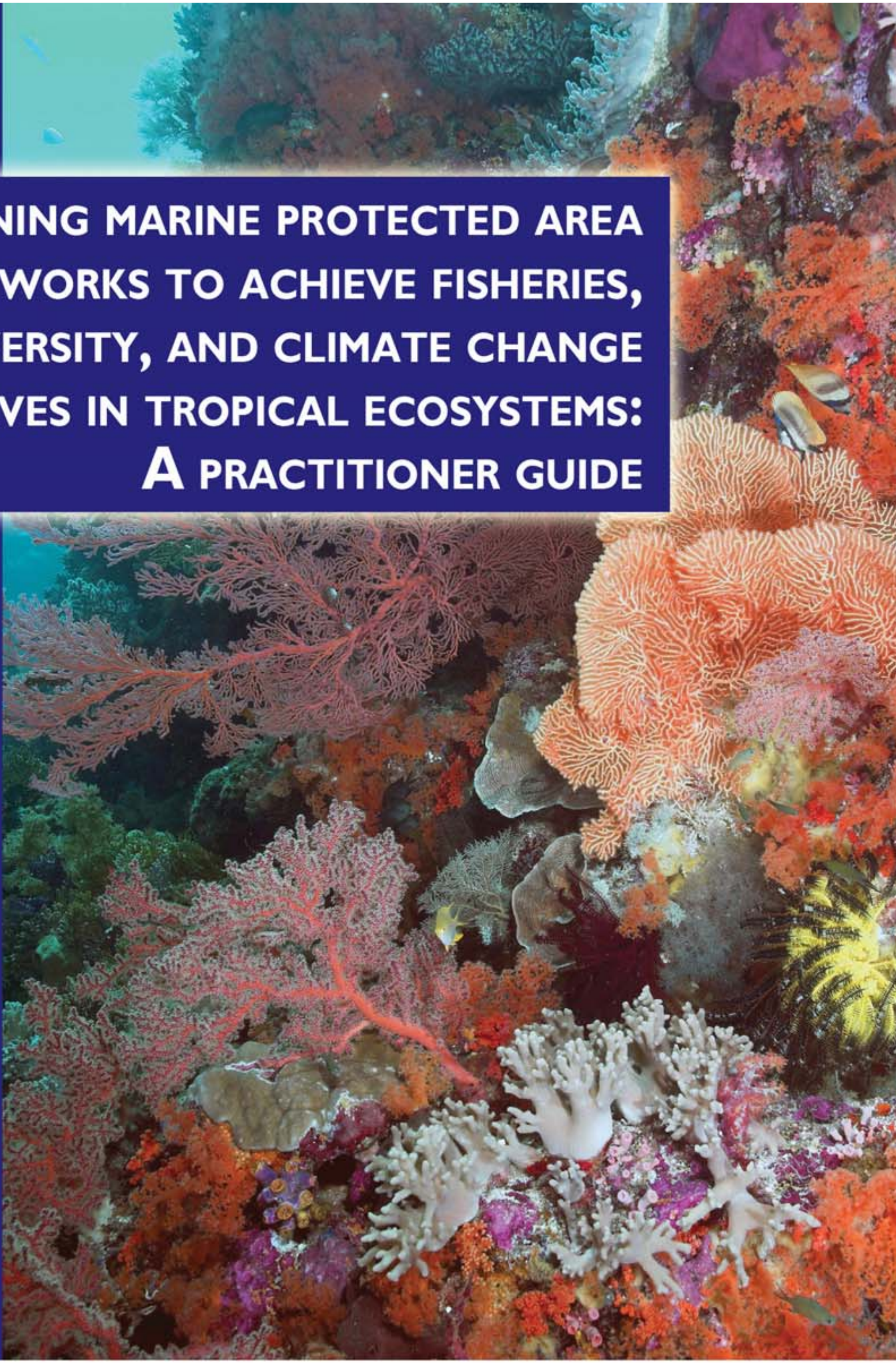

DESIGNING MARINE PROTECTED AREA NETWORKS TO ACHIEVE FISHERIES, BIODIVERSITY, AND CLIMATE CHANGE OBJECTIVES IN TROPICAL ECOSYSTEMS: A PRACTITIONER GUIDE

CORAL TRIANGLE INITIATIVE
ON CORAL REEFS, FISHERIES AND FOOD SECURITY

A publication supporting the **Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF)**

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DESIGNING MARINE PROTECTED AREA NETWORKS TO ACHIEVE FISHERIES, BIODIVERSITY, AND CLIMATE CHANGE OBJECTIVES IN TROPICAL ECOSYSTEMS:

A practitioner guide

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This publication was produced and printed with support
from the United States Agency for International Development's
regional Asia program through the
Coral Triangle Support Partnership

Designing marine protected area networks to achieve fisheries, biodiversity, and climate change objectives in tropical ecosystems: A practitioner guide

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All illustrations: Gombos, M., Atkinson, S., Green, A., and K. Flower (eds.), 2013. Designing Resilient Locally Managed Areas in Tropical Marine Environments: A Guide for Community Based Managers. USAID Coral Triangle Support Partnership, Jakarta, Indonesia. Illustrations on pages 8, 9, 11, 12, 16, 19, 25, and 27 designed by Meghan Gombos, Scott Atkinson, and Sevuloni Tora and illustrated by Sevuloni Tora. These illustrations incorporate several marine species paintings that have been reproduced with the kind permission of the Secretariat of the Pacific Community, Noumea, New Caledonia. The artists of the marine species paintings are: Rachel O'Shea: Pacific yellow tail emperor, mangrove red snapper, emperor read snapper, white teatfish, sandfish, black teatfish, lobster, trochus; Les Hata: thumbprint emperor, trumpet emperor, spangled emperor, peacock hind, honeycom grouper, leopard grouper, yellow-edged lyretail, green humphead parrotfish, daisy parrotfish, steephead parrotfish, darkcapped parrotfish, humpback red snapper, common bluestripe snapper, blacktail snapper, bluefin trevally, giant trevally.

USAID Project Number: GCP LWA Award # LAG-A-00-99-00048-00
Citation: Green, A., White, A., Kilarski, S. (Eds.) 2013. Designing marine protected area networks to achieve fisheries, biodiversity, and climate change objectives in tropical ecosystems: A practitioner guide. The Nature Conservancy, and the USAID Coral Triangle Support Partnership, Cebu City, Philippines. viii + 35 pp.
Printed in: Cebu City, Philippines, February 2013

Funding for the preparation of this document was provided by the USAID-funded Coral Triangle Support Partnership (CTSP). CTSP is a consortium led by the World Wildlife Fund, The Nature Conservancy and Conservation International.

