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MARINE RESERVE NETWORK DESIGN

A CASE STUDY IN APPLYING ECOLOGICAL DESIGN PRINCIPLES TO DANAJON REEF MKBA

Ecosystem Improved for Sustainable Harvests (ECOFISH) Project

April 2017

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MARINE RESERVE NETWORK DESIGN

A CASE STUDY IN APPLYING ECOLOGICAL DESIGN PRINCIPLES TO DANAJON REEF MARINE KEY BIODIVERSITY AREA (MKBA)

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ACRONYMS

BISU	Bohol Island State University
CI	Compact Index
CRMP	Coastal Resource Management Project
DA-BFAR	Philippine Department of Agriculture-Bureau of Fisheries and Aquatic Resources
EAFM	Ecosystem Approach to Fisheries Management
EBM	Ecosystem-Based management
ECOFISH	Ecosystems Improved for Sustainable Harvests
FISH	Fisheries Improved for Sustainable Harvests
GIS	Geographic Information Systems
ICM	Integrated Coastal Management
IUCN	International Union for Conservation of Nature
LGU	Local Government Unit
MEAT	Marine Protected Area Effectiveness Assessment Tool
MFARMC	Municipal Fisheries and Aquatic Resource Management Councils
MKBA	Marine Key Biodiversity Area
MPA	Marine Protected Area
NGO	Nongovernmental Organization
PCRA	Participatory Coastal Resource Assessment
SST	Sea Surface Temperature
UPVFI	Philippines in the Visayas Foundation, Inc.
USAID	United States Agency for International Development

1 INTRODUCTION

The United States Agency for International Development (USAID)/Philippines' Ecosystems Improved for Sustainable Harvests (ECOFISH) Project was a 5-year technical assistance project implemented by Tetra Tech, Inc. The main objective of the ECOFISH Project was to improve the management of marine and coastal resources and associated ecosystems that support local economies. ECOFISH aimed to conserve biological diversity, enhance ecosystem productivity, and restore profitability of fisheries in eight marine key biodiversity areas (MKBAs) using an ecosystem approach to fisheries management (EAFM) to improve social, economic, and environmental benefits. The assessment and refinement of marine reserve networks in the eight MKBAs are key deliverables of the project.

1.1 MARINE PROTECTED AREAS, MARINE RESERVES, AND NETWORKS

Marine protected areas (MPAs) have emerged as an essential spatial management tool for coral reef ecosystems. MPAs are areas of restricted access or activity that vary in size, spacing, location, and whose primary objective is the protection of a coastal or marine ecosystem, the resources they contain, and processes essential to maintain ecosystem function and productivity (IUCN-WCPA 2008). Marine reserves, or no-take areas, are a specific type of MPA in which all extractive activities are prohibited. They provide long-term protection for the marine community to recover from human impacts and optimize the long-term, permanent biodiversity benefits beyond the protected area boundaries (IUCN-WCPA 2008).

The establishment of MPAs, including marine reserves, has occurred at community, local government, national government, and transboundary scales, covering exclusive economic zones. In the six Coral Triangle countries – Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands, and Timor-Leste – MPAs have emerged at the national and local levels with more than 1,900 MPAs covering over 200,880 square kilometers (km^2) or 1.6 percent of the exclusive economic zone for the region (White et al., 2014). These MPAs have been established over the last 40 years under legal mandates that range from village level traditional law to national legal frameworks to mandate the protection of large areas such as MPAs. As a result, *de facto* networks have evolved, composed of MPAs of various sizes, shapes, spacing, legally defined uses and restrictions, and levels of management.

A comprehensive review of the effectiveness of MPAs in biodiversity conservation in the Philippines indicated that the current extent, distribution, and size of MPAs were inadequate to fulfill biodiversity conservation objectives at this scale (Weeks et al., 2009). The conservation effectiveness of nearly 1,000 MPAs (community-based and nationally designated) was evaluated to the degree to which marine bioregions and conservation priority areas are represented within existing MPAs. The analysis found that the current extent and distribution of MPAs did not adequately represent biodiversity. Three key recommendations emerged to improve biodiversity conservation outcomes: (1) increase the number and, where possible, size of community-based MPAs and (2) designate additional large no-take areas specifically to address conservation goals, and (3) continue to build capacity of both local government-supported MPAs and national agency-managed MPAs to improve overall management effectiveness and governance of individual sites.

Interest in scaling up MPAs as networks to achieve multiple management objectives, including biodiversity conservation, sustainable fishing, and climate resilience, has emerged over the last 10 years. In a review of MPA networks in the Coral Triangle, Green, White, and Christie (2011) characterized three types of networks: ecologically and scientifically planned networks, administrative networks designed for management feasibility and efficiency, and learning networks characterized by a socially-oriented adaptive management process. Ideally, these different network types would be mutually reinforcing where ecological principles would provide the underpinning of network design adjusted for management feasibility and refined over time based on performance and changing socio-ecological conditions.

An emphasis on designing networks of marine reserves based on ecological principles has emerged to help coral reef managers, practitioners, and communities develop networks that support the multiple objectives of sustainable fisheries, biodiversity conservation, and climate resilience (IUCN-WCPA 2008, Cabral, Mamauag, and Aliño, 2015, Horigue et al., 2015, Varney et al., 2010, McLeod et al., 2009, Fernandes et al., 2012, Green, White, and Kilarski, 2013, Fernandes et al., 2005). The application of these ecological design principles pose challenges in many developing country settings for several reasons. First, the data needed to understand ecological functions and processes are limited. Information about ocean circulation, larval transport, habitat extent and condition, are often not available at the scale and scope necessary to apply these principles. Second, the feasibility of managing a network of marine reserves becomes difficult if the network includes marine reserves that are distant from a community or local jurisdiction or may cross multiple jurisdictions. Third, socio-political factors may make it difficult to re-design existing or add new marine reserves that require social acceptance and new legislation.

1.2 EVOLUTION OF THE ECOLOGICAL DESIGN PRINCIPLES

Ecological principles for marine reserve network design have evolved with new scientific studies and as new threats, such as climate change, have emerged. Biophysical operational principles to help achieve ecological objectives of representative areas were identified for the Great Barrier Reef (Table 1). The International Union for Conservation of Nature (IUCN) also identified ecological guidelines for MPA networks that could be applied in different ecosystems globally (Table 2) (IUCN-WCPA, 2008).

TABLE 1. BIOPHYSICAL OPERATIONAL PRINCIPLES TO HELP ACHIEVE ECOLOGICAL OBJECTIVES OF REPRESENTATIVE AREAS (FERNANDES ET AL., 2005)

ENSURE LOCAL INTEGRITY: No-take areas should be at least 20 kilometers (km) long on the smallest dimension (except for coastal bioregions). Maximize the amount of protection larger (vs. smaller) no-take areas have.

REPLICATE: Have sufficient no-take areas to ensure against negative impacts on some part of a bioregion.

AVOID FRAGMENTATION: Where a reef is incorporated into a no-take area, the whole reef should be included.

SET MINIMUM AMOUNT OF PROTECTION: Represent a minimum amount of each reef and non-reef bioregion in the no-take area.

MAINTAIN GEOGRAPHIC DIVERSITY: Represent cross-shelf and latitudinal diversity in the network of no-take areas.

REPRESENT ALL HABITATS: Represent a minimum of each community type and physical environment type in the overall network.

APPLY ALL AVAILABLE INFORMATION ON PROCESSES: Maximize the use of environmental information to determine the configuration of no-take areas to form viable networks.

PROTECT UNIQUENESS: Include biophysically special/unique places.

TABLE 2. IUCN ECOLOGICAL GUIDELINES FOR RESILIENT MPA NETWORK DESIGN (IUCN-WCPA 2008)

GUIDELINE 1: INCLUDE THE FULL RANGE OF BIODIVERSITY PRESENT IN THE BIOGEOGRAPHIC REGION

- Representation
- Replication
- Representation of resilient and resistant characteristics

GUIDELINE 2: ENSURE ECOLOGICALLY SIGNIFICANT AREAS ARE INCORPORATED

- Protection of unique or vulnerable habitats
- Protection of foraging or breeding grounds
- Protection of source populations

GUIDELINE 3: MAINTAIN LONG-TERM PROTECTION

- Spillover of larvae, juveniles, and adults from long-term protection
- Adaptive strategies to long-term protection

GUIDELINE 4: ENSURE ECOLOGICAL LINKAGES

- Connectivity
- Adult movement patterns
- Larval dispersal

GUIDELINE 5: ENSURE MAXIMUM CONTRIBUTION OF INDIVIDUAL MPAS TO THE NETWORK

- Size
- Spacing
- Shape

Building on these efforts, the US Coral Triangle Initiative Support Program supported the development of ecological design principles for marine reserve networks in the Coral Triangle (Green et al., 2015, Green et al., 2014, Abesamis et al., 2014). Based on a comprehensive review of the literature, the ecological design principles were developed to guide the development of resilient marine reserve networks (Table 3). A practitioner's guide was also developed to define the meaning of each principle (Green, White, and Kilarski, 2013). Still, for many of these design principles, the application to assess existing networks or design new networks is not straightforward. Some of the design principles are applied at the individual marine reserve level, while others must be applied at a larger scale. Some of the design principles to evaluate the size and shape of a marine reserve are straightforward, while others require scientific studies of biophysical processes, such as ocean circulation, fish life history, and other ecological data. Finally, some of the design principles may require stakeholders from distant areas to collaborate on design and ultimately on management of the network. As such, a process was needed to help local managers and other stakeholders apply the ecological principles to address some of these constraints.

TABLE 3. ECOLOGICAL PRINCIPLES FOR DESIGNING RESILIENT NETWORKS OF MARINE RESERVES FOR BIODIVERSITY CONSERVATION, FISHERIES MANAGEMENT, AND CLIMATE CHANGE ADAPTATION

THEME	ECOLOGICAL DESIGN PRINCIPLES
Habitat Representation	Represent 20-40% of each major habitat (i.e., each type of coral reef, mangrove, and seagrass community) in marine reserves, depending on fishing pressure status of effective fisheries management outside reserves (Green et al., 2014).
Risk Spreading	Replicate protection of each major habitat within at least three widely separated marine reserves (Green et al., 2014).
Protecting Critical, Special, and Unique Areas	Protect critical areas (e.g. fish spawning areas, nursery, nesting, breeding, and feeding areas) in the life history of focal species (including key fisheries species, herbivores, and rare/threatened species e.g. turtles, dugong and cetaceans) in permanent or seasonal marine reserves (Green et al., 2014, Green et al., 2015).
	Protect special or unique areas (e.g. isolated habitats with unique assemblages and populations, important habitats for endemic species, and highly diverse areas) in marine reserves (Green et al., 2014).
Incorporating Connectivity	Marine reserves should be more than twice the size of the home range of focal species (in all directions), thus marine reserves of various sizes will be required depending on which species require protection, how far they move, and if other effective management is in place outside reserves (Green et al., 2015). Recommendations regarding minimum reserve size must be applied to the specific habitats that focal species use (in all directions), rather than the overall size of the reserve (which may include other habitats)(Green et al., 2014).
	Space marine reserves <15 km to 10s of km apart, with smaller reserves closer together (Green et al., 2014, Green et al., 2015).
	Marine reserves should include habitats that are critical to the life history of focal species (e.g., home ranges, nursery grounds, migration corridors, and spawning aggregations), and be located to accommodate movement patterns among these (e.g.,

	ontogenetic habitat shifts and spawning migrations (Green et al., 2014, Green et al., 2015).
	Include whole ecological units (e.g., offshore reefs) in marine reserves (Green et al., 2014).
	Use compact marine reserve shapes (e.g., squares or circles) rather than elongated ones (Green et al., 2014), except when protecting naturally elongated habitats (e.g. long narrow reefs (Green et al., 2017)).
	Locate more marine reserves upstream relative to fished areas if there is a strong, consistent, unidirectional current (Green et al., 2014, Green et al., 2015).
	Protect spatially isolated areas or populations (i.e. those that are separated by >30 km from similar habitats) in marine reserves (Green et al., 2014, Green et al., 2015).
Allowing Time for Recovery	Ensure marine reserves are in place for the long term (20-40 years), preferably permanently, to allow for full population recovery and maximum biomass export to fished areas of the full range of highly targeted species (Abesamis et al., 2014, Green et al., 2014). Strict compliance to marine reserves is required to avoid considerable delays in recovery (Abesamis et al., 2014).
	Short term (<5 years) or periodically harvested marine reserves should be used in addition to, rather than instead of, long-term or permanent reserves (Abesamis et al., 2014). Where periodic closures are used, the timing and intensity of harvesting must be carefully controlled to ensure long-term fishery benefits (Jupiter et al., 2012, Abesamis et al., 2014).
Adapting to Changes in Climate and Ocean Chemistry	Protect refugia in marine reserves where habitats and species are likely to be more resilient to climate and ocean change including (Green et al., 2014): • Areas where habitats and species are known to have withstood environmental changes (or extremes) in the past (e.g., coral communities that appear more resilient to high SSTs); • Areas with historically variable SSTs and ocean carbonate chemistry, where habitats and species are more likely to withstand changes in those parameters in future; and • Areas adjacent to low-lying inland areas without infrastructure that coastal habitats (e.g., mangroves, tidal marshes, and turtle nesting beaches) can expand into as sea levels rise.
Minimizing and Avoiding Local Threats	Avoid placing marine reserves in areas that have been, or are likely to be, impacted by local threats (e.g., land based runoff) that cannot be managed effectively (Green et al., 2014).
	Place marine reserves in areas that have not been, or are less likely to be, impacted by local threats including (Green et al., 2014): • Areas where threats (e.g., overfishing or destructive fishing) can be managed effectively; and • Areas within or adjacent to other effectively managed marine or terrestrial areas.
	Integrate marine reserves within broader spatial planning and management regimes (e.g., large multiple-use MPAs, EAFM, EBM, and ICM (Green et al., 2014).

2 CASE STUDY OBJECTIVES

This case study describes efforts to develop and test a process to help local managers and other stakeholders apply the ecological principles in an assessment of *de facto* marine reserve networks in order to improve network performance or in the design of new marine reserve networks. The primary objectives of this case study are to:

- Use the best available science to improve network design of marine reserves by applying ecological design principles
- Develop tools to help managers apply the ecological principles together with local stakeholders
- Promote science-based decision making in marine and coastal management

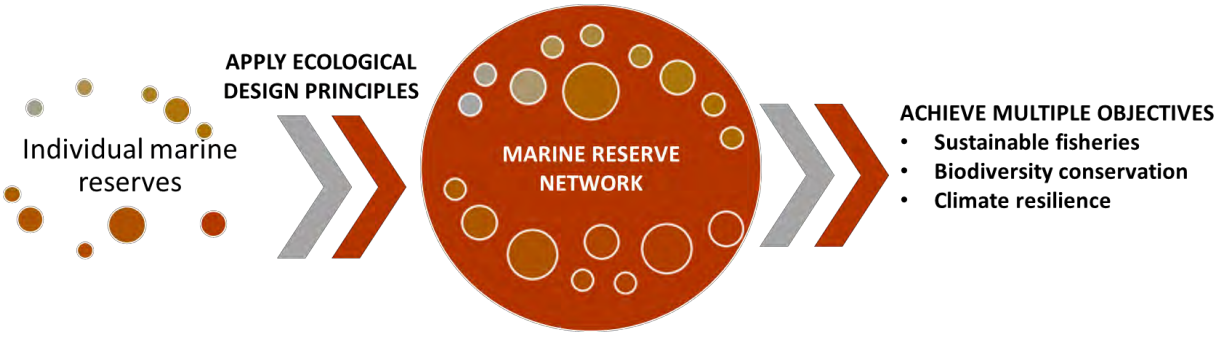

FIGURE 1. APPLYING ECOLOGICAL DESIGN PRINCIPLES TO IMPROVE MARINE RESERVE NETWORK PERFORMANCE

The case study describes efforts to apply ecological design principles to an existing network of marine reserves in a portion of the Danajon MKBA focused on municipalities in Bohol, Philippines. Marine reserves in this area were the central focus of the case study. While the term "MPA" is often used interchangeably with "marine reserve" in the Philippines, for the purpose of this case study, the term marine reserve will be used predominantly for discussion of the application of the ecological principles to network design. The term MPA will be retained for Philippine-specific institutions, names of marine reserves, and protocols. As the ecological principles are applied at different scales, the term "marine managed area" is used to refer to the case study area which includes different scales of management including municipal waters of an individual or multiple municipal jurisdictions and the entire Danajon Reef MKBA.

3 DANAJON REEF MARINE KEY BIODIVERSITY AREA

The Danajon Reef MKBA encompasses 18 municipalities in four provinces in the Central Visayas region of the Philippines (Table 4) Local jurisdiction for managing nearshore waters out to 15 km from the shoreline was mandated by national law in 1991 by the Local Government Code, and reinforced in 1998 by the Philippines Fisheries Code. Municipalities, in consultation with their Municipal Fisheries and Aquatic Resource Management Councils (MFARMCs) and other stakeholders, are responsible for fisheries management and protecting habitats from destructive activities.

A central ecological feature of this MKBA is the double barrier reef known as Danajon Bank. Danajon Bank is the only double barrier reef in the Philippines and one of only three such sites in the Indo-Pacific (Pichon 1977). The reef spreads across almost 130 km and consists of three large reefs and five smaller reefs. The overall area of the Danajon Bank is 272 km^2 with an aggregate coastline of 381 km including 40 islands. Danajon Bank has a high degree of diversity of species and habitat types including coral reef, mangrove forests, and wide areas of seagrass beds. Almost all species of seagrass that occur in the Philippines are represented. The Bank is also important as a source of biodiversity and known source area for fish and invertebrate larvae in the Visayan and Camotes Seas. It is also a migratory pathway for birds and large marine animals.

