend from rivals.	3
		Pandalus borealis	Spiny or northern pink shrimp	–	1 to 10	–	50-100 (pelagic)	1380	No documentation of large movements by adults (except diel migrations for feeding). Occurs chiefly in mainland inlets from 54-90 m.	9, 11, 12

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Invetebrates	Crustac-eans	*Pollicipes polymerus*	Gooseneck barnacle	–	0	0.01	(+) 2-5	5	Sessile.	11, 49
		Lopholithodes mandtii	Puget Sound King Crab	–	U	–	6-137	137	Movement information not available.	55
	Echinoderms	*Strongylocentrotus droebachiensis*	Green urchin	–	<0.05	0.05	<10	130	Urchin barren fronts reported to move up to 6.9 cm/day. (Small movement category inferred).	11, 57, 101
		Pisaster ochraceus	Ochre star	–	<0.05	–	–	–	Small movement category inferred.	
		Mesocentrotus franciscanus	Red urchin	–	<1	1	<10	125	Movement rate reported between 7.5-50 cm/day. (Limited movement category inferred)	11, 51, 73 101
		Pycnopodia helianthoides	Sunflower sea star	–	<0.05	–	–	–	Small movement category inferred.	55
	Molluscs	*Saxidomus gigantea*	Butter clam	–	0	0.01	–	–	Highly limited movement.	11, 109
		Mytilus californianus	California mussel	–	0	0.01	(+) 2 to 5	5	Sessile.	11, 49
		Clinocardium nuttalli	Cockles	–	0	0.01	0-30	30	Highly limited movement.	11, 109
		Panopea generosa	Geoduck	–	0	0.01	9 to 18	120	Highly limited movement.	11, 109
	Molluscs	*Tresus capax*	Horse clam/ Fat Gaper	–	0	0.01	0-20	20	Highly limited movement.	11, 109
		Tresus nuttallii	Horse clam/ Pacific Gaper	–	0	0.01	0-20	20	Highly limited movement.	11, 109
		Leukoma staminea	Littleneck Clam	–	0	0.01	0-5	5	Highly limited movement.	11, 55
		Littorina sp.	*Littorina* snail	–	<0.05	–	–	–	Small movement category inferred	55
		Haliotis kamtschatkana	Northern Abalone	Up to 0.125	<1	0.125	5 to 15	35	Often immobile if habitat conditions suitable. Maximal movements from different studies report 20 m, 50 m, and 125 m.	11, 32, 95
		Ostrea lurida	Olympia Oyster	–	0	0.01	–	–	Sessile.	11, 109
		Siliqua patula	Razor clam	–	0	0.01	–	–	Highly limited movement.	55
		Patinopecten caurinus	Weathervane scallop	–	<0.05	–	–	–	Small movement category inferred.	55

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Plants	Large algae	*Nereocystis leutkeana*	Bull kelp	–	0	0.01	–	–	Sessile.	55
		Macrocystis sp.	Giant Kelp	–	0	0.01	–	–	Sessile.	55
	Seagrasses	*Zostera marina*	Eelgrass	–	0	0.01	–	–	Sessile.	55
		Phyllospadix sp.	Surfgrass	–	0	0.01	–	–	Sessile.	55

(b) Nearshore-Shelf/Slope

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Skates & Sharks	*Raja binoculata*	Big Skate	21 km (up to 1000)	10-50	21	3-800; mostly at 100-200	800	Despite being a demersal species that is considered to be relatively sedentary, the Big Skate is capable of large movements. For example, in British Columbia, a study revealed that ~75% of tagged individuals were recaptured within 21 km of the tagging locations, but 15 of the tagged individuals (0.1%) moved over 1,000 km. They are most common at depths of less than 200 m, although they have been found to depths of 800 m. In the GOA this species is the most commonly encountered species of skate in the inshore continental shelf waters at 100–200 m depth.	51
		Raja rhina	Longnose Skate	–	U	–	usually <400 m (100-350)	1069	Little is known about their movements. This species is found on the shelf to upper slope and inhabits mud-cobble bottoms near vertical relief from nearshore to 1000 m depth. However, records below 400 m are rare.	1, 11, 22, 74
		Lamna ditropis	Salmon Shark	–	1000+	–	–	–	Highly mobile species.	11, 31, 43
		Squalus suckleyi	Spiny Dogfish	250-7000	1000+	–	<350	1244	Inshore-offshore movement. Highly mobile.	8, 11, 74, 75
	Flatfish	*Eopsetta jordani*	Petrale Sole	–	50-1000	–	25-550 m; Common at 100-150 m on outer shelf	550	Petrale sole move from shallow summer feeding grounds to deep-water spawning grounds in the winter. There seems to be little north-south movement up and down the coast, but movements as great as 628 km have been reported. Eggs and larvae are transported from offshore spawning areas to nearshore nursery areas by oceanic currents and wind. Tend to move into deeper water with increased age and size. Young juveniles are generally found at 18-82 m, and larger juveniles at 25-145 m. Adults are found from the surf line to 550 m, but their highest abundance is found in <300 m. Adults migrate seasonally between deep-water, winter spawning areas to shallower, spring feeding grounds.	74
		Glyptocephalus zachirus	Rex Sole	–	50-1000	–	50-450; spawning between 100-300	850	Rex sole move inshore in the summer and make offshore spawning movements in the winter. They undergo a modest ontogenetic movement from the shelf to upperslope habitat. The maximum movement of a recaptured tagged rex sole was 54 km, suggesting only limited movement. Rex sole is a middle shelf-mesobenthal species, occurring in depths from 0-850 m. In survey catches, most (96%) occurred at 50-450 m. Probably the most widely distributed sole on the continental shelf and upper slope off Oregon, occupying a large depth range with diverse sediments. They can occur in water as shallow as 18 m. Do not appear to have specific spawning sites, but appear to spawn at 100-300 m.	74