More information on the six-nation Coral Triangle Initiative and support by USAID can be found at:
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Front cover photos: Coral reef in the Indo-Pacific (© Colin Zylka/Marine Photobank). Back cover photos: Bigeye Trevally in Balicasag Island Fish Sanctuary, central Philippines © Aileen Maypa: Fishermen with his catch in Wakatobi National Park, Indonesia (© Bridget Besaw)

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FOREWORD AND PREFACE

This Guide provides a timely input to the design of our marine protection efforts around the world. Since the Coral Triangle Countries of Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Island and Timor Leste have formed the Coral Triangle Initiative for Coral Reefs, Fisheries and Food Security[1] in 2009, the need to address multiple issues and objectives to effectively sustain marine and coastal resources has become ever more urgent.

One of the primary strategies being used almost everywhere to serve the needs of marine conservation and marine resource management is the design and implementation of marine protected area networks. But networks of marine protected areas will not be effective unless they can combine the multiple objectives important to stakeholders.

Thus, this Guide provides an integrated set of biophysical principles to help practitioners design networks of tropical marine protected areas to achieve fisheries sustainability, biodiversity conservation and ecosystem resilience in the face of climate change. The document also provides a succinct, graphic and user-friendly synthesis of the best available scientific information for practitioners who may not have access to, or the time to review, the increasing amount of research literature regarding this issue.

The scientific basis for this Guide is provided in a detailed technical report: *Biophysical principles for designing resilient networks of marine protected areas to integrate fisheries biodiversity and climate change objectives in the Coral Triangle.*[23] While this Guide has been developed in the context of the Coral Triangle countries, the principles presented are general and can be applied to tropical marine ecosystems at any scale worldwide. The 15 principles as elaborated are highly relevant for field practitioners, are user-friendly and easy to apply to the design, planning and implementation of marine protected and managed areas. Please make good use of this excellent guidance to take our marine managed areas to a higher level of effectiveness!

Lynne Hale
Director, Global Marine Initiative
The Nature Conservancy

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[1] www.coraltriangleinitiative.org

ACKNOWLEDGEMENTS

The key contributors listed above (all co-authors of the technical report on which this document is based: Fernandes et al. 2012) are thanked for their significant contributions. In addition we thank Aileen Maypa (Coastal Conservation and Education Foundation) and Glenn Almany (ARC Centre of Excellence for Coral Reef Studies) for allowing us to use their unpublished work regarding fish connectivity and implications for marine reserve design. Special thanks are extended to Scott Atkinson and Meghan Gombos for their input and the use of figures they developed to share this information with local communities through a separate publication[2].

Others who provided inputs and assisted with the review of the technical report upon which this practitioner guide is based include: Vera Agostini (The Nature Conservancy), Nygiel Armada (United States Coral Triangle Initiative), Rusty Brainard (National Oceanic and Atmospheric Administration), Darmawan (Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security Interim Regional Secretariat), Eddie Game (The Nature Conservancy), Hedley Grantham (Conservation International), Rick Hamilton (The Nature Conservancy), Jose Ingles (World Wildlife Fund - Philippines), Kenneth Kassem (World Wildlife Fund - Malaysia), Elizabeth McLeod (The Nature Conservancy), Joel Palma (World Wildlife Fund-Philippines), Nate Peterson (The Nature Conservancy), Lida Pet-Soede (World Wildlife Fund – Indonesia), Garry Russ (ARC Centre of Excellence for Coral Reef Studies), Rod Salm (The Nature Conservancy), Andrew Smith (The Nature Conservancy), John Reuben Sulu (WorldFish) and Scott Wooldridge (Australian Institute for Marine Science). The development of this Guide has also been supported by the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security Interim Regional Secretariat under the direction of Dr. Sukoyono Suseno, Executive Chair, and the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security MPA Technical Working Group Chair, Director Mundita Lim.

We also thank others who contributed through informal discussions or other means and apologize for not listing all. Finally, this guide is supported by numerous excellent published scientific papers and references essential to making this Guide rigorous and complete. And, without the support of the Coral Triangle Support Partnership, funded by the United States Agency for International Development, this project would not have proceeded.

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[2] Gombos, M., Atkinson, S., Green, A., and K. Flower (eds.), 2013. Designing Resilient Locally Managed Areas in Tropical Marine Environments: A Guide for Community Based Managers. USAID Coral Triangle Support Partnership, Jakarta, Indonesia. 82 pp.

EXECUTIVE SUMMARY

Overfishing, degradation and loss of key habitats due to local and global threats are undermining food security, livelihoods and long term sustainability of tropical marine ecosystems. If well designed, marine protected areas (MPAs) can reduce local threats, and contribute to sustaining fisheries and conserving biodiversity in the face of global threats such as climate change.

Existing biophysical design principles take account of biological and physical processes to recommend how to design MPA networks to achieve fisheries, biodiversity or climate change objectives. While there are many similarities among existing principles for achieving each of these objectives, there are some differences that provide conflicting advice.

This document was developed in response to numerous requests from field practitioners for concise, user friendly advice regarding how to design MPA networks to achieve fisheries, biodiversity and climate change objectives simultaneously. Here we synthesize and reconcile existing approaches to provide an integrated set of 15 biophysical principles that field practitioners can use to design MPA networks to achieve all three objectives simultaneously, based primarily on a detailed technical report by Fernandes et al 2012[3]. These principles are designed to be used in combination with important social, economic and political considerations in marine spatial planning.

There are often information gaps and socio-economic, cultural, political and other reasons that can prevent full application of these principles. When required to compromise, managers should aim to achieve as many principles as possible in the order presented below.

The 15 biophysical principles for designing marine protected area networks to achieve fisheries, biodiversity, and climate change objectives in tropical ecosystems elaborated in this Guide are as follows:

1. Prohibit destructive activities throughout the management area.
2. Represent 20-40% of each habitat within marine reserves (depending on fishing pressure and if there is additional effective protection in place outside of reserves). Include habitats that are connected through movements of key species.