Danajon Bank plays a major role in the fishing industry of the Province of Bohol. Given its varied habitats of coral reefs, mangroves, and seagrass beds, Danajon Bank harbors various species of finfish, shellfish, crustacean, and invertebrates. These include reef fishes such as grouper and snapper, and small pelagics such as scads, round scads, and bullet tunas. Among the invertebrates that abound in the area are blue crabs, shrimps, squids and sea cucumbers. Seagrass-associated fish such as rabbitfish also inhabit the area as well as anchovies and garfish. About 54 percent of the fishers, 44 percent of the non-motorized boats, and 62 percent of the motorcrafts of the entire province are found in the 9 coastal municipalities bounding the Danajon Bank. In addition, it is a critical fishing ground for fishers from Cebu, Leyte, and Southern Leyte who have relied on fishing in the area for their subsistence and livelihood for many generations. As a result, the area has been subjected to extremely high fishing pressure, largely through illegal and destructive fishing methods. Fisheries outside of the shallow reef areas are also heavily exploited by a combination of small-scale locally based fishers and commercial fishing boats that fish illegally inside municipal waters.

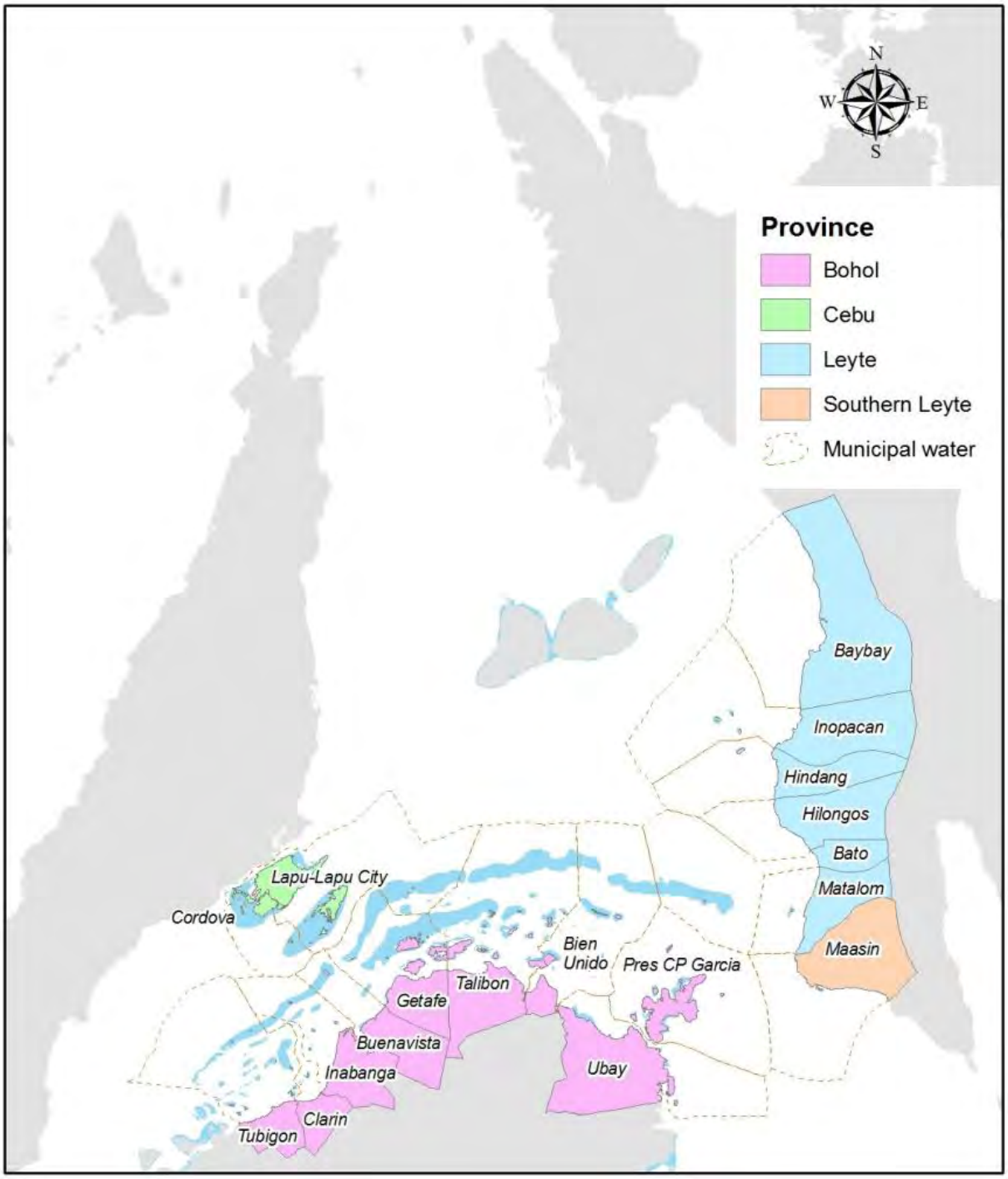

FIGURE 2. DANAJON DOUBLE BARRIER REEF (SHOWN IN BLUE) EXTENDS ACROSS MULTIPLE MUNICIPAL WATERS MARINE KEY BIODIVERSITY AREA

TABLE 4. AREA OF MUNICIPAL WATERS AND LENGTH OF COASTLINE IN EACH MUNICIPALITY IN THE DANAJON REEF MARINE KEY BIODIVERSITY AREA

PROVINCE	MUNICIPALITY	MUNICIPAL WATERS (KM^2)	LENGTH OF COASTLINE (KM)
Bohol	Pres. C.P. Garcia	473	74.7
	Ubay	207	47.8
	Bien Unido	363	32.5
	Talibon	453	69.3
	Getafe	198	67.8
	Buenavista	81	12.1
	Inabanga	144	22.2
	Clarin	41	6.5
	Tubigon	396	26.2
Cebu	Cordova	114	11.0
	Lapulapu City	439	90.4
Leyte	Baybay	345	41.5
	Inopacan	348	9.6
	Hindang	181	9.8
	Hilongos	109	11.3
	Bato	331	4.3
	Matalom	113	16.1
So. Leyte	Maasin	272	21.5
Total		**4,608**	**574.6**

Three major USAID-funded projects have provided technical assistance to local governments and communities: the Coastal Resource Management Project (CRMP), the Fisheries Improved for Sustainable Harvests (FISH) Project, and the ECOFISH Project. These projects have supported a progressive foundation for coastal and fisheries resource management with marine reserves as key components of that framework.

The CRMP (1996 – 2003) developed the capacity of municipal governments to manage municipal waters for the benefit of small-scale fisheries by promoting coastal resource management as a basic service. CRMP assisted municipalities to establish municipal water boundaries, strengthen enforcement of fishing regulations, and establish and strengthen small marine reserves.

The FISH Project (2003 – 2010) introduced fisheries management interventions and marine reserve network design, incorporating hydrodynamic and larval dispersal studies to provide information on current and larval distribution patterns and potential ecological interactions in focal area municipalities. The results of hydrodynamic and larval dispersal modeling highlight that water flow is predominantly to the west following the Danajon Reef structure, and indicate that predominant larval sources are likely from the north and northwest with sinks to the north and southwest (Figure 4). Based on these studies, the FISH Project identified, established, and strengthened 13 marine reserves in the four focal area municipalities to support connectivity in the Danajon network.

The ECOFISH Project (2012 – 2017) strengthened fisheries management, MPA management, and the use of marine spatial planning to support sustainable fishing and to reduce resource use conflicts. Right-sizing fishing effort and gear, marine spatial planning, and marine reserve management and network effectiveness were key project interventions.

4 APPLICATION OF ECOLOGICAL DESIGN PRINCIPLES

The overall approach focused on applying the ecological principles for marine reserve network design to a marine managed area through a process that engages stakeholders and scientists in the assessment and design of a network (Figure 3). Ecological principles were applied to an existing network to improve performance and identify gaps in achieving multiple management objectives of biodiversity conservation, sustainable fisheries, and climate change adaptation.

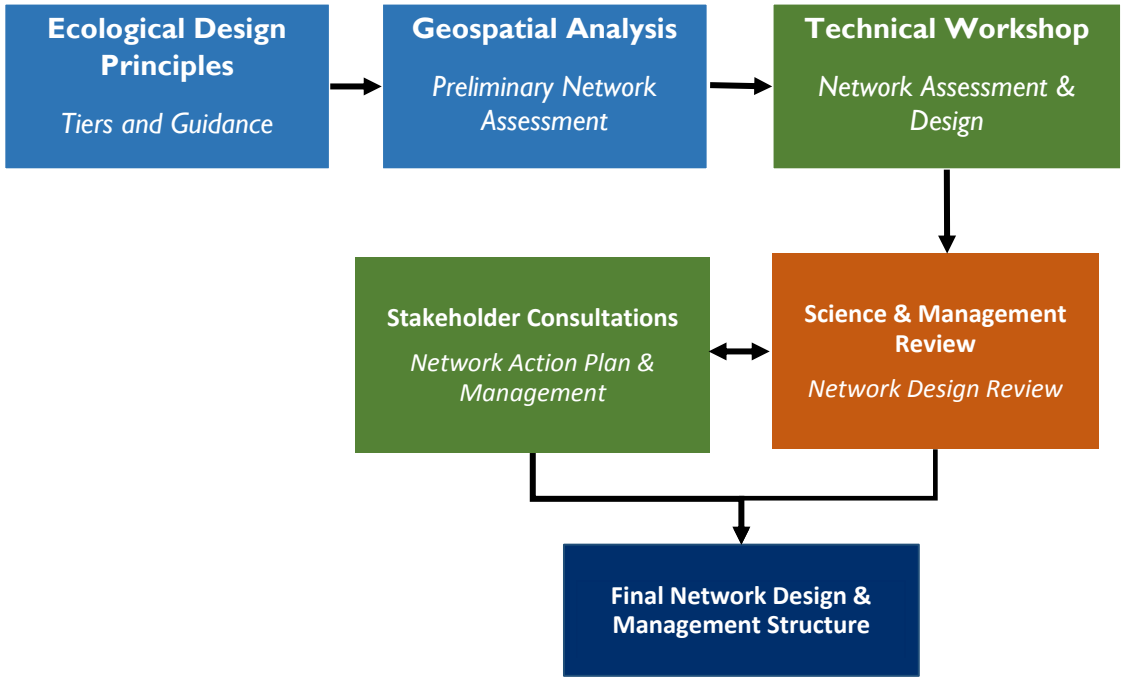

FIGURE 3. MULTI-STAKEHOLDER APPROACH FOR APPLYING ECOLOGICAL PRINCIPLES TO MARINE RESERVE NETWORK ASSESSMENT AND DESIGN

4.1 ECOLOGICAL DESIGN PRINCIPLES: TIERS AND GUIDANCE

The ecological design principles developed and revised by Green et al., (2014) (Table 3) were used as the basis for this case study. These principles were re-organized into two tiers based on the scale of application (Table 5). In addition, guidance was developed, along with a scoring tool, for each principle (see Appendix 1 and 2). The reorganization into tiers and development of guidance and scoring tools were intended to help stakeholders apply the principles in an efficient and effective manner.

Principles applied at the scale of individual marine reserves focusing on location, habitat composition, size, and shape of the marine reserve were grouped into Tier 1. Principles applied at the larger scale of a marine managed area, such as municipal waters of individual or multiple municipal jurisdictions, and the entire MKBA, were grouped into Tier 2.

Within Tier 1, the sequencing of the principles was also considered. Principles 1.1 through 1.3, which focused on the specific location of an individual marine reserve, were examined first in the assessment before principles on habitat composition, size, and shape (e.g., Principles 1.4 – 1.8; Table 5). The principles within Tier 2 were roughly organized in the same manner. Principal 2.8 was placed last to support the need to integrate marine reserves within a larger planning and management framework to ensure competing and conflicting uses of nearshore waters are addressed. In addition to reorganizing the ecological principles into tiers, guidance was developed to help managers use available information and data to apply the principles (see Appendix 1). The guidance was based on the description of each principle drawn from Green, White, and Kilarski (2013). In addition, a scoring guide was developed to provide basis for the assessment.

TABLE 5. ECOLOGICAL DESIGN PRINCIPLES ORGANIZED INTO TIERS FOR APPLICATION AT DIFFERENT SCALES

Tier 1: Ecological Design Principles (applied at individual marine reserve scale)	
1.1	Avoid placing marine reserves in areas that have been, or are likely to be, impacted by local threats (e.g. land-based activities) that cannot be managed effectively (Green et al., 2014).
1.2	Place marine reserves in areas that have not been, or are less likely to be, impacted by local threats including (Green et al., 2014): (a) areas where threats (e.g., overfishing or destructive fishing) can be managed effectively; and (b) areas within or adjacent to other effectively managed marine or terrestrial areas.
1.3	Protect refugia in marine reserves where habitats and species are likely to be more resilient to climate and ocean change (Green et al., 2014) including: (a) areas where habitats and species are known to have withstood environmental changes (or extremes) in the past (e.g., coral communities that appear more resilient to high SSTs); (b) areas with historically variable SSTs and ocean carbonate chemistry, where habitats and species are more likely to withstand changes in those parameters in future; and (c) areas adjacent to low-lying inland areas without infrastructure that coastal habitats (e.g., mangroves, tidal marshes and turtle nesting beaches) can expand into as sea levels rise.
1.4	Protect critical areas (e.g. fish spawning aggregations, nursery, nesting, breeding, and feeding areas) in the life history of focal species (key fisheries species and rare and threatened species) in permanent or seasonal marine reserves (Green et al., 2014, Green et al., 2015).
1.5	Include whole ecological units (e.g., offshore reefs) in marine reserves (Green et al., 2014).
1.6	Marine reserves should be more than twice the size of the home range of focal species (in all directions). Thus, marine reserves of various sizes will be required depending on which species require protection, how far they move, and if other effective management is in place outside reserves (Green et al., 2015), typically ranging from 2km to 20 km in diameter, which is likely to protect focal fish species that move <10 km. Recommendations regarding minimum reserve size must be applied to the specific habitats that focal species use (in all directions), rather than the overall size of the reserve (which may include other habitats (Green et al., 2014). However, marine reserves will need to be combined with other fisheries management tools to manage focal fish species that move wide ranging species.
1.7	Use compact marine reserve shapes (e.g., squares or circles) rather than elongated ones (Green et al., 2014), except when protecting naturally elongated habitats (e.g. long narrow reefs (Green et al., 2017))
1.8	Ensure marine reserves are in place for the long term (20-40 years), preferably permanently, to allow for full population recovery and maximum biomass export to fished areas of the full range of highly targeted species (Abesamis et al., 2014, Green et al., 2014). Strict compliance to marine reserves is required to avoid considerable delays in recovery (Abesamis et al., 2014).
1.9	Short term (<5 years) or periodically harvested marine reserves should be used in addition to, rather than instead of, long-term or permanent reserves (Abesamis et al., 2014). Where periodic closures are used, the timing and intensity of harvesting must be carefully controlled to ensure long-term fishery benefits (Abesamis et al., 2014, Jupiter et al., 2012).

Tier 2: Ecological Design Principles (applied at individual/multiple municipal/MKBA scale)	
2.1	Protect special or unique areas (e.g. isolated habitats with unique assemblages and populations, important habitats for endemic species, and highly diverse areas) in marine reserves (Green et al., 2014).
2.2	Protect spatially isolated areas or populations (i.e. those that are separated by >30 km from similar habitats) in marine reserves (Green et al., 2014, Green et al., 2015).
2.3	Space marine reserves <15 km to 10s of km apart, with smaller reserves closer together (Green et al., 2014, Green et al., 2015).
2.4	Represent 30% of each major habitat in marine reserves, depending on fishing pressure and if effective fisheries management is in place outside the reserves (Green et al., 2014).
2.5	Replicate protection of each major habitat within at least three widely separated marine reserves (Green et al., 2014).
2.6	Marine reserves should include habitats that are critical to the life history of focal species (e.g. home ranges, nursery grounds, migration corridors, and spawning aggregations), and be located to accommodate movement patterns among these (e.g., ontogenetic habitat shifts and spawning migrations (Green et al., 2014, Green et al., 2015).
2.7	Locate more marine reserves upstream relative to fished areas if there is a strong, consistent, unidirectional current (Green et al., 2014, Green et al., 2015).
2.8	Integrate marine reserves within broader spatial planning and management regimes (e.g., large multiple-use MPAs, EAFM, EBM, and ICM (Green et al., 2014)).

4.2 GEOSPATIAL ANALYSIS: PRELIMINARY NETWORK ASSESSMENT

Geospatial analysis was conducted based on a geographic information system (GIS) analysis of the best available information for each design principle. This analysis served as a preliminary network assessment and provided input needed for stakeholder assessment. In addition, the geospatial analysis helped identify which ecological principles could be supported by existing information and data. The key steps used for the geospatial analysis are described below.

DEFINE THE GEOGRAPHIC SCOPE OF THE NETWORK DESIGN PROCESS. The geographic scope for this case study focused on a portion of the Danajon Reef MKBA that encompasses nine municipalities along the northern and northwestern coast and municipal waters of the province of Bohol (Table 4). Circulation and dispersal modeling conducted by the University of the Philippines Marine Science Institute helped define the geographic scope of the study area (Figure 4). The different colored boxes indicate the sites where the model released particles to simulate a source of larvae. The associated colored dots show where the "larvae" dispersed from its respective release site. Overall flow is westerly and southwesterly along the western side of Bohol.