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Flatfish	*Lepidopsetta bilineata*	Rock Sole	–	10-50	–	10-275	732	Rock sole are sedentary. They undergo a movement to deeper waters in the winter to spawning grounds, and a post-spawning migration to summer feeding grounds in the shallow waters over the continental shelf. Immature rock sole reside in shallow waters in the winter and move to shallower waters in coastal areas in the spring and summer. Rock sole (mainly *L. polyxystra*) also move into deeper water with increased size. Adult rock sole are found intertidally to as deep as 732 m, but are uncommon below 300 m. Juveniles and adults are demersal and found primarily in shallow water bays and over the continental shelf. Caught in Alaska fisheries between 10-40 m, mostly at less than 20 m. Overwinter on the edge of the continental slope at 125-275 m and occupy the shelf during the summer at 18-80 m. In Puget Sound, uncommon below 55 m and spawning occurs in shallow water.	74
	Forage Fish	*Mallotus villosus*	Capelin	–	50-1000	–	2-125 (100)	590	Seasonal migrations between offshore areas and nearshore spawning grounds. (Large movement category inferred).	10
		Thaleichthys pacificus	Eulachon	–	50-1000	525	0-100	420	Migration between offshore feeding grounds and freshwater spawning areas (Large movement category inferred).	11, 59
		Sardinops sagax	Pacific Sardine	–	1000+	–	–	–	Complex seasonal migrations over large areas. (Large movement category inferred).	21
	Native Salmonids	*Oncorhynchus tshawytscha*	Chinook Salmon	–	1000+	–	–	–	Long distance spawning migrations.	11, 34
		Oncorhynchus keta	Chum Salmon	–	1000+	–	–	–	Long distance spawning migrations.	11, 34
		Oncorhynchus kisutch	Coho Salmon	–	1000+	–	–	–	Long distance spawning migrations.	11, 34
		Oncorhynchus gorbuscha	Pink Salmon	–	1000+	–	20-50	40	Long distance spawning migrations.	11, 34
		Oncorhynchus nerka	Sockeye Salmon	–	1000+	–	0-20	37	Long distance spawning migrations.	11, 34
		Oncorhynchus clarkii	Cutthroat Trout	–	10-50	–	–	–	Cutthroats and Steelhead migration out of streams - stick around in estuaries - about 8 km from creek mouth.	78
		Salvelinus malma lordi	Dolly Varden	114±33 206±62	10-50	38	–	–	In Alaska, tagging studies identified nearshore and offshore dispersers (38-140 km (mean 114±33 km) nearshore; 319-435 km (376±35 km) offshore).	18
		Oncorhynchus mykiss	Steelhead	–	1000+	–	0-20	23	Long distance spawning migrations.	11, 34, 78

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Rockfish	*Sebastes melanops*	Black Rockfish	0-619 (0.5)	<1	0.5	0-55	366	Tagged individuals mostly have very restricted movements (<500 m) for long periods, but are documented to relocate long distances periodically.	11, 33 65, 70, 85
		Sebastes pinniger	Canary Rockfish	Up to 700	50-1000	700	50-250	425	Capable of major movement.	11, 38, 58, 65, 69, 74
		Sebastes nebulosus	China Rockfish	Up to 0.01	<0.05	0.01	18-92	128	Tagging studies showed minimal movement and high site fidelity.	11, 58, 65, 74
		Sebastes caurinus	Copper Rockfish	0-0.3	<1	0.3	0-20	183	Home range most commonly reported as 'limited' (<30 m^2). Larger home ranges observed in low relief habitats (4000 m^2).	11, 65, 72, 106
		Sebastes nigrocinctus	Tiger Rockfish	0.02-0.03	<0.05	0.03	21-140	298	High site fidelity. Territorial.	11, 38, 65
		Sebastes maliger	Quillback Rockfish	0-2.8 (<0.05)	<1	0.05	14-143	2000	Home range most commonly reported as 'limited' (<30 m^2). Larger home ranges observed in low relief habitats (4000 m^2).	11, 65, 72, 111
		Sebastes miniatus	Vermilion Rockfish	–	1 to 10	–	15-274 (50-150)	436	Vermilion rockfish are usually found aggregating near or slightly above the bottom, often over high relief or artificial structures. Occur in shallow water when young and in deeper water as larger adults . Adults occur at depths up to 436 m, and commonly occur at 50-150 m. They probably move from reef to reef, particularly in deep water, but it is unknown how far they move. Results of tagging studies conducted off of central California suggested that this species has strong site fidelity and moves very little from its primary habitat type. Movements off reefs may be associated with following schools of prey such as squid. (1-10 km range inferred).	65, 74
		Sebastes ruberrimus	Yelloweye Rockfish	–	<0.05	0.05	50-200	2000	Sedentary and likely to have limited movement. (Small movement category inferred).	11,38, 65, 111
		Sebastes flavidus	Yellowtail Rockfish	140-1400	50-1000	770	90-180	549	Most show considerable movement	11, 58, 65, 70, 74
	Sturgeons	*Acipenser medirostris*	Green sturgeon	221-968	50-1000	594.5	40-70	100	Migratory species.	11, 24
Invertebrates	Coldwater corals	Antipatharia	Black corals	–	0	0.01	100-200	1000	Sessile. Typically found in relatively shallow continental shelf and slope waters, 50-1000 m depth, including shelf-edge canyons, deep channels between fishing banks.and on fjord walls. Limited submersible data to 367 m there found that corals were most abundant between 100-200 m, with mean coral abundance far exceeding that reported for other high-latitude ecosystems.	48, 90, 99