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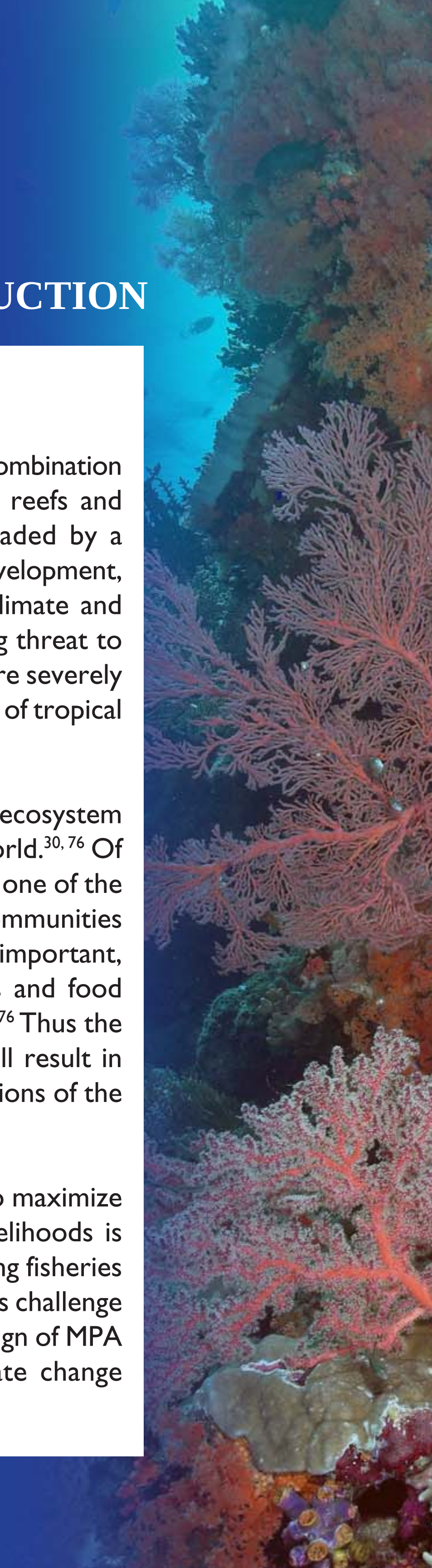
[3] Available at http://www.coraltriangleinitiative.org/library/guidelines-biophysical-principles-designing-resilient-networks- marine-protected-areas or http://www.uscti.org

3. Replicate protection of habitats within marine reserves.
4. Ensure marine reserves include critical habitats (e.g. spawning, feeding and nursery areas).
5. Ensure marine reserves are in place for the long-term (20-40 years), preferably permanently.
6. Create a multiple use marine protected area that is as large as possible.
7. Apply minimum and variable sizes to MPAs (depending on key species and how far they move, and if other effective marine resource management methods are in place).
8. Separate marine reserves by 1 to 20 km (with a mode between 1 and 10 km).
9. Include an additional 15% of key habitats in shorter-term marine reserves.
10. Locate MPA boundaries both within habitats and at habitat edges.
11. Have MPAs in more square or circular shapes.
12. Minimize and avoid local threats.
13. Include resilient sites (refugia) in marine reserves.
14. Include special or unique sites in marine reserves (e.g. habitats that are isolated or important for rare and threatened species).
15. Locate more protection upstream.

INTRODUCTION



Tropical Marine Ecosystems and Marine Protected Areas (MPAs)

Tropical marine ecosystems are threatened globally by a combination of local and global threats.[14] In many countries, coral reefs and associated habitats have been lost or seriously degraded by a combination of overfishing, destructive fishing, coastal development, watershed and marine-based pollution.[14] Changes in climate and ocean chemistry also represent a serious and increasing threat to coral reefs and associated ecosystems.[14] These threats are severely undermining biodiversity and the long-term sustainability of tropical marine ecosystems worldwide.[39, 30, 10, 53, 55]

Tropical marine ecosystems provide critically important ecosystem services to hundreds of millions of people around the world.[30, 76] Of particular importance are coral reef fisheries, which are one of the most important ecosystem services benefiting coastal communities in tropical countries.[30, 76] These fisheries are critically important, since they play a major role in supporting livelihoods and food security of local communities and other stakeholders.[30, 76] Thus the degradation and loss of tropical marine ecosystems will result in escalating hardship and economic instability in many regions of the world.[31, 77]

Better use of marine protected area (MPA) networks to maximize their contribution to food security and sustainable livelihoods is one of the key challenges for all concerned with managing fisheries and biodiversity to be resilient to climate change.[51, 22] This challenge requires a practical set of principles to underpin the design of MPA networks to achieve fisheries, biodiversity and climate change objectives simultaneously.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▲ **Coastal villages in the Solomon Islands depend on fish and other marine resources for income, food and livelihoods.**

Here we provide biophysical principles for designing resilient networks of MPAs to achieve all three objectives simultaneously for tropical marine ecosystems. These principles are designed to contribute to a larger planning process that must include implementing MPA networks in ways that complement human uses and values, and align with local legal, political and institutional requirements.[45, 16]

What are MPAs and MPA networks?

In this Guide, marine protected areas (MPAs) are defined as any clearly-delineated, marine managed area that contributes to protection of natural resources in some manner.[40, 19] They include, but are not limited to, areas with a variety of regulations including marine reserves (areas of ocean that are protected from extractive and destructive activities) and areas with fisheries restrictions upon gear, species, size and access. They also include areas with different governance systems, including government and community managed marine areas.

Networks of MPAs refer to a collection of individual areas that are ecologically connected.[40, 19] For the same amount of spatial coverage, MPA networks can potentially deliver most of the benefits of well managed individual marine protected areas, but with less costs due to greater flexibility and diversity in size, shape, distribution and location. They can also deliver additional benefits by acting as mutually replenishing networks to facilitate recovery after disturbance.[51] Because of the flexibility in design and application, MPA networks are particularly suited to addressing multiple objectives in various contexts.[22, 40]


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▲ **Rock Islands Southern Lagoon Management Area, Palau.**

What Can MPA Networks Achieve?

MPAs, particularly marine reserves, can be an effective tool for both conservation and fisheries management in tropical marine ecosystems.[64, 54, 47, 73, 28]

The benefits of MPAs are well documented, including an increase in the diversity, density, biomass, body size and reproductive potential of many species (particularly key fisheries species) within their boundaries.[64, 34, 58, 47, 8] MPAs can also provide conservation and fisheries benefits to surrounding areas through the export of eggs, larvae and adults to other reserves and fished areas.[64, 29, 1, 28, 59, 36]

For MPAs to be effective, they need to be embedded within a broader management framework.[56, 20, 2, 3, 5]


FISHERMEN IN PAPUA NEW GUINEA © RICHARD HAMILTON

▲ **MPAs that are designed as part of an ecosystem-based approach to management consider the human context of the ecosystem.**

Thus, MPAs are most likely to achieve their objectives if they are applied as part of an ecosystem-based approach to management[16, 48] which considers the entire ecosystem (including humans) and aims to maintain healthy, productive and resilient ecosystems so they can provide the ecosystem services humans require.

The design and effective implementation of networks of MPAs is critical to maximize their benefits to both conservation and fisheries management.[28, 40] If well designed and effectively managed, MPAs can play an important role in ecosystem-based management, including achieving sustainable use of marine resources at multiple scales.[21, 22]

What are MPA Network Design Principles?

