BALANCING CONSERVATION AND NEARSHORE FISHERIES: A COMPARATIVE SPATIAL ANALYSIS OF TWO MARINE RESERVE NETWORKS IN OREGON

By

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A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

WASHINGTON STATE UNIVERSITY
School of the Environment

May 2013

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ACKNOWLEDGEMENT

This research was supported by generous and seemingly endless teaching assistantships at WSUV, a GK-12 fellowship from the National Science Foundation, and the Hershman and Knauss fellowships from WA Sea Grant.

My research has been smelted several times, and the impurities that may remain are no fault of my committee. Brian Tissot, thank you for the inspiration for this project and motivation to keep it going despite my best distractions. John Bishop, thank you for removing the slag and your insightful comments. Mark Stephan, thank you for patience and acceptance.

I am grateful to the various sources of data – both data requested and those borrowed from the internet. Specifically, this thesis would not have happened if not for many people at the Marine Resources Program ODFW – thank you to Melissa Murphey, Cristen Don, Alix Laferriere, Anna Pakenham, Dave Fox, Mark Freeman, Mark Karnowski, Kelly Corbett, Justin Ainsworth, Troy Buell, and Mitch Vance. Also, thank you to Chris Romsos at OSU.

Over the past five years I have been honored to have a series of thoughtful, effective, and inspiring mentors. Penny Dalton, thank you for your patience, belief in my abilities, and guidance through the minutia of fellowships, academia, and public service. Brian Lynn, thank you for the perspective and wit - I will always remember the presentation you gave during the Western Coastal Managers' Meeting and that you had the room in stitches from 700 miles away. Jennifer Hennessey, thank you for taking the training wheels off my fellowship when you went on maternity leave, I was scared. Kristy Schneider, thank you for helping me understand children and not letting me be one.

During my time in Pullman and Vancouver, I have met some well-rounded individuals that have supported my education and general happiness. Among those that have directly contributed to my thesis are Josh Emerson, Todd Stevenson, Emily Munday, Erica Henry, Joanne Breckenridge, Jen Blaine, Sean Rooney, Molly Bogeberg, Katie Wrubel, Laura Friedenburg, Chris Pell, Laura Johnston, Kate Skaggs, and Krista Sirois; but of course there are too many to list here, so I thank you all.

Finally, I want to express my deepest thanks to my supportive and loving family including my parents Don and Celia, my sisters Sara, Andrea, and Laura, my brothers-in-law Jason, David, and Jonathan, my grandmothers Mary and Alder, my aunts Gaby, Susi, Peg, and Steph, my uncles Alan, Dennis, and Sam, and my cousins. Of course I also want to thank the 11 (at the time of this writing) nieces and nephews Andrew, Mat, Unnamed1, Savannah, Gabriel, Caroline, Lydia, Isabelle, Ethan, Ezekiel, and Unnamed2 who are ever-growing and never-boring.

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Abstract

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May 2013

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Marine conservation efforts, specifically marine protected areas (MPAs), are important recourses for balancing the often opposing values inherent in economic growth and environmental impacts. Following a yearlong proposal process, the Oregon Ocean Policy Advisory Council (OPAC) approved a network of five sites, with the goal of protecting the biodiversity of the state's nearshore marine ecosystem without adversely affecting the socioeconomics of coastal communities. However, from the pool of proposals OPAC selected, only one used fisheries data to quantify the potential impacts, and none used uniform and spatially explicit data to quantify the ecological benefits of the proposed sites. To understand how data might inform the MPA proposal process we added uniform, quantitative, and spatially explicit data for fisheries, physical, and ecological characteristics to the original site proposals. We then compared the network selected by OPAC to a network proposed by a conservation group, *Our Ocean*, and identified the tradeoffs of each network, and also at one site in particular, Cascade Head. Overall, we found that the *Our Ocean* network covered nearly a third of the territorial sea, had large sites with diverse habitats, and harbored many more marine mammals and seabirds with a 'cost' of approximately twice the impact to the important fisheries in the

territorial sea when compared to the OPAC network, and therefore the tradeoffs were not equal between the two network scenarios. Understanding the balance between fisheries and conservation of these two networks shed light on the efficacy of the proposal process, highlighted the importance of data gaps in such a process, and provided feedback to the state on future site selection.

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INTRODUCTION

Marine Conservation

The ocean is subjected to many anthropogenic stressors such as pollution, climate change, fishing pressure, as well as their cumulative impacts (Suchanek 1994, Vitousek, et al. 1997, Halpern, Walbridge, et al. 2008). Together these stressors can change physical and biological characteristics, degrade overall resilience, and threaten ecosystem services of the ocean (Pauly and Alder 2005, Murray, et al. 1999). To avoid further degradation of ecosystem services, policy-makers and resource managers have shifted toward a precautionary approach employing various marine conservation methods to deal with the uncertainty posed by large ecosystems (Lauck 1998, U.N. Conference on Environment and Development 1992). The challenge of marine conservation lies in striking a balance between anthropogenic stress and ocean productivity while minimizing social and economic impacts. The goal of this paper is to examine the balance between environmental protection and fishery productivity made by the state of Oregon in designing a network of marine reserves.

Among the strategies and tools for conserving marine resources are marine protected areas (MPAs) and the most restrictive type of MPA, the marine reserve (MR). Generally, MPAs vary in restrictions, may allow some types of extractive activities, but have some level of protection or goal for conservation. In contrast, MRs prohibit all extractive activities such as fishing, harvesting, drilling, and dredging (Lubchenco, Palumbi and Gaines 2001). Conservation objectives for MPAs and MRs can include protection of life stages, protection of biodiversity, precautionary and ecosystem-based approaches to management, enhancement of non-extractive activities, and scientific observation and analysis (Lauck 1998, Murray, et al. 1999, J. Lubchenco, S. Palumbi, et al. 2003). In Oregon, the conservation goals of the proposed MPAs and MRs were to protect biodiversity and important habitats, while avoiding significant adverse social and economic impacts. The proposed MPAs made allowances for low-impact fishing gear, and thus combined with the proposed MR, served to increase the overall protection of marine habitats and biodiversity and minimize the potential impact to fisheries.

Current literature reviews demonstrate significant increases in biomass, density, size, and diversity of commercially important species inside MPAs relative to unprotected areas (Lester, et al. 2009). As Shears, et al. (2006) demonstrate, these benefits can hold true even in partially protected areas and over long temporal scales. Given these potential ecological benefits, it is not surprising that reserves have been suggested to restore fisheries, and to safeguard against natural catastrophes (Lauck 1998). Besides the benefits to fisheries, the ecological health of the reserve, in terms of promoting strong community structure and interactions, can be maintained (Guidetti 2006). Additionally, elements of reserve design, such as habitat heterogeneity and structure, or the physical characteristics of the site can influence the diversity of fish assemblages (Garcia-Charton, et al. 2004, Aburto-Oropeza and Balart 2001), and modeling exercises show that given the appropriate size and spacing for MPAs larval transport and replenishment can be beneficial to both fisheries and protection of biodiversity (Hastings and Botsford 2003).

Despite the evidence for ecological benefits, the economic and social impacts of MPAs are less clear and more difficult to understand because short-term losses may mask the long-term benefits to many users (Murray, et al. 1999, Pauly and Alder 2005). Thus, it is equally important to quantify the impact to the current extractive users of the coastal and marine areas (Christie, et al. 2003, Mascia, Claus and Naidoo 2010). Economic modeling studies demonstrate that when designing a MPA, the immediate impact to fisheries decrease if more detailed and spatial fisheries information is used to avoid profitable sites (Richardson, et al. 2006), and that a lack of information on the distribution of fishing effort during MPA planning can result in misleading conclusions regarding the potential success, and make it more difficult to objectively balance the costs with the benefits of MPAs (Smith and Wilen 2003).

Although the science of MPAs is developing, guidance, quantitative measures, and methods of designing MR networks have been proposed, including bioeconomic modeling (Sanchirico 2004), siting algorithms (Villa, et al. 2002, Leslie, et al. 2003), and multi-criteria analysis (Brown, et al. 2001). The various methods are used in different planning environments that can range from highly participatory, scientific, driven by managers, or a mix of these environments (Saarman and Carr 2013). In this paper, we examine the Oregon process for developing a network of MRs and MPAs, and analyze the tradeoffs made between potential conservation benefits and potential negative impacts in two networks which illustrate the importance of quantitative and objective biological and fishery data to a MR designation process.

Oregon's MPA Process

The process of MPA development in Oregon began in July of 2000 with a request for information about MRs from Governor John Kitzhaber to the Oregon Ocean Policy Advisory Council (OPAC). In 2002, OPAC produced initial recommendations for further review and analysis of MPA establishment in the Oregon territorial sea. However, it was not until Governor Ted Kulongoski's issued Executive Order 08-07 in March 2008 that Oregon began a public process to establish a network of MPAs within the territorial sea to preserve biodiversity of the state's nearshore marine ecosystem while not adversely affecting the socioeconomic status quo of coastal communities (Kulongoski 2008).

The initial site proposal process began in June 2008, when OPAC issued a directive on the content of proposals. The OPAC worksheet asked proposing groups for information on the characteristics of each nominated site, including:

1. How scientific evaluation is facilitated;
2. How adverse economic and social impacts are avoided;
3. What organisms and habitats are present;
4. How enforcement is facilitated;
5. What community support exists; and
6. What potential research can be conducted.

Question 2, regarding avoidance of adverse economic and social impacts, was particularly interesting as only one proposal (Redfish Rocks) *quantified* the impact to fisheries; instead, most proposals provided a *qualitative* description of impacts and displacement of fisheries to other places. However, these approaches were either not uniform, or were not quantitative and spatially explicit. Both Questions 1 and 3 were also dealt with in a cursory fashion in the proposals, and without uniform data or sources of information. The Redfish Rocks proposal did quantify the potential impact to fisheries but cited data collected by a method unique to the port of Port Orford at the time (Billings and Golden 2008).

The nomination process for MR sites yielded 20 proposals, covering 9 unique areas within the Oregon territorial sea. Proposals came from various community groups and individuals along the coast, some of which collaborated closely with local fishermen while others did not. *Our Ocean*, a coalition of conservation groups, scientists, and local representatives including some fishermen, submitted eight proposals that were designed as an integrated network along the coast (Figure 1). The *Our Ocean* proposals included both MRs and adjacent MPAs in seven of eight proposals. The intent of this approach was to increase overall protection while reducing adverse impacts to important fisheries in the MPAs that use low-impact gear, such as the crab (pots) and nearshore (hook-and-line, pot, and jig) fisheries.

At OPAC's November 2008 meeting, final proposals were reviewed, voted on, and six of the 20 sites were recommended to Gov. Kulongoski. Both Redfish Rocks and Otter Rock were recommended as pilot sites, along with Cape Falcon, Cascade Head, Cape Perpetua, and Cape Arago recommended for further analysis by the state and adjacent communities before implementation (McMullen 2008) (Figure 1). Cape Arago was later dropped from the process and is not studied here. Of these six sites, only the Redfish Rocks MR was approved with an adjacent MPA, while the approved sites were exclusively MRs. In March of 2009, Oregon legislators approved, and Gov. Kulongoski signed into law, House Bill 3013 which codified the recommendations of OPAC. This law provided a funding mechanism and charged the Oregon Department of Fish and Wildlife (ODFW) to spearhead the effort of evaluating Cape Falcon, Cascade Head, and Cape Perpetua for further consideration sites through a public process.

Goals of Study

This study, focused on two goals for the Oregon MPA proposal and selection processes: 1) to protect nearshore biodiversity and; 2) to avoid significant adverse economic or social impacts to coastal communities. Around these goals several policies and guidelines were established to impart transparency and clarity to the process (OPAC 2008a, OPAC 2008b). However, we observed that the submitted proposals lacked relevant and uniform data, which drove us to question the objectivity of the decision-making process. Almost no fisheries data were used to address impacts of individual reserve sites; instead, most impacts to fisheries were anecdotally qualified. Similarly, ecological data included in the proposals were estimated and not quantified in a uniform way. To address the lack of quantitative and spatially-explicit data, we gathered spatially-explicit fisheries and ecological data to augment the original proposals and evaluate the tradeoffs between potential impacts to fisheries and the ecological benefits in two different networks – the network of five sites chosen by OPAC, and the eight sites proposed by *Our Ocean*. Accordingly, the objectives for this thesis are:

1. Add quantitative information to the original data-poor proposals;

2. Analyze potential impacts to fisheries and ecological benefits of each site;

3. Compare these tradeoffs at the network level for both networks and at one specific site (Cascade Head); and,

4. Illustrate the importance of data in a quantitative process for MPA designation.

Together these objectives will meet our goals of examining the process Oregon used to create the network of five MPAs, and suggestions for improvements to that process.

METHODS

Network and Site Specific Comparisons

The criteria chosen to compare the MPA networks were obtained from documents produced by the state of Oregon, such as the objectives and guidelines established by Governor Kulongoski, and OPAC's Scientific and Technical Advisory Committee's (STAC) recommendations on size and spacing of MPAs. The Governor stipulated that a network of no more than nine reserves should be created in the Oregon territorial sea to protect biodiversity and allow for scientific evaluation of ecological benefits while avoiding significant economic or social impact (Kulongoski 2008, McMullen 2008). Among STAC's recommendations were the minimum recommended size, spacing, bioregions, and habitats that should be protected in the territorial sea (Heppell, Barth and Reiff 2008). In addition to using these criteria, we examined the ecological significance of each site and their associated networks. None of the literature offered an explicit definition or metric for 'significant economic or social impact' (Hanna and Sampson 2008, McMullen 2008), and thus it was not explored in this analysis; however, the comparison of the *potential* economic impact attributed to each network is useful, and can be quantified to some extent using spatially-explicit commercial fishery landing data. We applied these analyses to Cascade Head as one specific site in both networks, to illustrate tradeoffs between ecological value and potential adverse impacts.

Data Compilation and Processing

Data were evaluated based on three broad categories: size and spacing, biodiversity, and economic value. The data available to characterize the ecological attributes (size and spacing and biodiversity) were ocean depth ranges, reserve boundaries, the primary seafloor lithology (a proxy for habitat), diversity of habitats, potential species richness, number of marine mammal haulouts, and number of seabird nesting sites. The economic value of sites was quantified by summarizing logbook data that was available for three fisheries – trawl, nearshore, and crab (Table 1). All spatial analyses were conducted using the ArcINFO package of ArcGIS Desktop version 10 by Environmental Systems Research Institute, and several extensions of the program. The datasets used in this study were provided by multiple federal, state, and academic sources and were delivered in various coordinate systems and datums. To conduct uniform and accurate spatial analyses and measurements, all datasets were transformed to the Universal Transverse Mercator Zone 10N (UTM Zone 10N) projected coordinate system and the World Geodetic

System 1984 (WGS 84) datum. This coordinate system and datum are well suited for spatial analyses specific to the coast of Oregon, and yield distance and areal measurements in metric units.

Potential Ecological Value

For this study, one potential "ecological value" of a site or network is maximization of biodiversity protection, characterized by habitat and species diversity, relative to other sites or networks. Habitat diversity was quantified by measuring the predominant benthic substrate, or primary lithology, which is widely used as an indicator of associated communities of animals (Fox, Amend and Merems 1999, Whitmire, et al. 2007, Hixon, Tissot and Pearcy 1991). The lithology GIS layer used to measure habitats was 2008 Version 3 Surficial Geologic Habitat Maps for Oregon, and was product of the Active Tectonic and Seafloor Mapping Lab at Oregon State University. These layers were produced through an interpretive process that is based on data collected through several techniques including seafloor sampling, multibeam bathymetry, backscatter and sidescan sonar (Goldfinger 2009).

For the Oregon territorial sea, habitas were classified into seven general types: sand, shell, mud, rock, gravel, boulder and cobble, although not all were represented at each of the proposed sites. The area of each habitat type was measured for each site using the Intersect tool in ArcMap 10, and the number of types was reported as habitat richness for each site. The boundaries of each MPA and MR were imposed on the habitat layer by creating new polygons for each patch of habitat within the sites. Areas were measured using the Calculate Geometry tool of ArcGIS 10, and then summed by habitat type within each site, and across networks. Using these areas, the Shannon Diversity Index (H') was calculated using the proportion of each habitat at a site (p_i) to quantify the richness and evenness of habitats across each site.

$$H' = -\sum_{i=1}^{H} (p_i \ln p_i)$$

The remainder of the ecological data used in the study was downloaded from the Pacific Coast Ocean Observing System (PaCOOS) West Coast Habitat Portal (PaCOOS n.d.). The PaCOOS portal offers a habitat use database, developed by the National Oceanic and Atmospheric Administration (NOAA) Northwest Fisheries Science Center. The habitat use database can be queried through an interactive map where users select an area and lists of the potential species present will pop-up based on the depth, species' geographic ranges, and habitats present in the selection. The total number of species on the list is the potential species richness for the area selected, and is a uniform way of collecting the data across all sites as field observations and studies have not been conducted in all of the sites in question (Heppell, Barth and Reiff 2008). Within each MPA and MR, a species list was generated for each of the habitat types present, in both the shallow and deep portions (above and below ~30 meters depth) of the site. The resulting species lists were exported to Microsoft Access for sorting and counting. Next, a 1 km^2 grid layer for each site was created in ArcGIS, and 1 km^2 cells were labeled. In each grid cell species richness was calculated by finding the unique and common species between all habitat types found in that cell. In this way, potential species richness was estimated for each square kilometer of each MPA and MR in both networks. Species-area curves were then created for both network proposals in Primer 5, using 500 permutations of the original data. Range size for each species was calculated as the total number of square kilometers, or grid cells, in which a given species was expected to be present in all sites and for both networks, which is the potential area of protection each site or network offered each species. Finally, the median and mean range sizes for each site and network were also calculated.