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Invertebrates	Coldwater corals	Scleractinia	Hard or stony corals	–	0	0.01	100-200	1000	Sessile. Typically found in relatively shallow continental shelf and slope waters, 50-1000 m depth, including shelf-edge canyons, deep channels between fishing banks.and on fjord walls. Limited submersible data to 367 m there found that corals were most abundant between 100-200 m, with mean coral abundance far exceeding that reported for other high-latitude ecosystems.	48, 90, 99
		Pennatulacea	Sea pens	–	<0.05	0.05	–	–	Sea pens live in unconsolidated ocean bottom sediments. They are not fastened to the substrate and are capable of locomotion by crawling out of the sediment, inflating with water, and drifting in the currents. However, they are considered sessile. Orange sea pens are found throughout the northeastern Pacific from Alaska to Southern California at a depth range that includes the lowest intertidal zone to depths of about 150 m, but they are most abundant in shallow waters. (Highly limited movement inferred).	93
		Alcyonacea	Soft corals	–	0	0.01	100-200	1000	Sessile. Typically found in relatively shallow continental shelf and slope waters, 50-1000 m depth, including shelf-edge canyons, deep channels between fishing banks.and on fjord walls. Limited submersible data to 367 m there found that corals were most abundant between 100-200 m, with mean coral abundance far exceeding that reported for other high-latitude ecosystems.	48, 90, 99
	Crustaceans	*Metacarcinus magister*	Dungeness Crab	–	10-50	30	–	–	Crabs travelled distances ranging from 0.27-90.68 km (Table 1). 65% of crabs traveled <20 km, 77.7% of crabs traveled <30 km, and 95.5% of crabs traveled <50 km. Crabs moved primarily in the alongshore direction, with minimal across shelf movement.	28, 40
		Euphausiacea	Euphausiids	–	1000+	–	>20	2000	Highly mobile species.	80
		Chionoecetes bairdi	Inshore tanner crab	4.5-75	10-50	39.75	6-474	474	Tagging studies in Alaska show range averaging between 24-75 km. However, tagging in Rivers Inlet, BC showed movement to be relatively localized (maximum 4.5 km)	11, 27, 39, 54
		Pandalus platyceros	Prawn	Up to 1.7	1 to 10	1.7	100-220	485	Following maturation and migration from shallow nursery habitats, deeper residing adults remain in a restricted area (limited to the size of the habitat patch they inhabit). Diel migrations reported in more protected waters.	9, 11, 66, 67
		Pandalopsis dispar	Sidestripe Shrimp	–	U	–	>50 (90-201)	2000	Vertical and horizontal migrations observed for multiple species of Pandalus ranging from local (<16 km) to greater distances.	9, 11
	Molluscs	*Enteroctopus dofleini*	Giant Pacific Octopus	Up to 2	1 to 10	2	0-100	1500	Generally move within a relatively small area (13.2 m) with periods of larger-scale movement.	11, 17

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Invertebrates	Molluscs	*Doryteuthis opalescens*	Opal squid	–	10-50	–	20-55 for spawning	–	Opal squid inhabit continental shelf waters off the west coast of North America. Schools occur primarily in waters where temperatures range from 10-16ºC. Before reproducing, opal squid appear more dispersed, with some individuals in deeper water.However, for spawning they generally form dense schools and migrate to near shore areas of 20-55 m in depth. While these depths are typical, spawning adults have also been found depositing eggs in depths as shallow as 3 m and occasionally eggs have been observed at 200 m, on salmon net pens at 5-10 m and in the intertidal zone. At maturity they tend to form large spawning aggregations usually in relatively shallow waters.	108
		Chlamys rubida	Pink Scallop	–	<0.05	0.05	0-150	150	"Swimming" response to predators.	11, 20
		Chlamys hastata	Spiny Scallop	–	<0.05	0.05	0-150	150	"Swimming" response to predators.	11, 20
		Crassadoma gigantea	Purple hinged Rock Scallop	–	0	0.01	0-80	80	Sessile.	11, 50, 109
	Sponges	Demospongiae	Demosponges	–	0	0.01			Sessile.	60
		Hexactinellida	Glass Sponges	–	0	0.01	16-650	670	Sessile. Hexactinellids are widely distributed throughout all fjords at 16-650 m depths, and in some fjords abundances reach 240 individuals/10 m^2. In all fjords hexactinellids were most abundant at 20-260 m, even where water depths exceeded 500 m.	60
		Aphrocallistes vastus	Cloud Sponge	–	0	0.01	2-240	642	Sessile.	60
		Farrea occa	Glass Sponge	–	0	0.01	16-650	670	Sessile. Hexactinellids are widely distributed throughout all fjords at 16-650 m depths, and in some fjords abundances reach 240 individuals/10 m^2. In all fjords hexactinellids were most abundant at 20-260 m, even where water depths exceeded 500 m.	60
		Heterochone calyx	Glass Sponge	–	0	0.01	16-650	670	Sessile. Hexactinellids are widely distributed throughout all fjords at 16-650 m depths, and in some fjords abundances reach 240 individuals/10 m^2. In all fjords hexactinellids were most abundant at 20-260 m, even where water depths exceeded 500 m.	60