Approximately 87 marine reserves were inventoried for the case study (Figure 5). The most recent marine reserve was established in 2007. Most marine reserves encompass small areas. The smallest marine reserve is 2.4 hectares, while the largest is over 7,000 hectares. Management effectiveness ratings of most marine reserves are at the first level of "established" with only a few rated as the second level of "strengthened." These marine reserves formed the existing network used to assess network performance using the ecological design principles.

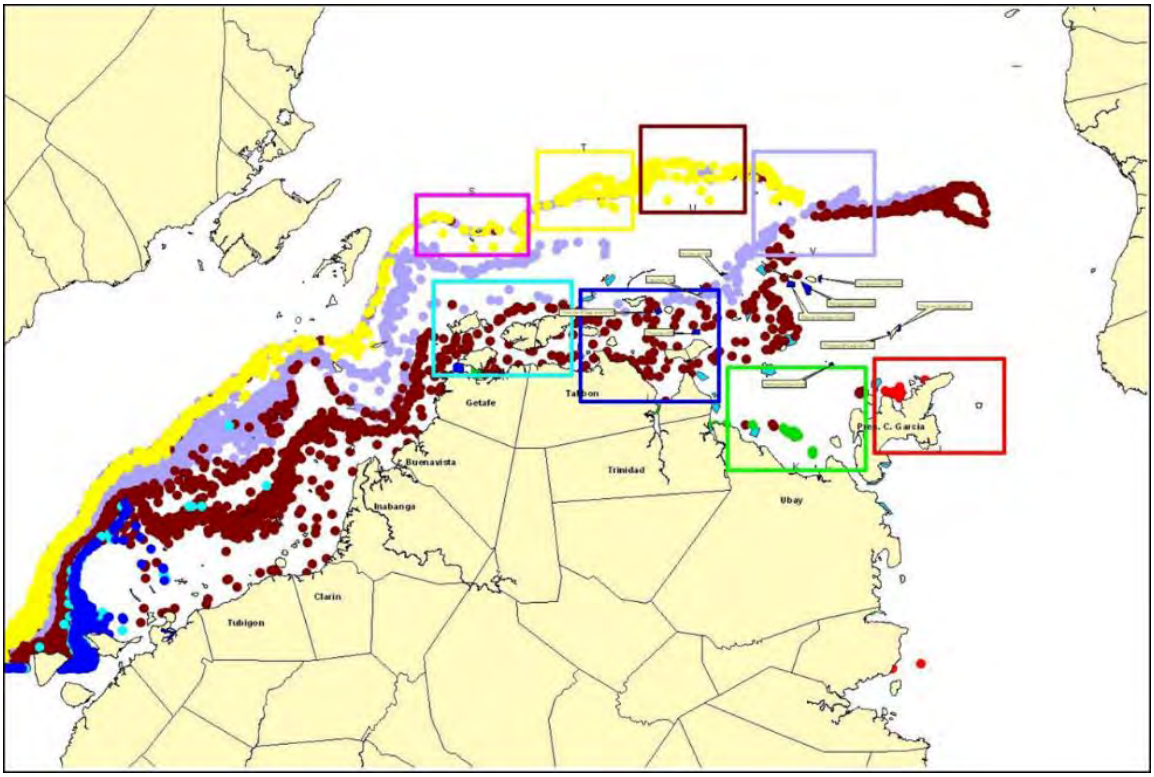

FIGURE 4. RESULTS OF HYDROGRAPHIC MODELLING AROUND BOHOL INDICATE PREDOMINANTLY WESTWARD FLOW OF WATER ALONG DANAJON REEF (VILLANOY ET AL., 2006)

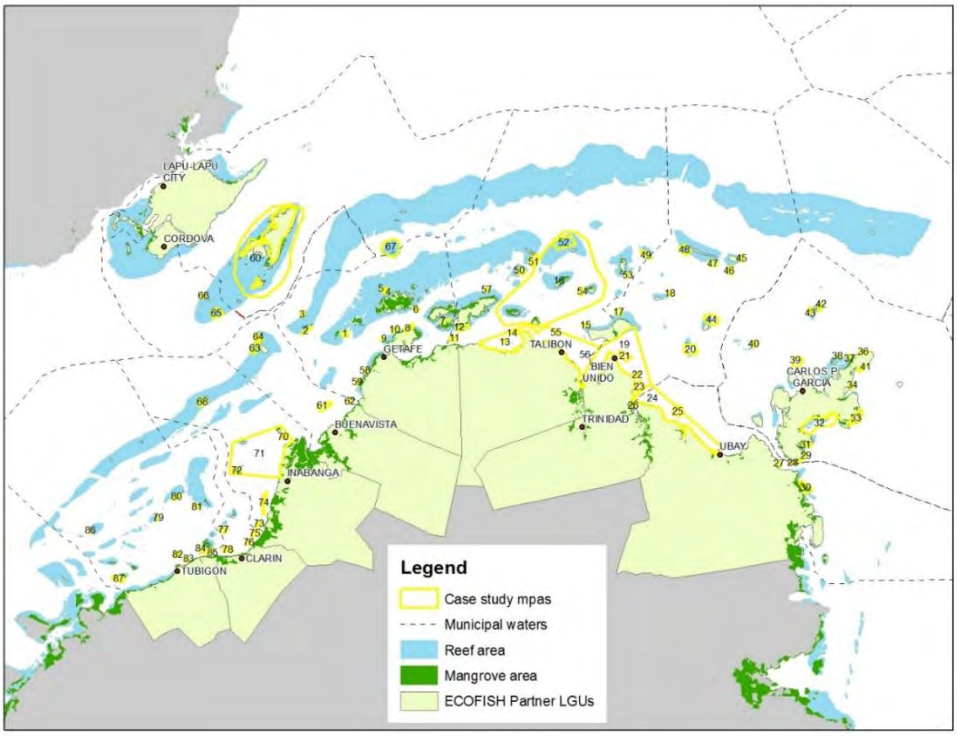

FIGURE 5. MARINE RESERVES IN THE CASE STUDY AREA

COMPILE EXISTING INFORMATION AND DATA INTO A GEOGRAPHIC INFORMATION SYSTEM (GIS) DATABASE. The boundaries of individual marine reserves, as well as local and national jurisdictional boundaries, were incorporated in a GIS database with data on the types and distribution of marine habitats. Accurate marine reserve boundaries are needed for an analysis of compactness, habitat representation, and other ecological design principles. In addition, a focal list of both target species for fishing and threatened, rare, or endangered species is necessary to evaluate many of the ecological principles. Global and national datasets were used to estimate the area of different habitats within the study region. In addition, information on sea surface temperature variation and the potential for bleaching was obtained from Coral Reef Watch (Figure 6). Information on the management status and community values was compiled for each marine reserve.

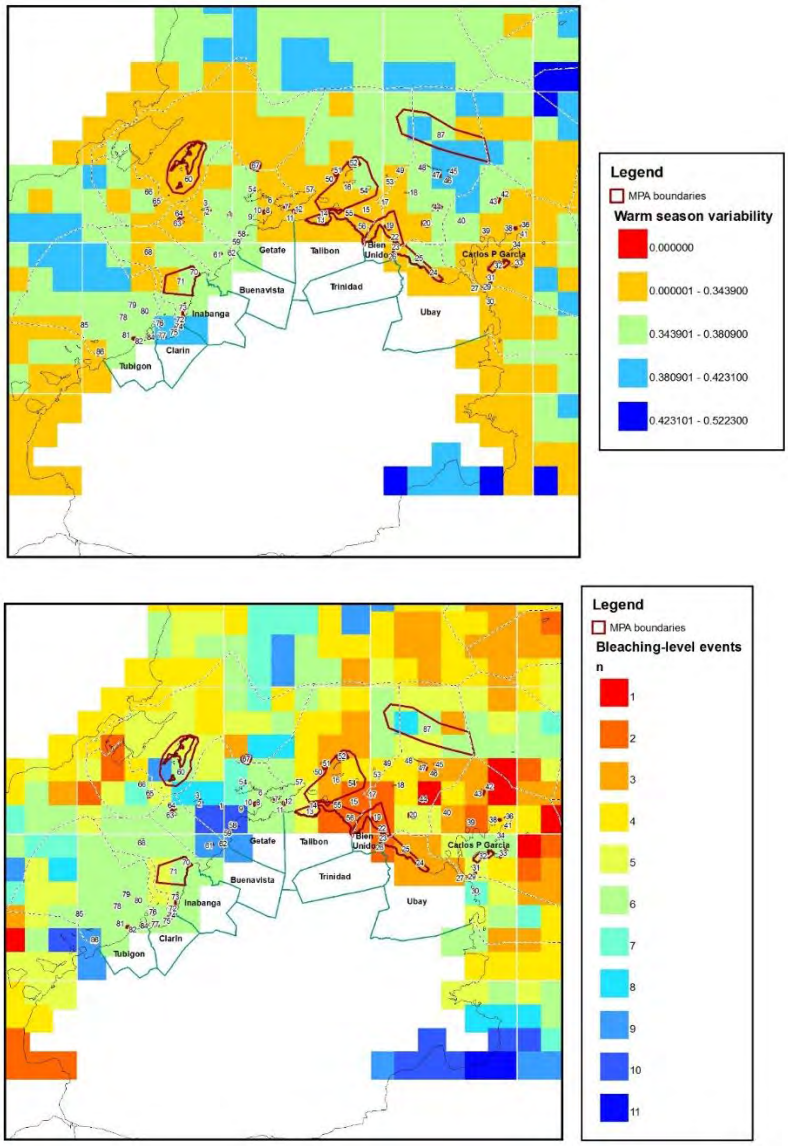

FIGURE 6. AREAS OF DANAJON BANK MKBA SHOWING SEASONAL SEA SURFACE TEMPERATURE VARIABILITY (TOP) AND POTENTIAL BLEACHING-LEVEL EVENT TEMPERATURES (BOTTOM) DEVELOPED BY CORAL REEF WATCH FOR THE CASE STUDY

CONDUCT GEOSPATIAL ANALYSIS OF ECOLOGICAL DESIGN PRINCIPLES WHERE FEASIBLE. A geospatial analysis of existing or proposed new marine reserves is needed for as many of the ecological principles as is feasible to produce. For this case study, geospatial analysis was conducted for 12 of the 17 ecological principles using available information and data (Table 6).

TABLE 6. GEOSPATIAL ANALYSIS OF ECOLOGICAL PRINCIPLES CONDUCTED FOR THE DANAJON REEF MKBA

ECOLOGICAL PRINCIPLE (SEE APPENDIX 1)		GEOSPATIAL ANALYSIS
1.1, 1.2	Presence/absence of local threats	Map showing locations of land and marine-based threats in the study area based on the results of participatory coastal resource assessment conducted in each municipality
1.3	Climate refugia	Map showing areas with high seasonal water temperature variability and low bleaching potential based on data from Coral Reef Watch; and mangrove forests and turtle nesting beaches to evaluate potential landward migration of critical habitats with sea levels rise
1.6	Size	Calculation of the diameter of each marine reserve based on the smallest circle that can completely encompass the marine reserve
1.5	Whole ecological units	Map showing whole ecological units in marine reserves
1.7	Compactness	Compact index calculated as the area of the marine reserve divided by the perimeter of the marine reserve
2.3	Spacing	Distances between all marine reserves in a municipality up to 20 km from each other
2.2	Spatially isolated areas or populations	Map showing locations of offshore reefs or areas with unique populations
2.4	Habitat representation	Map showing habitats in the study area and spatial analysis of percentages of each habitat type within existing or proposed new marine reserves
2.5	Replication of habitat protection	Maximum distances between three marine reserves protecting each habitat type
2.6	Critical areas	Map showing locations of nursery, nesting, breeding, and feeding areas based on known life history requirements for target fish species (See Appendix 2)
2.7	Upstream protection	Maps showing results of circulation and dispersal modeling
2.8	Area of marine reserves in relation to larger marine managed area	Percent of managed area (individual and multiple municipal waters) protected as marine reserves

4.3 TECHNICAL WORKSHOP: NETWORK ASSESSMENT AND DESIGN

The ECOFISH Project conducted a 2-day workshop (March 2016) in Bohol to apply ecological design principles to an existing network in the Danajon MKBA. Workshop participants included technical staff

and scientists from national government agencies, local government units (LGUs), non-governmental organizations (NGOs), and academic institutions. During the workshop, stakeholders used geospatial analysis, scientific information, and local knowledge to assess the existing marine reserve network by applying ecological design criteria. As a result, participants identified areas for new marine reserves and changes to existing marine reserve boundaries and locations, then developed action plans to implement these changes (

Figure 7, Table 7). The key sessions of the workshop are described below.

REVIEW PRELIMINARY NETWORK ASSESSMENT. This session provided in-depth discussion of each ecological design principle and rationale for scoring as a basis for network design. Participants were first introduced to the ecological design principles used to conduct the preliminary network assessment using geospatial analysis of existing information in each tier (Table 6). The remaining principles were then reviewed. The key goal of this session was for participants to validate the preliminary assessment results and identify corrections or changes needed. For example, in some cases, the location of existing marine reserves mapped based on the legal description did not match the actual location, highlighting a common discrepancy.

IDENTIFY FOCAL SPECIES FOR NETWORK DESIGN ASSESSMENT. Participants identified focal species needed to apply specific ecological design criteria. The fish ecological characteristics and benefits matrix (Appendix 2) was used to identify focal species of interest in network design and examine the life history requirements. The ecological design principles that consider specific ecological characteristics, such as the size of marine reserves being dependent on the home range of focal species, were reintroduced in this session.

CONDUCT NETWORK ASSESSMENT. During this session, participants conducted an assessment of each ecological principle at either the individual marine reserve level or managed area level. Participants were grouped by municipality to assess marine reserves under that municipality's jurisdiction individually and as a network. In some cases, the assessment also included national MPAs.

Upon completing the network assessment at the municipal level, participants discussed their findings in plenary across the study area. Gaps in network design were highlighted within and across municipalities. This discussion was critical before moving onto the next step of network design. For example, in assessing the ecological principle for connectivity, it was quickly realized that municipalities in the northernmost extent of the study area were important source areas for larval transport and recruitment to municipalities along the southwestern coast of Bohol. The plenary discussion illustrated the important contribution of ecologically designed and well managed marine reserves in northern municipalities to supporting the fisheries management objectives of the southwestern municipalities.

DESIGN NETWORK REFINEMENTS. Using the results of the network assessment, the participants identified refinements in design to improve network performance at municipal and multi-municipal levels. These refinements were expressed categorized as follows:

- **Retain** the marine reserve without any changes
- **Alter** the marine reserve to address the ecological principle
- Establish **new** marine reserve(s) to address the ecological principle
- **Remove** the marine reserve if it does not support the ecological principle or does not currently, or is not expected to, contribute to achieving one or more management objective(s)

- Resolve **data gaps** in boundary or condition of an existing marine reserve before further action is taken

Participants identified these changes using different colored stickers on large maps of the study area (

Figure 7). Again, participants reviewed the proposed changes and discussed further refinements beyond the individual municipality.

PREPARE IMPLEMENTATION ACTION PLAN. Participants developed an action plan for implementing the network refinements (Table 7). The proposed network refinements were updated in the GIS database as a basis for science review and stakeholder follow-up.