Both seabird nest sites and marine mammal haulouts were mapped and counted. The Oregon Seabird Colony Locations layer (PaCOOS n.d.), last updated by the U.S. Fish and Wildlife Service (USFWS) in 2008 (Naughton, et al. 2007), was used to estimate the number of seabird colonies found within each site. On the coastal bluffs, and offshore rocks and islands of the Oregon territorial sea, a total of 393 seabird colonies were found that included 15 species of seabirds, most common among them were the pigeon guillemot (*Cepphus columba*), the glaucous-winged gull (*Larus glaucescens*), and the pelagic cormorant (*Phalacrocorax pelagicus*). The point data represent the centroids of rocks, islands, or onshore groups of nests where surveyors recorded seabird nesting and resting. The dataset is redundant spatially, as some rocks can have more than one point at the site because of the presence of several species, each with its' own point, or more than one year of sampling. In this study we counted each rock or island once, despite the total number of points found, and we used the most recent year (2006) of data as a snapshot of seabird colonies. After the data were downloaded from PaCOOS, all entries for 2006 were selected and exported to create a data layer. The Select By Location tool of ArcGIS 10 was used to identify and count seabird colonies (only once in the case of redundancy) within each MR/MPA within each of the two networks.

The Marine Mammal Haulout Sites layer, also downloaded from PaCOOS, was last updated by ODFW Marine Mammal Research Program staff in 2007, and includes average counts from aerial surveys over the preceding 5-10 years (Pitcher, et al. 2007). This point data layer describes 114 known areas of marine mammal haulouts, rookeries, and more general-use areas, and represents the centroid of those areas for several species - Pacific harbor seals (*Phoca vitulina*), northern elephant seals (*Mirounga angustirostris*), Steller sea lions (*Eumetopias* *jubatus)*, and California sea lions (*Zalophus californianus*). The Select By Location tool was used to identify and count haulout sites within each MR/MPA across the two networks.

Potential Economic Value

One aspect of potential "economic value" was assessed based on reported commercial fisheries landings. The analysis was limited to only those fishery logbooks readily available in a digital format such as spreadsheets or databases, and did not include data from anecdotally important fisheries such as the recreational and salmon fisheries. Logbook information was requested from the ODFW Marine Resources Program for several fisheries including the nearshore, trawl, crab fisheries (Table 1). ODFW staff provided a summarized table of the Dungeness crab (*Cancer magister*) fishery data for each site in both networks. Nearshore and trawl data were summarized for each network and site by the author during temporary employment at ODFW.

Strict confidentiality rules apply to the use of Oregon logbook data, and data are not released for a given area and time period if less than three unique vessels are represented in the data. We assumed that this loss of data was negligible as even where the minimum three vessels fished those catches were generally low. Dollar values were provided in the data package for the crab fishery by the Marine Resources Program at ODFW; however, values had to be estimated for the nearshore and trawl fisheries using ex-vessel price (the price paid to fishermen at the time of landing the catch) and landings data from the ODFW Landing Statistics website (ODFW Fish Division 2013) to calculate average price per metric ton for species caught in the trawl and nearshore fisheries for each year in the study period. Data were reported in metric tons (mt), dollar amount ($), and percentage of the total fishery. All dollar values were adjusted to 2008 values.

Trawl Logbook (Point Data) Analysis

The trawl fishery off the coast of Oregon occurs mostly in federal waters, and targets many groundfish and pelagic species. Within state waters, the targets of the trawl fishery are largely flatfish (Pleuronectiformes) with an occasional pelagic tow for Pacific hake (*Merluccius productus*). The logbook provided coordinates (latitude and longitude) of fishing activities, which were used to create point features in a geographic information system (GIS). Trawlers recorded beginning and end location in the logbooks, however, in between these two points the behavior and location of fishing activities are unknown. Therefore, only the beginning locations of tows inside of proposed MR and MPA were used to estimate catch within a reserve while sets that start outside but end inside the sites were ignored. This is justified by the assumption that these two scenarios on average will offset each other and thus the data will accurately represent trawling within the reserve.

Each record in the logbook contains a gross adjusted weight for each tow. The gross adjusted weight is a proportional amount, calculated by dividing the vessel hail weight for each tow (captain's visual estimate of catch as it comes on board) by the total landing weight for the trip (measured by a scale at the dock), and using this proportion to calculate the weight attributable to a given tow. By reviewing the attribute table of the selected points, catches were totaled using the gross adjusted weight column. Within each fishery, metric tons of fish over all years were summed, and divided by the total number of years studied. This approach yielded catch in metric tons for each year in the study period for each fishery in each proposed MR and MPA, these values were then averaged over those years. The individual year catches were multiplied by average price per metric ton for species for the appropriate years, and those dollar values were averaged over the years studied.

Nearshore Logbook (Polygon Data) Analysis

The nearshore fishery is a small commercial fishery that targets groundfish such as lingcod (*Ophiodon elongatus*), rockfish (Sebastidae), greenlings (Hexagrammidae), and cabezon (*Scorpaenichthys marmoratus)* with hook and line, longline, pot or trap gear. The ODFW requires fishermen to report where fishing occurred in a 1' x 1' (in minutes) geographic grid, where each block of this grid was represented as a polygon in the GIS. Consequently, for this study we developed a method to identify how much of each fishing block overlapped proposed MRs and MPAs by assuming that fishing catch data were uniform over the blocks; i.e., any fraction of the entire block contained a similar fraction of the entire catch from that block.

The catch information contained in the nearshore logbook was the captain's hail weight – an eyeball estimate that can vary in accuracy based on the experience of the captain. This measure of catch is the best alternative in the nearshore fishery because of the several confounding issues associated with using weights measured at delivery. Fish tickets are issued by land-based processors for every delivery made by a vessel. These tickets list the weight of each species caught on a trip, and the nearshore blocks (a grid issued by ODFW for this fishery) in which the fisherman operated. However, the fish ticket does not attribute the weight information to the various blocks fished, and therefore is not spatially explicit.

For the nearshore catch data, a similar 1'x1' geographic grid was recreated in the GIS labeled with the fishing block numbers used by ODFW. Using the Intersect tool, the fishing blocks were intersected with the proposed networks, creating a layer where only the portions of fishing blocks that fell inside reserve boundaries were kept. The areas of overlap of fishing and reserve polygons were calculated, and divided by the original area of each grid cell, yielding the proportion of each MR or MPA that overlapped the nearshore grid. These proportions were used to calculate the proportion of catch that can be attributed to the overlapping areas inside the MRs and MPAs. This process was performed for each of the three years of data, and averaged across those years. Each individual year's catch was multiplied by the average price per metric ton for appropriate years for the four species in the fishery, and those dollar values were averaged over the study period, after being adjusted to 2008 dollars.

RESULTS

Size and Spacing

The overall area of the OPAC proposed network was 238 km^2 and the *Our Ocean* network was 1,043 km^2. These areas represented 7% and 32% of the territorial sea, respectively. The OPAC network was composed of 94% MRs and 6% MPA, while the *Our Ocean* network included 44% MRs and 56% MPAs. The STAC recommended minimum alongshore length for each reserve was 5-10 km, with a preferred length of 10-20 km. The only reserves that did not meet the minimum guidelines for alongshore length were the pilot sites, Redfish Rocks and Otter Rock, two of the five in the OPAC network.

Overall, the total alongshore length of the OPAC network was shorter than that of the *Our Ocean* network, at 50 and 185 km respectively (Table 2). The STAC recommended that sites in a network be spaced approximately 50-100 km apart. The *Our Ocean* network satisfied the spacing guideline with a range of 0-100 km spacing between all sites (some sites were directly adjacent), and an average of 45 km between sites. However, the OPAC network did not meet this guideline with a range of 29-160 km and an average spacing of 76 km, and a large gap of 160 km was measured between Redfish Rocks and Cape Perpetua. The *Our Ocean* network also encompassed deeper water than the OPAC network, as average maximum depths were 69 and 57 m, respectively. The STAC recommended that reserves span a large range of depths to maximize protection for many life stages. Both networks include at least one reserve to the South of Cape Blanco, Redfish Rocks (OPAC) and Mack Reef (*Our Ocean*) however neither contained replicates within that bioregion (only one South of Cape Blanco) as suggested by the STAC (Heppell, Barth and Reiff 2008).

Potential Ecological Value

The Oregon territorial sea is dominated by sandy habitat, and the same trend was found in both the OPAC (94%) and *Our Ocean* (86%) networks (Table 2). Rock habitats were second in abundance in both networks, and distributed throughout both. In the OPAC network, rock habitat comprised 7.6 km^2 or about 3% of the network (Table 2). The largest nearly-contiguous rock habitat was 2.5 km^2 at Redfish Rocks MR. The *Our Ocean* network contained much larger rocky reef complexes that spanned several sites, e.g. Siletz Reef at Cascade Head MR and MPA spanned approximately 20 km^2. Rock habitats were more abundant in the *Our Ocean* network, and comprised 60.7 km^2 or about 6% of the network. Mud habitats in both networks were primarily found at the sites South of Cape Blanco. All of the mud habitat found in OPAC was at Redfish Rocks MPA, and comprised 3.2 km^2 or about 1% of the network. Several sites in the *Our Ocean* network contained small patches of mud, but the majority, 68.3 km^2 was found at Mack Reef MPA. Overall, mud habitats in the *Our Ocean* network comprised an area of 72.8 km^2 or about 7% of the network. Relatively small areas of gravel, shell and cobble were found in both networks.

The Shannon Index (H') diversity values for each site (Table 2) in the OPAC network ranged from 0.07-0.90, with an average of 0.41. In the *Our Ocean* network, H' ranged from 0.00-0.81, with an average of 0.30. In both networks, the sites with the highest H', or highest diversity and evenness of habitats were South of Cape Blanco – Redfish Rocks MR (OPAC) and Mack Reef MPA (*Our Ocean*) where large patches of mud contributed to the increase in evenness. The Cape Perpetua MPA, in *Our Ocean,* contained only sand habitats yielding the lowest H' possible, 0.00. Similarly, Cape Falcon MR and Cascade Head MR in the OPAC network were dominated by sand habitats and also yielded the lowest H' for that network, 0.07. When H' was plotted against the area of corresponding sites measured (Figure 2), the H' for OPAC decreased with increasing area; conversely, the *Our Ocean* network H' increased with increasing area.

Based on our sampling of the NOAA habitat use database, species richness in the two networks differed by two species: *Sebastes melanosema* (Semaphore Rockfish) and *Haliotis cracherodii* (Black Abalone). These two species were predicted to be found on shallow rock habitats at two sites in the *Our Ocean* network; however, the abalone species does not occur in Oregon and was therefore removed from subsequent analyses. Thus, apart from the rockfish mentioned above, there was no difference between the other fish, invertebrates, and plants and algae that were represented at the network level (Table 3).

Differences in species richness among habitats were found between networks (Figure 6). Gravel habitats in the *Our Ocean* network included 15 more species than in the OPAC network; those species included 11 fishes, 3 invertebrates (including *Cancer magister,* Dungeness crab), and surfgrass. Six species were present in mud habitats in the *Our Ocean* network that were not found in the OPAC network: five fishes, and a species of surfgrass. Shell habitat in *Our Ocean* also represented more species than shell habitat in OPAC – three fish and surfgrass. Finally, differences in species richness were also observed between the two depth ranges sampled in both networks (Figure 7). Deep areas of the *Our Ocean* network contained one more rockfish species, and shallow areas contained 3 more rockfish species, when compared with the OPAC depth categories.

The species-area curves generated for the two networks showed a steeper increase for species richness over area in the *Our Ocean* network, leveling off around 50 km^2 (Figure 3). The curve for the OPAC network was relatively shallower, and leveled around 100 km^2. This indicated that sampling any given area under 100 km^2, the *Our Ocean* network will likely yield a higher number of species. This was supported by the distribution of range sizes produced for each network (Figure 4). The majority (75%) of species in the *Our Ocean* network were found in range sizes larger than the entire area of the OPAC network, which was also supported by Figure 5 where the total area of habitat was higher for every species in the *Our Ocean* network. This trend indicated that a random sample of the *Our Ocean* network would likely yield more diverse results, and larger areas of important habitats are protected for a greater number of species in that network.

Marine mammal haulouts and seabird nesting sites were more abundant in the *Our Ocean* network relative to the OPAC network (Table 3). The site with the most marine mammal haulout sites was Cape Perpetua MR, which is included in both networks. All sites in the *Our Ocean* network contained at least one marine mammal haulout, except for Siltcoos MPA and Cape Perpetua MPA – both were offshore sites with no islands, emergent rocks, or beaches. Redfish Rocks MR and MPA, in the OPAC network, both did not encompass marine mammal haulout sites, despite the small islands, emergent rocks, and beaches in the MR. The *Our Ocean* network included 33% of all marine mammal haulouts in the territorial sea, and the OPAC network included 12%. Seabird nesting sites were most abundant at Cape Falcon MPA and

Mack Reef MPA in the *Our Ocean* network. The *Our Ocean* network included 57% of all seabird nesting sites in the territorial sea, and 19% were included in the OPAC network.

Potential Economic Value

Based on the commercial fisheries data, the largest fishery in terms of weight occurring off of the coast of Oregon was the trawl fishery with an average annual catch of approximately 47,800 metric tons (MT) worth $24.9 million in 2008 dollars. However, most trawling occurs offshore federal waters (> 5.5 km offshore) and not in the Oregon territorial sea. Trawling occurred in the OPAC network, however less than three unique vessels were represented in the data and therefore these could not be reported but accounted for less than 0.01% of the overall trawl fishery. Trawling occurred in all of the sites in the *Our Ocean* network; however, data from seven of the 15 were confidential and could not be reported. The remaining sites yielded an average of 18.2 MT per year, an average value of $8,630 in 2008 dollars, and represented 0.03% of the total fishery. The average for *Our Ocean* was influenced by large and uncommon catches of *Merluccius productus* (Pacific Whiting), where single catches were often 45 mt or more.

Second in catch weight, but most valuable, was the Dungeness crab fishery where approximately 5,600 metric tons were landed over the 2007-2008 season, valued at $29.2 million in 2008 dollars. This fishery also spans both state and federal waters, but a larger portion occurs in the territorial sea, and potential impacts from reserves to this fishery were higher than with the trawl fishery. All of the sites in the OPAC network, except for Otter Rock MR, were fished for Dungeness crab. Within these sites an average annual catch of 168.9 mt (3% of the fishery) occurred worth $0.9 million in 2008 dollars. All sites in the *Our Ocean* network were fished for crab, and the potential impact comprised 632.4 mt (11% of the total fishery) which was worth approximately $3.4 million in 2008 dollars.

The nearshore fishery was the smallest fishery and had a yearly average of approximately 135 mt landed over the three year period, from 2007 to 2009, worth $0.8 million dollars in 2008 dollars. This fishery almost exclusively occurred in the territorial sea over rocky habitats where the target species are found. Only Cape Perpetua MR (OPAC) which is dominated by sand did not yield any landings in this fishery. The other sites in the OPAC network yielded an average of 4.1 mt per year which was approximately 3% of the total fishery, at a value of approximately $24,400 in 2008 dollars. The impact from OPAC MRs only on the nearshore fishery was slightly less at 3.6 mt, $21,600 in 2008 dollars. Again, Cape Perpetua MR as well as Cape Perpetua MPA, Siltcoos MR and MPA did not yield any landings in this fishery for the *Our Ocean* network, due to their poor habitat for target species - rocky reefs. The remaining sites in the *Our Ocean* network yielded an average of 8.4 mt per year, or approximately 6% of the fishery, valued at $50,400 in 2008 dollars. However, looking at the *Our Ocean* MRs only, the impact was about a third less at 5 mt and $30,200 in 2008 dollars, or about 4%.

Site Specific Comparison – Cascade Head

The *Our Ocean* proposal in the Cascade Head area included both a MR and a MPA, that covered an area of 205 km^2, and had an alongshore length of 34 km. The OPAC MR at Cascade Head was smaller with an area of 62 km^2 and an alongshore length of 10 km. The *Our Ocean* MPA connected the Cascade Head MR with the Cape Foulweather MR creating a continuous protection area over 41 km alongshore (Figure 8). Comparatively, the OPAC protection in that same area by both Otter Rock MR and the Cascade Head MR comprised 14 km alongshore. In this area, the OPAC network encompasses 2.9 km^2 of rock and 0.3 km^2 of gravel, whereas the *Our Ocean* network encompasses 34.8 km^2 of rocky habitat, and 2.3 km^2 of gravel habitat.

Habitats were more diverse and H' higher in both the *Our Ocean* MR and MPA, 0.33 and 0.62 respectively, than the OPAC MR at 0.19.

The species richness at Cascade Head in both networks were very similar, except that both the MR and MPA in the *Our Ocean* network contained three more species of fish – shortspine thornyhead (*Sebastolobus alascanus*), soupfin shark (*Galeorhinus galeus*), and spiny dogfish shark (*Squalus acanthias*). Figure 9 shows the species-area curves generated for the OPAC MR, and the *Our Ocean* MR and MPA. The curves generated for the two *Our Ocean* sites showed a steeper increase for species richness after leveling off around 5 km^2 (MPA) and 10 km^2 (MR), while the curve for the OPAC site was relatively shallower, and leveled around 20 km^2. Marine mammals and seabird nesting sites were the same for the MR in both networks; however, the MPA in the *Our Ocean* network increased the protection for marine mammals from 5 haulouts to 9 haulouts (4% to 8%), and for seabirds from 28 nesting sites to 38 sites (7% to 10%).

The potential impact to the crab fishery from the *Our Ocean* MR at Cascade Head was 67.3 mt, valued at $377,000 in 2008 dollars, or approximately 1% of the total fishery. The potential impact of the OPAC MR to the crab was 52.8 mt, valued at $281,000 in 2008 dollars which was also about 1% of the total fishery. In both the OPAC and *Our Ocean* networks the nearshore and trawling data was confidential or absent, and thus we observed no potential impacts to these fisheries during the study period.