c) Shelf/Slope

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Flatfish	*Atheresthes stomias*	Arrowtooth	–	50-1000	525	50-500	500	Migrate from shallow water feeding grounds to continental slope for spawning (large movement category inferred).	11, 74, 83
		Microstomus pacificus	Dover Sole	37-360 (<93)	50-1000	93	50-1000	1000	Inshore (summer)- offshore (winter) movement.	6, 11, 64, 74,
		Hippoglossus stenolepis	Pacific Halibut	Up to 1420 (200)	50-1000	200	50-650	650	Onshore-offshore spawning migrations, seasonal summer site fidelity (<50 m displacement).	11, 44, 62, 63
	Ground-fish	*Anoplopoma fimbria*	Sablefish	Up to 2000 (<200)	50-1000	200	200-700	1500	Resident behaviour common (<50 km).	7, 11
	Meso-pelagic fish	*Stenobrachius leucopsarus*	Northern Lampfish	–	U	–	–	–	Movement information not available.	–
		Leuroglossus schmidti	Northern Smoothtongue	–	U	–	–	–	Movement information not available.	–
	Pelagic Fish	*Thunnus alalunga*	Albacore Tuna	>1000	1000+		0-250 (<25)	1125	Highly mobile species.	11, 14, 102
		Mola mola	Ocean Sunfish	–	1000+	–	–	–	Highly mobile species. Long-term tagging studies found that *M. mola* remained within ~300 km of the coast, and nearly all exhibited seasonal movement between the Southern California Bight and adjacent waters off northern and central Baja California, Mexico. Individuals track upwelling fronts along their migration paths, which exceeded 800 km and ranged from 6 to 128 km from the coast. Satellite tag and ecosystem data suggest that bio-physical interactions in coastal upwelling fronts create favorable foraging habitat.	105
	Rock-fish	*Sebastes proriger*	Redstripe Rockfish	–	<0.05	0.05	150-275	425	Reported as very sedentary. Minimal movement category inferred.	11, 65, 74

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Rockfish	*Sebastes crameri*	Darkblotched Rockfish	–	<1	1	150-435 m	904	Immature darkblotched rockfish have low dispersal capability (<100 km) and adults appear to be highly sedentary. Using population density estimates and genetic isolation-by-distance data, average dispersal distance of immature darkblotched rockfish is estimated to be 0.87 km. The density estimates, however, assume uniform abundance, which may not be realistic for rockfish populations. The authors also employed an alternative dispersal function independent of density, resulting in an estimate of dispersal distance of immature darkblotched rockfish of 100 km. The apparently low dispersal suggests that oceanographic and/or behavioural mechanisms play a role in larval retention despite the relatively long pelagic early development phase. In general, once mature rockfish settle in an area they tend to be extremely sedentary. Although most live at 140-210 m, they have been found 25-904 m. Young darkblotched rockfish are found shallower than many other rockfishes, often perching on the highest bit of available benthic habitat structure. They have also been seen around the bottoms of deepwater oil platforms. As they age, they move deeper, and are typically found resting on mud near boulders or cobble, not usually rising above the seafloor.	16, 65
		Sebastes elongatus	Greenstriped Rockfish		<1	1	100-250	828	Reported as sedentary. (Small movement category inferred).	11, 65, 74, 87
		Sebastolobus altivelis	Longspine Thornyhead	–	1 to 10	–	600-1000	1755	Exhibit no ontogenetic migration patterns and their mean size is similar at all depths. Adults lay lethargically on the bottom and can be approached in a submersible within a few centimeters before they swim away for several meters and then resume resting quietly on the bottom. (Movement category inferred). Off Oregon and California, found at 201-1755 m, but most common at 600-1000 m in the oxygen minimum zone. Spawn at 600-1000m. After settling at 600-1200 m, they are completely benthic and live on soft bottoms, preferably sand or mud, or in muddy areas associated with rocks and sponges. Also associated with seamounts.	64, 65, 74
		Sebastes paucispinis	Bocaccio	>12	10-50	25	50-250	475	Most tagged individuals observed to move outside of a 12 km^2 study area (estimated 10-50 km movement category).	11, 65, 74, 97
		Sebastes alutus	Pacific Ocean Perch	–	10-50	–	55-350	825	Very little movement data available. Studies report discrete populations within 30 km, which suggests movements may be limited. (Movement category inferred).	11, 35, 65, 74

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Rockfish	*Sebastolobus alascanus*	Shortspine Thornyhead	–	50-1000	–	100-850; highest abundance between 200-400	1524	Shortspine thornyheads undergo ontogenetic migration from shallow into deep water. (Large movement category inferred). Inhabit areas over the continental shelf and slope. They constitute a deep-water assemblage along with Pacific ocean perch, and darkblotched, splitnose, red-banded, and rougheye rockfishes . Shortspines occur at 20-1524 m, most commonly between 100 and 850 m. The highest abundance of adults has also been reported between 200 and 400 m. Juveniles usually occupy shallower waters than adults, usually at 100-600 m, over muddy bottoms near rocks.	65, 74
		Sebastes brevispinis	Silvergray Rockfish	–	U	–	100-300	580	No reported information on movement.	11, 65, 96
		Sebastes helvomaculatus	Rosethorn Rockfish	–	U	–	25-549; mostly between 100 to 350	549	Movements and migrations unknown. Occur at 25-549 m and are generally categorized with other deep-water rockfishes. Most (96%) occur from 100 to 350 m.	74
		Sebastes aleutianus	Rougheye Rockfish	–	U	–	Mostly between 50-450	875	Movements and migrations unknown. Common in offshore waters and rare in nearshore waters. Occur from 25 to 875 m, but about 94% occur at 50-450 m. Records of rougheye rockfish occurring to 2820 m are probably misidentification of shortraker rockfish. Have also been reported to commonly occur at 100-450 m, and 201-400 m in the Gulf of Alaska.	74
		Sebastes borealis	Shortraker Rockfish	–	U	–	50-650	875 (1200)	May perform seasonal vertical migration, with the depth range expanding during the months of June through November and decreasing from spring to autumn. Shortraker are an offshore, demersal species occurring at 0-875 m, primarily inhabiting the middle shelf to the mesobenthal slope with 95% at 50-650 m. Most common reported at 100–600 m. Found as deep as 1200 m around the Kamchatka Peninsula and most abundant in the Gulf of Alaska at 300-400 m.	74
		Sebastes melanostictus	Blackspotted Rockfish	–	U	–	–	–	Movements and migrations unknown. See rougheye rockfish.	–
		Sebastes entomelas	Widow Rockfish	–	U	–	100-350	–	Adults form dense, irregular, mid-water and semi-demersal schools deeper than 100 m at night and disperse in mid-water during the day. An acoustic survey of widow rockfish near the edge of the BC continental shelf reported that they had a strong affinity for the high-relief bottom during the day. Adults are sublittoral to bathyal over depths of 24-549 m, most commonly at 100-350 m. All life stages are pelagic, but older juveniles and adults are often associated with the bottom. Aggregations of widow rockfish have been reported around offshore seamounts, including Cobb and Bowie seamounts.	74