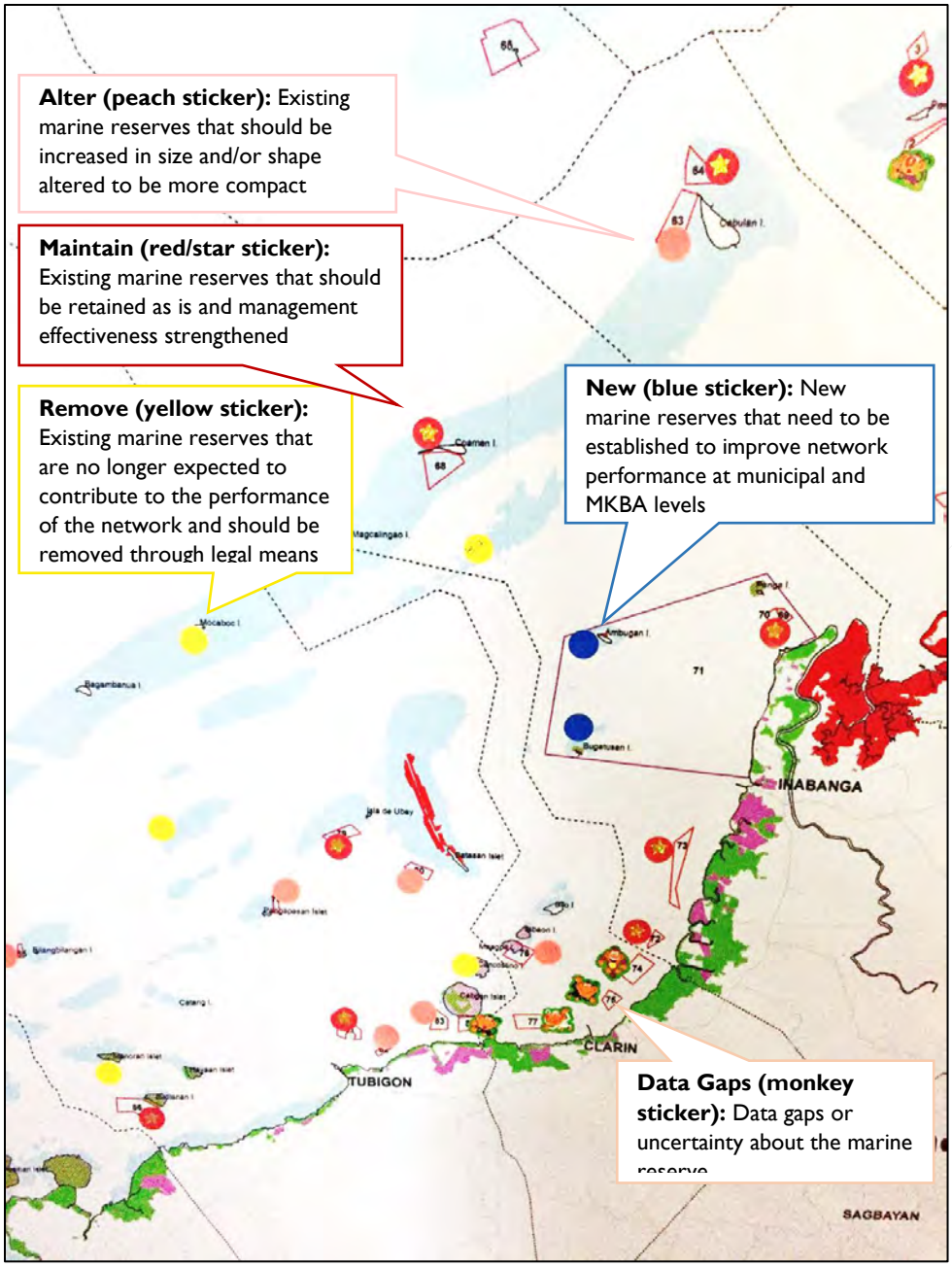

FIGURE 7. EXAMPLE OUTPUT OF APPLYING ECOLOGICAL DESIGN PRINCIPLES TO IMPROVE MARINE RESERVE NETWORK DESIGN

TABLE 7. EXAMPLE ACTION PLAN FOR IMPROVING MARINE RESERVE NETWORK PERFORMANCE IN TUBIGON, BOHOL

MPA	ACTION	DATE	LEAD/ PARTNERS
Cabulijan Tinangnan Batasan Panggapasan Bilangbilangan	**Adjust boundaries and improve management**	June – Sept 2016	MAO, ZSL, EcoFISH, BFAR, PCG, PNP-Maritime, PNP-PEDO, BLGU, POs
	▪ Partners' meeting/ Tasking		
	▪ Biophysical assessment		
	▪ Community consultation		
	▪ Drafting of MPA ordinance		
	▪ Formulate/ Review MPA management plan		
	▪ Installation of MPA Facilities		
Matabao Ubay Centro	**Improve management**	June – December 2016	MAO, ZSL, EcoFISH, BFAR, PCG, PNP-Maritime, PNP-PEDO, BLGU, POs
	▪ Partners' meeting		
	▪ Conduct Marine Protected Area Effectiveness Assessment Tool (MEAT)		
	▪ Review Management Plan		
	▪ Capability building for MPA management bodies		
Kanlangi Mocaboc Inanuran	**Establish and expand new resource uses through zoning**	Sept - December 2016	MAO, ZSL, EcoFISH, BFAR, PCG, PNP-Maritime, PNP-PEDO, BLGU, POs
	▪ Community consultations (BLGU/Community)		
	▪ Biophysical assessment		
	▪ Drafting of MPA Ordinance		
	▪ MPA management planning		
Macaas	Existing, uncertain how to proceed with many issues.		

A number of refinements to the existing network were proposed by participants of the technical workshop based on their review of the ecological design principles, geospatial analysis, and local knowledge (Table 8). These refinements included changes in boundaries and size, coverage of additional habitats, including sea grass beds and mangroves, and addition of new marine reserves. Action plans by municipality were developed to address proposed changes in marine reserve network design.

TABLE 8. SUMMARY OF RESULTS FROM THE TECHNICAL WORKSHOP

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
Pres. Carlos P. Garcia	**Retain:** Existing marine reserves that should be prioritized for strengthening	3	• Actions to strengthen management for existing MPAs refer primarily to fishery law enforcement and capacitating the LGU staff and communities or people's organizations that comprise the MPA management councils. This entails revisiting and
	Alter: Existing marine reserves that should be increased in size	8	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
	and/or shape altered to be more compact		updating the municipal fishery ordinances, including MPA ordinances, and propose amendments to incorporate elements of the amended Fishery Code (RA 10654) to enhance support to fishery law enforcement in general. Other specific actions include: o Crafting measures to secure tenure of fishery law enforcers, enrolling all deputized fish wardens with the PCIC (to provide insurance), and providing livelihood incentives for fish wardens' families; o Specifying appropriations for M&E and fisheries law enforcement in the amended ordinances; o Institutionalizing regular monitoring and evaluation of MPAs (e.g. at least once per semester) in partnership with the DA-BFAR, NGO groups, and academic institutions. The conduct of trainings to develop local capabilities for MPA monitoring and evaluation is a strategic part of the plan to contribute to long-term sustainability; and o Formulate policies that focus on the management of the MPAs as a network. • Actions to improve individual reserve designs for existing MPAs refer primarily to adjusting the boundaries to modify the size, shape, or coverage (e.g. to include mangroves). This then would necessitate an updating of the technical descriptions of the MPAs through amendments of the respective MPA ordinances. Thereafter, regular conduct of bio-physical assessments, or at the least Participatory Coastal Resource Assessment (PCRA), is necessary to monitor the status of these MPAs. • Consider GEF program as a potential source of technical and financial support in the conduct of capability trainings, community re-organizing, and in strengthening law enforcement.
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	--	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	4 (already legislated but lacking technical descriptions)	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	3 (due to breakdown of MPA management councils/POs)	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
Talibon	**Retain:** Existing marine reserves that should be prioritized for strengthening	5	• Strengthen local enforcement of marine reserves to improve support to management (c/o the barangay-municipality) for data gap MPAs – re-evaluation of site (and potential relocation) or delete • Re-organize MPA management councils • Consider establishing a refugia for rabbitfish (closed season during spawning, with existing ordinance) in the outer reef instead of within the Talibon seagrass area that is adjacent to mainland and receives high motorboat traffic. The existing ordinance for the close season of rabbitfish harvest therefore needs to be refined. • Refine zoning maps to incorporate updated technical descriptions of the protection zones.
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	--	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	2	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	3	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	4	
Getafe	**Retain:** Existing marine reserves that should be prioritized for strengthening	10	• Actions to strengthen management for existing MPAs refer primarily to establish baseline information, conduct IEC activities, update the MPA management plans, re-organize the MPA management councils, and strengthen enforcement via increasing the capability of MPA guards to conduct patrolling and apprehension of violators; Provision of one patrol boat per MPA is seen as the most ideal • The boundary adjustments needed for one of the MPAs has more to do with a boundary dispute with a neighboring community rather than for any ecological basis • Identify relocation sites for MPAs that are to be removed; apart from the ecological bases, spatial use conflicts and community acceptance are equally important considerations
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	1	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	3	
	New: New marine reserves that need to be established to improve network performance at	--	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
	municipal and MKBA levels		• ZSL to extend their support to other MPAs and not just Handumon MPA
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	--	
Ubay	**Retain:** Existing marine reserves that should be prioritized for strengthening	2	• Actions to strengthen management of existing MPAs refer primarily to continue the good practices of close coordination with the LGU and people's organization in monitoring and patrolling of the MPA; will also consider the GEF program as a potential source of technical and financial support in the conduct of capability trainings, community re-organizing, and in strengthening law enforcement. • Attend consultative sessions in the barangay where the non-functioning MPA is located and present the case for its removal. • The 5 new MPAs were proposed to reduce the total distance between the existing MPAs and enhance connectivity; groundwork will be initiated after the elections and in cooperation with partner agencies DA-BFAR and DENR, the academe (e.g. BISU and UPVFI), and other NGO partners (e.g. ZSL)
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	--	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	1 (near the pier with high vehicle traffic, poor water conditions)	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	5	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	--	
Bien Unido	**Retain:** Existing marine reserves that should be prioritized for strengthening	9	• Actions to strengthen management of existing MPAs include: o Conduct of MEAT to involve the communities in the evaluation of MPA management (Quarter 3, 2016) o Conduct planning workshops to review and update the respective MPA management plans o Re-organize MPA management councils and re-orient members on their roles and responsibilities o Conduct bio-physical assessment to monitor and update the status
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	1	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the	--	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
	network and should be removed through legal means		(Oct-Nov 2016) with the support from key partners o Various IEC activities; one in particular that is to be sponsored by the MAO is an MPA Festival to be held during the Fish Conservation Week o Strengthen fisheries law enforcement in general • Where changes in technical descriptions are needed, habitat assessments and community consultations shall be done jointly (Oct-Nov 2016) • Attend consultative sessions in the barangays where the non-functioning MPAs are located and discuss how to move forward.
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	--	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	2 ("paper MPAs", no functioning mgt. council or organization)	
Buenavista	**Retain:** Existing marine reserves that should be prioritized for strengthening	2	• Actions to strengthen management of existing MPAs include the following: o LGU technical staff to undergo a refresher course in MPA establishment o Undergo bio-physical assessment training both at the local level (community - PCRA) and at the LGU level (technical team – earn SCUBA diving and underwater assessment skills) to support local monitoring o Review, update, and enhance MPA management plans to incorporate the ecological principles and identified institutional needs o Continue 24/7 fisheries law enforcement o Enhance enforcement capabilities of fish wardens through additional trainings o IEC activities to include local high schools • Conduct talks to settle boundary disputes with neighboring municipality
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	1	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	--	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	--	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	1 (dispute with another municipality; uncertainty over jurisdiction)	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
Inabanga	**Retain:** Existing marine reserves that should be prioritized for strengthening	4	• Immediate actions include the review of the existing CRM Codes and to review the MPA management plans, and identify sections that may be improved with the incorporation of the workshop outcomes (ecological considerations) • Review the MPA ordinances for the 2 "monkey" MPAs (data gaps) and verify whether or not these have official technical descriptions
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	--	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	1	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	--	
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	2 (no technical descriptions)	
Clarin	**Retain:** Existing marine reserves that should be prioritized for strengthening	--	• Initiate the adjustment of MPA boundaries, the plan of action includes the following activities: o Conduct re-assessment of bio-physical status of the MPA o Follow-up on Sanggunian Bayan resolution for the boundary adjustments o Re-construct the MPA guardhouse and install new marker buoys to delineate the adjusted boundaries of the MPA • For all other MPAs: o Conduct re-assessment to update current status of the MPAs o Present the assessment results to the barangay councils during consultation meetings
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	1 (to encompass reef, mangrove, and seagrass habitats and reduce spatial use conflicts with fishers)	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	--	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	--	o Amend MPA ordinances to incorporate scientific survey findings (e.g. incorporate more habitats under protection) and outputs of consultation meetings o Incorporate ZSL's initial recommendation to increase the size of the better performing MPAs in order to enhance the larval sink function of Clarin o Strengthen POs to improve local management o Improve facilities to support enforcement such as rehabilitate guardhouse and install marker buoys
	Data Gap: Existing marine reserves with many uncertainties, questions; Uncertain how to proceed	3 (with legal basis but POs are weak in the management; dilapidated guardhouses, marker buoys are gone; spatial use conflicts with local fishers; high siltation may also be the cause of poor performance)	
Tubigon	**Retain:** Existing marine reserves that should be prioritized for strengthening	3	• Actions to strengthen management of existing MPAs include the following: • Conduct MEAT and engage local partners' participation • Review and update the MPA management plans • Conduct capability-building of MPA management bodies (e.g. via refresher trainings in habitat assessment, workshops to strengthen the organization) o To initiate the adjustment of MPA boundaries, the plan of action includes the following activities: o Conduct bio-physical assessments and presentation of results during community consultation meetings o Incorporate the modifications in the amended MPA ordinance o Formulate review of the respective MPA management plans o To initiate the adjustment of MPA boundaries, the plan of action includes the following activities: o Conduct bio-physical assessments and presentation of
	Alter: Existing marine reserves that should be increased in size and/or shape altered to be more compact	5	
	Remove: Existing marine reserves that are no longer expected to contribute to the performance of the network and should be removed through legal means	--	
	New: New marine reserves that need to be established to improve network performance at municipal and MKBA levels	4 (to increase area under protection and representation of different habitat types)	
	Data Gap: Existing marine reserves with many uncertainties,	--	

MUNICIPALITY	MARINE RESERVE CATEGORIES	NUMBER OF MARINE RESERVES	ACTION PLAN HIGHLIGHTS
	questions; Uncertain how to proceed		results during community consultation meetings o Review the municipality's marine spatial use plan to enhance MPA network design in consonance with the zoning plan and vice-versa

4.4 SCIENCE AND MANAGEMENT REVIEW: NETWORK REFINEMENT

After the technical workshop, a science review was conducted to further refine the network design that emerged from the technical workshop. The purpose of the science review is to ensure that ecological principles were appropriately applied and to evaluate the robustness of the overall design. ECOFISH scientists and partners from the University of the Philippines in the Visayas Foundation, Inc. (UPVFI) and the Bohol Island State University (BISU) worked with key stakeholders in each municipality to finalize the network design. Using output of the technical workshop combined with management considerations, 21 marine reserves (18 existing, 3 proposed) out of 35 marine reserves were prioritized as the Danajon Reef MPA Network (Table 9). Size, location, presence of linked habitats, and high probabilities still for future expansion were major determinants in identifying which marine reserves to include in the network.

TABLE 9. SUMMARY OF RESULTS OF THE SCIENCE REVIEW PROCESS THAT FURTHER REFINED THE DESIGN OF THE DANAJON MPA NETWORK

MUNICIPALITY	MARINE RESERVE	LOCATION		AREA (HA)	HABITATS		
		NORTH	EAST		CORALS	SEAGRASS	MANGROVE
Tubigon	Ubay Island Marine Protected Area	10.02081	123.95975	27.5	X	X	-
	Pangapasan Marine Sanctuary	10.0004	123.9431	6.7	X	X	X
	Batasan Marine Sanctuary	10.010322	123.98936	21.0	X	-	-
	Centro Marine Sanctuary	9.964528	123.96194	19.1	X	X	-
	Cabulijan Marine Sanctuary	9.968588	123.97671	20.83	X	X	-
	Bilang-bilangan Marine Sanctuary	9.987428	123.87887	10.5	X	X	-
	Macaas Marine Sanctuary	9.967887	123.99386	12.7	X	X	-
	Tinangnan Marine Sanctuary	9.959958	123.96856	7	X	X	-
	Matabao Marine Sanctuary	9.944699	123.90802	52.6	X	X	-

MUNICIPALITY	MARINE RESERVE	LOCATION		AREA (HA)	HABITATS		
		NORTH	EAST		CORALS	SEAGRASS	MANGROVE
	Mocaboc Marine Sanctuary*	10.072796	123.92551	20	X	X	-
Clarin	Majigpit Island Fish Sanctuary	9.994724	124.00407	23.6	X	X	-
Inabangga	Cuaming Fish Sanctuary	10.119071	123.98989	14.3	X	X	-
	Hambungan Marine Sanctuary	10.074533	124.03372	14.1	X	X	-
	Bagatusan Marine Sanctuary*	10.043216	124.01815	30	X	X	X
Buenavista	Asinan Reef Sanctuary	10.093889	124.09193	50	X	X	-
	E. Cabul-an Marine Sanctuary	10.151256	124.04997	50	X	X	-
Getafe	Pandanon Marine Sanctuary	10.18312	124.07794	25	X	X	-
	Jandayan Sur Marine Sanctuary	10.167015	124.15565	4.7	X	X	X
	Nasingin Marine Sanctuary	10.177113	124.11841	30	X	X	-
	Handumon Marine Sanctuary	10.17976	124.18361	50	X	X	X
	Mahanay Marine Sanctuary*	10.17407	124.22721	45	X	-	X

Several gaps in the network were identified. The current network of marine reserves represents only five municipalities from the Western Danajon Bank namely, Getafe, Buenavista, Inabanga, Clarin, and Tubigon, which comprise the focal area of ECOFISH. To be a truly comprehensive network, there is still room for expansion to include the marine reserves further west (Mactan Island & northeast Cebu) and northeast (north Bohol and south Leyte) of the Danajon Reef system.

4.5 STAKEHOLDER CONSULTATIONS: NETWORK ACTION PLANS AND MANAGEMENT

Once the network design was finalized, ECOFISH and partners from the UPVFI and BISU held a series of workshops with the LGUs and local stakeholders to draft and update individual marine reserve management plans and finalize the municipal action plans for the network. A final stakeholder workshop was conducted to further consolidate the municipal action plans of all five municipalities into a unified Western Danajon MPA Network Action Plan. Elected officers of the management network passed a resolution to adopt the MPA Network Action Plan across all member municipalities. This was formalized with the signing of a Memorandum of Understanding by the local chief executives of the five municipalities, representatives of the partner agencies, and the chairpersons of the five municipal MPA Networks. For its first quarter meeting agenda, the MPA Management Network will embark upon harmonizing the individual barangay resolutions for MPA management, decide what gears will be allowed or prohibited within the buffer zone of MPAs. The network will establish an MPA database that can be accessed by all network members to facilitate data sharing and collective monitoring of violations.