DISCUSSION

The addition of spatially explicit and quantitative data to the original OPAC and *Our Ocean* site proposals helped to illustrate the tradeoffs each network made between ecological value and economic impact. Generally, we found the OPAC network was approximately a quarter of the area, less diverse in terms of species and habitats protected, and did not meet science-supported design guidelines when compared to the *Our Ocean* network. Thus, many of the benefits of a marine reserve network such as spillover and larval seeding are likely to occur in the *Our Ocean* network but not in the one proposed by OPAC. The impact to both crab and nearshore fisheries was about twice the impact or less in the *Our* Ocean network when compared to the OPAC, and we found that the impact to the trawl fishery from both networks was negligible. Relatively speaking, the *Our Ocean* network afforded a much greater conservation benefit with a proportionally smaller increase in potential economic impact (albeit a larger absolute potential impact) when compared to the OPAC network.

Size and Spacing

In Oregon, the STAC MR size and spacing recommendations described the minimum sizes of MRs needed to protect the majority of species within a MR, and the minimum distances needed to maintain connectivity among reserves. This was done by reviewing the literature and data for the state of Oregon, and building on available science from the California Marine Life Protection Act (MLPA) process (Heppell 2008). To meet biodiversity protection goals, at least 90% of species for given habitats should be protected, and for Oregon that required a minimum alongshore length of 5-10 km, with 10-20 km recommended. An assumption made by STAC is that the alongshore protection would extend out to the territorial sea boundary approximately 5.5 km offshore. Some biological benefits of MRs include positive changes to biomass, density, size, and diversity inside the MRs (Leslie, et al. 2003), and spillover of adults outside the MRs (Johnson, Funicelli and Bohnsack 1999). These benefits can increase with increasing size and depths encompassed by a MR (Halpern 2003). The only two sites reviewed in this study to not meet the guidelines were Otter Rock MR and Redfish Rocks MR, both part of the OPAC network. While Otter Rock was close to meeting the alongshore length threshold at 4.1 km, it only extended one km offshore and protected a much smaller area.

The STAC guideline also provided recommendations for spacing of the sites in a network based on analyses of species home ranges and larval dispersion ranges used in the California MLPA process. The dispersal patterns of larvae and juveniles can be very important for reserve design (Kinlan and Gaines 2003, Gaines, Gaylord and Largier 2003), and additional studies to document those patterns for Oregon specifically would have ideally occurred prior to the MRs process there. However, a starting point of 50 to 100 km inter-reserve distance was recommended, which accounted for connectivity between the sites for movement of both adult and larvae of species of interest. The *Our Ocean* network, as proposed, met this range for spacing between sites, and would have provided connectivity to the northern most site in the California system of MPAs less than 20 kilometers away from the Mack Reef MPA. In comparison, the OPAC network did not allow for sufficient potential connectivity among sites along the coast, and most notably contained a gap of 160 km between Redfish Rocks and Cape Perpetua, and was nearly 80 km from the California sites. The STAC agreed that Oregon's coast can be separated into two distinct bioregions demarcated by Cape Blanco (Heppell, Barth and Reiff 2008). To ensure the greatest biodiversity protection, replicate reserves sites should have been located both North and South of Cape Blanco; however, both networks only protected one site South of Cape Blanco.

In summary, the *Our Ocean* network met the size and spacing guidelines provided by STAC which indicates the network would likely provide adequate protection for 90% of local species and provide connectivity between sites for larval dispersal and refuge for species with large home ranges. In contrast, the OPAC network failed to meet the minimum size at the two small pilot sites, and had a large gap between Cape Perpetua and Redfish Rocks MRs, indicating that this network may not maximize protection of biodiversity or function effectively along the coast.

Potential Ecological Value

In addition to the factors of reserve size and spacing, determining what species could potentially be protected was also paramount to designing the Oregon MR network. Similar to the California MPLA Process, STAC defined "special places" in the territorial sea as, "areas with high biological diversity, rare or specific oceanographic characteristics, and rare or distinctive habitats" (Heppell, Barth and Reiff 2008, 7). At least a portion of each proposed site in both the OPAC and *Our Ocean* network were considered a special place in the Oregon territorial sea. Most of these sites encompassed a high diversity of habitats or distinctive habitats such as headlands, offshore islands, and subtidal reefs. Even the sandy bottomed sites were considered special like those at the Cape Perpetua and Siltcoos sites, which were identified in the workshop report as a "unique feature…that is likely to affect the distribution of organisms…between Florence and Coos Bay" (Heppell, Barth and Reiff 2008, 7).

Habitat diversity in marine ecosystems can be considered a proxy for species diversity because marine communities are habitat dependent (Ward, et al. 1999, Fox, et al. 2004, Weeks and Merems 2004), and the STAC workshop attendees supported increasing the diversity of habitats in a reserve to increase biodiversity of the area (Heppell 2008). We found both networks contain sites with a high level of habitat diversity in terms of richness and evenness; however, the diverse OPAC sites were much smaller in number and size, whereas two of the three largest *Our Ocean* sites were the most diverse. Finally, rocky habitats have been known for higher species diversity in some systems (Aburto-Oropeza and Balart 2001, Hamilton and Konar 2007), and that was supported in this study by analyses whereby rocky habitats were 40-100% more diverse than others (Figure 6). Rock habitat areas were both relatively and absolutely more abundant in the *Our Ocean* network.

The species-area curves showed a distinct difference between the two networks. These curves depicted the relationship between the area of a habitat sampled at random and the number of species expected in that sample, and generally the curve increased asymptotically (Neigel 2003). At the network-level the species diversity in the OPAC network was less and accumulates less species at the same areas as in the *Our Oceans* network, which was due to the small sites with a large portion of rocky reef and associated species at Otter Rock and Redfish Rocks sites in the OPAC network relative to the more homogenous sand habitats found at the three larger sites in the network. In contrast, the numerous large and diverse sites in the *Our Ocean* network contributed more species over the same areas sampled. This indicated that adding diverse sites, and at larger sizes, to a network will greatly increase the potential species richness but only up to a certain size of MR. This is consistent with the STAC guidelines which found that as the size of the reserve increases the number of species that can reach natural densities and size structures also increases (Heppell, Barth and Reiff 2008).

Range size was defined as the number of grid cells in which a species was found; this was the number of square kilometers where we counted a given species. This value quantified the level of protection for each species in the two networks. The histograms of range size displayed a similar pattern, where 50-60 species had large range sizes or were common throughout the networks, while the majority was present in less than half of the network. The difference in these two graphs was the scale for the x-axis – the *Our Ocean* network protects many more species above the level that OPAC offered. Some of the more common species, with higher range sizes, happened to also be important commercial species, such as the Dungeness crab which had a range size of 860 km^2 in the *Our Ocean* network, and 227 km^2 in the OPAC network.

Finally, both marine mammal haulouts and seabird nesting sites were 2 and 3 times greater, respectively, in abundance in the *Our Ocean* network over the OPAC site. Given that the *Our Ocean* network was more than 4 times larger in area and encompassed a higher number of important habitats like rocky islands and rocky intertidal areas, the difference in haulouts and nesting sites should be expected. Many of these sites in the territorial sea were already under the protection of the Marine Mammal Act, National Wildlife Refuges, or State Marine Gardens. The additional protection of a reserve network will benefit the sites by increasing protected habitat for forage fish, improving the quality of surrounding habitat, and decreasing the amount of human interactions with marine mammals and seabirds which can disrupt feeding, breeding, and nesting activities. The importance of seabird protection has not been lost on the state or coastal communities. For example, the final 2010 recommendations from the Cape Perpetua community team meeting included a "Seabird Protection Zone" that prohibits forage fish trawling in that area to avoid disruption of seabird colonies.

In summary, based on the results of this study, the potential protected species and habitat diversity was higher in the *Our Ocean* network relative to the OPAC network. Habitats were more diverse and evenly spread across the larger sites in the *Our Ocean* network, reflected those habitats found in the territorial sea well, and were larger in area. Due to the overall larger size of the *Our Ocean* network, we expect a larger number of individuals in various life stages to be protected. This fact, coupled with the differences in habitat diversity, number of marine mammal haulouts, number of seabird nesting sites, and effective size and spacing of sites indicated higher potential ecological value overall in the Our Ocean network. Ultimately, while the ecological data discussed here are useful, and MLPA size and spacing standards defensible, additional studies are needed to quantify the biodiversity, connectivity of habitats in terms of larval and adult movements, and spatial distribution of that diversity of the Oregon territorial sea.

Potential Economic Value

Although the total catches from crabbing and nearshore fishing were summed for the two proposed networks, those sums may overestimate the actual potential impact to fisheries within the networks. According to discussions which occurred during public evaluation of site proposals, fishing with low-impact gear such as pots, traps, jigs, longline and hook and line would be allowed within most all of the MPAs. Thus the true potential impact of a site was less if it included an MPA component rather than only a MR, because some fisheries would be allowed within the MPAs. Again, the purpose of MPAs in the Oregon process was to increase the overall protection of coastal ecosystems but allow some low-impact activities; however, high-impact gear such as the various bottom trawl gear would be disallowed in both the MRs and most MPAs and thus the potential impact is not reduced within the trawl fishery. Despite this prohibition on trawling within both MRs and MPAs, we expect the displacement of trawling to be minimal as these sites were scarcely used over the years studied, and most trawling occurs further offshore in federal waters. Exceptions to this restriction have recently been discussed in community team meetings for MPAs, i.e. Cape Perpetua potentially allowing some ‘pineapple’ trawling (a specific type of net) for flatfish within the reserve.

The potential impact to the crab fishery from MRs in the OPAC network was about 3% of the state-wide catch from the 2007-2008 season, and 6% from the MRs in the *Our Ocean* network, which indicated that those sites avoided most fishing grounds for crab. The maximum potential impact to the nearshore fishery within the reserves of the *Our Ocean* network was about twice that of the impact to OPAC, 6% compared to 3%. Again most of this fishery occurred outside of the proposed networks. Generally, the smaller footprint of the OPAC network in the territorial sea posed a smaller potential impact to the commercial fisheries within the territorial sea; conversely, the impact was much larger in the *Our Ocean* network by virtue of its greater size. The potential impacts to the crab fishery was approximately two times as great in the *Our Ocean* MRs compared to the OPAC MRs only, and very similar impact with respect to the nearshore fishery at 4% and 3% respectively. The potential impact from the trawl fishery due to the MRs and MPAs was less than 0.01% in the OPAC network, and 0.03% in the *Our Ocean* network – both exceedingly small portions of the entire trawl fishery. We found that over 99% of the trawl fishery would not be impacted by either network, which occurs further offshore (>5.5 km). Overall, we found that the *Our Ocean* network would have twice the impact on all commercial fisheries, an average of $1.79 million (3.2%) per year, compared to $0.90 million (1.6%) for OPAC. However, for that doubling of the potential cost, the larger network would protect four times the area, more species over more diverse habitats, and more than double the important marine mammal haulout and seabird nesting sites.

Although the stated goal for the MR network in Oregon was to ensure biodiversity protection and rather than fisheries management, the *Our Ocean* network would have benefited all three fisheries as a well-connected and appropriately sized network. Despite the immediate negative impacts of displacement and crowding from a network the size of *Our Ocean* on surrounding areas that remain open to fishing (Hilborn 2004), the long-term benefits such as replenishment and spillover of larvae and adults (Johnson, Funicelli and Bohnsack 1999, Kinlan and Gaines 2003), resiliency to disturbances (Allison, et al. 2003), and increased biomass overall can have positive effects for fisheries (Gaines, White, et al. 2010). This tradeoff is an important one to make, especially if the sustainability of the fishery well into the future is prioritized. The tradeoff is not only important to those commercially important species that have high range sizes in both networks, such as Dungeness crab and lingcod, but also to the less common and commercially important species such as Dover sole (*Solea solea*) (ODFW Fish Division 2013). Dover sole is caught in the trawl fishery which has a small footprint in the territorial sea, but the benefits to this fishery will still be realized by the species' protection in the network, and at a small cost to the trawlers themselves. Finally, species that are currently considered overfished such as canary rockfish (*Sebastes pinniger*) and yelloweye rockfish (*Sebastes ruberrimus*), also stand to benefit from larger range sizes in the *Our Ocean* network compared to the OPAC network, and the protection of more of the rocky reefs that are critical to rebuilding these threatened stocks.

Specific Site Comparison – Cascade Head

The Cascade Head proposal by *Our Ocean* was an example of the use of a MPA to increase the ecological value of a site overall while avoiding adverse economic impacts. This MPA connected the Cascade Head Reserve (to the North) with the Cape Foulweather Reserve (to the South) (Figure 7), and encompassed the Boiler Ridge and Siletz Reef complexes. The MPA would allow the nearshore, crab, and recreational fisheries, thus the only impact from the MPA would be to the trawl fishery, which was so small that the data were confidential. Overall, the tradeoffs for the larger *Our Ocean* proposal at Cascade Head were the protection of 205 km^2 that contained a high diversity of habitats and protection for species including marine mammals and seabirds, at a potential cost of $377,000 in 2008 dollars to the crab fishery alone. The tradeoffs for the OPAC proposal were the protection of 62 km^2 with lower diversity of species and habitats with a potential cost of $281,000 in 2008 dollars. For double the protection to marine mammals, a third more protection for seabirds, much higher habitat diversity, and an overall larger area, the *Our Ocean* proposal would potentially cost $1,800/$km^2$; whereas the OPAC network would be less efficient in every ecological category at a cost of $4,650/$km^2$. These tradeoffs were not quantitatively assessed by OPAC in the proposal process, but the information could have created more support for the larger proposal.

General Considerations

The MRs policy recommendations set forth by OPAC specifically states, "size and spacing guidelines developed [by STAC] will be used to help understand potential ecological benefits of MR site proposals, rather than dictate minimums or maximums needed" (OPAC 2008, 2). The site selection process by OPAC was a bottleneck for potential reserve sites, and limited the sites that were analyzed with additional data to understand tradeoffs of fishery impacts and ecological values. Six unique sites in the territorial sea were eliminated due to this process –Three Arch Rock, Siletz and Boiler Ridge Reefs, Cape Foulweather, Siltcoos and Mack Reef. This inability to acquire appropriate data prior to the proposal process was most likely driven by the governor's short timeline of eight months (Kulongoski 2008). Despite the timing, further evaluation of proposals should not have happened after site selection, but rather before, allowing for a more informed decision on the tradeoffs. In addition to the lack of data, the motions voted on during the November 2008 OPAC meeting focused on each proposal individually, and did not allow for broad comparisons between sites or for the configurations of various networks. The data used in this thesis existed in 2008, and given enough staff at the various agencies could have been compiled and analyzed within the eight month timeframe.

OPAC voted on all the proposals based on minimal information regarding the ecological value and potential economic impacts of each site, and seemed biased toward erring on the side of caution regarding impacts. Those proposals that were approved as pilot sites were supported by groups of fishermen as well as the larger community and therefore, the community support also played an important role in the decision. The three MRs under further consideration and analysis during 2010 at Cape Falcon, Cascade Head and Cape Perpetua were all proposed more than once by different groups, thus also had a broader community support. In fact, those three sites and associated community teams benefitted greatly from more information regarding costs and benefits, slight modifications to rules and boundaries, and honest open debate. Additional proposed sites could have easily been incorporated into that fact-finding and community development process along the coast if not for the OPAC bottleneck at the proposal vetting stage.

This analysis reviewed only available commercial fishery information to approximate a potential economic impact due to restrictions in the proposed sites and networks. Full review of the maximum potential impact would include impacts to other undocumented fisheries, especially recreational, and the economic multiplier effects of those fisheries on local communities (Southwick, et al. 2006), and potential social impacts on fishers' well-being or livelihood (Stevenson, Tissot and Walsh 2013). It is generally known that marine recreational fisheries have been, and remain, an important contributor to local economies along the Oregon coast, but the extent is unknown at this time. Some work has been done to quantify the impact that recreational fisheries in Oregon have on local economies, and by some estimates this impact can be near 80% ($115 million, in 2004 dollars) of the impact commercial fisheries have ($145 million, in 2004 dollars) (Southwick, et al. 2006). Additional studies are needed to identify the spatial distribution of effort and catch throughout recreational fishery grounds to help identify how a network of MRs will impact those fisheries. Although recreational fishing opportunities may be reduced in the short term, those long term ecological benefits of a MR network like larval dispersal and adult spillover would could improve recreational fisheries.

Despite the potential for immediate losses to recreational fishermen, charter boats, and related support industries, other non-consumptive activities such as diving, snorkeling, kayaking, and surfing may increase in abundance and value, as well as businesses that support the tourism industry such as gas stations, restaurants and grocers, lodgings, and other tourist shops. Surfrider, Ecotrust, and Natural Equity conducted a survey during the summer of 2010, which mapped the non-consumptive activities of users as well as how much they spent during their last trip to the coast and the value of these activities overall to the coast of Oregon. Approximately $2.4 billion (LaFranchi and Daugherty 2011) was spent on these activities, which could likely increase due to the presence of a network of MRs or MPAs and subsequent marketing efforts by the State of Oregon. Given enough resources for quantitative data collection and analysis, appropriate studies such as the two mentioned above can facilitate more informed decision making on reserve network design to minimize economic impacts.

Some MR design processes have relied on physical and biological data alone to optimize reserves, and then used socioeconomic data to refine the analysis after sites were selected (Ban 2009, Stewart and Possingham 2005); whereas, other examples such as the California Marine Life Protection Act (MLPA) process focus on incorporating social and economic data into site analysis and selection from the start (Klein, et al. 2008). This MLPA method has evolved over the past 14 years since the act was passed, and did not begin smoothly (C. M. Weible 2008), but public engagement has increased throughout the nomination and analysis process. In addition to the biological, physical, and social and economic data informing the tradeoffs at each site, California has also relied on public engagement for site analysis. Generally, Oregon has engaged stakeholders and the general public in the reserves designation process by accepting proposals and allowing three community teams to discuss Cape Falcon, Cascade Head, and Cape Perpetua after they had been selected. However, the accelerated eight month timeframe for site nominations (Kulongoski 2008), combined with data-poor and qualitative criteria for analysis, created a bottleneck that limited the possibilities for development of sites with ecological and fisheries data by the public.