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Fishes	Roundfish	*Sebastes reedi*	Yellowmouth Rockfish	–	U	–	100-431 (180-275)	431	No reported information on movement. Occur at 100-431 m, usually between 180 and 275 m over rough bottom. They are found on the rocky shelf on the continental slope/basin.	74
		Gadus macrocephalus	Pacific Cod	>1000	1000+	–	50-300	900	Highly mobile species.	11, 55, 74, 83, 92
		Merluccius productus	Pacific Hake	–	1000+	–	50-200	1000	Highly migratory species on outer coast. (Large movement category inferred).	11, 25
		Theragra chalcogramma	Walleye Pollock	>500	1000+	–	100-300	970	Highly mobile species.	11, 53, 55, 79, 103, 107
	Sharks and Skates	*Hexanchus griseus*	Bluntnose Sixgill Shark	Up to 1500 (5-10)	1000+	7.5	>100	1600	Residential behaviour (movement within ~10 km) and long distance (1000+ km) ontogenetic shifts to coastal waters.	2, 11, 19
		Somniosus pacificus	Pacific Sleeper Shark	–	50-1000	100	–	–	Tagging data from Alaska indicate that Pacific sleeper sharks (76%) were within 100 km of release locations, 16% were within 100-250 km and 8% were within 250-500 km.	43
		Cetorhinus maximus	Basking Shark	120-6480 (1904)	1000+		200-1000	2000	Highly mobile species.	11, 15, 94
		Prionace glauca	Blue Shark	–	1000+	–	–	–	Highly mobile species. Probably the most wide-ranging of all sharks, found throughout tropical and temperate seas from 60°N to 50°S latitude. In the Pacific, it is present in greatest abundance between 20°N and 50°N, where it shows strong fluctuations in seasonal abundance related to population shifts northward in summer and southward in winter.	82
		Bathyraja interrupta	Sandpaper skate	–	U	–	200-500	1372	Movement information not available. Most commonly found at 200-500 m and is usually found in deeper water in the southern portion of its range, possibly to 1372 m.	26, 112, 133
		Bathyraja trachura	Roughtail Skate	–	U	–	400-2000; most commonly >600	2000	Movement information not available. Found at 213-2550 m, with abundance increasing >600 m.	74

Group	Functional Group	Species	Common Name	Home Range (Mean) [km]	Movement Category [km]	Assigned HR value [km]	Depth Range [m]	Max Depth [m]	Notes	Source
Invertebrates	Crustaceans	*Pandalus danae*	Coonstripe/ dock Shrimp	–	U	–	>50 (90-201)	2000	Vertical and horizontal migrations observed for *Pandalus* spp. ranging from local (<16 km) to greater distances.	11, 12
		Chionoecetes tanneri	Deepwater grooved tanner crab	–	10-50	30	458-1784	3000	Movement of deep water Tanner crabs are not well understood. Movement is thought to be random although some documentation of breeding migrations. Based on information for similar species, movement estimated to be <75 km over adult lifespan.	11, 39,54, 86
		Pandalus hypsinotus	Humpback Shrimp	–	U	–	>50 (90-201)	2000	Vertical and horizontal migrations observed for *Pandalus* spp. ranging from local (<16 km) to greater distances.	11, 12
		Pandalus jordani	Smooth pink shrimp	–	U	–	>50 (90-201)	2000	Vertical and horizontal migrations observed for *Pandalus* spp. ranging from local (<16 km) to greater distances.	11, 12

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APPENDIX 11: DATA AND LITERATURE ON PELAGIC LARVAL DURATION AND DISPERSAL DISTANCES TO INFORM MPA SIZE AND SPACING RECOMMENDATIONS

*Table 34. Estimated larval dispersal distances (km) based on Pelagic Larval Duration (PLD) for species found in the Northern Shelf Bioregion (Adapted from Burt et al. 2014 [4]). Dispersal distance (km) was estimated from PLD using a regression of PLD to dispersal distance reported in the literature (Dispersal distance (km) = 0.0917*PLD(hours);(Shanks 2009 [7]) n = 64,R^2 =0.48; p = 0.00001)*