Design principles are guidelines that provide advice on how to design a MPA network to achieve its objectives. In many situations, field practitioners have used two types of design principles: biophysical and socioeconomic. Where: biophysical principles are aimed at achieving biological objectives by taking key biological and physical processes into account; and socioeconomic principles are aimed at maximizing benefits and minimizing costs to local communities and sustainable industries.[23, 33, 78] The biophysical principles in this guide are designed to contribute to a larger process that includes implementing MPA networks in ways that complement human uses and values and align with local legal, political and institutional requirements. Thus implementation of an MPA network will require that these biophysical principles be coupled with socioeconomic principles that address local human contextual factors.

Integrating Fisheries, Biodiversity and Climate Change Objectives in MPA Network Design

If well designed, MPA networks can be an effective strategy for achieving fisheries, biodiversity and climate change objectives in tropical marine ecosystems. In the past, biophysical design principles have tended to focus on achieving only one or two of these objectives – not all three simultaneously.

In many cases, biophysical principles developed for MPA network design have tended to focus on protecting biodiversity, often in the face of climate change.[40, 51, 33, 78] Fisheries issues, while usually considered, have not always been addressed fully in the design process (e.g. fisheries issues are generally considered in terms of avoiding conflicting use with marine reserves, rather than positioning MPAs to maximize


FISHERMAN IN INDONESIA © ALESSIO VIORA/MARINE PHOTOBANK

▲ **Fisheries issues have not always been addressed adequately in the MPA design process.**

fisheries production in fished areas). Similarly, biophysical principles developed to maximize benefits for fisheries management are seldom designed to maximize their contribution to protecting biodiversity in the face of climate change.

While there are many similarities among existing principles for achieving each of these objectives, there are some differences that provide conflicting advice. Thus there is a need to integrate the various approaches to improve the design of MPAs so that they can achieve all three objectives simultaneously.

Biophysical Principles for Achieving Fisheries, Biodiversity and Climate Change Objectives in Marine Protected Area Network Design in Tropical Ecosystems

An in depth literature review by Fernandes et al. 2012 showed that many biophysical design principles for achieving biodiversity protection also apply to supporting sustainable fisheries and enhancing resilience to climate change,[34, 51, 28] because design principles that focus on fisheries species[12, 25] apply to unfished species also.[51] Other principles were different for different objectives, and needed to be integrated to achieve all three objectives simultaneously (particularly regarding size and duration of marine reserves).

Here we provide 15 principles for integrating fisheries, biodiversity and climate change objectives into MPA network design simultaneously, and the rationale for each. These principles each contribute to five broad categories that relate to resilient MPA network design: risk spreading (representation and replication), protecting critical areas, incorporating connectivity, threat reduction and sustainable use.[40, 51, 23]

The principles, and the scientific rationale and an illustration for each, are provided below. These principles will need to be refined in each location based on local knowledge of biophysical characteristics of the area.

There are often information gaps and socio-economic, cultural, political and other reasons that can prevent the full application of all the principles.[45, 16] When required to compromise, the authors recommend that field practitioners aim to achieve as many principles as possible, and that the principles be prioritized in the order presented below. Adaptive management systems should also be used that will allow managers to improve protection as more information becomes available.

If information is sparse, it becomes more important to apply the principles regarding: prohibition of destructive activities, and risk spreading through representation and replication of habitat types (Principles 1 through 3). Even in those situations, application of these three principles: increases the likelihood of protecting the entire range of known and unknown species, habitats and processes of importance; and of insuring against the impact of unpredictable disturbances. In addition, recommendations regarding minimum size and spacing of marine protected areas (Principles 7 and 8) and protecting critical habitats and special and unique sites (where known: Principles 4 and 14) can often be implemented with lower levels of information.

Principle 1: Prohibit destructive activities throughout the management area.

Coastal habitats, and their ecosystem values, are vulnerable to destructive activities (e.g. blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, and night time spearing), which can decrease the health and productivity of the ecosystem and, consequently, all species living within it (including targeted fish species).[15] Destructive activities also decrease ecosystem resilience to other stressors. When an area of the ecosystem is damaged, the benefits it provides to the community and other natural areas will be lost (Figures 1 and 2).


© ALAN WHITE

▲ **In the Philippines, banned muro-ami fishing boats have damaged large areas of reef.**