CONCLUSIONS

Comparing site or network scenarios with appropriate supporting data are likely to reveal tradeoffs in an easily understood context by managers and coastal interests. Measuring the ecological characteristics such as potential biodiversity, habitat diversity objective planning of MRs and MPAs in the Oregon territorial sea is vital to a successful and effective network of protection. In this thesis I have demonstrated that varying configurations of MRs and MPAs networks can vary the tradeoffs between economic impacts versus and ecological value. Moreover, it has been shown that increasing the size of a reserve network does not necessarily directly increase the impact or benefit to the same degree. These relative tradeoffs are important to consider and explore fully as networks are developed.

The *Our Ocean* network covers nearly a third of the territorial sea, had large sites with diverse habitats and depths, and harbored many more marine mammals and seabirds when compared to the OPAC network. This four-fold increase in area and biodiversity came at a 'cost' of approximately twice the impact to the important fisheries in the territorial sea. By comparing two different networks, we have shown that the conservation benefits of a MR network are best measured and held up against the potential economic impacts to fully understand the tradeoffs inherent in that reserve network.

As a special case of marine spatial planning, MR designation should involve the public throughout the process; as a requirement for public participation, the process should embrace objective and quantitative information for public analyses to illustrate clearly the ecological and economic value of sites and networks. This can minimize subjectivity and inform decision-making by avoiding data-poor planning scenarios. Overall this study shows objective planning with sound scientific data is vital to the conservation of the Oregon territorial sea, and an effective MR network.

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Table 1 Commercial fishery logbook data obtained to estimate maximum potential economic impact within proposed sites - including study period, target species, gear types, and GIS feature type.

Commercial Fishery (common name)	Years Available	Species/Group Targeted	Gear Type	GIS Feature Type
Crab	2007-2008 season	Dungeness Crab (*Cancer magister*)	Pots	Point
Nearshore	2007-2009	Rockfish (Sebastidae), Cabezon (*Scorpaenichthys marmoratus*), Lingcod (*Ophiodon elongatus*), Greenlings (Hexagrammidae)	Hook and Line, Longline, Pot or Trap	Polygon
Trawl	2007-2009	Flatfish (Pleuronectiformes), and occasionally Hake (*Merluccius productus*)	Non-pelagic or Pelagic nets	Point

Table 2 Physical and biological characteristics of both networks, and each site within each network. Summary rows for each network are either summations or averages, and can include percentage of the total. Sites in both networks are listed from North to South.

Site	Overall Area	Coastline Length	Maximum Depth	*Spacing	Habitat Richness	Shannon Index (H')	Rock	Sand	Gravel	Mud	Shell	Cobble
	Km^2	Km	m	Km between sites	#	Σ pi ln pi	Km^2 (%)	Km^2 (%)	Km^2 (%)	Km^2 (%)	Km^2 (%)	Km^2 (%)
OPAC Network	**238.0**	**49.8**	**57 (avg)**	**76 (avg)**	**6**	**0.41 (avg)**	**7.6 (3)**	**223.9 (94)**	**0.4 (0.2)**	**3.2 (1)**	**0.6 (<0.1)**	**0.1 (<0.1)**
Cape Falcon MR	51.6	6.89	74	71	3	0.07	0.6	50.9	0.1	0.0	0.0	0.0
Cascade Head MR	61.9	9.9	69	29	5	0.19	2.0	59.4	0.3	0.0	0.1	0.0
Otter Rock MR	3.4	4.1	18	44	2	0.59	0.9	2.2	0.0	0.0	0.0	0.0
Cape Perpetua MR	99.4	26.1	53	160	4	0.07	1.1	98.0	0.1	0.0	0.0	0.1
Redfish Rocks MPA	14.9	--	88		3	0.69	0.4	9.6	0.0	3.2	0.0	0.0
Redfish Rocks MR	6.8	2.9	39		4	0.90	2.5	3.8	0.0	0.0	0.5	0.0
Our Ocean Network	**1043.4**	**185.0**	**69 (avg)**	**45 (avg)**	**6**	**0.30 (avg)**	**60.7 (6)**	**896.4 (86)**	**12.7 (1)**	**72.8 (7)**	**0.5 (<0.1)**	**0.1 (<0.1)**
Cape Falcon MPA	145.0	19.0	79		5	0.09	2.2	142.6	0.0	0.2	0.0	0.0
Cape Falcon MR	51.6	6.9	74	26	3	0.07	0.6	50.9	0.1	0.0	0.0	0.0
Three Arch Rocks MR	63.4	8.9	73		5	0.41	4.6	56.8	1.9	0.1	0.1	0.0
Three Arch Rocks MPA	70.6	10.4	80	25	5	0.11	1.3	69.1	0.1	0.1	0.0	0.0
Cascade Head MR	87.8	14.3	69		5	0.33	7.1	80.0	0.3	0.2	0.1	0.0
Cascade Head MPA	117.3	19.8	67		5	0.62	24.0	90.8	2.0	0.3	0.1	0.0
Cape Foulweather MR	43.9	7.0	63	44	2	0.29	3.7	40.3	0.0	0.0	0.0	0.0
Cape Perpetua MR	99.4	26.05	53		4	0.07	1.1	98.0	0.1	0.0	0.0	0.1
Cape Perpetua MPA	51.4	NA	57	22	1	0.00	0.0	51.4	0.0	0.0	0.0	0.0
Siltcoos MR	22.5	11.4	26		2	0.04	0.0	22.4	0.1	0.0	0.0	0.0
Siltcoos MPA	42.8	NA	73	53	2	0.28	0.0	39.4	0.0	3.4	0.0	0.0
Cape Arago MPA	49.7	14.8	93		3	0.61	2.3	39.7	7.7	0.0	0.0	0.0
Cape Arago MR	48.9	10.2	64	100	4	0.27	2.8	45.7	0.3	0.0	0.0	0.0
Mack Reef MPA	111.8	22.5	112		4	0.81	5.2	38.2	0.0	68.3	0.0	0.0
Mack Reef MR	37.3	13.8	53		5	0.49	5.9	31.2	0.0	0.2	0.1	0.0

Table 3 Overall species richness in broad groups (fish, invertebrates, plants/algae), number of marine mammal haulouts, and number of seabird nesting sites for both networks.

Site	Fish	Invertebrates	Plants/Algae	Marine Mammal Haulouts	Seabird Nesting Sites
	#	#	#	#	#
OPAC	136	23	4	14	73
Our Ocean	137	23	4	38	223

Table 4 Average catches (over study period) in metric tons (mt) and average value (adjusted to 2008 $) for three fisheries in the whole networks and reserves only. *Trawl fishery would be disallowed in both MRs and MPAs; therefore, there is no reduction of maximum potential impact between sums for the entire network and only reserves. Confidential (--) information was not included in this study. **Crab fishery data is not averaged, and only represents one season (2007-2008) of data.

Site	Crab**			Trawl*			Nearshore		
	mt/year	$ in millions /year	% of fishery/ year	mt/year	$/year	% of fishery/ year	mt/year	$/year	% of fishery/ year
OPAC	168.9	0.90	3	--	--	<0.01	4.1	24,400	3
Reserves Only	165.5	0.88	3				3.6	21,600	3
Our Ocean	632.4	3.37	11	18.2	8,600	0.03	8.4	50,400	6
Reserves Only	328.0	1.75	6				5.0	30,200	4

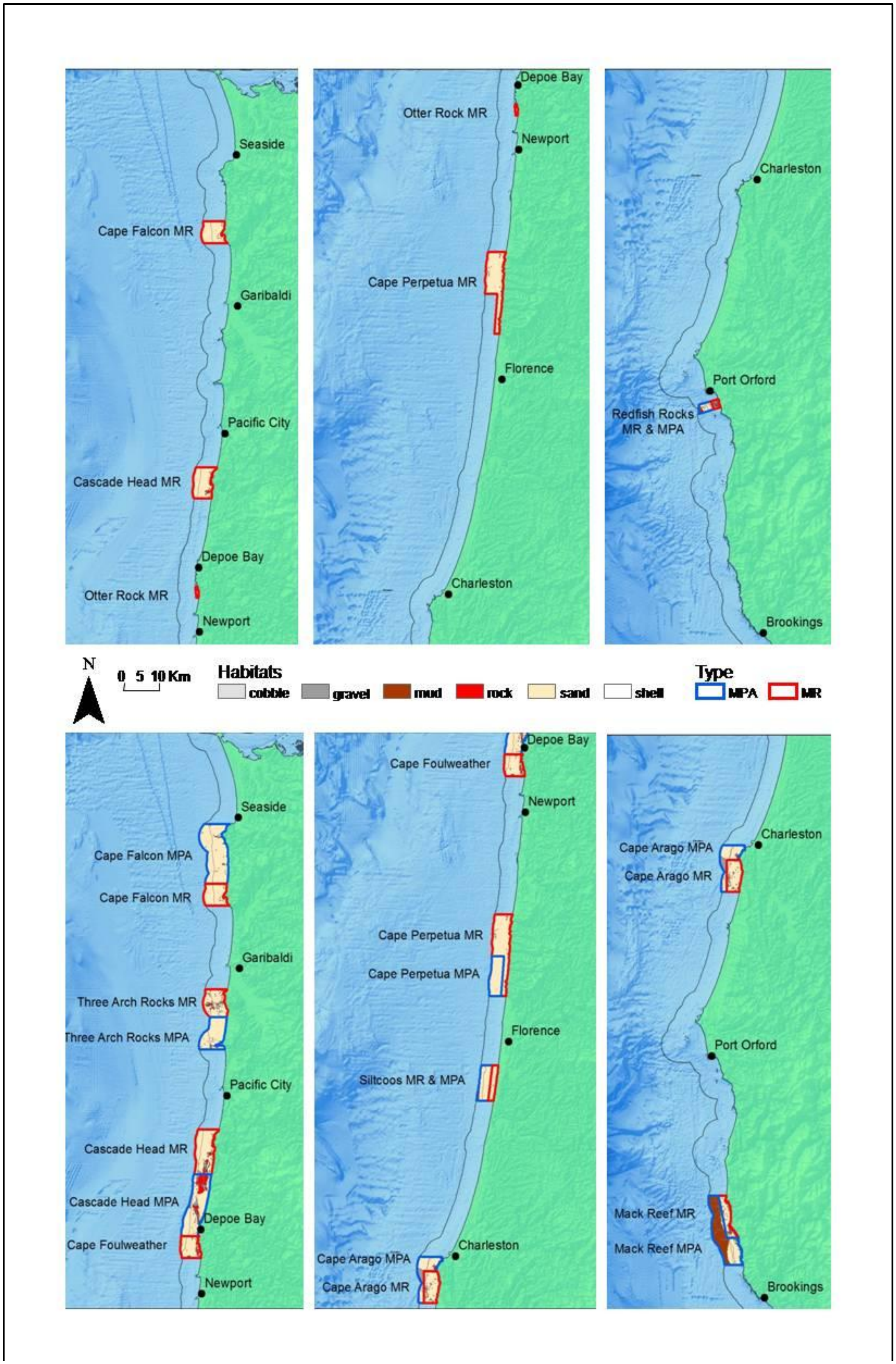


Figure 1 – Map of the OPAC (top panels) and Our Ocean (bottom panels) networks. Map panels are arranged from North to South (left to right).

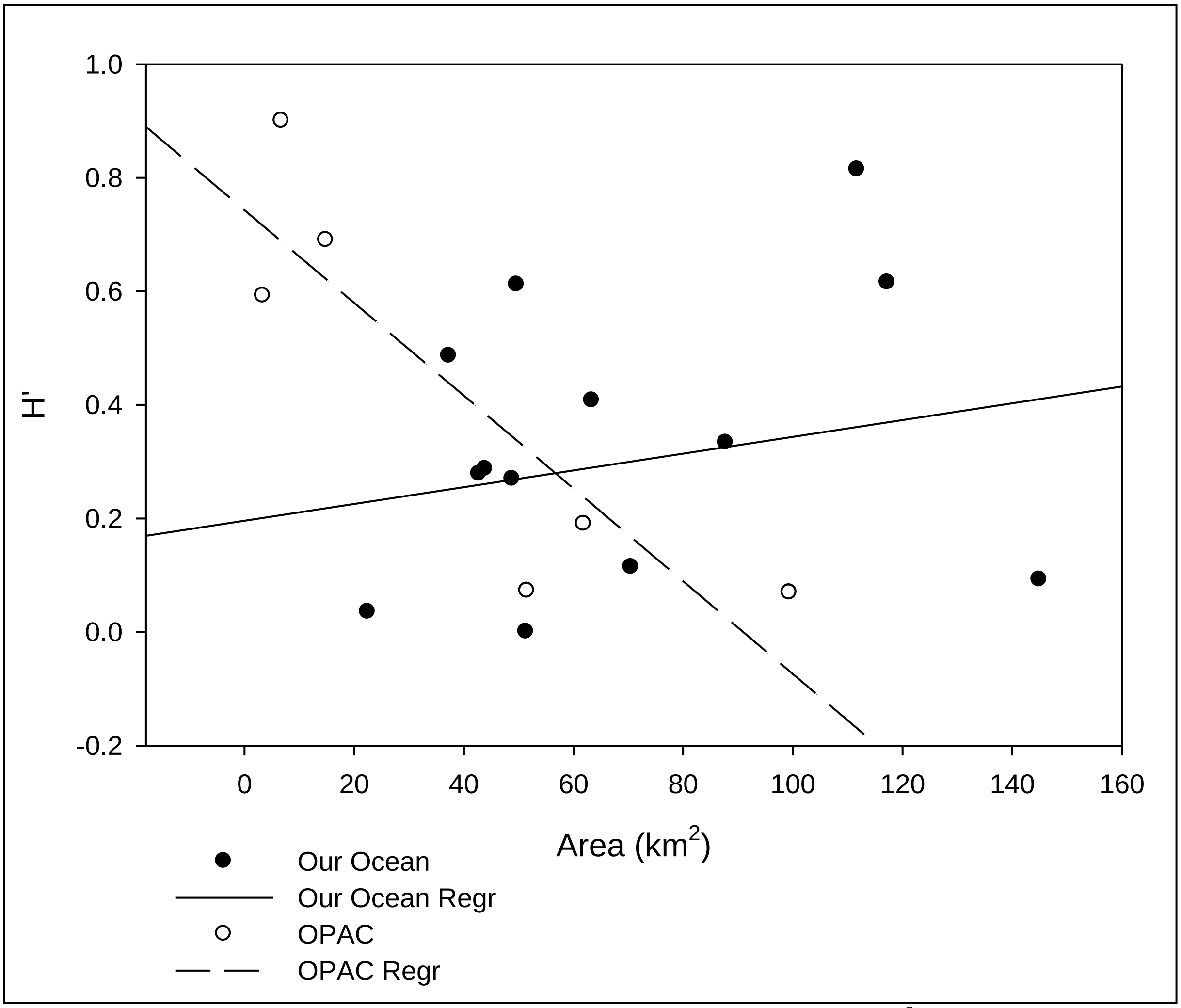


Figure 2 Shannon-Wiener index of habitat diversity (H') plotted against area (km^2) for individual MRs and MPAs in the OPAC (open) and the Our Ocean (solid) networks.

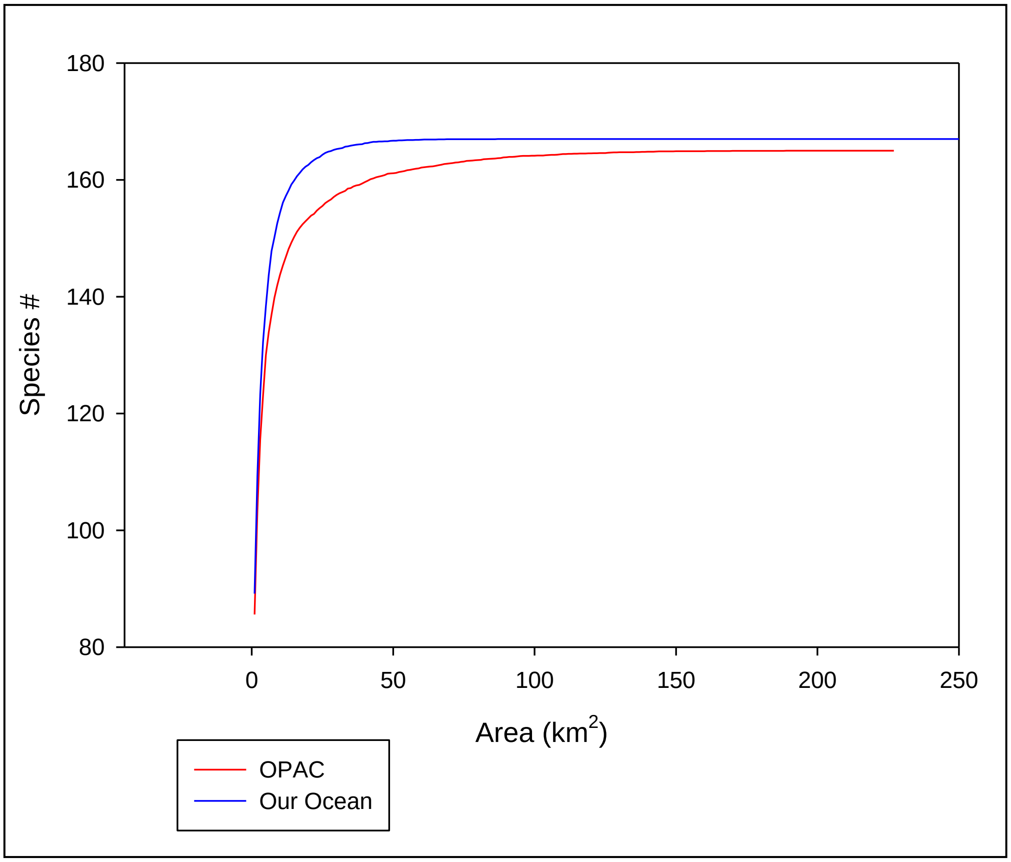


Figure 3 Species Area curves for both networks generated from 500 permutations of species richness grid sampling data. The number of species is plotted against area (km^2) in each network.