Area	Group	Functional Group	Species	Common Name	PLD [hrs]	PLD [days/ months/ years]	Estimated Dispersal Distance (DD) [km] -mean	DD Lower Range [km]	DD Upper Range [km]	Source
Nearshore-Intertidal	**Plants**	Seagrasses	*Phyllospadix* sp.	Surfgrass	–	–	0.05*	–	–	1
	Invertebrates	Gastropods	*Littorina* sp.	*Littorina* Snail	720	30d	42*	2*	82*	2
		Bivalves	*Mytilus californianus*	California Mussel	216	9d	19.8	–	–	3, 4
			Clinocardium nuttalli	Cockle	216	9d	19.8	–	–	3, 4, 5
			Leukoma staminea	Littleneck Clam	504-672	21-28d	53.9	46.2	61.6	4, 5, 6
			Ruditapes philippinarum	Manila Clam	504-672	21-28d	53.9	46.2	61.6	4, 5, 6, 7
			Saxidomus gigantea	Butter Clam	672	28d	61.6	–	–	4, 5, 8, 9
			Tresus capax	Horse Clam/ Fat Gaper	576-816	24-34d	63.8	52.8	74.8	4, 5
			Tresus nuttallii	Horse Clam/ Pacific Gaper	576-816	24-34d	63.8	52.8	74.8	4, 5
		Barnacles	*Pollicipes polymerus*	Gooseneck Barnacle	504	21d	46.2	–	–	3, 4, 5
Nearshore-Subtidal	**Plants**	Large algae	*Macrocystis* sp.	Giant Kelp	32	1.3d	2.9	–	–	1, 2, 4, 7
		Seagrasses	*Zostera marina*	Eelgrass	–	–	6*	–	–	2
	Invertebrates	Abalone	*Haliotis kamtschatkana*	Northern Abalone	168-288	7-12d	28.6	15.4	26.4	3, 4, 5, 10
		Bivalves	*Panopea generosa*	Geoduck	384-1128	16-47d	69.3	35.2	103.4	4, 5, 12, 13, 14
			Crassadoma gigantea	Purple-hinged Rock Scallop	504-672	21-28d	53.9	46.2	61.6	4, 11
		Cephalopods	*Enteroctopus dofleini*	Giant Pacific Octopus	720-2160	30-90d	132.0	66.0	198.4	4, 15
		Echinoderms	*Mesocentrotus franciscanus*	Red Sea Urchin	1008-1512	42-63d	115.5	92.4	138.7	4, 5, 16
			Strongylocentrotus droebachiensis	Green Sea Urchin	672-3696	28-154d	200.3	61.6	338.9	4, 5, 17, 18, 19

Area	Group	Functional Group	Species	Common Name	PLD [hrs]	PLD [days/ months/ years]	Estimated Dispersal Distance (DD) [km] -mean	DD Lower Range [km]	DD Upper Range [km]	Source
Nearshore-Subtidal	**Fishes**	Forage Fish	*Ammodytes hexapterus*	Pacific Sand Lance	2160-2880	3-4mo	231.1	198.1	264.1	4, 20, 21
			Clupea pallasii	Pacific Herring	1440-2160	2-3mo	165.1	132.1	198.1	22, 23, 24, 25
			Hypomesus pretiosus	Surf Smelt	2160	3mo	198.1	–	–	4, 26, 27
		Groundfish	*Anarrhichthys ocellatus*	Wolf-eel	2160-17520+	3mo-2yr+	902.34	198.1	1606.6	4, 28, 29, 30
			Ophiodon elongatus	Lingcod	2160	3mo	198.1	–	–	4, 31, 32
Nearshore-Offshore	**Invertebrates**	Sponges	Demospongiae	Demospongiae	–	–	0.002*	–	–	7
			Hexactinellida	Glass Sponges	–	–	0.002*	–	–	7
			Aphrocallistes vastus	Cloud Sponge	–	–	0.002*	–	–	7
			Farrea occa	*Farrea occa*	–	–	0.002*	–	–	7
			Heterochone calyx	*Heterochone calyx*	–	–	0.002*	–	–	7
		Coldwater corals	Antipatharia	Black Corals	–	–	0.05*	–	–	33
			Pennatulacea	Sea Pens	168	7d	15.4	–	–	34
		Shrimps and crabs	*Metacarcinus magister*	Dungeness Crab	1920-3840	80-160d	264.1	176.1	352.1	3, 5, 7, 35
			Pandalus borealis	Spiny/Northern Pink Shrimp	720	30d	66.0	–	–	3, 4, 5
			Pandalus danae	Coonstripe/Dock Shrimp	720	30d	66.0	–	–	3, 4, 5
			Pandalopsis dispar	Sidestripe Shrimp	720	30d	66.0	–	–	3, 4, 5
			Pandalus hypsinotus	Humpback Shrimp	720	30d	66.0	–	–	3, 4, 5
			Pandalus jordani	Smooth pink shrimp	720	30d	66.0	–	–	3, 4, 5
			Pandalus platyceros	Prawn	480-840	20-35d	60.5	44.0	77.0	4, 36, 37
		Epibenthic Bivalves	*Chlamys hastata*	Spiny Scallop	840-1008	35-42d	84.7	77.0	92.4	4, 5, 38
			Chlamys rubida	Pink Scallop	840-1008	35-42d	84.7	77.0	92.4	4, 38
		Zooplankton	Euphausiacea	Euphausiids	1440	2mo	132.1	–	–	4, 39