Three proposed new marine reserves, Mocaboc (Tubigon), Bugatusan (Inabanga) and Mahanay (Getafe), have undergone the necessary stakeholder consultations and underwater baseline assessments to initiate the establishment process. During the consultations for the Mocaboc marine reserve, the stakeholders agreed to expand the boundaries to include seagrass areas. All three critical habitats – mangroves, coral reefs, and seagrass beds – were represented in the proposed Bugatusan MPA. Lastly, the boundaries for the proposed Mahanay marine reserve were adjusted based on these consultations to improve habitat representation and coverage, avoid potential spatial use conflicts (e.g. seaweeds culture activities) and increase the distance from an area where blast fishing is still rampant.

Marine reserves requiring boundary or location changes to satisfy the ecological design principles were in the process of ordinance amendments. Majigpit Fish Sanctuary (Clarin), East Cabul-an MPA (Buenavista), Batasan Marine Sanctuary (Tubigon), and Pangapasan Marine Sanctuary (Tubigon) have already advanced to nearing formalization of these amendments. Majigpit Fish Sanctuary and East Cabulan MPA were subjected to biophysical surveys, and stakeholder consultations were subsequently conducted to present the results and the proposed revisions (Table 10). Consultations with stakeholders of the Batasan and Pangapasan marine sanctuaries in Tubigon have also been concluded.

TABLE 10. STATUS OF IMPLEMENTATION MARINE RESERVES REQUIRING BOUNDARY CHANGES

MARINE RESERVE	PROPOSED REVISIONS	STATUS
Majigpit Fish Sanctuary, Clarin	Expansion from 26.3 has to about 97 has to cover the NE portion of the reef area	Process on-going; Action plan drawn, including amending the municipal resolution to incorporate details for the MPA expansion; LGU Clarin sponsored the construction of a new MPA guardhouse in the island
East Cabul-an MPA, Buenavista	Relocation to the SE portion of the island to facilitate MPA patrolling and guarding; new MPA size to cover 67 has from the original 50 has	Process on-going; High acceptance of stakeholders for the relocation was acquired after presenting the survey results that showed relatively higher live hard coral cover, fish abundance, abundance of indicator and target species, and fish biomass in the proposed relocation site
Batasan Marine Sanctuary, Tubigon	Relocation to improve overall effectiveness	Process on-going
Pangapasan Marine Sanctuary, Tubigon	Expansion to increase coverage of reefs under protection	Process on-going

As part of the series of stakeholder workshops to formally establish the Danajon MPA Network, stakeholders of the individual marine reserves were trained in basic methods for habitat assessment for mangrove, seagrass, and coral reefs (see details in Campos et al., 2013). Where needed, re-organization and re-activation of local MPA management councils were also conducted.

The formalization of the Danajon MPA Network and the MPA Network Plan that incorporates the ecological principles in the design of protection zones in the Danajon Bank within one year of the technical workshop is a major accomplishment for the Danajon LGUs, local stakeholders, and academic partners. At this early stage in the implementation of the action plans, the academic partners were on hand to provide both technical expertise and support in mobilizing the communities and the LGUs to ensure that the activities were carried out relatively smoothly. The next step is to put in place a regular monitoring and evaluation system in order to document network performance in achieving multiple management objectives together with other EAFM interventions such as right-sizing and marine spatial planning.

5 KEY FINDINGS AND RECOMMENDATIONS FOR FUTURE PROJECTS

This case study demonstrated a multi-stakeholder approach for applying ecological principles to an existing network with the objectives of increasing network performance and supporting multiple management objectives. While local government and communities in the Philippines and Bohol in particular have a solid understanding of the important role marine reserves play as part of an ecosystem approach to fisheries management, the use of ecological principles for scaling up individual marine reserves into networks was new and helped broaden understanding of the connectivity and complexity of the ecosystems entrusted to them. Several key findings and recommendations for future projects are described below.

USE THE ECOLOGICAL DESIGN PRINCIPLES AS AN OPPORTUNITY TO EXPAND KNOWLEDGE TO LOCAL MANAGERS AND OTHER STAKEHOLDERS. Municipal officers charged with the responsibility of designing and implementing fisheries and coastal management in municipal waters and other local stakeholders supporting management efforts have limited and varying degrees of ecological knowledge of target fish species, habitat requirements, and oceanographic processes. Through the process of reviewing and applying the ecological principles, even seasoned municipal fisheries officers expressed a new appreciation for the complexity of ecosystem processes and life history requirements of important target fish species. The use of reference tools and geospatial analysis products – such as target fish species life history, dispersal modeling, and sea surface temperature characteristics – expanded stakeholder knowledge and helped managers appreciate the complexities of managing for multiple objectives. For example, using this knowledge, participants recognized the need to increase the size of several marine reserves to better accommodate a target fish species home range. A similar matrix is needed for protected, threatened, and endangered species summarizing the life history requirements and migratory patterns of these species based on the latest scientific studies. Past efforts for marine reserve establishment were focused in predominantly coral reef habitats. Seagrass beds and mangroves were rarely represented in marine reserves. The graphic representation of the home ranges of different fish and invertebrate species helped the participants understand the equal importance of these component habitats in the marine ecosystem and the need to have them represented in the protection zones. A one-day course based on the ecological principles for marine reserve network design could be developed for local municipal fisheries managers and their partners to address this gap in knowledge. This course would be added as a pre-requisite for attending the technical workshop.

EMPHASIZE ECOLOGICAL PRINCIPLES AS A PRIMARY DRIVER OF NETWORK PERFORMANCE AND MANAGEMENT EFFECTIVENESS. Marine and coastal projects throughout the Philippines have mainstreamed the use of marine reserves as an essential coastal and fisheries resource management tool. Communities and local government with increased awareness of the value of marine reserves have responded by establishing marine reserves in many cases, one per barangay. In the past, social and political "design principles" have driven the size, shape, location, and rules governing these marine reserves. With the proliferation of marine reserves, new financial and human resource limitations have emerged as local managers become tasked with strengthening and maintaining effective management and enforcement. By considering ecological principles as the primary driver of marine reserves and network design, marine reserves that were unlikely to improve network performance were removed. Marine reserves that are removed from the network help focus

management efforts to those that are most likely to support multiple management objectives of sustainable fisheries, biodiversity conservation, and climate resilience.

The application of ecological design principles also helped participants of the technical workshop reflect on the contribution of individual marine reserves to the larger network of marine reserves as connected sources and sinks of larvae for recruitment. Hydrodynamic and larval dispersal modelling was a critical input to this discussion. The results of circulation and dispersal modelling helped stakeholders understand these network-wide dynamics. The role of connectivity in network design was especially recognized when representatives from "downstream" municipalities realized that much of their larval recruitment was dependent on their "upstream" neighbors. While local stakeholder acceptance and governance considerations are essential components for effective management, ecological principles should be used as the starting point for establishing marine reserves and scaling up to networks. The challenge is to broaden stakeholder appreciation for the significant benefits gained from an ecologically-designed network of marine reserves.

USE MARINE RESERVE NETWORK DESIGN AS AN EARLY INTERVENTION FOR ECOSYSTEM-BASED FISHERIES MANAGEMENT. The application of ecological principles for marine reserve network design can serve as a foundation for other ecosystem-based management interventions such as right-sizing and marine spatial planning. A well-designed network of marine reserves together with the delineation of traditional and customary fishing grounds sets the stage for defining preferential use rights for small-scale fishers in nearshore waters. In Bohol, the adjusted technical descriptions (marine reserve boundaries and locations) of both existing and proposed new marine reserves are now incorporated in the respective zoning plans of the five LGUs that are members of the Danajon MPA Network, fully reflecting the application of ecological principles for enhanced effectiveness of the protection zones within the MKBA. Furthermore, area-based valuation has already been conducted in the Danajon Bank as a novel feature of the Marine Spatial Plan. Discrete values (per unit hectare) of the different zones, including the protection zones, are now available to aid in decision-making and prioritization. Results have shown that the protection zones are one of the highest contributors to the total value of the municipal waters per unit hectare.

Ideally, an ecologically-designed marine reserve network should be put in place first, concurrent with the delineation of traditional and customary fishing grounds to support preferential use rights of small-scale fishers. Marine spatial planning efforts can then focus on ensuring that existing and planned land- and marine-based resource uses do not conflict or compete with network objectives or jeopardize preferential use rights of small-scale fishers.

STRENGTHEN CO-MANAGEMENT ARRANGEMENTS FOR NETWORK MANAGEMENT. Effective co-management of small-scale fisheries, which requires legislation, empowered communities, institutional linkages, and human and financial resources, remains a challenge for small-scale fisheries management in the context of ecosystem-based management. The co-management roles and responsibilities of national, provincial, and local governments and communities for managing a marine reserve network need to be articulated and institutionalized.

After stakeholders agreed on a network design, a municipal ordinance was drafted that outlines the constitution and by-laws of the Western Danajon MPA Network Association. The ordinance defines the roles and obligations of the municipal agriculture officer, coastal resource management coordinator, and

fisheries technician to the municipal MPA network in each municipality and delegates their inter-LGU responsibilities. The final constitution and by-laws will be submitted to the Department of Labor and Employment as part of the network's application for legalization. With the network's legalization, its recognition as one of the official members of the Provincial Technical Working Group of the province of Bohol, bolsters its legitimacy to engage with partner agencies, ensure that local issues are included in the provincial agenda, and access vital sources of financial and technical support for the activities of the MPA network. The continued active participation and support of the local academic institution, BISU, is needed to provide technical support and conduct community-mobilizing activities for the Danajon MPA network as part of the University's Responsive Extension Program.

Sustaining funding for the network's activities and personnel remains a challenge. Several steps have been taken to address budgeting, personnel, and other issues. An additional stakeholder workshop was conducted to support institutionalization of a regular budget allocation for network management. As a result, a municipal ordinance was drafted to institutionalize the municipal MPA network with a budget allocation. Each LGU is now in the process of adopting this ordinance through their respective Sangguniang Bayan or municipal councils.

BUILD CAPACITY FOR MONITORING AND EVALUATION TO DEMONSTRATE NETWORK EFFECTIVENESS. Monitoring and evaluation is one aspect of marine reserve network management that requires improvement. Monitoring and evaluation encompasses both biophysical and management effectiveness monitoring. Ideally, a monitoring and evaluation plan should be developed that encompasses the entire network, articulating roles and responsibilities of network members, methodology for biophysical assessment, protocols, data management, reporting, and schedule. Local government, partners, and community members need to be trained in standard monitoring and evaluation practices to ensure regular and timely monitoring of their marine reserves. Training on basic marine habitat assessment and fisheries monitoring needs to be conducted in each municipality. For Bohol, the existing MPA Provincial Technical Working Group can be tapped to provide technical support, overall coordination, and documentation of monitoring and evaluation activities across the network. Robust evidence of network performance in achieving multiple management objectives will sustain social-political acceptance and investment.

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APPENDIX 1: SCORING GUIDE FOR APPLYING ECOLOGICAL PRINCIPLES TO THE DESIGN OF RESILIENT MARINE RESERVE NETWORKS

APPENDIX 1: SCORING GUIDE FOR APPLYING ECOLOGICAL PRINCIPLES TO THE DESIGN OF RESILIENT MARINE RESERVE NETWORKS.....A-i

SCORING GUIDE FOR TIER 1 ECOLOGICAL PRINCIPLES..... A-1

SCORING GUIDE FOR TIER 2 ECOLOGICAL PRINCIPLES..... A-13

SCORING GUIDE FOR TIER 1 ECOLOGICAL PRINCIPLES

The scoring guide was developed to assist practitioners to evaluate the extent to which existing marine reserves and proposed new marine reserves in municipal waters or larger marine managed areas meet key ecological design principles for resilient marine reserve networks. The ecological principles are based on the current state of knowledge and guidelines for designing marine reserve networks to achieve sustainable fisheries, biodiversity conservation, and climate resilience objectives (Jupiter et al., 2012, Green et al., 2014, Abesamis et al., 2014, Green et al., 2015). The rationale and illustrations of many of the ecological design principles are based on work conducted as part of the US Coral Triangle Initiative (Green, White, and Kilarski 2013, Gombos et al., 2013).

The ecological principles were binned into two tiers related to the scale of analysis (marine reserve and larger marine managed area (e.g. municipal waters, Marine Key Biodiversity Areas (MKBAs)). **Tier 1 ecological principles should be applied to individual existing marine reserves or proposed new marine reserves (Table A-1). Marine reserves evaluated using Tier 1 ecological principles should then be reviewed in the context of Tier 2 ecological principles.**

TABLE A-I. TIER I: ECOLOGICAL DESIGN PRINCIPLES (APPLIED AT INDIVIDUAL MARINE RESERVE SCALE)

Tier 1: Ecological Design Principles (applied at individual marine reserve scale)	
1.1	Avoid placing marine reserves in areas that have been, or are likely to be, impacted by local threats (e.g. land-based activities) that cannot be managed effectively (Green et al., 2014).
1.2	Place marine reserves in areas that have not been, or are less likely to be, impacted by local threats including (Green et al., 2014): (a) areas where threats (e.g., overfishing or destructive fishing) can be managed effectively; and (b) areas within or adjacent to other effectively managed marine or terrestrial areas.
1.3	Protect refugia in marine reserves where habitats and species are likely to be more resilient to climate and ocean change (Green et al., 2014) including: (a) areas where habitats and species are known to have withstood environmental changes (or extremes) in the past (e.g., coral communities that appear more resilient to high SSTs); (b) areas with historically variable SSTs and ocean carbonate chemistry, where habitats and species are more likely to withstand changes in those parameters in future; and (c) areas adjacent to low-lying inland areas without infrastructure that coastal habitats (e.g., mangroves, tidal marshes and turtle nesting beaches) can expand into as sea levels rise.
1.4	Protect critical areas (e.g. fish spawning aggregations, nursery, nesting, breeding, and feeding areas) in the life history of focal species (key fisheries species and rare and threatened species) in permanent or seasonal marine reserves (Green et al., 2014, Green et al., 2015).
1.5	Include whole ecological units (e.g., offshore reefs) in marine reserves (Green et al., 2014).
1.6	Marine reserves should be more than twice the size of the home range of focal species (in all directions). Thus, marine reserves of various sizes will be required depending on which species require protection, how far they move, and if other effective management is in place outside reserves (Green et al., 2015), typically ranging from 2km to 20 km in diameter, which is likely to protect focal fish species that move <10 km. Recommendations regarding minimum reserve size must be applied to the specific habitats that focal species use (in all directions), rather than the overall size of the reserve (which may include other habitats (Green et al., 2014). However, marine reserves will need to be combined with other fisheries management tools to manage focal fish species that move wide ranging species.
1.7	Use compact marine reserve shapes (e.g., squares or circles) rather than elongated ones (Green et al., 2014), except when protecting naturally elongated habitats (e.g. long narrow reefs (Green et al., 2017))
1.8	Ensure marine reserves are in place for the long term (20-40 years), preferably permanently, to allow for full population recovery and maximum biomass export to fished areas of the full range of highly targeted

1.8	Ensure marine reserves are in place for the long term (20-40 years), preferably permanently, to allow for full population recovery and maximum biomass export to fished areas of the full range of highly targeted species (Abesamis et al., 2014, Green et al., 2014). Strict compliance to marine reserves is required to avoid considerable delays in recovery (Abesamis et al., 2014).
1.9	Short term (<5 years) or periodically harvested marine reserves should be used in addition to, rather than instead of, long-term or permanent reserves (Abesamis et al., 2014). Where periodic closures are used, the timing and intensity of harvesting must be carefully controlled to ensure long-term fishery benefits (Abesamis et al., 2014, Jupiter et al., 2012).

MINIMIZE AND AVOID LOCAL THREATS

1.1 Avoid placing marine reserves in areas that have been, or are likely to be, impacted by local threats (e.g. land-based activities) that cannot be managed effectively (Green et al., 2014).

Description

In order to optimize protection of areas that are less likely to be exposed to local threats and most likely to recover from disturbance, avoid areas that have been or are likely to be impacted by stressors such as land based runoff, pollution, and other damaging land-based human uses. Choose areas for protection that have been, and are likely to be, subjected to lower levels of damaging impacts.

Assessment Questions

- *What are the types and locations of local threats from land-based activities?*
- *Is the existing marine reserve or proposed new marine reserve location exposed to local land-based threats?*

Information/Data Sources

- Map of municipality showing locations of land-based threats such as rivers, population centers, coastal development, upland mining and agriculture that leads to sedimentation and runoff
- In the absence of maps, stakeholder discussions and participatory mapping can be used to identify and map local land-based threats

Potential Actions

- **Retain** marine reserve as is if it experiences minimal or no impacts from local land-based threats.
- **Alter** the marine reserve by shifting its existing or proposed location to minimize impacts from land-based threats
- **Establish new** marine reserve in a new location to avoid local land-based threats
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
Marine reserve location (existing or proposed) is in an area with minimal land-based threats	3
Marine reserve (existing or proposed) is exposed to low levels of damaging impacts from land-based threats	2
Marine reserve location (existing or proposed) is exposed to medium levels of damaging impacts from land-based threats	1
Principle not considered in network design (Marine reserve location (existing or proposed) is exposed to high levels of damaging impacts from land-based threats)	0

MINIMIZE AND AVOID LOCAL THREATS

1.2 Place marine reserves in areas that have not been, or are less likely to be, impacted by local threats including (Green et al., 2014): (a) areas where threats (e.g., overfishing or destructive fishing) can be managed effectively; and (b) areas within or adjacent to other effectively managed marine or terrestrial areas.

Description

Coastal habitats, and their ecosystem values, are vulnerable to local marine-based threats from destructive fishing (e.g. blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, and nighttime spearing) as well as other uses of the marine environment such as aquaculture, maritime traffic, and offshore oil and gas development. These marine-based threats can decrease the health and productivity of the ecosystem and, consequently, all species living within it (including focal species).