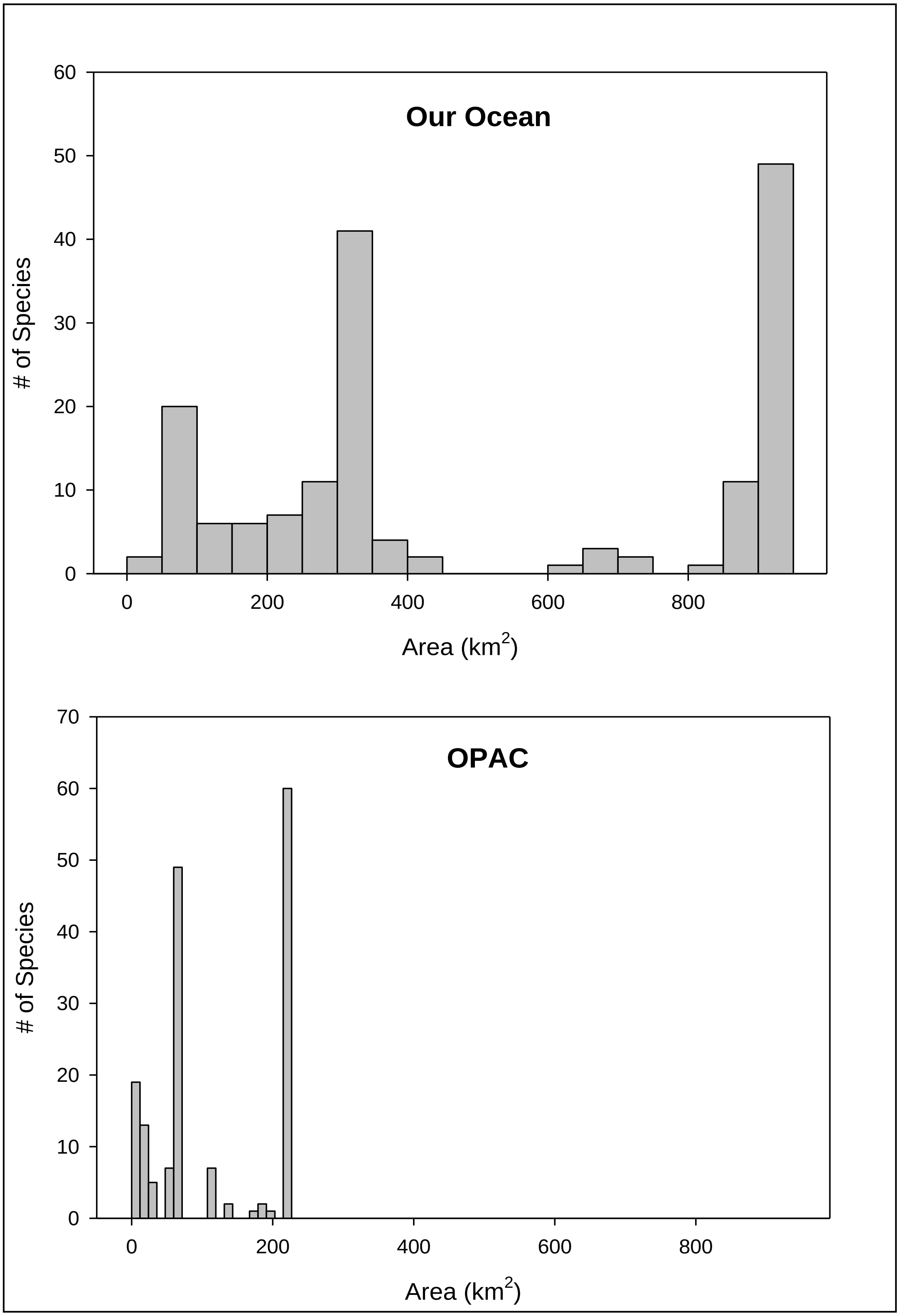


Figure 4 Distribution of species range sizes (km^2) for OPAC (bottom) and *Our Ocean* (top). These distributions clearly show the difference in potential area of habitat protected for each species, and that for the majority of species in the Our Ocean network, there is a higher level of protection than the entirety of the OPAC network.

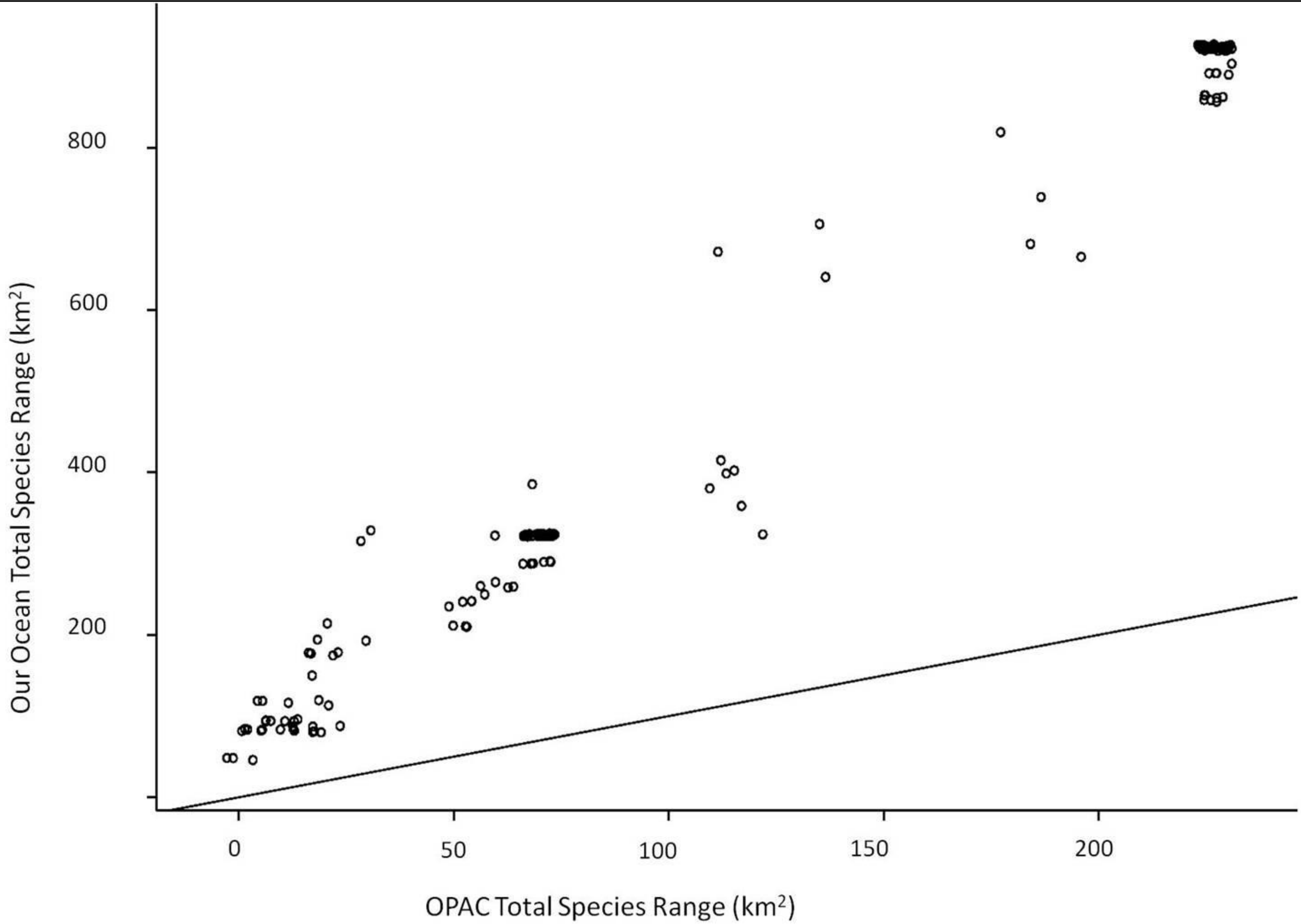


Figure 5 Species range size (km^2), or area of habitat protected, in OPAC (x-axis) and Our Ocean (y-axis) networks. In all cases, species area potentially protected by a larger total area in the Our Ocean network, relative to the OPAC network, as all data points fall above the 1:1 plotted line.

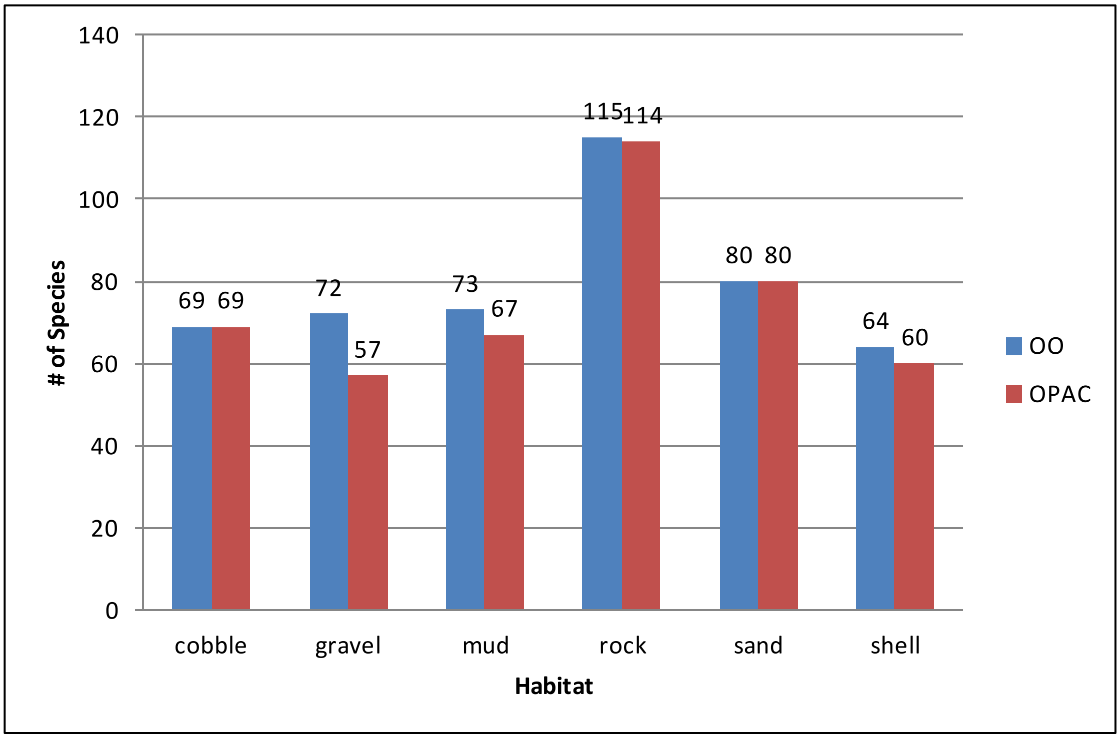


Figure 6 Species richness over each habitat type in the OPAC (red) and *Our Ocean* (blue) networks. The habitat that potentially harbors most species diversity in the Oregon territorial sea is rocky habitat.

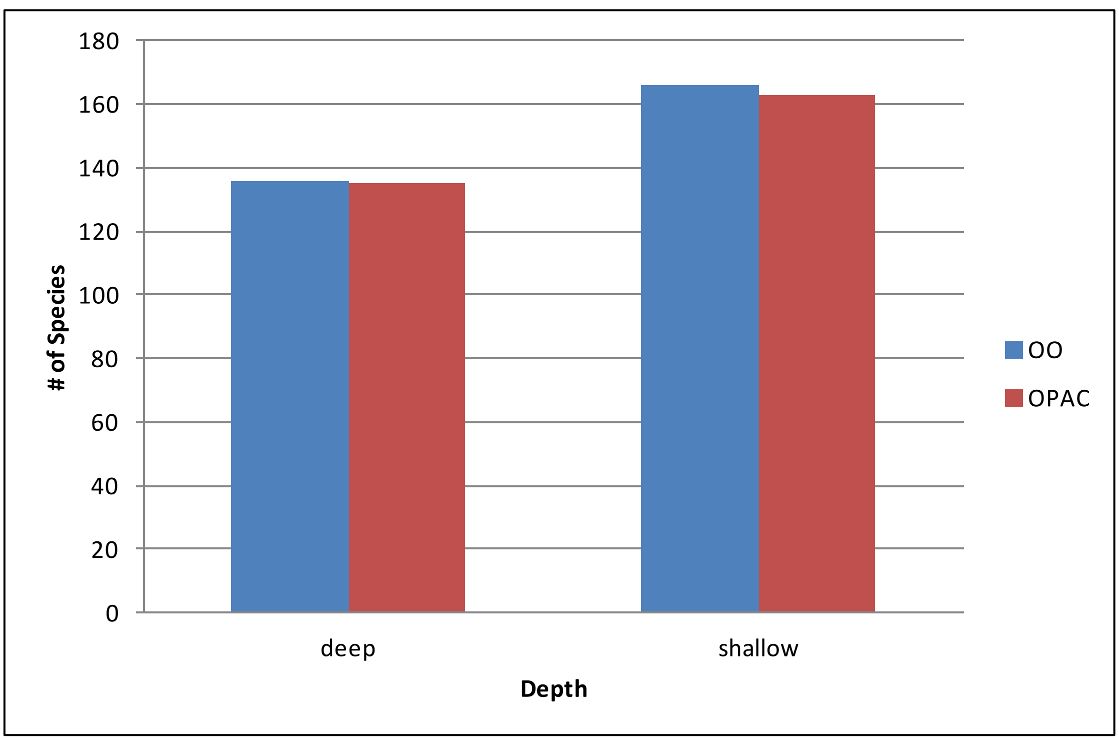


Figure 7 Species Richness over two depth ranges (> 30m<) in the OPAC (red) and *Our Ocean* (blue) networks. Species diversity was similar in both networks and both depths.

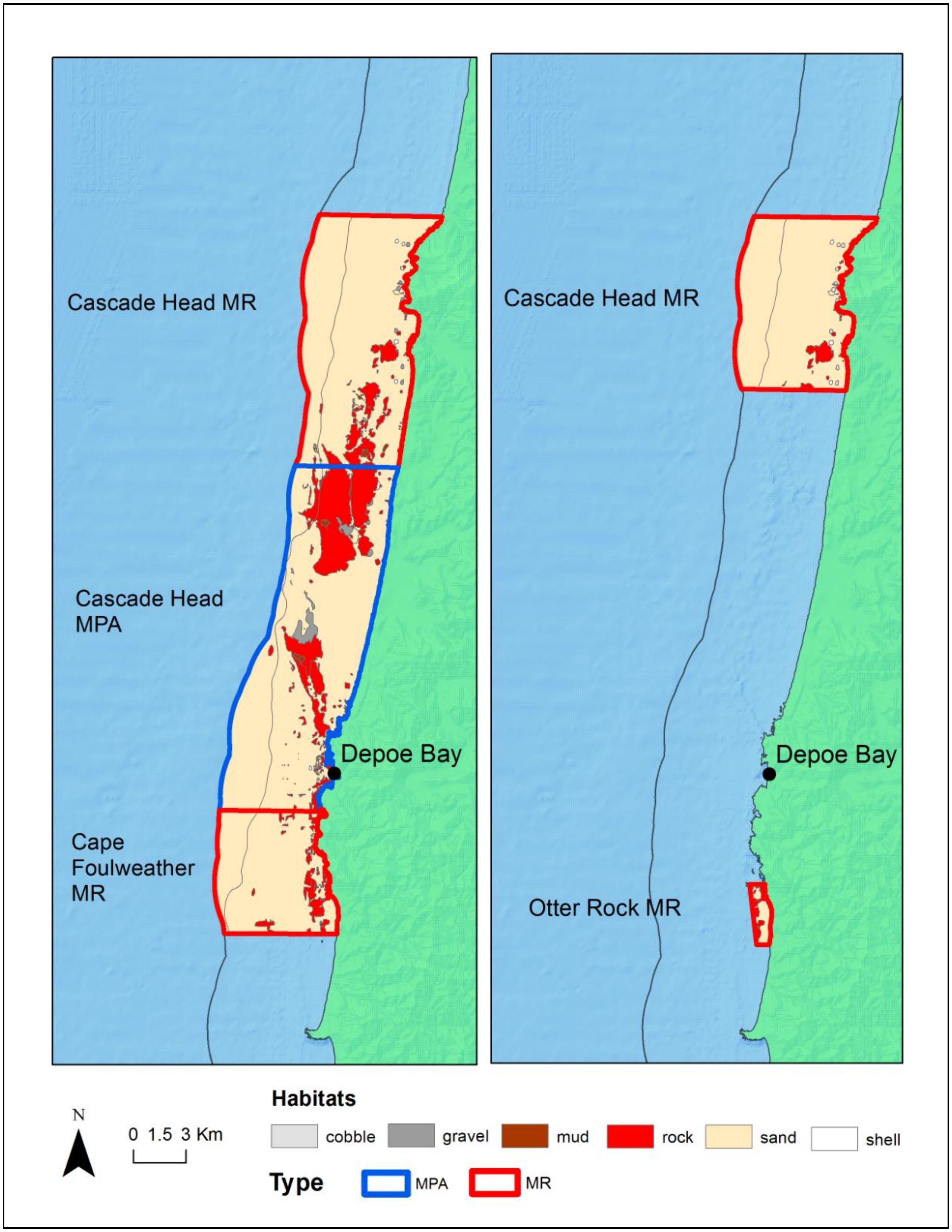


Figure 8 Map of the proposed MRs and MPAs between Cascade Head (in the North) and Cape Foulweather (in the South) for *Our Ocean* (left) and OPAC (right) networks.