Area	Group	Functional Group	Species	Common Name	PLD [hrs]	PLD [days/ months/ years]	Estimated Dispersal Distance (DD) [km] -mean	DD Lower Range [km]	DD Upper Range [km]	Source
Nearshore-Offshore	**Fishes**	Rockfish	*Sebastes aleutianus*	Rougheye Rockfish	720-1440	1-2mo	99.0	66.0	132.1	4, 40
			Sebastes alutus	Pacific Ocean Perch	720-1440	1-2mo	99.0	66.0	132.1	4, 40, 41
			Sebastes brevispinis	Silvergray Rockfish	720-1440	1-2mo	99.0	–	–	4, 40
			Sebastes caurinus	Copper Rockfish	1272-1512	51-63d	127.7	116.6	138.7	4, 40, 42
			Sebastes crameri	Darkblotched Rockfish	720-1440	1-2mo	99.0	–	–	4, 40, 41
			Sebastes entomelas	Widow Rockfish	720-1440	1-2mo	99.0	–	–	4, 40
			Sebastes flavidus	Yellowtail Rockfish	2520	3.5mo	231.1	–	–	4, 40
			Sebastes maliger	Quillback Rockfish	1272-1512	51-63d	127.7	116.6	138.7	4, 40, 42, 43
			Sebastes melanops	Black Rockfish	1032-2712	43-113d	171.7	94.6	248.7	4, 40, 44
			Sebastes miniatus	Vermilion Rockfish	2520	3-4mo	231.1	–	–	41
			Sebastes nebulosus	China Rockfish	720-1440	1-2mo	99.0	66.0	132.1	4, 40
			Sebastes nigrocinctus	Tiger Rockfish	720-1440	1-2mo	99.0	–	–	4, 40, 45
			Sebastes pinniger	Canary Rockfish	2160-2880	3-4mo	231.1	198.1	264.1	4, 40
			Sebastes proriger	Redstripe Rockfish	720-1440	1-2mo	99.0	66.0	132.1	4, 40, 41
			Sebastes reedi	Yellowmouth Rockfish	720-2160	1-3mo	99.0	66.0	132.1	4, 46
			Sebastes ruberrimus	Yelloweye Rockfish	720-1440	1-2mo	99.0	66.0	132.1	4, 40, 47
		Forage Fish	*Sardinops sagax*	Pacific Sardine	1440	2mo	132.1	–	–	4, 48, 49, 50
Offshore	**Inverts**	Shrimps and crabs	*Chionoecetes bairdi*	Inshore Tanner Crab	1440	2 mo	132.1	–	–	4, 51, 52
			Chionoecetes tanneri	Deepwater Grooved Tanner Crab	2160-2880	3-4mo	231.1	198.1	264.1	4, 53, 54
	Fishes	Pelagic fish	*Thunnus alalunga*	Albacore Tuna	480	20d	44.0	–	–	4, 55, 56
		Groundfish	*Anoplopoma fimbria*	Sablefish	2160	3mo	198.1	–	–	4, 57, 58
		Roundfish	*Gadus macrocephalus*	Pacific Cod	1656-3048	69-127d	215.7	151.9	279.5	4, 48, 59
			Merluccius productus	Pacific Hake	2688	112d	246.5	–	–	4, 60, 61

Area	Group	Functional Group	Species	Common Name	PLD [hrs]	PLD [days/ months/ years]	Estimated Dispersal Distance (DD) [km] -mean	DD Lower Range [km]	DD Upper Range [km]	Source
Offshore	**Fishes**	Roundfish	*Theragra chalcogramma*	Walleye Pollock	2880	70d	264.1	–	–	4, 62, 63, 64
		Flatfish	*Atheresthes stomias*	Arrowtooth	3480	145d	319.1	–	–	4, 41, 65, 66, 67, 68
			Eopsetta jordani	Petrale Sole	4320	180d	396.1	–	–	2
			Glyptocephalus zachirus	Rex Sole	8760	1 yr	803.3	–	–	41
			Hippoglossus stenolepis	Pacific Halibut	4320	6mo	396.1	–	–	4, 29, 69, 70
			Microstomus pacificus	Dover Sole	8760-17520	1-2y	1204.9	803.3	1606.6	41, 71
		Rockfish	*Sebastes elongatus*	Greenstriped Rockfish	1440-2880	2-4mo	198.1	132.1	264.1	4, 40, 41
			Sebastes paucispinis	Bocaccio	1440-2880	2-4mo	198.1	132.1	264.1	4, 40, 41, 72
			Sebastolobus alascanus	Shortspine Thornyhead	8640-10800	12-15mo	891.3	792.3	990.4	40, 41
			Sebastolobus altivelis	Longspine Thornyhead	12768-14112	18-20mo	1232.4	1170.8	1294.1	41

* Dispersal distance assigned based on values in the literature

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APPENDIX 12: GLOSSARY OF TERMS

Biodiversity: The full range of variety and variability within and among living organisms and the ecological complexes of which they are a part (Canada – British Columbia Marine Protected Area Network Strategy 2014).

Biogenic habitat: Habitat created by a living organism (e.g., eelgrass beds, sponge reefs, etc.).

Bioregion: A biogeographic division of Canada's marine waters out to the edge of the Exclusive Economic Zone, based on attributes such as bathymetry, influence of freshwater inflows, distribution of multi-year ice, and species distribution.

Coastal and marine areas: In a Canadian MPA network planning context, this includes Canada's marine estate extending to and including the Great Lakes, from the high water mark in coastal or shoreline areas to the outer edge of the Exclusive Economic Zone.

Connectivity: Ecological spatial connectivity refers to processes by which genes, species, populations, nutrients, and/or energy move among spatially distinct populations, communities, or ecosystems (Marine Protected Area Federal Advisory Committee 2017). Genetic connectivity refers to the movement of genes (gene flow) of a single species through space. Population (or demographic) connectivity results from the movement of individuals among patchily distributed “local” or “subpopulations” of a single species. Community connectivity results from the movement of multiple species between distinct ecological communities. Ecosystem connectivity refers to the movement of multiple species among distinct ecological communities, as well as the movement of chemicals, energy, and physical materials.