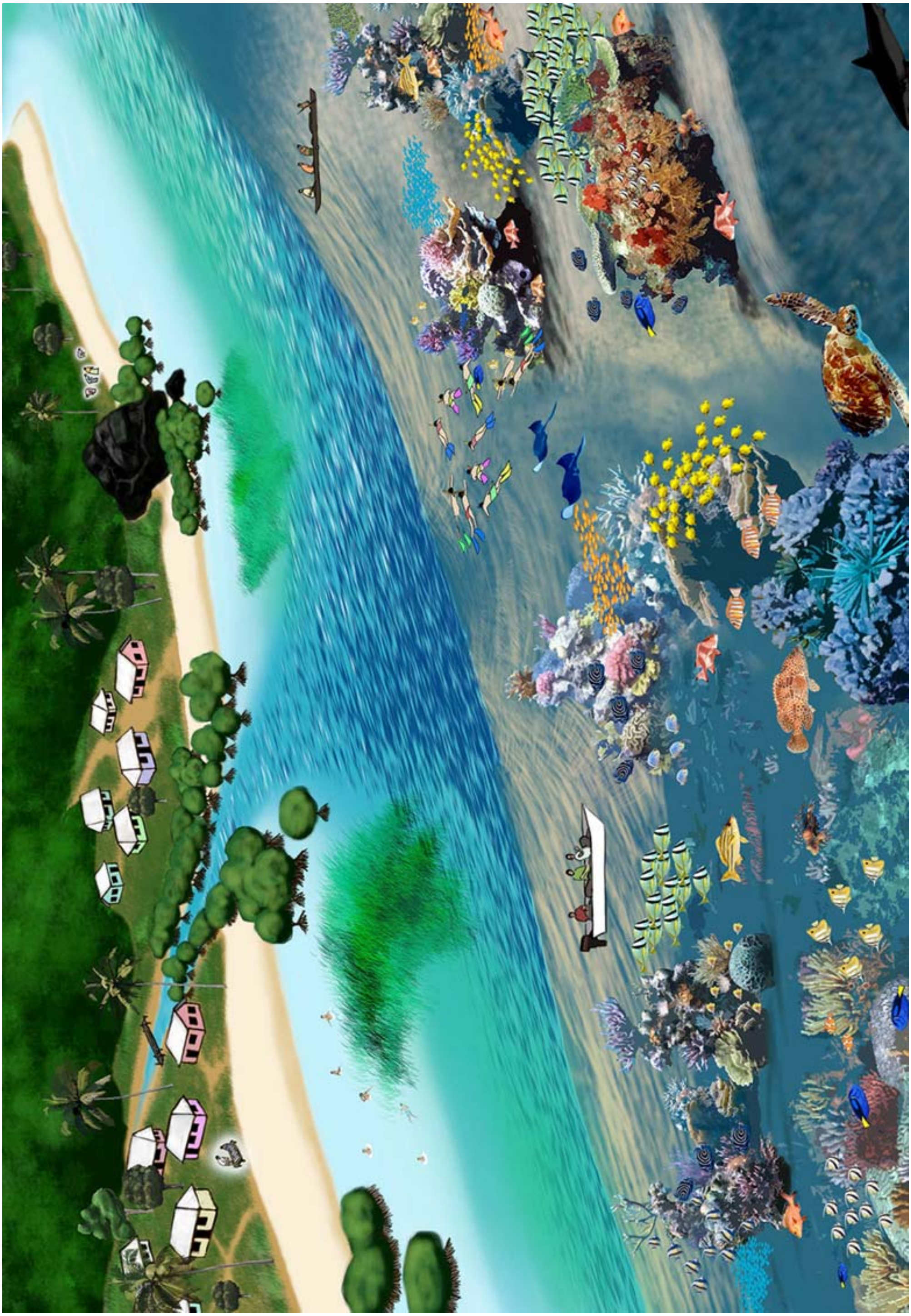

Figure 1. Healthy marine ecosystems provide abundant resources for people.

Figure 2. Unhealthy marine ecosystems, damaged by destructive activities such as blast fishing, are unable to provide as many resources for people.

Principle 2: Represent 20-40% of each habitat within marine reserves.

Since different species use different habitats (Figure 3), protection of all plants and animals and the maintenance of ecosystem health, integrity and resilience can only be achieved if adequate examples of each habitat are protected within marine reserves.[58, 40, 51, 28] Habitats (e.g. mangroves, coral reefs and seagrass) that are connected through regular movements of species should also be protected (Figure 4).[33, 70]

A key consideration is the amount of habitat to include. To ensure achievement of fisheries objectives, biodiversity conservation and ecosystem resilience in the face of climate change, marine reserves should encompass at least 20-40% of each habitat type, with the recommended percentage varying with several factors including fishing pressure and if there is additional effective protection (e.g. fisheries management) in place outside of reserves.

Since a population can only be maintained if it produces enough eggs and larvae to sustain itself, fisheries ecologists recommend that it is necessary to protect ~35% of unfished stock levels to ensure adequate replacement over a range of species.[11, 13, 25] Therefore, if fishing pressure is high and the only protection offered is marine reserves, then the proportion of each habitat in reserves should be ~35% (where habitat protection is used as a proxy for protecting fisheries stocks). A higher level of protection (40%) may also be required to provide insurance against impacts of severe disturbances to the environment.[6] Lesser levels (20%) can be applied in areas with low fishing pressure or in areas where effective protection is offered outside of marine reserves (e.g. effective fisheries management).[11,13] If aiming to protect species with lower reproductive output or delayed maturation (e.g. sharks or large groupers), more area will be required.[25]

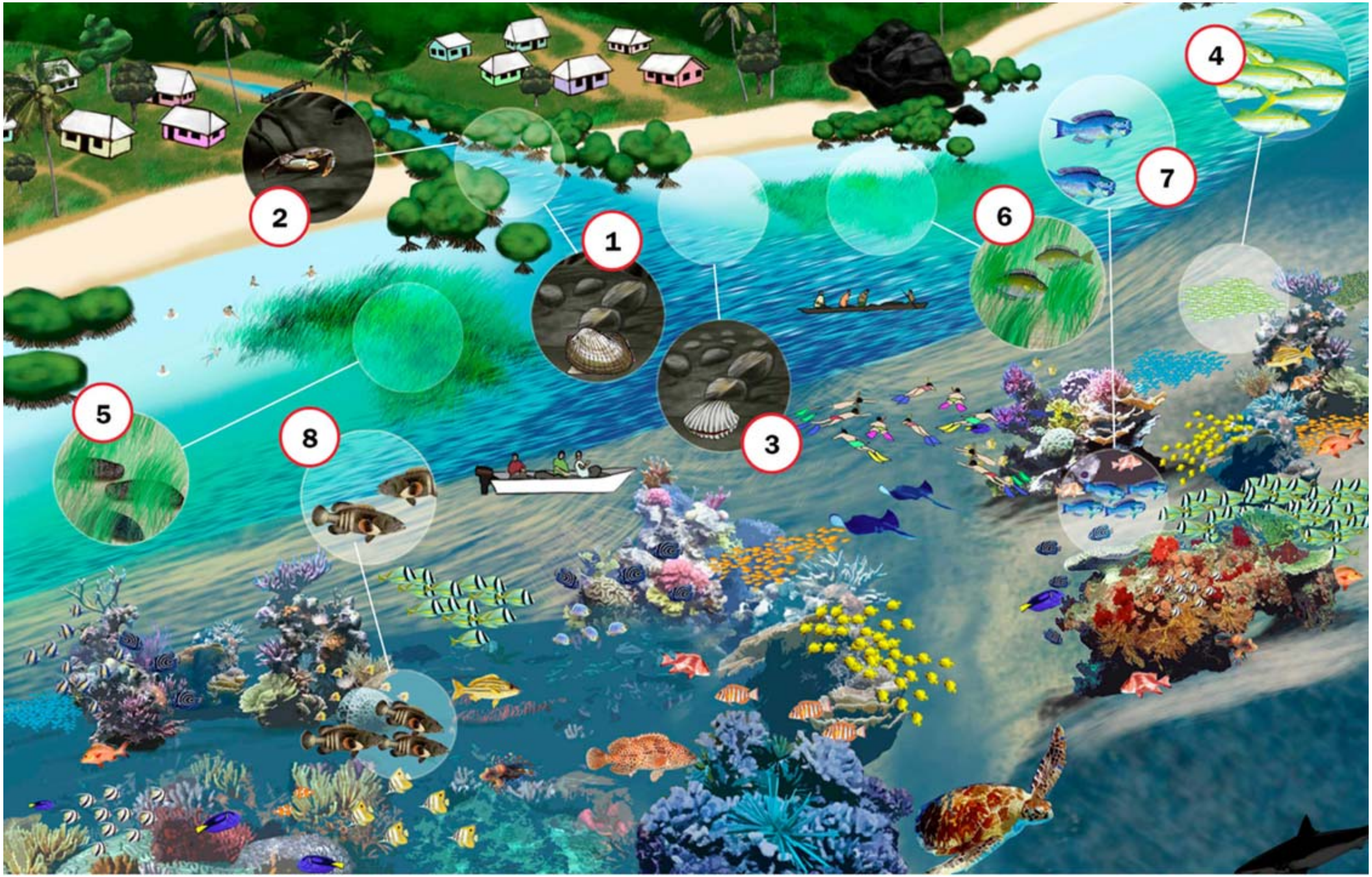

Figure 3. Different species use different habitats. For example, some bivalves, crabs and sea cucumbers use river mouths, estuaries, mangroves and seagrass beds (1, 2, 3 and 5), while some fish use sandy bottoms (4), seagrasses (6) and coral reefs (7 and 8).