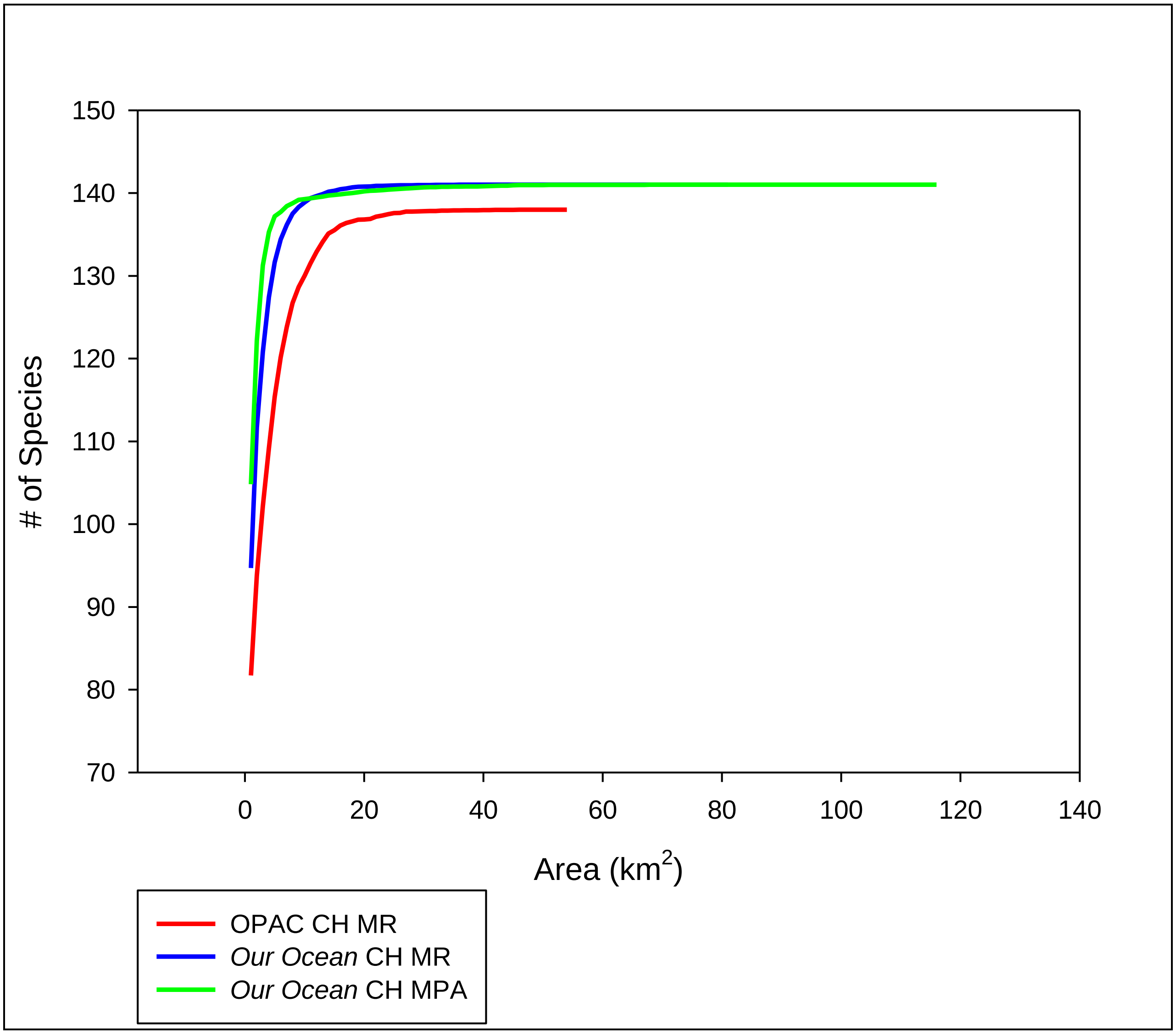
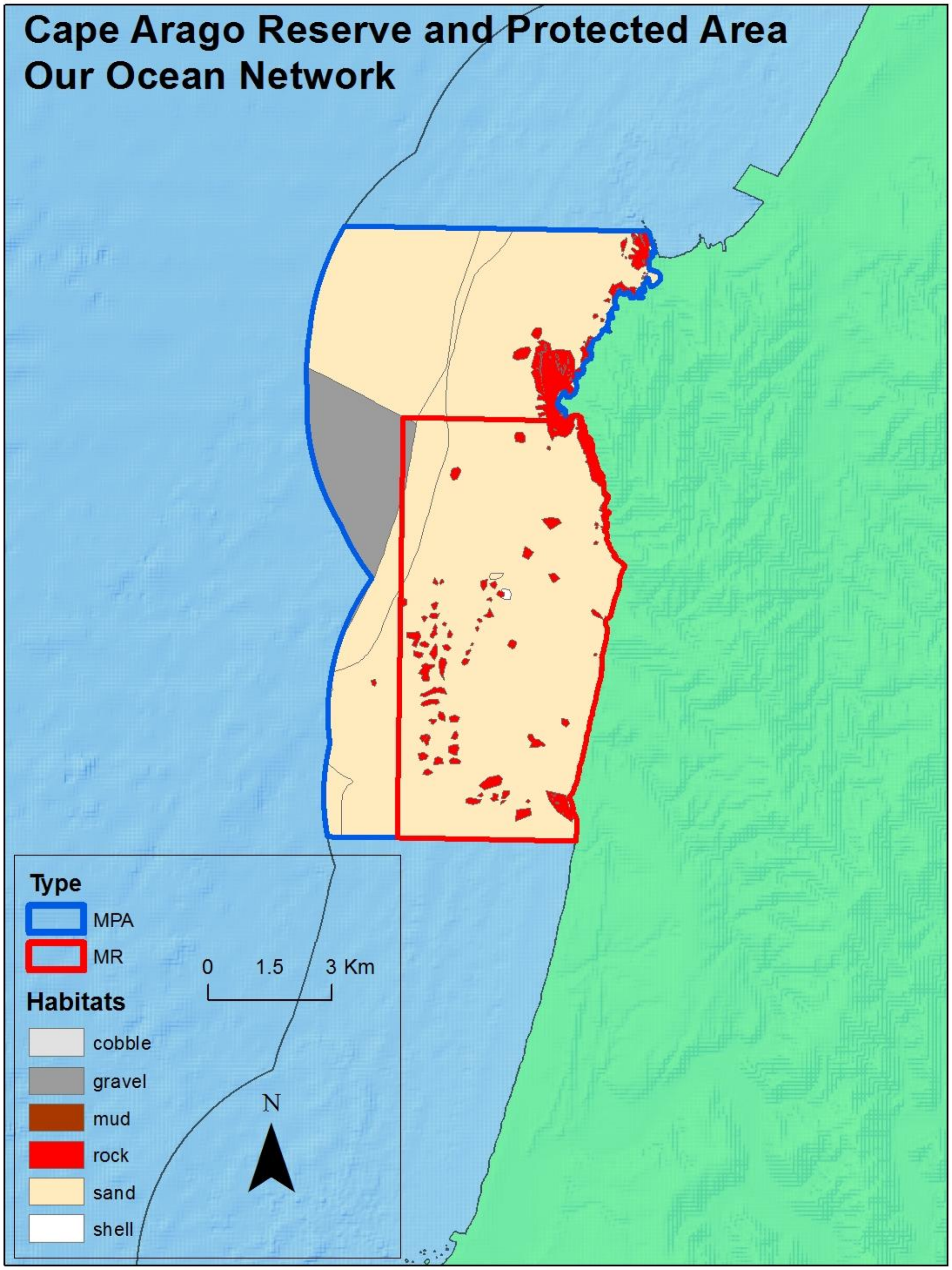
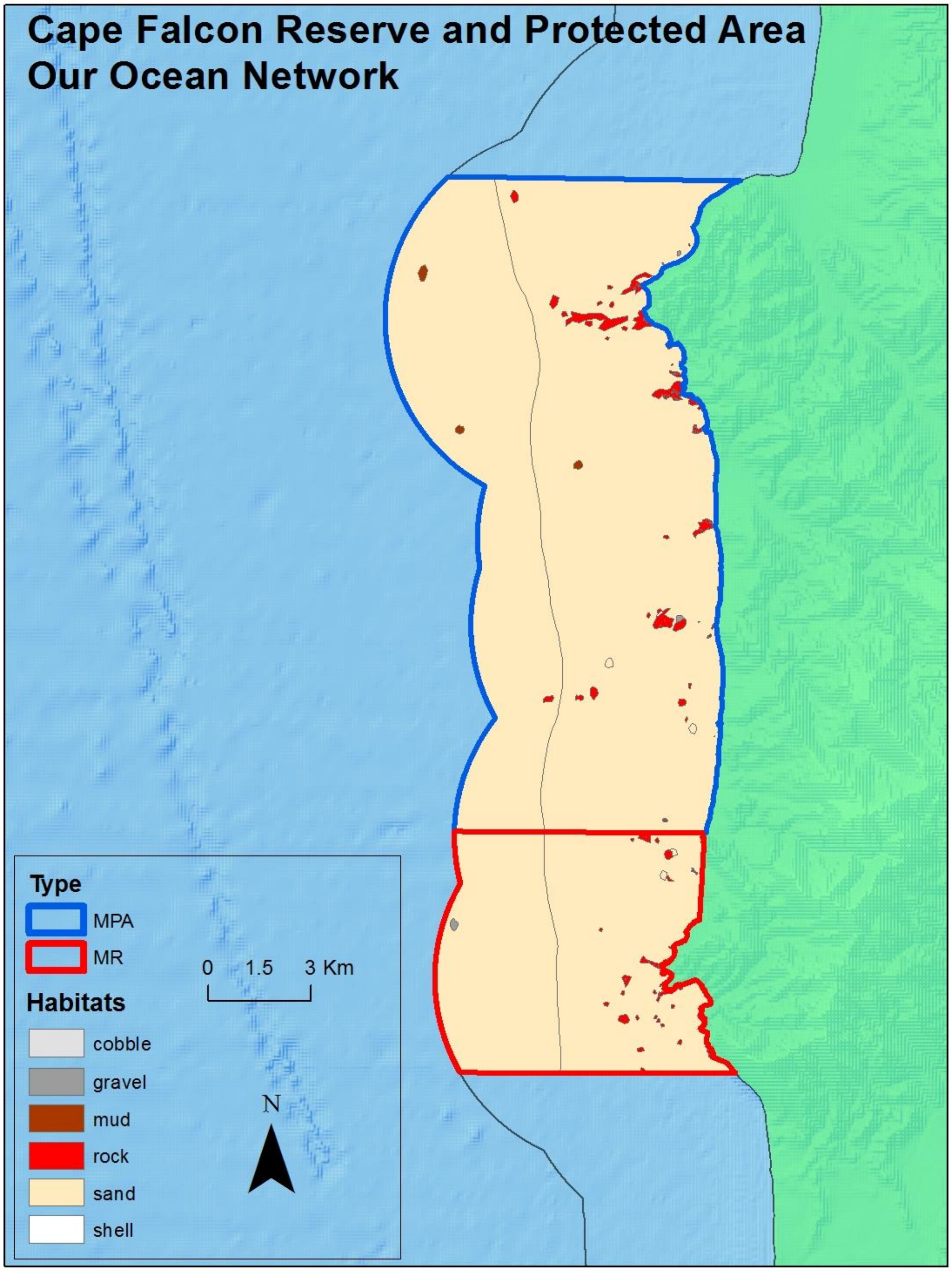


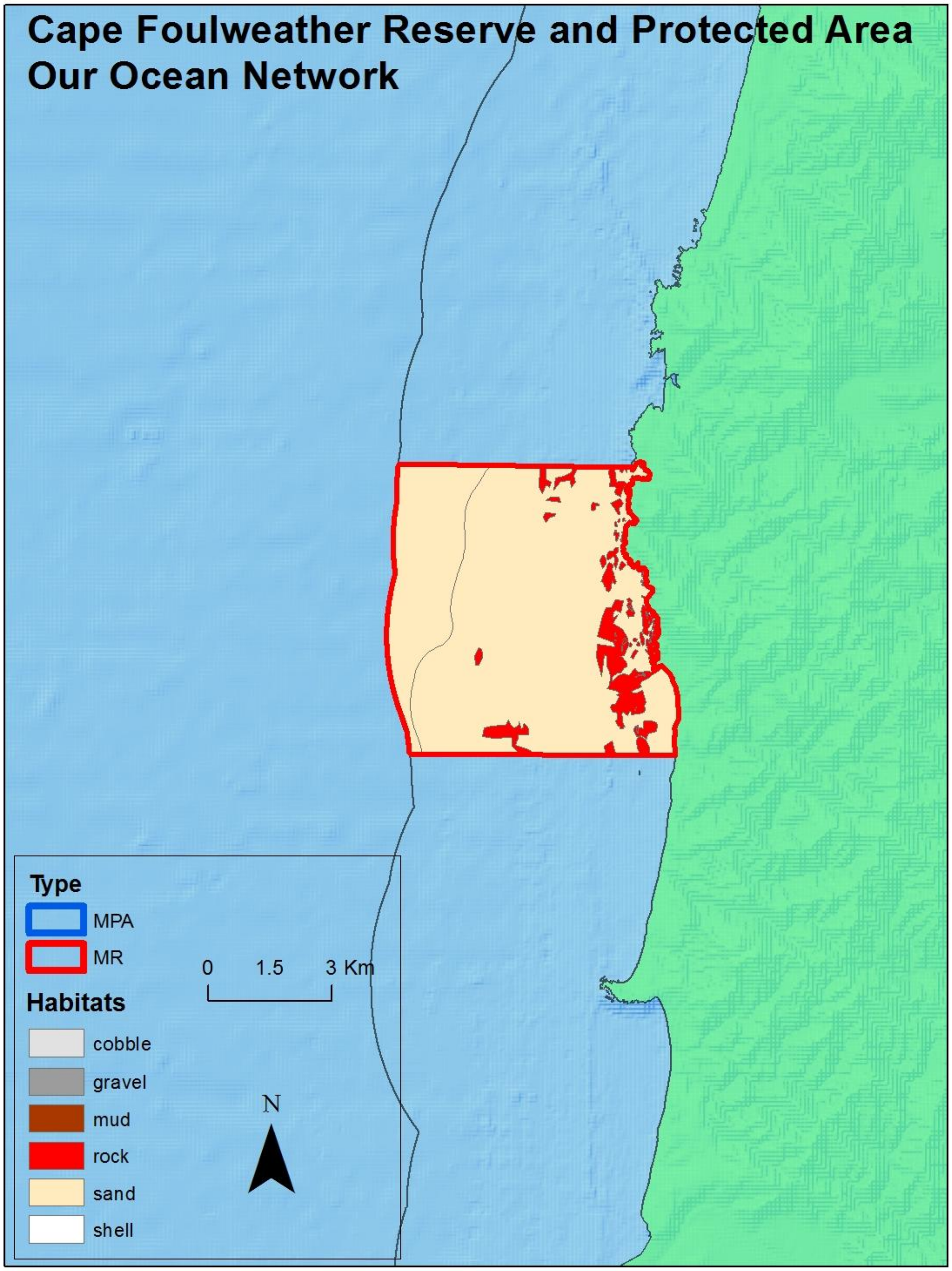
Figure 9 Species Area curves for the three sites in both networks for the Cascade Head area generated from 500 permutations of species richness grid sampling data. The number of species is plotted against area (km^2) in each individual site.

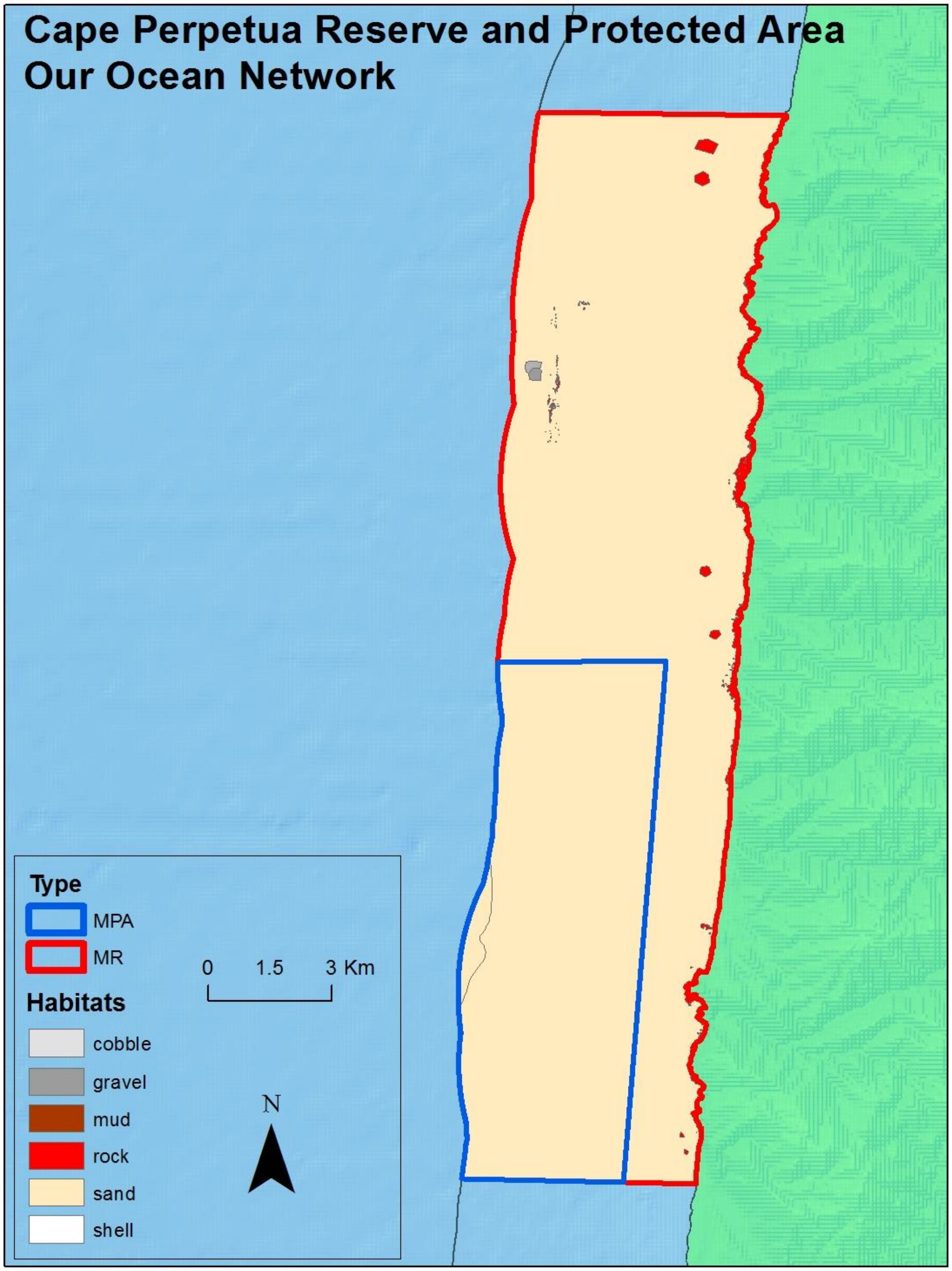
Appendix – Individual Site Maps for each network.