Assessment Questions

- *What are the types of local threats from marine-based activities?*
- *Is the existing marine reserve or proposed new marine reserve exposed to local marine-based threats?*

Information/Data Sources

- Map of municipality showing locations of marine-based threats such as illegal fishing and destructive practices, offshore development/aquaculture
- In the absence of maps, stakeholder discussions and participatory mapping can be used to identify and map local marine-based threats

Potential Actions

- **Retain** the marine reserve if it is located in an area that is protected from land or marine-based threats
- **Alter** the marine reserve by shifting its existing or proposed location to minimize impacts from marine-based threats
- **Establish new** marine reserve in a location where threats are minimal
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
Marine reserve location (existing or proposed) is in a relatively pristine area or in a well-managed marine area	3
Marine reserve location (existing or proposed) is an area where some destructive activities are prohibited and moderately enforced	2
Marine reserve location (existing or proposed) is an area where few destructive activities are prohibited and weakly enforced	1
Principle not considered in network design (Destructive activities are not prohibited and are rampant in the area)	0

ADAPT TO CHANGES IN CLIMATE AND OCEAN CHEMISTRY

1.3 Protect refugia in marine reserves where habitats and species are likely to be more resistant and resilient to climate and ocean change including (Green et al., 2014): (a) areas where habitats and species are known to have withstood environmental changes (or extremes) in the past (e.g., coral communities that appear more resilient to high sea surface temperature (SST); (b) areas with historically variable SSTs and ocean carbonate chemistry, where habitats and species are more likely to withstand changes in those parameters in future; and (c) areas adjacent to low-lying inland areas without infrastructure that coastal habitats (e.g., mangroves, tidal marshes, and turtle nesting beaches) can expand into as sea levels rise.

Description

Refugia are areas are most likely to withstand climate change impacts. These areas may include: (a) areas where habitats and species are known to have withstood environmental changes (or extremes) in the past (e.g., coral communities that appear more resilient to high SSTs); (b) areas with historically variable SSTs and ocean carbonate chemistry, where habitats and species are more likely to withstand changes in those parameters in future; and (c) areas adjacent to low-lying inland areas without settlements where coastal habitats, in particular, mangroves, tidal marshes and beaches (needed for turtle nesting) can expand into as sea levels rise.

Assessment Questions

- *Is there room for landward expansion of mangroves or tidal marshes and sandy beaches for turtle nesting in response to sea level rise? If yes, is there interest in or ability to restrict development landward of the mangrove or tidal marsh?*
- *Have corals in the area experienced bleaching and then recovered?*
- *Have corals not experienced bleaching but neighboring reefs have?*
- *Are there oceanographic conditions that are likely to enable habitats to be more resistant or resilient to climate and ocean change such as areas with high sea surface temperature variability?*

Information/Data Sources

- Coral reef studies that have documented early onset and recovery of coral reefs to bleaching events
- Inventory of mangroves or tidal marshes and turtle nesting beaches that currently have no landward settlement or may be suitable for landward migration in the future
- Geological surveys of land areas with sand deposits that could facilitate beach migration with sea level rise
- Oceanographic studies of variations in ocean chemistry, temperature profiles
- Maps of coral bleaching potential and temperature variability from Coral Reef Watch http://coralreefwatch.noaa.gov/satellite/index.php

Potential Actions

- **Retain** marine reserve as is and continue to improve management
- **Alter** location of marine reserve to serve as a climate refugia (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Establish new** marine reserve to serve as climate refugia (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
Coral: Existing or proposed marine reserve is located in an area likely to be more resilient to climate and ocean change based on observations, scientific studies, and monitoring **Mangrove/tidal marshes/turtle nesting beaches:** Area for landward expansion specifically set aside in the Comprehensive Land Use Plan	3

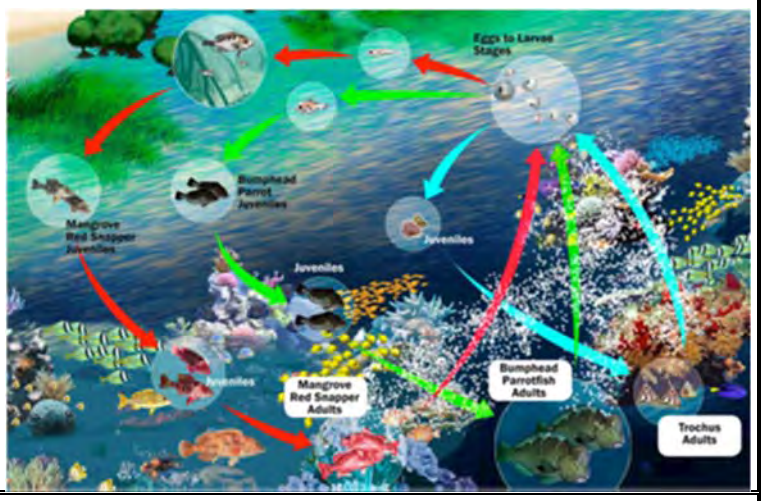
Coral: Existing or proposed location of new marine reserve has experienced impacts from climate and ocean change but has recovered **Mangrove/ tidal marshes/turtle nesting beaches:** Area for landward expansion currently exists but not in policy	2
Coral: Existing or proposed location of new marine reserve has experienced impacts from climate change and has not recovered or is located in an area not likely to be resilient to climate and ocean change **Mangrove/ tidal marshes/turtle nesting beaches:** No area for landward expansion	1
Principle not considered in MPA network design, and unlikely to protect climate refugia	0

PROTECT CRITICAL, SPECIAL, AND UNIQUE AREAS

1.4 Protect critical areas (e.g. fish spawning aggregations, nursery, nesting, breeding, and feeding areas) in the life history of focal species (key fisheries species and rare and threatened species) in permanent or seasonal marine reserves (Green et al., 2014, Green et al., 2015).

Description

Marine reserves should protect areas and habitats (e.g. FSAs, nursery, nesting, breeding, and feeding areas) critical in the life history of focal species (including key fisheries species, herbivores, and rare and threatened species e.g. turtles, dugong and cetaceans) in permanent or seasonal marine reserves. Some fisheries species (including groupers, snappers, emperors, and rabbitfishes) travel long distances to form fish spawning aggregations for a relatively short period of time (days or weeks). Other species group together to feed or in nursery areas where juveniles use different habitats than adults. Other species use different habitats in different life history stages (e.g. nursery habitats).



Assessment Questions

- *What are the focal species (fish species, rare and threatened species)?*
- *What are their critical habitats (nursery, breeding, nesting, and feeding areas)?*
- *Do marine reserves include critical areas for focal species?*

Information/Data Sources

- Location of nursery, breeding, nesting, feeding, and spawning areas for focal species
- Location of marine reserves

Potential Actions

- **Retain** marine reserve
- **Alter** size of marine reserve to better protect critical habitat of target species
- **Establish new** marine reserve to protect critical habitats of all target species
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
All critical habitats for multiple focal species are included in marine reserves	3
Some critical habitats for some focal species are included in marine reserves	2
Some critical habitats for one focal species are included in marine reserves	1
Network has not considered the design principle (marine reserves do not protect critical habitats for one focal species)	0

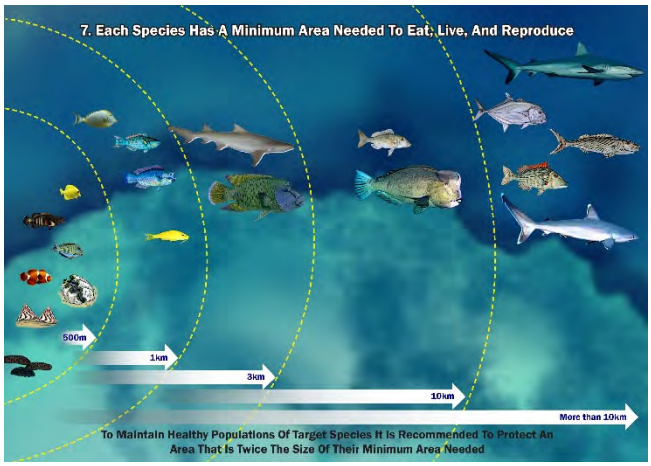
INCORPORATE CONNECTIVITY	
1.5 Include whole ecological units (e.g., offshore reefs) in marine reserves (Green et al., 2014).	
Description Boundaries that are located at habitat edges (e.g. beyond the edge of coral reef habitats) are recommended for achieving biodiversity, climate change, and some fisheries production objectives, since they minimize spillover of adult fished species and maintain the integrity of the marine reserve.	
Assessment Questions • *Does the existing/proposed new marine reserve include entire ecological units (e.g. offshore reefs) with boundaries that extend beyond the habitat edge?* **Information/Data Sources** • Biophysical surveys of the area that characterize types of habitats **Potential Actions** • **Retain** marine reserve as is • **Alter** size of marine reserve to include multiple habitats as an entire ecological units • **Establish new** marine reserve to protect whole ecological units • **Remove** marine reserve unless it serves another ecological principle	
Scoring Criteria	**Rating**
Marine reserve encompasses whole ecological units of >3 or more habitat types (including coral, seagrass, mangrove, sandy, rubble, rocky, muddy, offshore areas such as deep-water reefs/banks)	3
Marine reserve encompasses whole ecological units of 2-3 habitat types	2
Marine reserve encompasses whole ecological unit of 1 habitat type	1
Principle not considered in MPA network design (individual reserve does not include whole ecological unit)	0

INCORPORATE CONNECTIVITY

1.6 Marine reserves should be more than twice the size of the home range of focal species (in all directions). Thus, marine reserves of various sizes will be required depending on which species require protection, how far they move, and if other effective management is in place outside reserves (Green et al., 2015), typically ranging from 2 - 20 km in diameter, which is likely to protect focal fish species that move <10 km. Recommendations regarding minimum reserve size must be applied to the specific habitats that focal species use (in all directions), rather than the overall size of the reserve (which may include other habitats (Green et al., 2014). However, marine reserves will need to be combined with other fisheries management tools to manage focal fish species that move wide ranging species.

Description

Marine reserves of various sizes will be required depending on which species require protection, how far they move, and if other effective protection is in place outside reserves. Recommendations regarding minimum reserve size must be applied to the specific habitats that focal species use, rather than the overall size of the reserve (which may include other habitats).
For marine reserves to protect biodiversity and contribute to fisheries enhancement outside their boundaries, they must be able to sustain target species within their boundaries. This will allow for the maintenance of spawning stock by allowing individuals to grow to maturity, increase in biomass, and contribute more to stock recruitment and regeneration.



Assessment Questions

- *What are the focal species?*
- *What are their home ranges?*
- *To what extent does the diameter of the existing marine reserve or proposed new reserve protect more than twice the size of the home range of each focal species?*

Information/Data Sources

- List of focal species
- Home range summary table (see Appendix 2)
- Diameter determined by the smallest circle that can completely encompass the shape of the marine reserve

Potential Actions

- **Retain** marine reserve as its diameter is sufficient for protecting multiple focal species
- **Alter** marine reserve by increasing size to protect multiple focal species
- **Establish new** marine reserve with a diameter more than 2X the home range of the focal species
- **Remove** marine reserve unless it serves another ecological principle

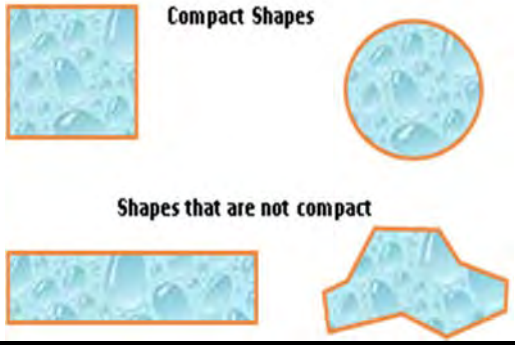
Scoring Criteria	Rating
Marine reserve diameter is >10 km	3
Marine reserve diameter is between >2 km – 10 km	2
Marine reserves diameter is between 1 – 2 km in diameter	1
Principle not considered in network design (marine reserve diameter is <1 km in diameter)	0

INCORPORATE CONNECTIVITY

1.7 Use compact marine reserve shapes (e.g., squares or circles) rather than elongated ones (Green et al., 2014), except when protecting naturally elongated habitats (e.g. long narrow reefs (Green et al., 2017))

Description

Squares or circles are compact shapes that limit adult spillover more than other shapes (e.g. long rectangles or triangles). Reducing adult spillover helps maintain the integrity of the protected areas and, therefore, the sustainability of their contribution to biodiversity protection, fisheries production, and ecosystem resilience. Square shapes are preferable to circles as they are easier to enforce.



Assessment Questions

- *What is the shape of the existing or proposed new marine reserve?*
- *To what extent is the existing or proposed new marine reserve compact?*

Data/Information Sources

- Compact index (CI) calculated as the area of the marine reserve divided by the perimeter (CI = area/perimeter) (Li, Goodchild, and Church 2013). The CI ranges from 0.1 – 1.0.

Potential Actions

- **Retain** the marine reserve with sufficient compactness to support multiple objectives
- **Alter** the marine reserve shape to a square to improve compactness and reduce spillover
- **Establish new** marine reserve to incorporate this principle
- **Remove** marine reserve unless it serves another ecological principle

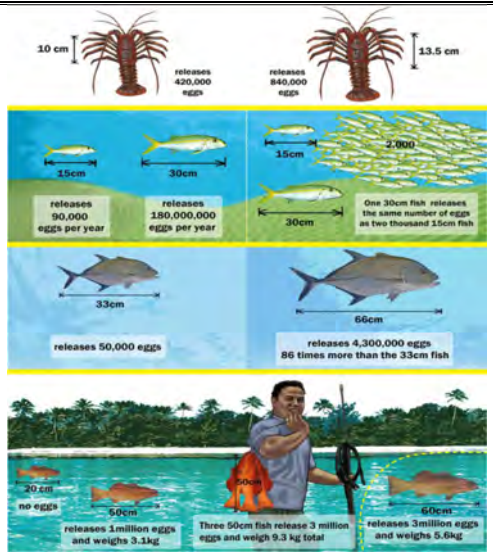
Scoring Criteria	Rating
Marine reserve has a high compact index (CI 0.80 – 1.0)	3
Marine reserve has a medium compact index (CI 0.60 – 0.79)	2
Marine reserve has a low compact index (CI 0.40 - 0.59)	1
Principle not considered in network design (CI <0.39)	0

ALLOW TIME FOR RECOVERY

1.8 Ensure marine reserves are in place for the long term (20-40 years), preferably permanently, to allow for full population recovery and maximum biomass export to fished areas of the full range of highly targeted species (Abesamis et al., 2014, Green et al., 2014). Where strict compliance to marine reserves is required to avoid considerable delays in recovery (Abesamis et al., 2014).

Description

Long-term protection in marine reserves allows the entire range of species and habitats to recover, then maintain, ecosystem health and associated fishery benefits. Some benefits can be realized in the short term (1-5 years), especially if fishing pressure has not been heavy. However, 20-40 years of protection is required to allow heavily fished species, particularly longer-lived fisheries species (e.g. sharks and other large predators), the opportunity to grow to maturity, increase in biomass and contribute more, and more robust, eggs to stock recruitment and regeneration.



Assessment Questions

- *How long has the marine reserve been in place?*
- *What focal species are intended for protection and recovery by the marine reserve?*
- *Is there evidence that the marine reserve is sustaining or improving focal species biomass?*
- *To what extent is the marine reserve providing long-term benefits recognized by the community?*

Information/Data Sources

- Legal document with date that the marine reserve established
- Data from scientific surveys indicating trends in biomass of focal species inside the marine reserve and outside
- In the absence of surveys, stakeholder discussions can be used to characterize trends in biomass of focal species and recognition of long-term benefits

Potential Actions

- **Retain** marine reserve as is and continue to improve management
- **Alter** size and shape of marine reserve to reduce spillover and increase biomass
- **Establish new** permanent marine reserve to promote recovery of target species
- **Remove** marine reserve unless it serves another ecological principle

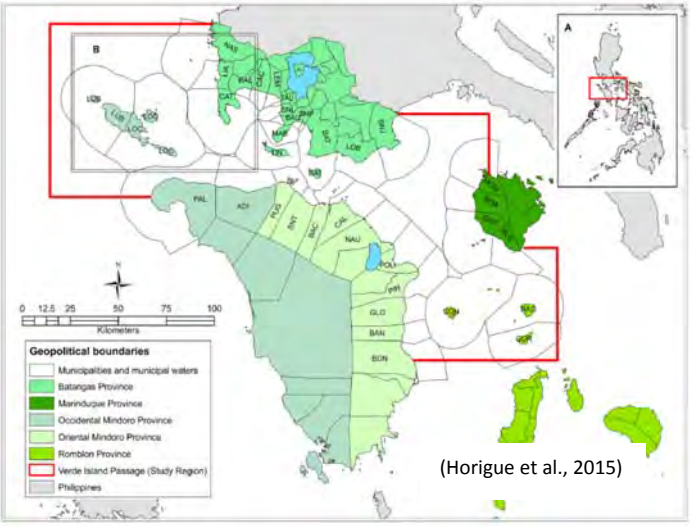
Scoring Criteria	Rating
Marine reserve in place for at least 7 years with sustained or improved biomass for more species	3
Marine reserve in place less than 7 years with sustained or improved biomass for some species	2
Marine reserve in place with no measured change or decline	1
Marine reserve newly established or no monitoring	0

ALLOW TIME FOR RECOVERY

1.9 Short term (<5 years) or periodically harvested marine reserves should be used in addition to, rather than instead of, long-term or permanent reserves (Abesamis et al., 2014). Where periodic closures are used, the timing and intensity of harvesting must be carefully controlled to ensure long-term fishery benefits (Abesamis et al., 2014, Jupiter et al., 2012).