Conservation: The *in situ* maintenance of ecosystems and natural and semi-natural habitats and of viable populations of species in their natural surroundings (Dudley 2013).

Conservation concern: In the context of the NSB MPA network planning process, this term applies to species which have been assessed/designated as “at risk” or of conservation concern through global, national and regional lists of conservation status (COSEWIC, SARA, IUCN Red List, the General Status of Species in Canada, NatureServe, BCList, and CITES), supplemented by expert advice for species such as invertebrates and fishes that are under-represented on formal lists (Gale et al. 2019).

Design guideline: Provides guidance on the application and implementation of the principles outlined in the Strategy. Design guidelines consider ecological, socio-economic and cultural factors in the overall design of the network to influence where MPAs are located, and how they are selected, refined, and zoned to achieve the design principles.

Design principle: Specify the design, planning and management values to which the MPA network will adhere. Together with the goals and objectives, the suite of 16 ecological, cultural, and socioeconomic guiding principles help to guide site selection and shape the network planning process (Canada – British Columbia Marine Protected Area Network Strategy 2014).

Design scenario: Informed by all previous stages of the NSB MPA network planning process, network design scenarios identify priority areas for conservation and options for possible configurations of marine protected areas in the NSB.

Design strategy: In the NSB MPA network planning context, a design strategy is a detailed statement that specifies: (1) the types of areas or features to be conserved; (2) the relative ecological conservation targets for those area types, and; (3) guidance on the size, shape, connectivity, and protection levels of MPAs.

Ecological conservation priority: A species, habitat or other ecological feature that the MPA network aims to protect. Fine-filter features are priority species or spatially discrete area-based features. Coarse-filter features are broad-scale ecological classification systems that span the bioregion. Identified in Gale et al. (2019) for the NSB MPA network planning process.

Ecological conservation target: The amount or proportion of each spatial feature representing each ecological conservation priority that is recommended for inclusion in the MPA network, described as a range following best practices for Marxan analyses. Target ranges were developed based on the attributes of the conservation priorities (e.g., Steller sea lion) and applied to the spatial features representing each conservation priority (e.g., Steller sea lion rookeries).

Ecological role: Within the NSB MPA network planning context, species were assessed for inclusion as a conservation priority in part due to their role(s) as an upper level predator, forage species, nutrient transporter and/or structural species.

Ecologically and Biologically Significant Area (EBSA): Area deemed to be ecologically or biologically significant because of either its structural properties and/or the function that it serves in an ecosystem (DFO 2004).

Ecosections: Habitat classification based on broad-scale oceanographic and physiographic variations in the Canadian Pacific, with units 100–1000s of km in extent (Province of British Columbia). Ecosections in the NSB include: North Coast Fjords, Johnstone Strait, Queen Charlotte Sound, Queen Charlotte Strait, Strait of Georgia, Continental Slope, Dixon Entrance, Hecate Strait, Subarctic Pacific, Transitional Pacific, and Vancouver Island Shelf.

Highly mobile species: Within the NSB bioregion MPA network planning context, highly mobile species are those with adult movement ranges beyond 50 km.

Marine protected area (MPA): A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley 2013).

MPA network: A collection of individual MPAs that operates cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfill ecological aims more effectively and comprehensively than individual sites could alone (IUCN-WCPA 2007).

Marxan: A software program that uses simulated annealing to generate spatial reserve systems that achieve particular biodiversity representation goals with reasonable optimality. It is a decision support tool that is being used iteratively to assist NSB MPA network design.

MPA performance scaling factor: Scores derived from a global meta-analysis of fully and partially protected MPAs compared to open-fishing areas that estimate the impacts on fish assemblages based on the level of protection afforded to the MPA. Within the NSB MPA network planning context, MPA performance scaling factors are used to assess how well a potential design scenario meets ecological conservation targets in combination with a matrix of interactions between E-CPs and human activities.

Network objective: High-level statement that outlines what the NSB MPA network aims to achieve and describes a desired future state for a particular value. The network objectives identify and focus management priorities, provide a context for resolving issues, a rationale for decisions, and a means for assessing network effectiveness. Similar to ‘strategic objectives’ defined in MPA network planning processes in other Canadian bioregions.

Northern Shelf Bioregion (NSB): One of 13 ecologically distinct bioregions that have been delineated in Canada’s oceans and the Great lakes. The NSB covers 101,328 km^2, including two-thirds of the BC coastline, and extends from Quadra Island/Bute Inlet north to the Canada-Alaska border and out to the base of the continental slope.

Patch: A spatially contiguous and relatively homogenous unit of an ecological feature that is discrete from surrounding areas (e.g., individual eelgrass bed; seabird colony buffered to incorporate marine use area around the colony).

Pelagic larval duration (PLD): Amount of time a larva spends in the water prior to settling.

Representation: An MPA network design principle that prescribes the inclusion of areas representing the different biogeographical subdivisions of the global oceans and regional seas that reasonably reflect the full range of ecosystems, including the biotic and habitat diversity of those marine ecosystems (CBD 2008).

Replication: An MPA network design principle that prescribes the inclusion of spatially separated replicates of representative habitats and special or vulnerable features within MPA sites to provide insurance against uncertainty, natural variations, and local disturbances or environmental disasters (CBD 2008).

Spatial feature: A specific feature representing a conservation priority within the marine ecosystem that can be mapped spatially and assigned an ecological conservation target.

Subregion: A planning area demarcated with a combination of First Nation territorial and local government administrative boundaries and similar ecological characteristics in the NSB. The subregions include: Haida Gwaii, North Coast, Central Coast, and North Vancouver Island.

APPENDIX 12 REFERENCES

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