Cape Falcon Reserve and Protected Area
Our Ocean Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0 1.5 3 Km
N


Cape Foulweather Reserve and Protected Area
Our Ocean Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0
1.5
3 Km
N


Cape Perpetua Reserve and Protected Area
Our Ocean Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
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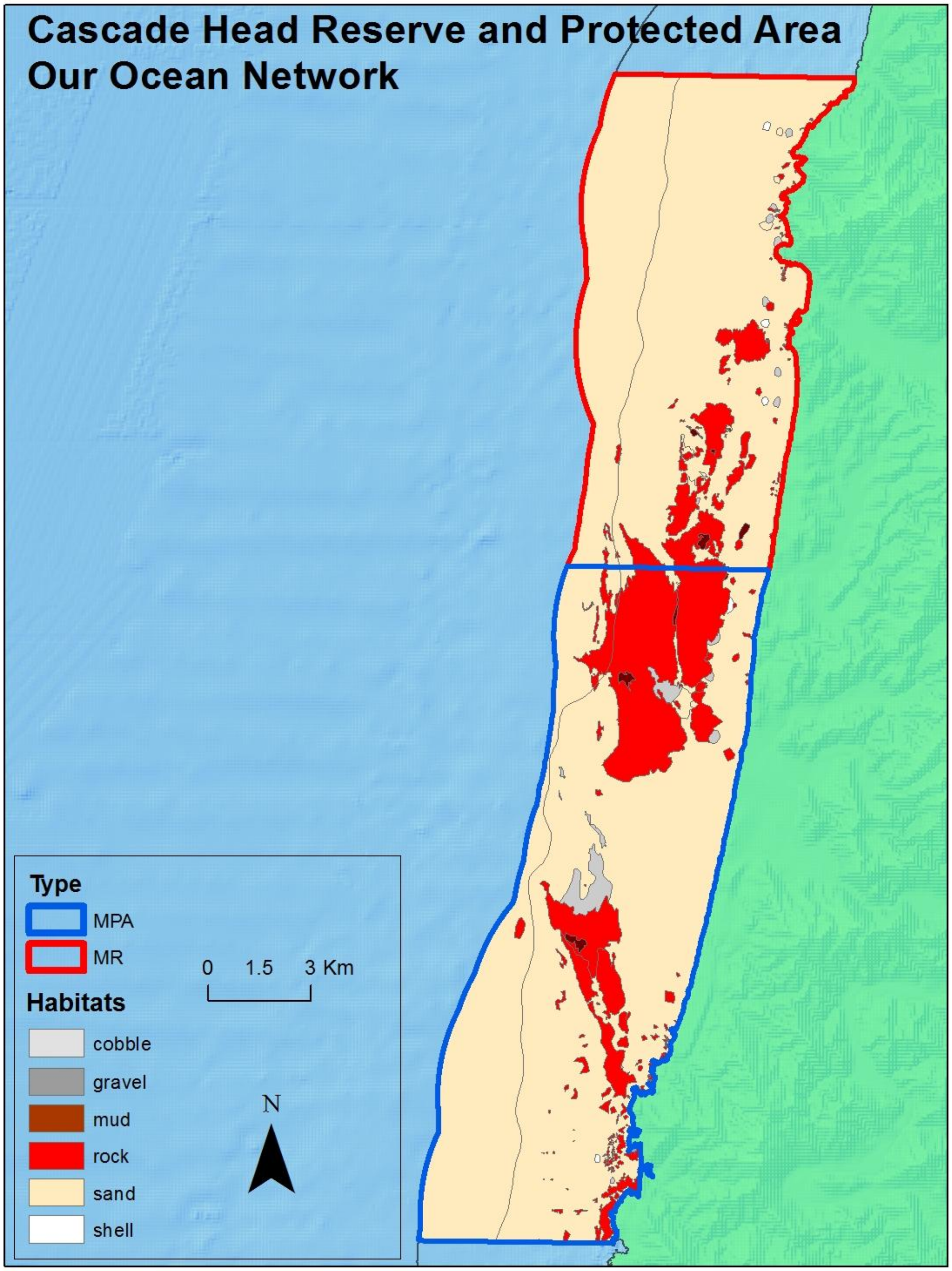
Cascade Head Reserve and Protected Area
Our Ocean Network
Type
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Habitats
cobble
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mud
rock
sand
shell
0 1.5 3 Km
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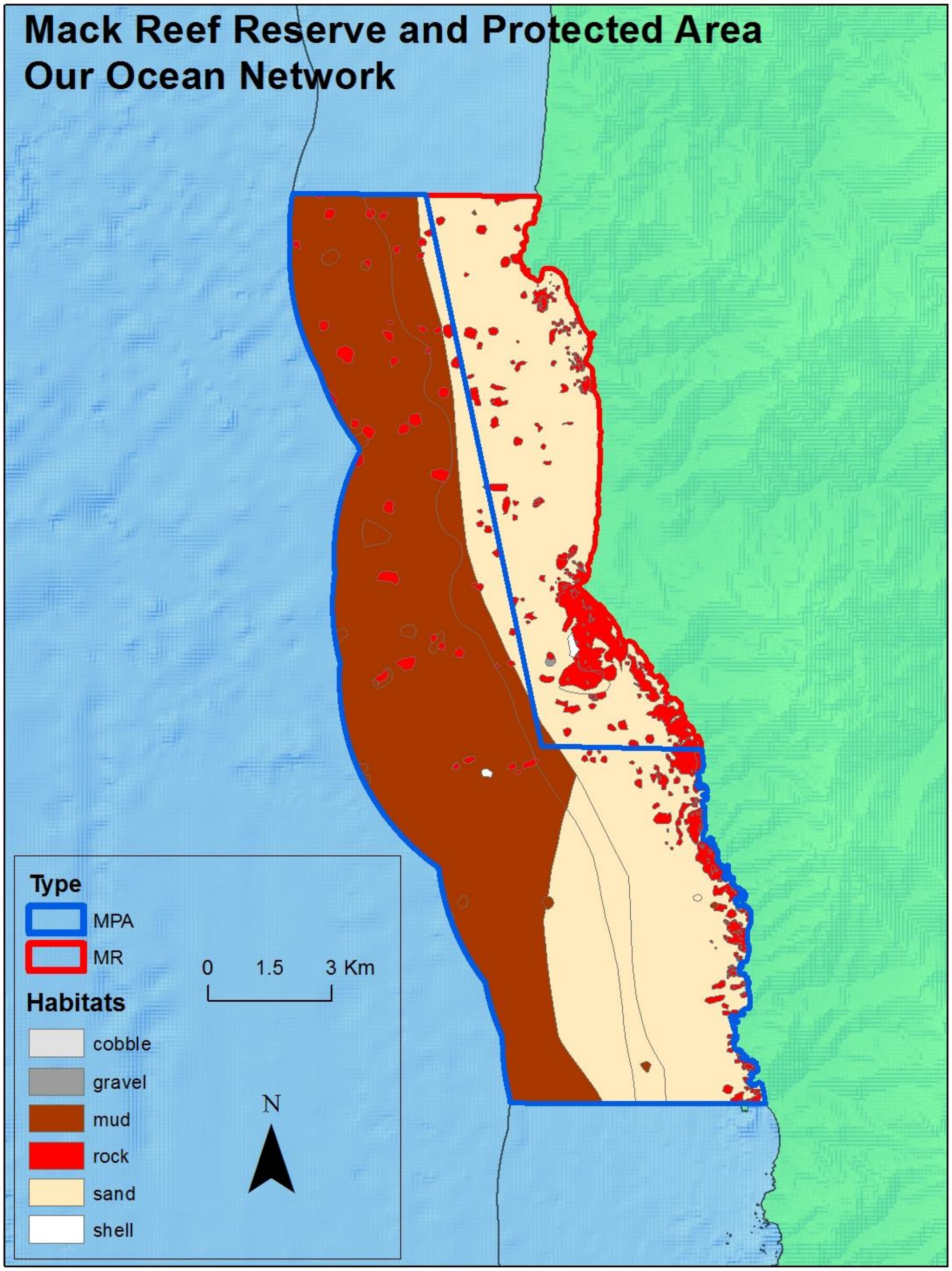
Mack Reef Reserve and Protected Area
Our Ocean Network
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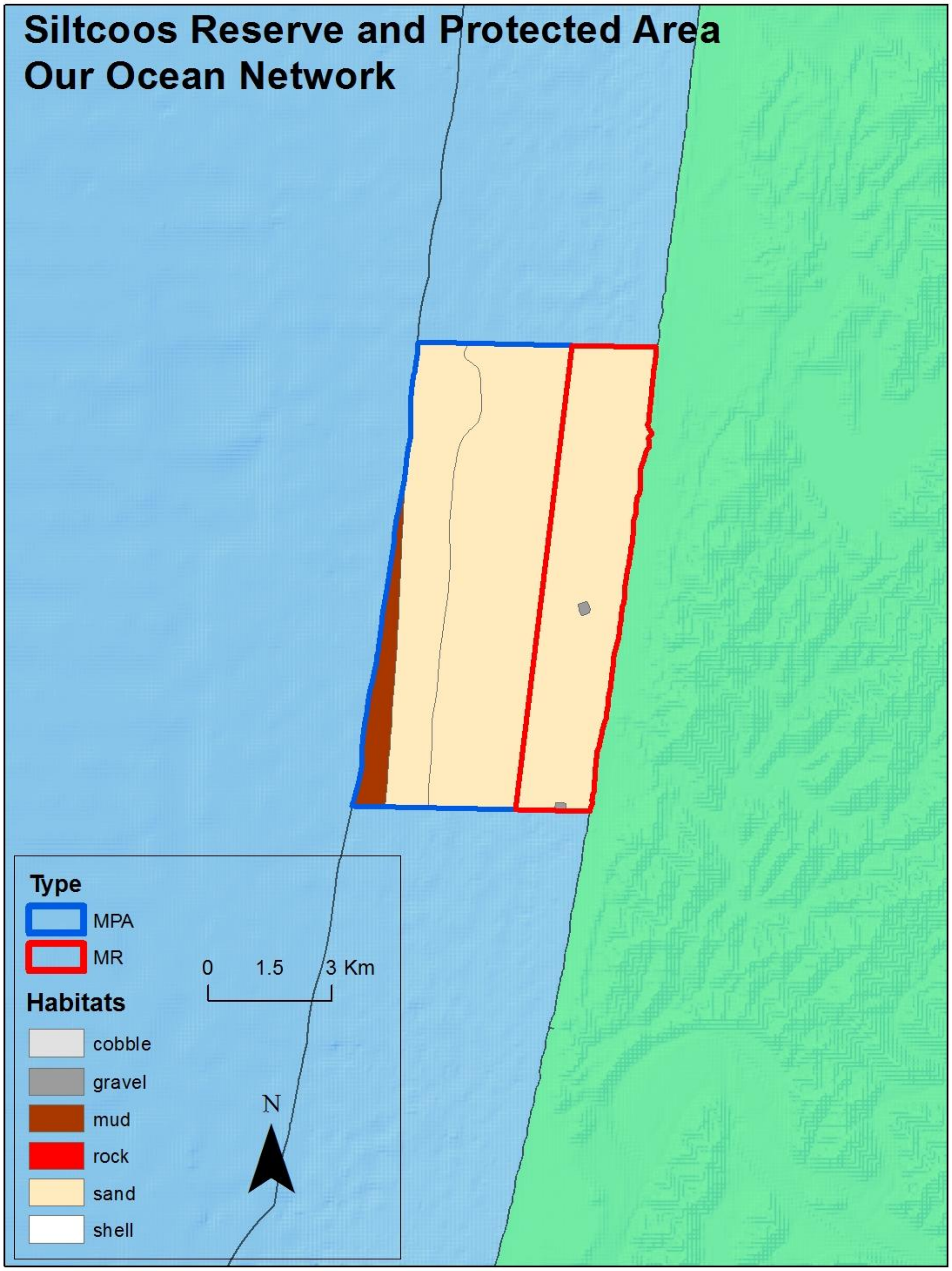
Siltcoos Reserve and Protected Area
Our Ocean Network
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rock
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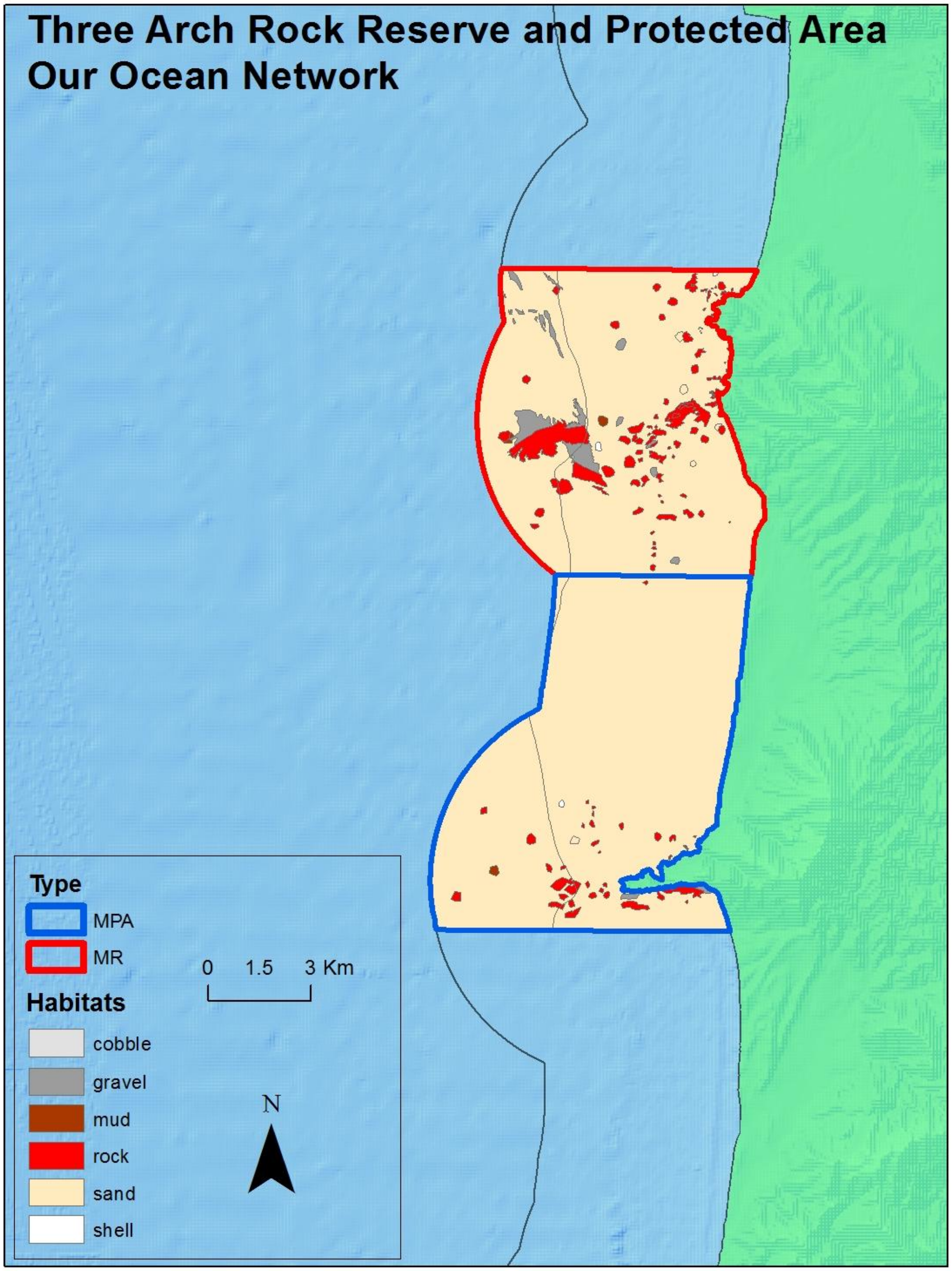
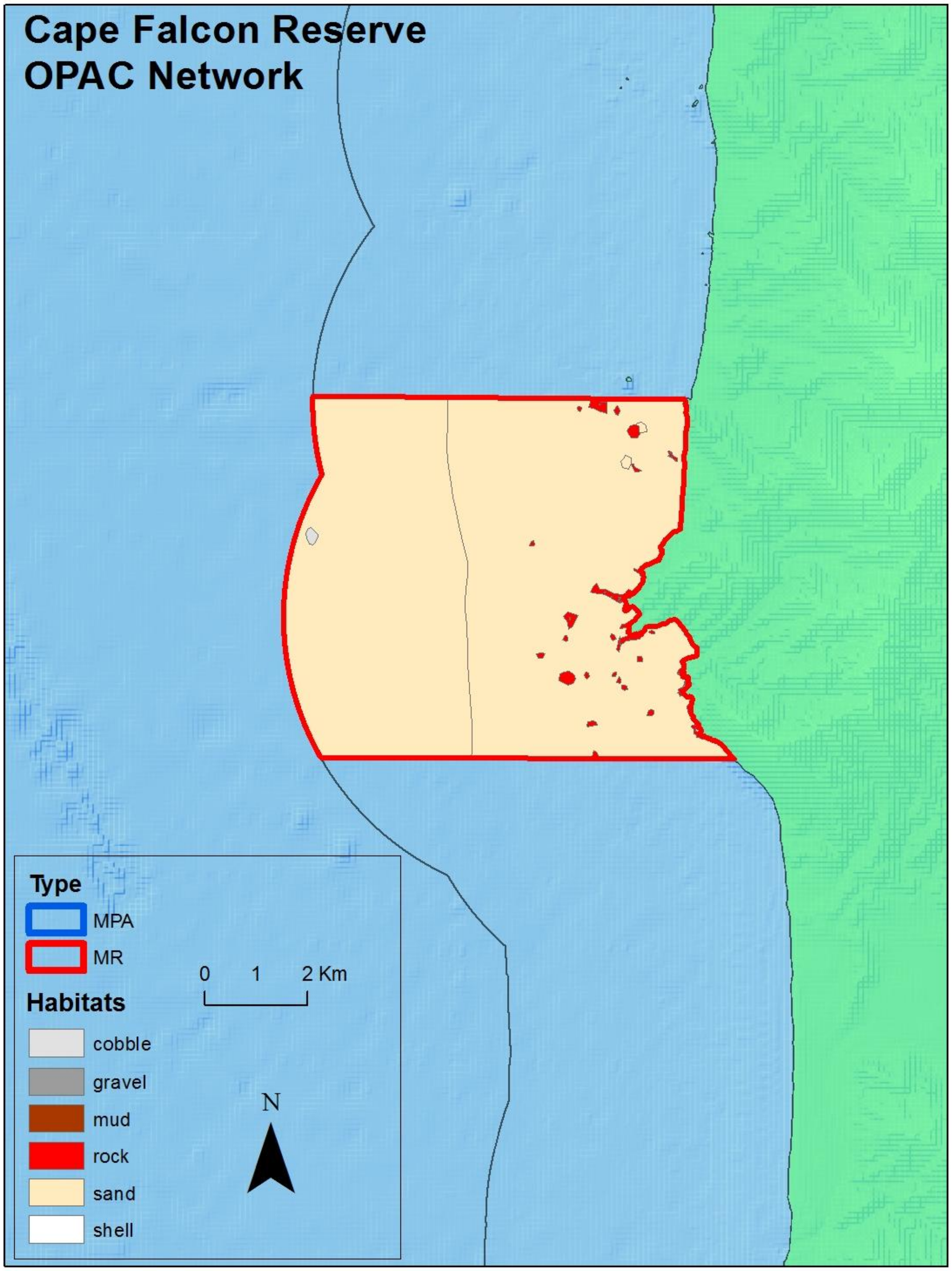