Description

Seasonal and short-term closure areas can provide additional benefits by protecting critical areas at critical times (e.g. fish spawning aggregations sites or nursery areas) if they are not protected in long-term marine reserves. Short-term spatial management tools, such as rotational, periodically harvested or other temporally variable marine reserves, should be used in addition to help address particular fisheries needs (e.g. where stocks need to be protected or restored). Seasonal closures in Verdes Island Passage and Zambonga have been effective in supporting sustainable fisheries.



(Horigue et al., 2015)

Assessment Questions (Note: assess and score seasonal closures and short-term closures separately)

- *What are focal species of interest?*
- *Are there target fish species that could benefit from seasonal closures? In designing seasonal closures, where are nursery areas and aggregation sites?*
- *Are there target fish species that could benefit from short-term closures? In designing short-term closures, what species have fast recovery rates that may benefit from short term/periodic closures, and which ones will not?*

Information/Data Sources

- Life history information of target fish species including: spawning periods, growth rates, number of spawners, average length of spawners, catch per unit effort following a seasonal closure, about target fish species
- Ocean circulation and dispersal modeling
- For seasonal closures, where are nursery areas and aggregation sites
- For short-term closures, what species have fast recovery rates that may benefit from short term/periodic closures, and which ones will not?

Potential Actions

- **Retain** seasonal/short-term closure area
- **Establish** new seasonal/short-term closure area
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
Seasonal/short-term closure areas exist (in addition to permanent reserves) with harvesting controls in place and consistently implemented	3
Seasonal/short-term closure areas exist (in addition to permanent reserves) with harvesting controls in place but not strictly implemented	2
Seasonal/short-term closure areas exist (in addition to permanent reserves) with harvesting controls in place but not implemented	1
Principle not considered in MPA network design (no seasonal/short-term closures)	0

SCORING GUIDE FOR TIER 2 ECOLOGICAL PRINCIPLES

The scoring guide was developed to assist practitioners evaluate the extent to which existing marine reserves and proposed new marine reserves in municipal waters or larger marine managed areas meet key ecological design principles for resilient marine reserve networks. The ecological principles are based on the current state of knowledge and guidelines for designing marine reserve networks to achieve sustainable fisheries, biodiversity conservation, and climate resilience objectives (Jupiter et al., 2012, Green et al., 2014, Abesamis et al., 2014, Green et al., 2015). The rationale and illustrations of many of the ecological design principles are based on work conducted as part of the US Coral Triangle Initiative (Green, White, and Kilarski 2013, Gombos et al., 2013).

The ecological principles were binned into two tiers related to the scale of analysis. **Tier 2 ecological principles should be applied at the larger marine managed area scale including municipal-level marine reserve networks and MKBA scale (Table A-2).**

TABLE A-2. TIER 2: ECOLOGICAL DESIGN PRINCIPLES APPLIED AT THE MUNICIPAL OR MKBA NETWORK SCALE

Tier 2: Ecological Design Principles (applied at individual/multiple municipal/MKBA scale)	
2.1	Protect special or unique areas (e.g. isolated habitats with unique assemblages and populations, important habitats for endemic species, and highly diverse areas) in marine reserves (Green et al., 2014).
2.2	Protect spatially isolated areas or populations (i.e. those that are separated by >30 km from similar habitats) in marine reserves (Green et al., 2014, Green et al., 2015).
2.3	Space marine reserves <15 km to 10s of km apart, with smaller reserves closer together (Green et al., 2014, Green et al., 2015).
2.4	Represent 30% of each major habitat in marine reserves, depending on fishing pressure and if effective fisheries management is in place outside the reserves (Green et al., 2014).
2.5	Replicate protection of each major habitat within at least three widely separated marine reserves (Green et al., 2014).
2.6	Marine reserves should include habitats that are critical to the life history of focal species (e.g. home ranges, nursery grounds, migration corridors, and spawning aggregations), and be located to accommodate movement patterns among these (e.g., ontogenetic habitat shifts and spawning migrations (Green et al., 2014, Green et al., 2015).
2.7	Locate more marine reserves upstream relative to fished areas if there is a strong, consistent, unidirectional current (Green et al., 2014, Green et al., 2015).
2.8	Integrate marine reserves within broader spatial planning and management regimes (e.g., large multiple-use MPAs, EAFM, EBM, and ICM (Green et al., 2014)).

PROTECT CRITICAL, SPECIAL AND UNIQUE AREAS

2.1 Protect special or unique areas (e.g. isolated habitats with unique assemblages and populations, important habitats for endemic species, and highly diverse areas) in marine reserves (Green et al., 2014).

Description

These areas may include isolated habitats that often have unique assemblages and populations, habitats that are important for rare, threatened or endemic species, and areas that are highly biodiverse. Some examples of special or unique areas include double barrier reefs, upwelling areas, areas with high abundance of apex predators, and habitats around small, isolated islands.

Assessment Questions

- *Are endemic species found in the area? What are their habitat requirements?*
- *Are isolated and special and unique habitats with unique assemblages and populations found in the area?*
- *To what extent do marine reserves in the network protect special and unique areas?*

Information/Data Sources

- Scientific studies of special or unique areas
- Participatory coastal resource assessments

Potential Actions

- **Retain** marine reserve as is and continue to improve management
- **Alter** size of marine reserve to better protect special or unique areas (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Establish new** marine reserve to protect special or unique areas (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Remove** marine reserve unless it serves another ecological principle

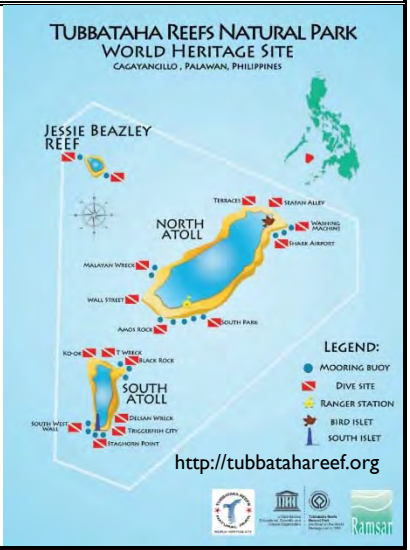
Scoring Criteria	Rating
Marine reserves protect most known special and unique areas	3
Marine reserves protect some known special and unique areas	2
Marine reserve protect only a few special or unique areas but are not managed	1
Principle not considered in MPA network design (special and unique areas exist but no protection in marine reserve)	0

INCORPORATE CONNECTIVITY

2.2 Protect spatially isolated areas or populations (i.e. those that are separated by >30 km from similar habitats) in marine reserves (Altman et al., 2011, Green et al., 2014, Green et al., 2015).

Description

A location or population >30 km from its nearest neighbor should be considered isolated and afforded greater protection. These may include remote atolls, islands, or islets. Tubbataha Reef is just one example of an isolated reef in the Philippines.



Assessment Questions

- *Are there spatially isolated areas or populations in the area?*
- *To what extent are spatially isolated areas or populations protected in marine reserves?*

Information/Data Sources

- Inventory of atolls, islands, or islets that are greater than 30 km from any similar environment or population
- Percent of isolated areas protected in marine reserves

Potential Actions

- **Retain** marine reserve as is and continue to improve management
- **Alter** size of marine reserve to better protect isolated areas (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Establish new** marine reserve to protect spatially isolated areas (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Remove** marine reserve unless it serves another ecological principle

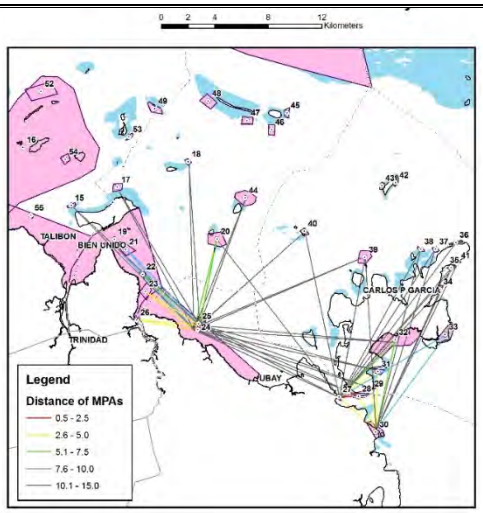
Screening Criteria	Rating
All (100%) isolated areas/populations protected in marine reserves	3
Some (50% – 99%) isolated areas/populations protected in marine reserves	2
Few (10 - <50%) isolated areas/populations protected in marine reserves	1
Principle not considered in MPA network design (<10% of isolated areas/population protected in marine reserves)	0

INCORPORATE CONNECTIVITY

2.3 Space marine reserves <15 km to 10s of km apart, with smaller reserves closer together (Green et al., 2014, Green et al., 2015).

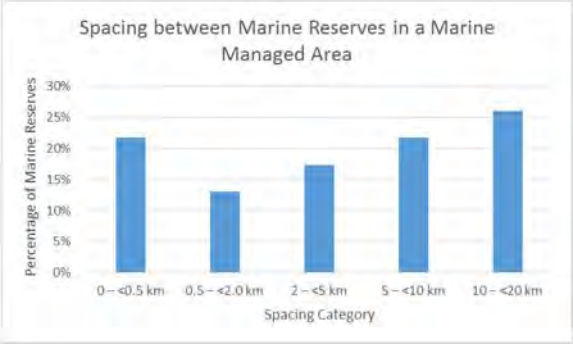
Description

The distance between marine reserves is important because it influences the degree to which populations are connected through adult, juvenile, and larval movement. This connectivity among populations helps maintain fish stocks, conserve diversity, and build ecosystem resilience by ensuring that marine reserves are mutually replenishing to facilitate recovery after disturbance.



Assessment Questions

- *What is spacing between marine reserves in the network?*
- *What is the frequency distribution of all marine reserves in the marine managed area (municipal waters, MKBA) by spacing category (0 – <0.5 km, 0.5 – <2.0 km, 2 – <5 km, 5 – <10 km, and 10 – <20 km)?*
- *What percentage of small marine reserves in the network are in the smallest spacing categories?*



Information/Data Sources

- Distances between all marine reserves up to 20 km from each other
- Frequency distribution of distances by spacing category
- Sizes of marine reserves

Potential Actions

- **Retain** the distribution of marine reserves as is
- **Alter** the size of some marine reserves to reduce distance between them
- **Establish new** marine reserves to fill in distance gaps
- **Remove** marine reserve unless it serves another ecological principle

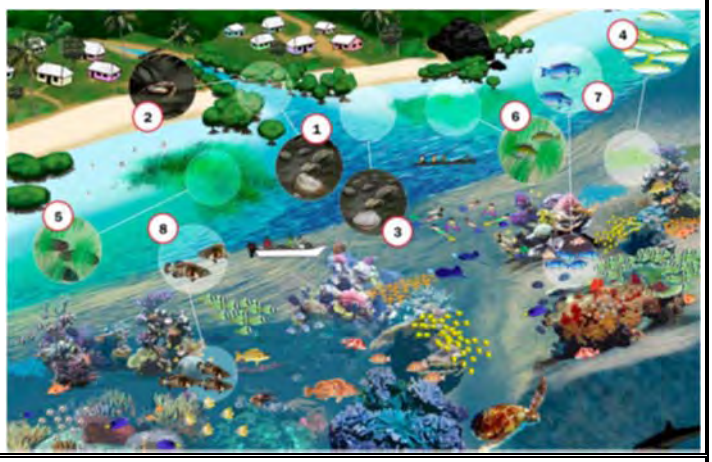
Scoring Criteria	Rating
The frequency distribution of marine reserve distances in each spacing category ranges from ~20% to < 30%, small marine reserves are located in the smallest spacing categories	3
The frequency distribution of marine reserve distances in each spacing category ranges from ~10% to < 40%	2
The frequency distribution of marine reserve distances in any one category is 30% to <40%	1
Principle not considered in MPA network design (distribution of marine reserve distances in any one frequency distribution spacing category is >40%, small marine reserves are separated by large distances)	0

HABITAT REPRESENTATION

2.4 Represent 30% of each major habitat in marine reserves, depending on fishing pressure and if effective fisheries management is in place outside the reserves (Green et al., 2014).

Description

Marine reserves should encompass at least 20-40% of each habitat type to achieve multiple of objectives of sustainable fisheries, biodiversity conservation, and ecosystem resilience in the face of climate change. Species use different habitats for their life history. Percentages may vary with several factors including fishing pressure and if there is additional effective protection (e.g. fisheries management) in place outside of reserves. If fishing pressure is high and the only protection offered is marine reserves, then the proportion of each habitat in reserves should be about 35%.



Assessment Questions

- *What are the major types of habitats in the area?*
- *Is each habitat type represented in marine reserves?*
- *To what extent is each habitat type (coral reef, seagrass, mangrove, estuarine) represented in marine reserves throughout the network?*

Information/Data Sources

- Area of each habitat type in municipal waters
- Percent of each habitat type in marine reserve

Potential Actions

- **Retain** marine reserves as they are because they support representation of all habitat types
- **Alter** increase the size of existing marine reserves to include multiple habitat types
- **Establish new** marine reserves to include habitat types not currently protected and to increase the percentage of each habitat type in marine reserves
- **Remove** marine reserve unless it serves another ecological principle

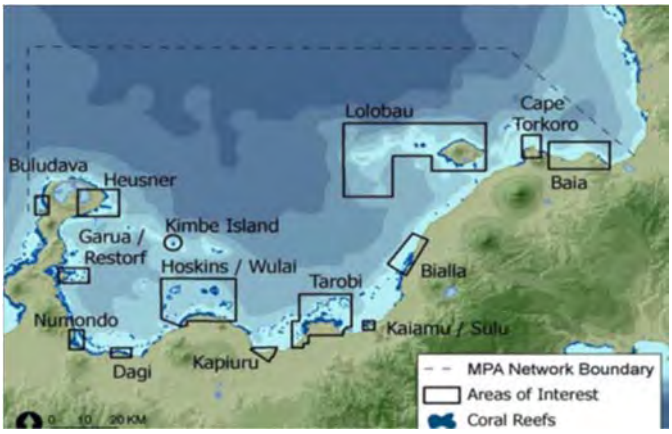
Scoring Criteria	Rating
20% - 40% of each habitat type is represented within marine reserves in the municipality	3
10% - 20% of each habitat type is represented within marine reserves in the municipality	2
5% - 10% of each habitat type is represented with marine reserves in the network	1
MPA network has not considered the design principle (<5% of any one habitat type represented in marine reserves	0

RISK SPREADING

2.5 Replicate protection of each major habitat within at least three widely separated marine reserves (Green et al., 2014).

Description

Protection of habitats in at least three widely separated marine reserves minimizes the risk that all examples of a habitat will be adversely impacted by the same disturbance (e.g. typhoon, extreme runoff from severe weather events, climate change-related disturbances). Thus, if some protected habitats survive the disturbance, they can act as a source of larvae to facilitate recovery in other areas. Depending on the size of the municipal waters, if replication of each major habitat type in widely spaced marine reserves is not possible within the municipality, it is highly recommended that collaboration with adjacent municipalities is explored in order to achieve this ecological principle.



Assessment Questions

- *What are the different types of habitats in the area?*
- *Do marine reserves protect replicate habitats?*
- *Are there marine reserves that protect replicate habitats and are widely separated within the network?*

Information/Data Sources

- Frequency and extent of historical and projected future disturbances that could impact each major habitat type
- Maximum distances between three marine reserves protecting each habitat type
- Maximum distances between similar habitat types

Potential Actions

- **Retain** existing marine reserves sufficiently separated to minimize risk from disturbances
- **Alter** existing marine reserves to include additional habitat types that support replication
- **Establish new** marine reserves to replicate habitat types
- **Remove** marine reserve unless it serves another ecological principle

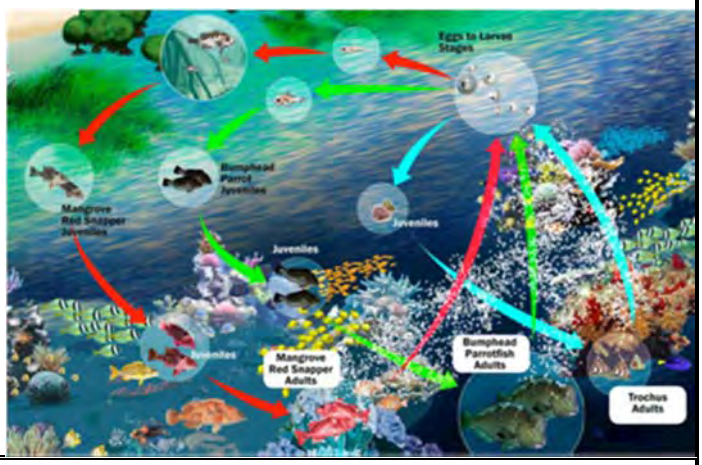
Scoring Criteria	Rating
All habitat types are replicated in marine reserves, spaced widely/located in different social/environmental conditions	3
Some habitat types are replicated in marine reserves spaced widely/located in different social/environmental conditions	2
Only one example of each habitat type is represented in marine reserves	1
MPA network has not considered the design principle	0

INCORPORATE CONNECTIVITY

2.6 Marine reserves should include habitats that are critical to the life history of focal species (e.g. home ranges, nursery grounds, migration corridors, and spawning aggregations), and be located to accommodate movement patterns among these (e.g., ontogenetic habitat shifts and spawning migrations (Green et al., 2014, Green et al., 2015).