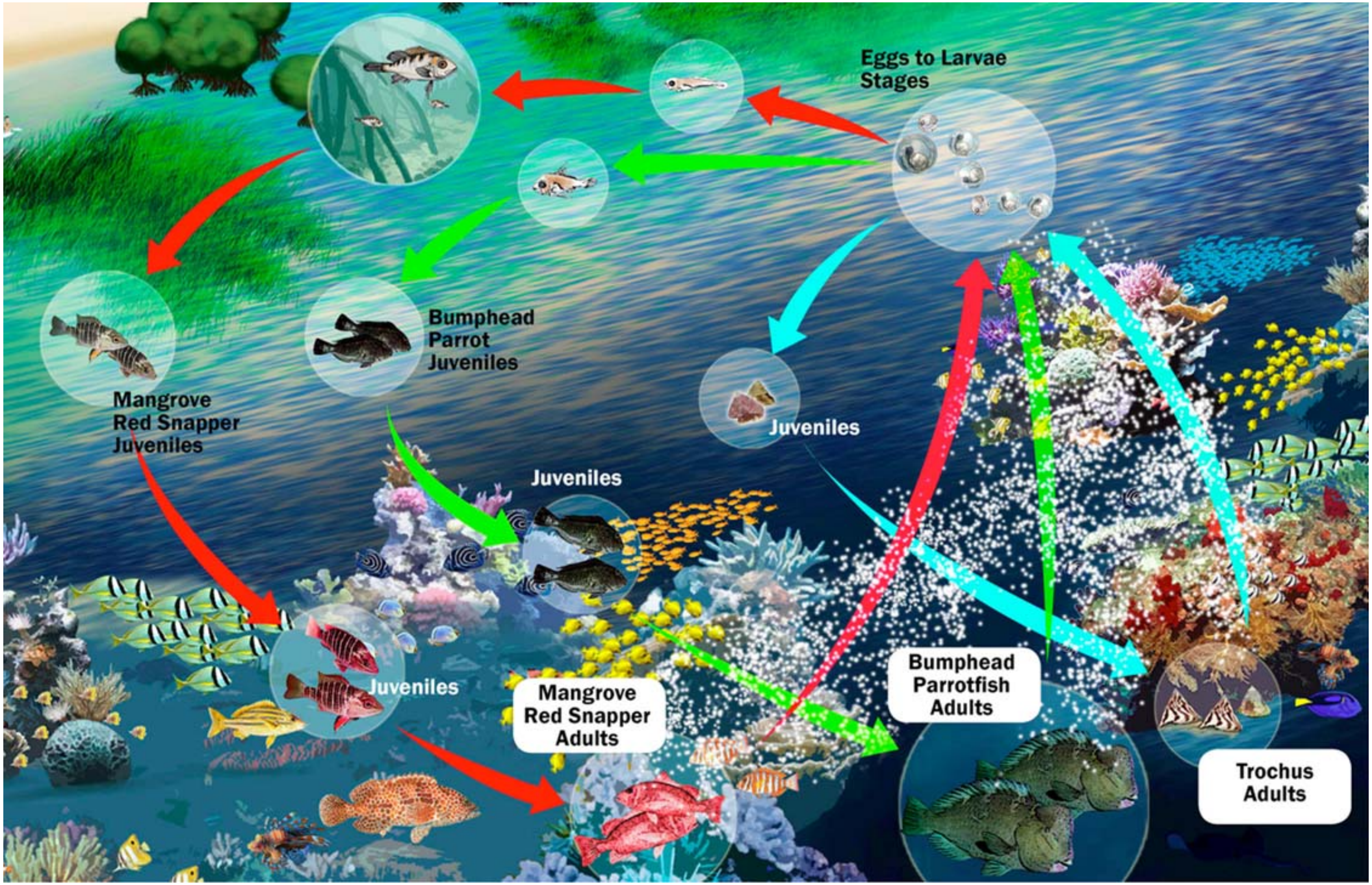

Figure 4. Some species use different habitats at different times in their lives.

Principle 3: Replicate protection of habitats within marine reserves.

Protection of habitats in at least three widely separated MPAs, ideally in marine reserves, minimizes the risk that all examples of a habitat will be adversely impacted by the same disturbance (Figure 5).[40,51] Thus if some protected habitats survive the disturbance, they can act as a source of larvae to facilitate recovery in other areas.

Replication also helps manage the uncertainty associated with biological heterogeneity within habitats. Since variations in communities and species within habitats are often poorly understood, habitat replication increases the likelihood that examples of each are represented within the network of protected areas.[51, 28]