Three Arch Rock Reserve and Protected Area
Our Ocean Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0 1.5 3 Km
N


Cape Falcon Reserve
OPAC Network
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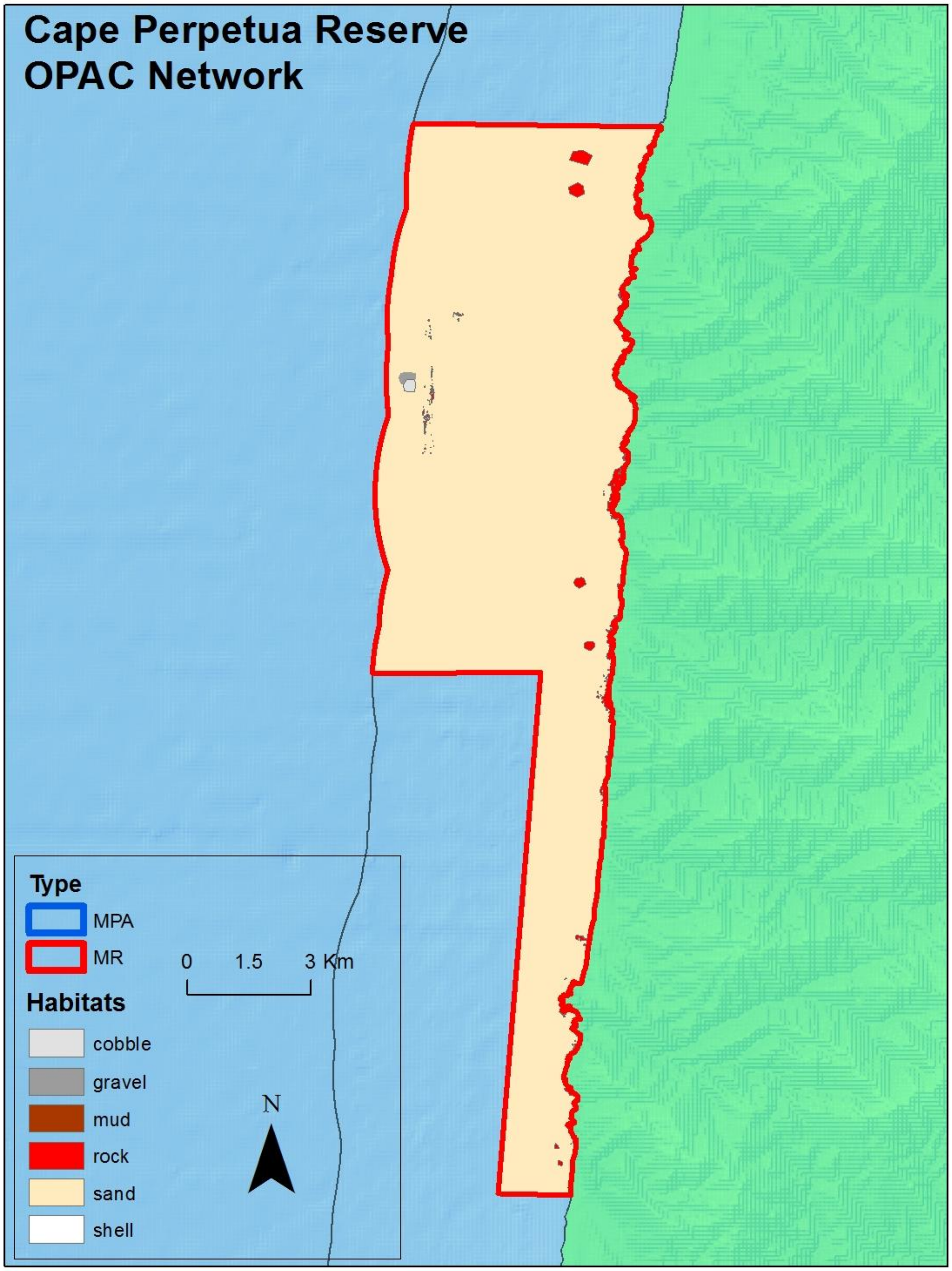
Cape Perpetua Reserve
OPAC Network
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Habitats
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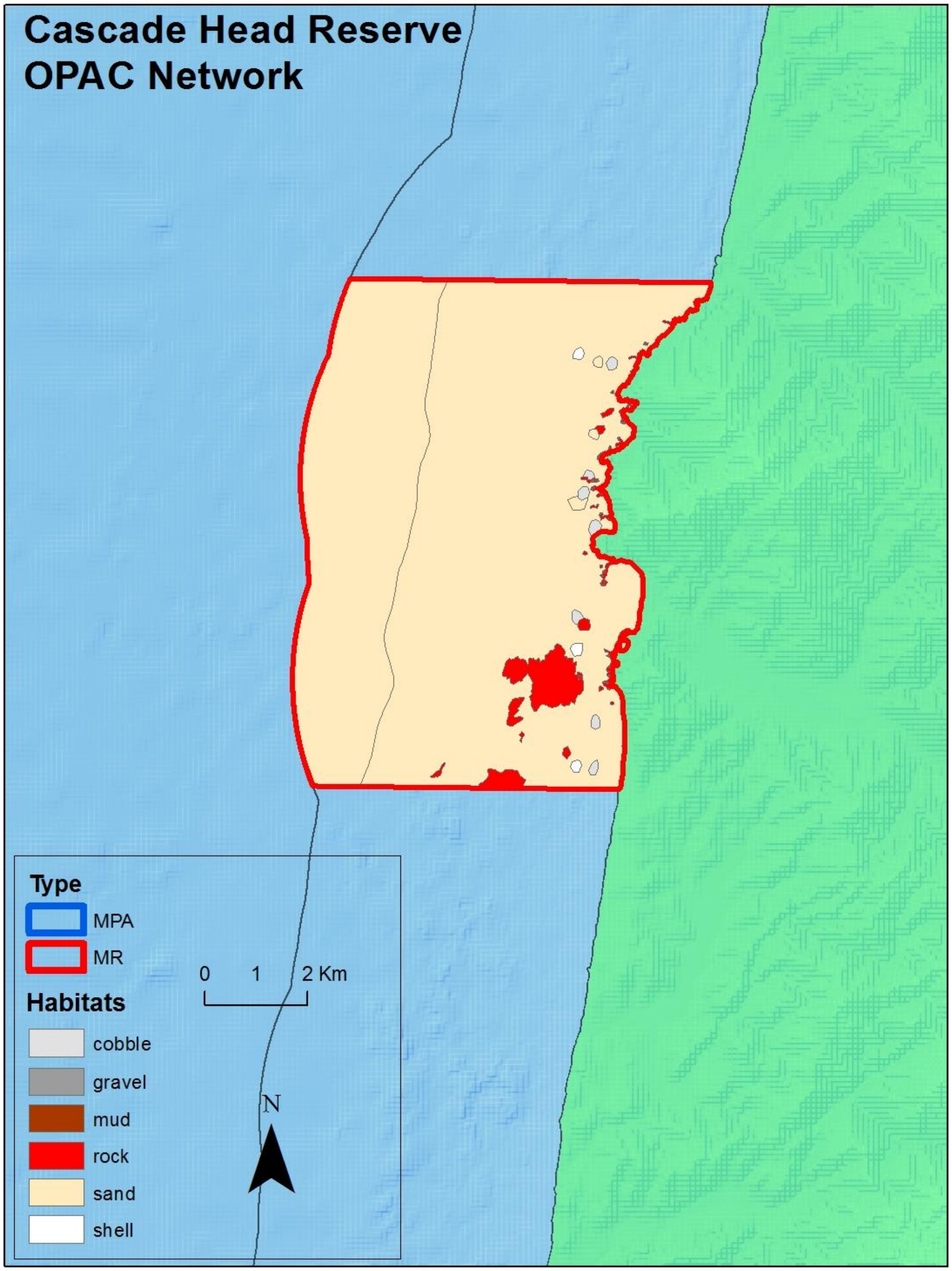
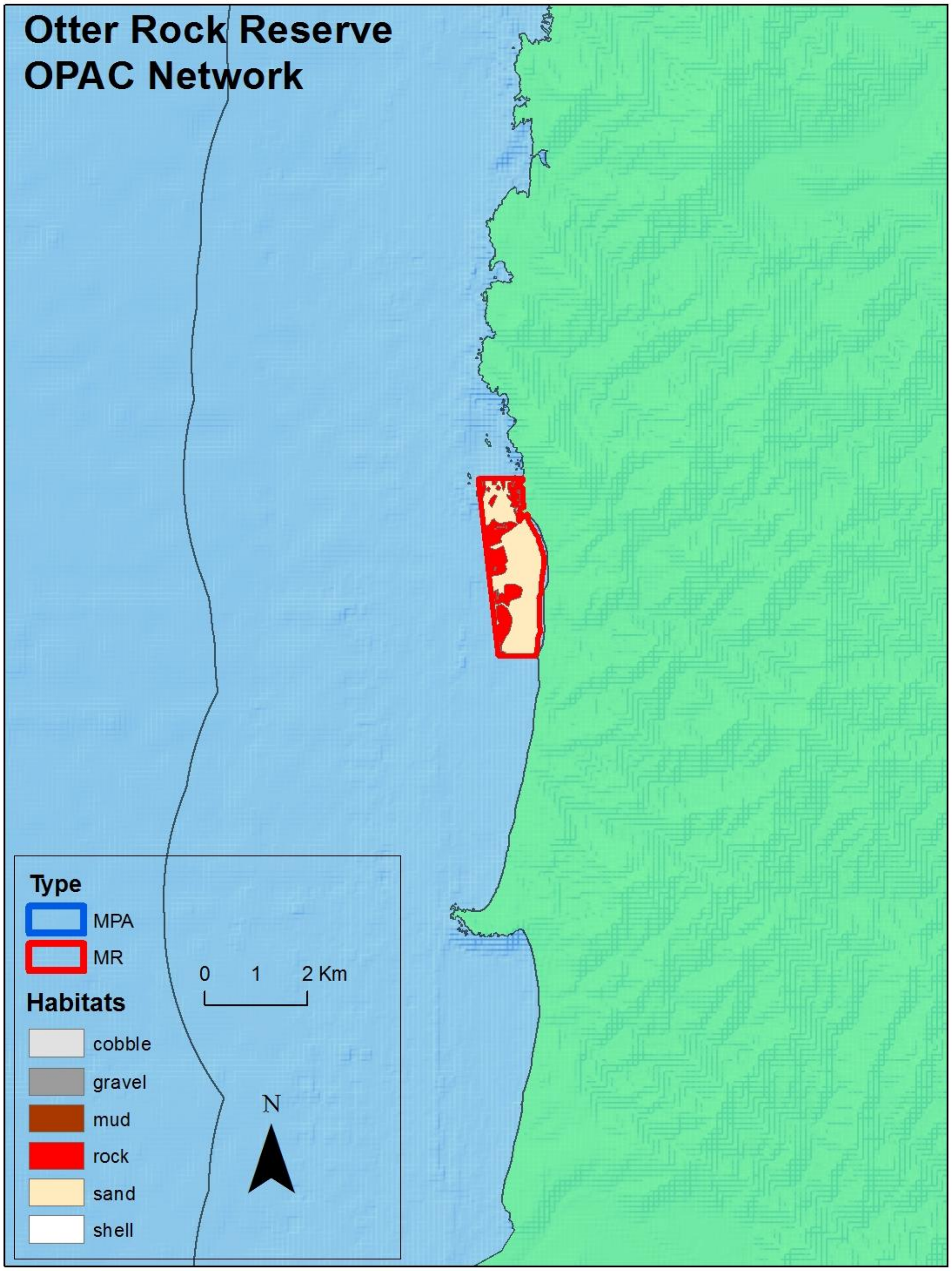
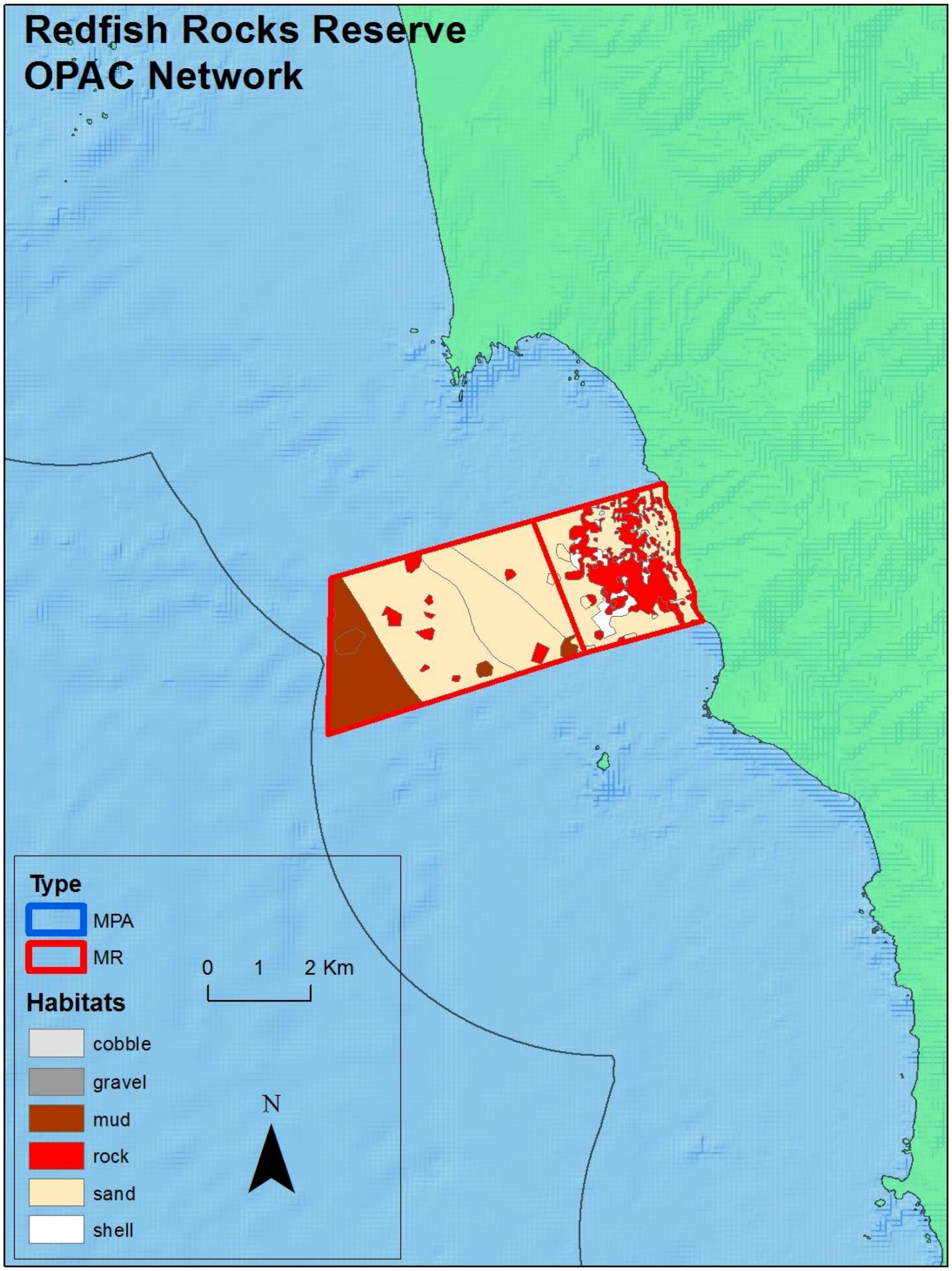
gravel
mud
rock
sand
shell
N


Cascade Head Reserve
OPAC Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0 1 2 Km
N


Otter Rock Reserve
OPAC Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0 1 2 Km
N


Redfish Rocks Reserve
OPAC Network
Type
MPA
MR
Habitats
cobble
gravel
mud
rock
sand
shell
0 1 2 Km
N