Description

Habitats critical to target fish species may be within municipal waters, range over multiple municipal waters, or include areas beyond. These species may require multiple habitats over their life cycle. In order to incorporate connectivity, habitats critical to the life history of focal species need to be protected in marine reserves, with reserves located to allow for movement among protected habitats.



Assessment Questions

- *What target fish species use multiple habitats within the managed area?*
- *To what extent do marine reserves within the network include habitats that are critical to the life history of target fish species (e.g. nursery, spawning areas) and consider movement patterns among them?*
- *Are the marine reserves close enough to allow target species to move among protected habitats?*

Information/Data Sources

- Life history information on target fish species (see Focal Species Characteristics Matrix; http://www.fishbase.se/search.php)
- Scientific studies of movement patterns of focal species (e.g. Green et al., 2014)

Potential Actions

- **Retain** marine reserve
- **Alter** the size and shape of marine reserve to better protect one or more habitat requirements throughout the life history of each target fish species (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also other Tier 2 ecological principles)
- **Establish new** marine reserves to protect one or more habitat requirements through the life history of each focal species.
- **Remove** marine reserve unless it serves another ecological principle

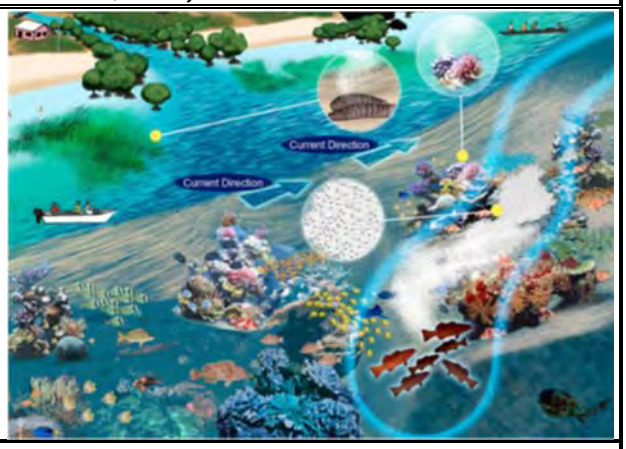
Scoring Criteria	Rating
Marine reserves include habitats needed for all target fish species	3
Marine reserves include habitats needed for many target fish species	2
Marine reserves include habitats needed for a few target fish species	1
Principle not considered in MPA network design, and reserves are not protecting habitats critical to the life history of target fish species	0

INCORPORATE CONNECTIVITY

2.7 Locate more marine reserves upstream relative to fished areas if there is a strong, consistent, unidirectional current (Green et al., 2014, Green et al., 2015).

Description

Marine reserves can become a source of larvae contributing disproportionately more to population recruitment. To the degree that currents influence larval dispersal, marine reserves will contribute disproportionately more to genetic connectivity and population recruitment of locations down-current. If connectivity patterns are unknown, and currents are known, strong, and consistent, then a greater number of the marine reserves should be located towards the upstream end of the management area.



Assessment Questions

- *What is the general circulation patterns in the marine managed area?*
- *Is there a dominant current flow and direction? What are seasonal variations?*
- *Is tidal flow an important factor larval transport?*
- *Where are source and sink areas for larvae?*
- *To what extent are known sources of larvae protected in marine reserves?*

Information/Data Sources

- Studies of ocean currents and larval distribution
- Hydrodynamic and larval dispersal modeling

Potential Actions

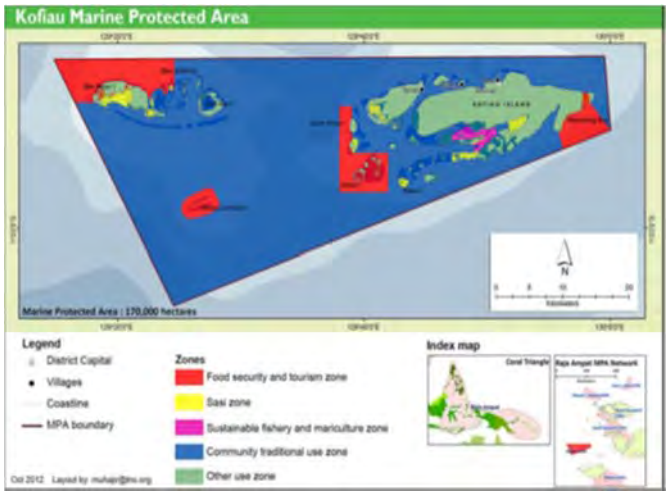
- **Retain** marine reserve as is and continue to improve management
- **Alter** the size and shape of marine reserve to reduce larval spillover (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Establish new** marine reserves to protect larval source and sink areas (See also ecological principles 1.2 – 1.5 for size, shape, and location. Consider also Tier 2 ecological principles)
- **Remove** marine reserve unless it serves another ecological principle

Most sources of larvae are protected by marine reserves in the network	3
Many sources of larvae are protected by marine reserves in the network	2
Few larval sources are protected by marine reserves in the network	1
Principle not considered in MPA network design, and important larval sources not protected	0

MINIMIZE AND AVOID LOCAL THREATS

2.8 Integrate marine reserves within broader spatial planning and management regimes (e.g., large multiple-use MPAs, EAFM, EBM, and ICM (Green et al., 2014).

Description



To maximize fisheries benefits and the range of biodiversity and habitats protected, and to mitigate against risks (including climate change impacts), all of the ecosystem should be included within multiple use marine managed areas that include marine reserves, which is integrated within broader planning and management regimes (e.g. EAFM, EBM, and ICM). In the Philippines, municipal waters are considered large multiple use marine managed areas where marine spatial planning should be used to develop different zones that can be used to help protect sensitive natural resources from over use, separate conflicting uses, and preserve the diversity of marine life in an area. The different types of protection offered within different zones can offer synergistic benefits (where two or more zones work together to produce results they can't obtain on their own), as seen within ecosystem based fisheries management. In addition, the Philippines Fisheries Code requires 15% of municipal waters in marine reserves.

Assessment Questions

- *To what extent (%) is the area of municipal waters designated as marine reserves (including no-take zones in NIPAS areas)?*
- *To what extent have marine reserves been incorporated into marine spatial plans and other types of management?*

Information/Data Sources

- Area of municipal waters and the area of marine reserves to determine percent of municipal waters protected as marine reserves

Potential Actions

- **Retain** marine reserves as they are if they protect a sufficient area of municipal waters (see also Tier 1 and other Tier 2 principles)
- **Alter** the marine reserves to increase the size of marine reserves to protect a greater area of municipal waters
- **Establish new** marine reserves to protect a greater area of municipal waters (see also Tier 1 ecological principles)
- **Remove** marine reserve unless it serves another ecological principle

Scoring Criteria	Rating
Marine reserves cover >10% of municipal waters and are incorporated into marine spatial plans	3
Marine reserves 2- 10% of municipal waters and are incorporated into marine spatial plans	2
Marine reserves cover <2% of municipal waters and not integrated into marine spatial plans	1
Principle not considered in MPA network design (no marine reserves)	0

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APPENDIX 2. MATRIX OF ECOLOGICAL CHARACTERISTICS OF TARGET FISH SPECIES

This matrix was provided by Dr. Alison Green based on Palau's Northern Reef Fisheries Management Plan (The Nature Conservancy, 2016). It provides a summary of ecological characteristics of target fish species (their intrinsic vulnerability to fishing pressure, key habitats, and movement patterns) and implications for the design of spatial management measures. Spatial management areas should include the key habitats used by focal species and should be more than twice the size of the home range of focal species (in all directions: (Green et al., 2015)). Species whose movement patterns (e.g. spawning migrations or longer term movements) are larger than the size of the spatial management area will only be afforded partial protection. However, these areas can provide benefits for wide ranging species if they protect their core areas of use or specific locations where individuals aggregate and become especially vulnerable to fishing mortality (e.g. fish spawning areas: (Green et al., 2015)).

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
Acanthuridae (Surgeonfishes)	*Naso unicornis*	High	Channels, moats, lagoons and seaward reefs, particularly areas of strong surge. Spawn on outer reef edges. Depths of 1 to 80 m.	Home ranges are <1 km (0.6 miles)	2 km (1.2 miles) should protect this species most of the time.
Carangidae (Jacks)	*Caranx ignobilis*	High to Very High	Adults range widely over the reef, occurring primarily on seaward reefs. Juveniles occur over sandy inshore bottoms, and use estuaries as nursery habitats. Spawn on shallow seaward reefs	Ontogenetic shifts are >3 km (1.9 miles) Core areas of use are <5 km (3.1 miles) Long term movements are <20-300 km (12 to 186 miles)	10 km (6 miles) should protect this species most of the time (for ontogenetic shifts and core areas of use), but not during longer term movements.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
			and offshore banks. Depths to 80 m.		
Epinephelidae (Groupers)	*Epinephelus fuscoguttatus*	Medium to High	Lagoon pinnacles, channels and outer reef slopes, generally in areas of rich coral growth and clear water. Spawn on seaward end of channels. Depths of 1 to 60 m.	Spawning migrations are <30 km (18.6 miles). No home range data is currently available. Until this data becomes available, the closest proxies to use may be other large congeneric species (e.g. *E. tauvina, E. coicoides, E. malabaricus, E. tukula*) where: home range/core areas of use are <3 to <5 km (1.9 to 3.1 miles); and long term movements are <10 to 20 km (6 to 12 miles)	10 km (6 miles) should protect this species most of the time (for home ranges and core areas of use), but not during spawning migrations or longer term movements.
	Epinephelus polyphekadion	Medium to High (if same as *E. fuscoguttatus*)	Clear waters of lagoon and seaward reefs, generally in areas of rich coral growth. Spawn on seaward end of channels. Depths of 1 to > 46 m.	Spawning migrations are < 40 km (25 miles) No home range data is currently available. Until this data becomes available, the closest proxies to use may be other large congeneric species *(e.g. E. tauvina, E. coicoides, E. malabaricus,*	10 km (6 miles) should protect this species most of the time (for home ranges and core areas of use), but not during spawning migrations or longer term movements

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
				E. tukula) where: home range/core areas of use are < 3 to < 5 km (1.9 to 3.1 miles); and long term movements are <10 to 20km (6 to 12 miles)	
	Plectropomus areolatus	High	Coastal, lagoon and seaward reefs. Spawn on seaward end of channels. Depths of 2 to > 20 m.	Home ranges are <1km (0.6 miles) Spawning migrations are < 30 km (18.6 miles)	2 km (1.2 miles) should protect this species most of the time (home ranges), but not during spawning migrations.
	Plectropomus laevis	High to Very High	Adults inhabit clear lagoon and seaward reefs in areas of rich coral growth. Juveniles occur in relatively turbid areas of deep lagoons. Depths of 4 to at least 90 m.	No data is currently available for this species. Until this data becomes available, the closest proxy to use may be *P. areolatus* where: home ranges are < 1 km (0.6 miles); and spawning migrations are < 30 km (18.6 miles).	2 km (1.2 miles) should protect this species most of the time (home ranges), but not during spawning migrations.
Epinephelidae (Groupers) cont.	*Plectropomus leopardus*	Medium to High	Coastal and lagoon reefs. Depths of 3-100 m.	Home ranges are < 3 km (1.9 miles). Spawning migrations are < 10 km (6 miles).	6 km (3.7 miles) should protect this species most of the time (home ranges), but not during spawning migrations.
	Variola louti	Medium to High (if assume similar to *P. leopardus*)	Lagoons, channels and seaward reefs. Adults prefer coral rich growth	Home ranges are < 3 km (1.9 miles)	6 km (3.7 miles) should protect this species most of the time.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
			in clear water below 15 m. Juveniles may occur in shallow water (i.e. 4 m). Depths of 3 to 240 m.		
Labridae (Wrasses)	*Cheilinus undulatus*	High to Very High	Adults occur along steep outer reef slopes, channel slopes, and occasionally on lagoon reefs. Juveniles occur in coral-rich areas of lagoon reefs, particularly among thickets of staghorn *Acropora* corals. Spawn in a range of habitats (i.e. outer reef shelf edges or adjacent to exposed reef passes near steep drop-offs). Depths 2 to at least 60 m.	Home ranges are mostly <10 km (6 miles)	20-24 km (12-15 miles) should protect this species most of the time.
Lujanidae (Snappers)	*Lutjanus bohar*	High to Very High	Exposed seaward reefs and adjacent lagoon and channel waters. Tends to be more abundant around atolls than around high islands. Spawn along outer reef slopes. Depths of 4 to 180 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *L. rivulatus* where: Core area of use are <3 km (1.9 miles) Long term movements are <200 km (124 miles)	6 km (3.7 miles) should protect this species most of the time (for core areas of use), but not during longer term movements.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
	Lutjanus gibbus	High (if assume less than *L. bohar*)	Adults prefer deeper lagoons, passes and seaward reefs, but occasionally occur on outer reef flats. Juveniles inhabit seagrass beds and mixed sand and coral habitats of shallow sheltered reefs. Spawn along outer reef slopes. Depths of 1 to 150 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *L. rivulatus* where: Core area of use are < 3 km (1.9 miles) Long term movements are <200 km (124 miles)	6 km (3.7 miles) should protect this species most of the time (for core areas of use), but not during longer term movements.
Lethrinidae (Emperors)	*Lethrinus olivaceus*	Medium	Sandy bottoms of lagoons and seaward reefs (outer reef slopes). Spawn along the edge of the reef. Depths of 1 to 20 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *L. miniatus* where: Core area of use are <5km (3.1 miles) Long term movements are <200 km (124 miles)	10 km (6.2 miles) should protect this species most of the time (for core areas of use), but not during longer term movements.
	Lethrinus xanthochilus	Medium (if assume similar to *L. olivaceus*)	Shallow lagoon areas of mixed coral rubble and sand as well as seagrass beds. Sand and rubble bottoms near reefs. Depths of 5 to 30 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *L. miniatus* where: Core area of use are <5 km (3.1 miles)	10 km (6.2 miles) should protect this species most of the time (for core areas of use), but not during longer term movements.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
				Long term movements are <200 km (124 miles)	
Scaridae (Parrofishes)	*Bolbometopon muricatum*	High to Very High	Adults inhabit clear outer lagoon, outer reef flat and seaward reefs. Juveniles and newly recruited individuals occur in coral-rich sheltered lagoonal habitats and inshore reefs, particularly among thickets of staghorn *Acropora* corals. They progressively colonize more exposed habitats with increasing size[2]. Spawn along outer reef edges. Depths 1 to 40 m.	Home ranges are <10 km (6 miles)	20 km (12 miles) should protect this species most of the time.
	Cetoscarus oscellatus (previously *C. bicolor)*	High to Very High	Clear lagoon and seaward reefs. Adults prefer the upper reaches of steep coral slopes. Depths of 1 to 30 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *S. rubroviolaceous* where: Home ranges are <2km (1.2 miles) Long term movements are <5 km (3.1 miles)	4 km (2.5 miles) should protect this species most of the time (for home ranges), but not during longer term movements.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
	Chlorurus microrhinos	Medium	Lagoon, sheltered and seaward reefs. Depths of 2 to 35 m.	Home ranges are <3 km (1.9 miles)	6 km (3.7 miles) should protect this species most of the time.
	Hipposcarus longiceps	Low to Medium	Adults and subadults inhabit sandy bottoms near lagoon and seaward reefs. Juveniles occur among coral rubble of lagoon patch reefs. Depths of 2 to 40 m (or more).	No data is currently available. Until this data becomes available, the closest proxy to use may be *S. ghobban* where: Home ranges are <2 km (1.2 miles) Long term movements <6km (3.7 miles)	4 km (2.5 miles) should protect this species most of the time (for home ranges), but not during longer term movements.
	Scarus rubroviolaceus	Medium (if assume similar to other large *Scarus* spp.)	Seaward reefs (outer reef slopes). Prefers rocky bottoms, particularly boulder-strewn slopes. Depths of 1 to >30 m.	Home ranges are <2 km (1.2 miles) Long term movements are <5 km (3.1 miles)	4 km (2.5 miles) should protect this species most of the time (for home ranges), but not during longer term movements.

FAMILY	SCIENTIFIC NAME	INTRINSIC VULNERABILITY TO FISHING[1]	KEY HABITATS TO BE INCLUDED IN SPATIAL MANAGEMENT AREAS[2]	MOVEMENT PATTERNS[3] (LINEAR DISTANCE IN KM)	MINIMUM RECOMMENDED SIZE OF KEY HABITATS IN SPATIAL MANAGEMENT AREAS (LINEAR DISTANCE IN KM)[3]
Siganidae (Rabbitfishes)	*Siganus canaliculatus*	Medium (estimate – no values available for this family)	Lagoons, coastal reefs and bay, but primarily on seagrass beds. Depths to 4 m.	No data is currently available. Until this data becomes available, the closest proxy to use may be *S. fuscens* where: Home ranges are <3 km (1.9 miles)	6 km (3.7 miles) should protect this species most of the time.

[1] Vulnerability Index from (Abesamis et al., 2014) (where species are not listed, we used the closest available species as a guide).

[2] All habitat information is from (Allen, Steene, and Humann 2003, Myers 1999), except for the information on juvenile *B.muricatum* (which is from (Aswani and Hamilton 2004) and *C. ignobilis* (which is from (Smith and Parrish 2002). Additional information on spawning habitats is from (Sadovy and Colin 2012) and the IUCN Red List website (http://www.iucnredlist.org) (NB: the information on spawning areas may need to be refined.)

[3] All movement data and recommended minimum size of spatial management areas are from (Green et al., 2015), except for more recent data for *C. undulatus* from (Weng et al., 2015).

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