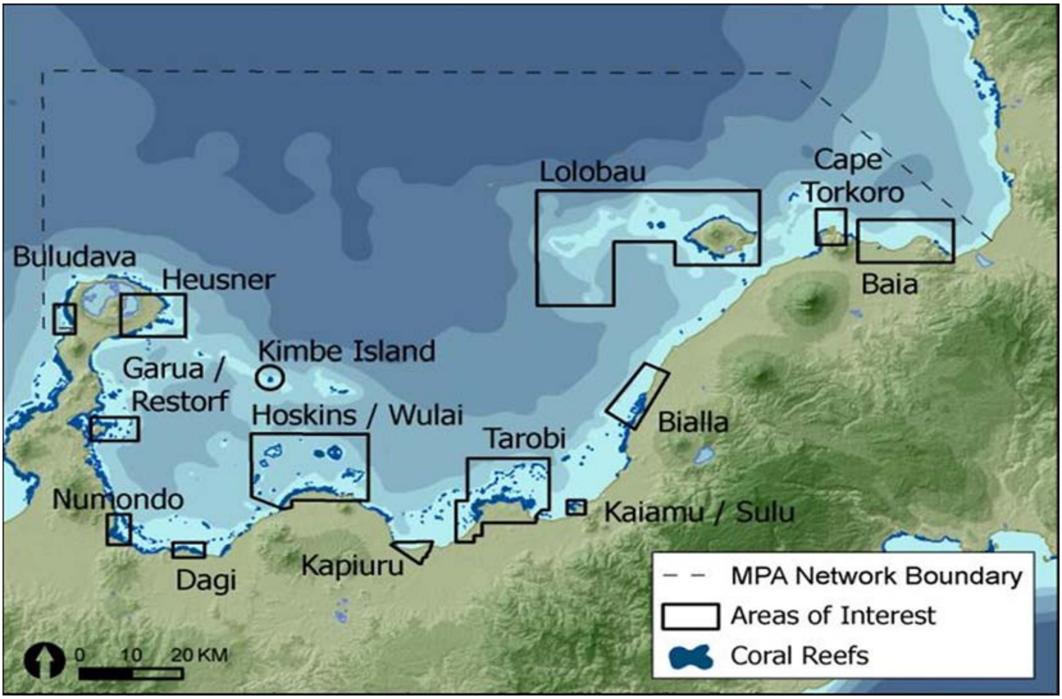

Figure 5. Spreading the risk: the design of a resilient MPA network in Kimbe Bay, Papua New Guinea shows where Areas of Interest were identified as potential MPAs. The design includes at least 3 widely separated examples of each habitat type in different Areas of Interest.[33]

Principle 4: Ensure marine reserves include critical habitats.

When animals aggregate they are particularly vulnerable and often, the reasons they aggregate are crucial to the maintenance of their populations.[68, 70] Therefore the main sites where they aggregate must be protected to help maintain and restore populations.[68, 41, 40, 70] Critical areas for protection include important aggregation sites (e.g. for spawning, feeding and breeding) and juvenile fish habitat.

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).[18, 68] Fish spawning aggregations (and the migration routes to and from them) are spatially- and temporally-predictable, which makes them particularly vulnerable to overfishing.[68] For these species, such gatherings are the only opportunities to reproduce, and they are crucial to the maintenance of the population. Unmanaged fishing of spawning aggregations can rapidly deplete fish populations with undesirable impacts on the livelihoods of those who depend on them.

Other species group together to feed or in nursery areas where juveniles use different habitats than adults (Figure 4). Therefore, it is important to protect the range of habitats that species use throughout their lives, particularly areas that they use during critical life history phases (nursery areas, fish spawning aggregations and migration corridors among them).[28, 61]

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▲ **Marine reserves should include critical areas, like fish spawning aggregation sites (top) and nursery areas (bottom).**

If the temporal and spatial location of these areas is known, they should be protected in permanent or seasonal marine reserves (see Principle 9).[79, 28, 61] If the scale of movement is too large to include in individual marine reserves, they can be protected within a network of marine reserves or using other management approaches (e.g. seasonal capture and sales restrictions during the spawning season).[68, 72, 28, 61]

Principle 5: Ensure MPAs are in place for the long-term (20-40 years), preferably permanently.

Long-term protection in marine reserves allows the entire range of species and habitats to recover, then maintain, ecosystem health and associated fishery benefits.[40] Some benefits can be realized in the short term (1-5 years), especially if fishing pressure has not been heavy.[66, 35] 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 (Figure 6). Permanent protection helps maintain these benefits for fishery productivity and biodiversity protection.[65, 26, 37, 44]

Shorter term protection may fail to achieve fisheries, biodiversity and ecosystem resilience objectives, because the benefits of improved ecosystem function and fisheries productivity can be quickly lost when marine reserves revert back to open access in heavily fished areas.[67,76,43] Thus, marine reserves should be in place for as long as possible, preferably permanently. Areas with other fisheries restrictions (e.g. limitations on gear, catch or access) will also be more effective if they are in place long term. Seasonal and shorter term closures (see Principle 9) would also deliver more sustained benefits from being implemented year-after-year.

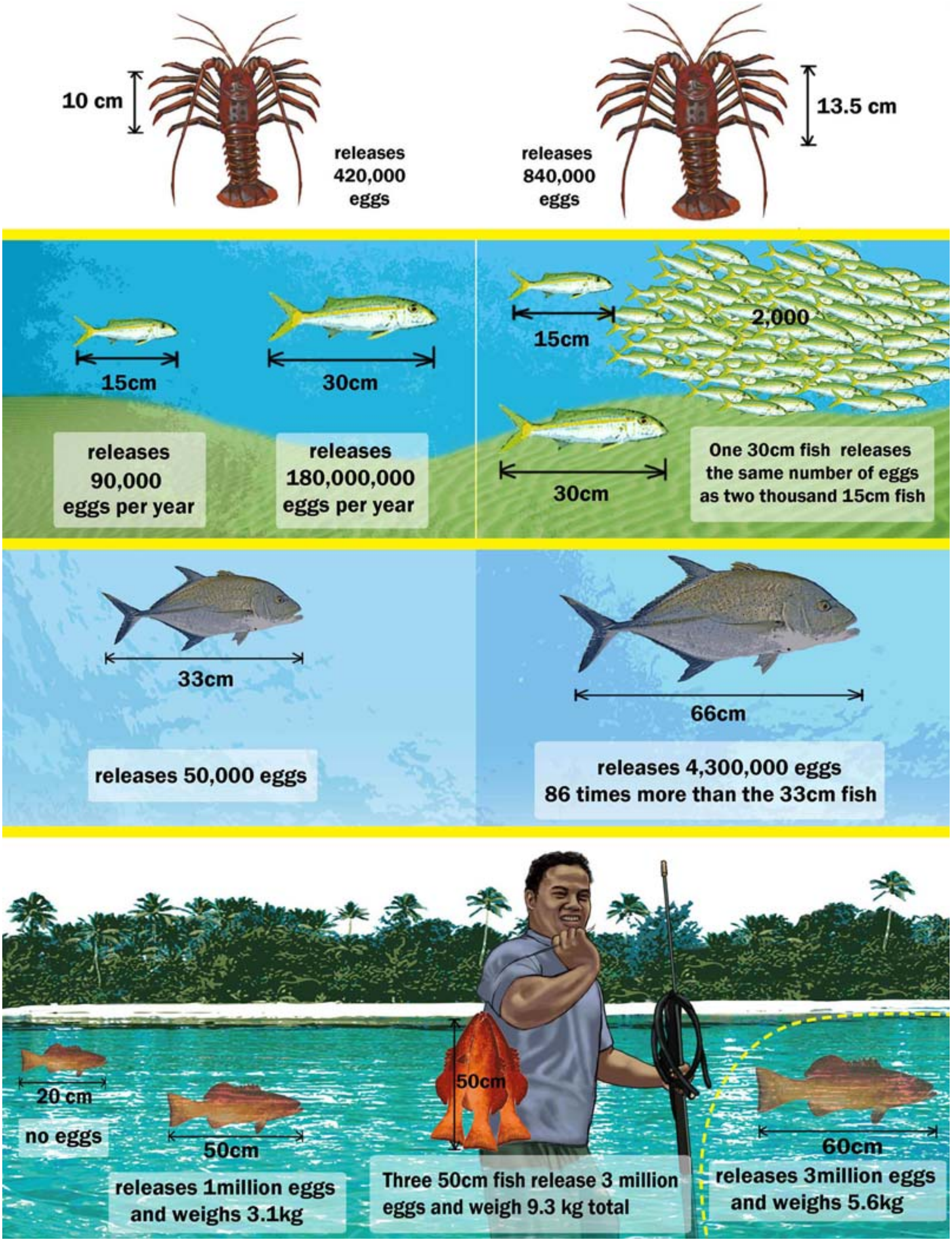

Figure 6. Larger individuals are more important for long-term health of populations than smaller ones, because they produce a lot more offspring.

Principle 6: Create a multiple use marine protected area that is as large as possible.

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 a multiple-use MPA that includes but is not limited to marine reserves.[16, 51, 70, 22]

Within a multiple use MPA, different zones 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 (Figure 7). 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.[48]

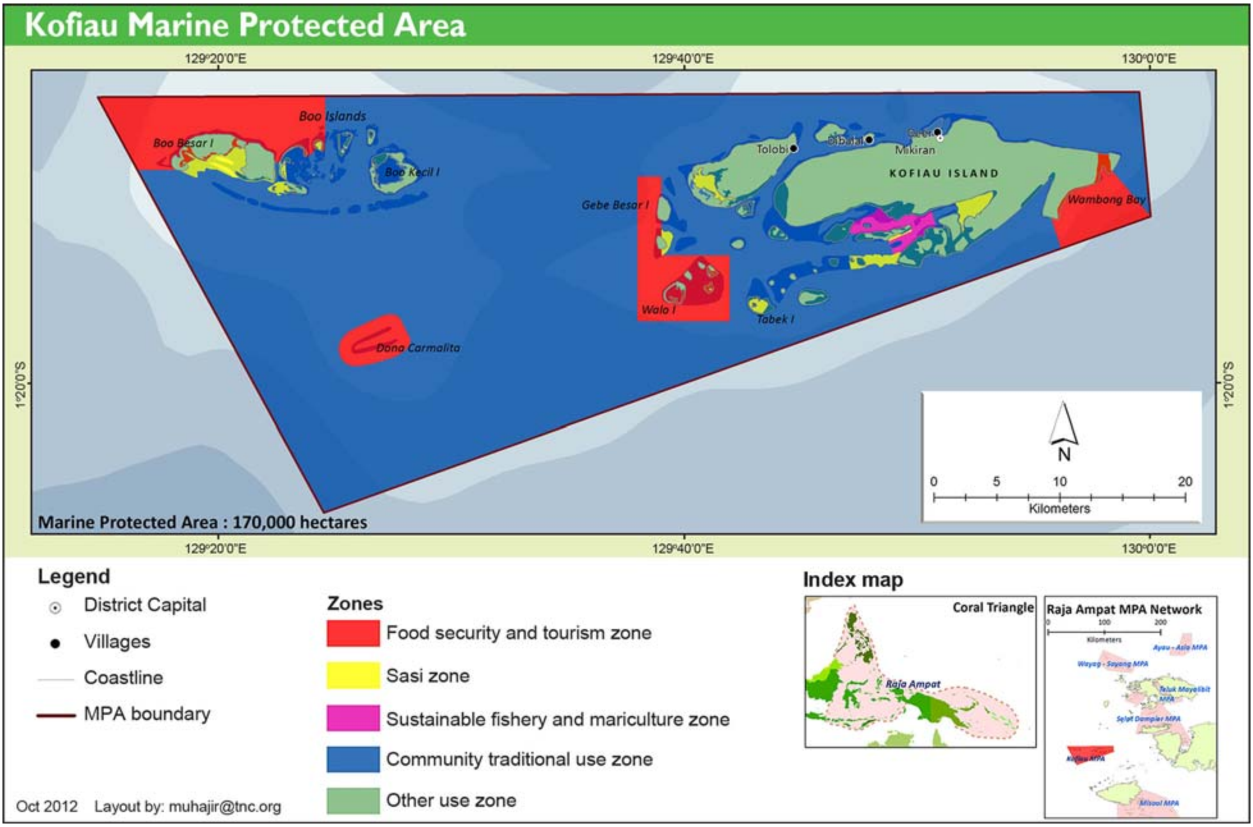

Figure 7. Kofiau Marine Protected Area Zoning Plan, Raja Ampat, Indonesia, is a large multiple use MPA that includes marine reserves (in red) and other zones with fisheries restrictions (yellow, pink and blue zones). Where Sasi is a traditional management practice e.g. using marine reserves to replenish stocks of important fisheries species (©Muhajir, TNC).

Principle 7: Apply minimum and variable sizes to MPAs

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.[58, 38, 28] 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 (Figure 6).[64]

Where movement patterns of target species are known (Figure 8), this information can be used to inform decisions about marine reserve size.[58, 41, 28] Some species (e.g. some parrotfishes, sharks, trevally, mackerel, snappers and emperors), need larger marine reserves because their home ranges (the area in which individuals spend the majority of their time) are larger.[58] While others (e.g. small grouper, most parrotfishes and surgeonfishes) need smaller marine reserves, because their home ranges are smaller (Figure 8).

From a conservation perspective, larger reserves (e.g. 10 to 20 km in diameter) are preferred, because they enhance population persistence by increasing the protection of larger populations of more species.[69, 40, 51, 28] While smaller reserves may be preferred for fisheries management (e.g. 40 ha or 0.4 km^2), since they allow for the export of more adults and larvae to fished areas, leading to increased levels of stock replenishment.[4, 41, 47, 35, 23]

Optimal size will also depend on the level of resource use and the efficacy of other management tools.[56] Where fishing pressure is high and there is no additional effective fisheries management for wide ranging species, then networks of both small (a minimum of 0.4 km^2) and large (e.g. 4 to 20 km across) marine reserves will be required to achieve biodiversity, climate change and fisheries objectives. If additional effective management is in place for wide ranging species, then networks of small marine reserves can achieve most objectives, particularly regarding fisheries management (provided they achieve 20-40% habitat protection; see Principle 2).

Other types of zones (e.g. with fishing gear or access restrictions), should be as large as possible up to the entire multiple use MPA (see Principle 6).

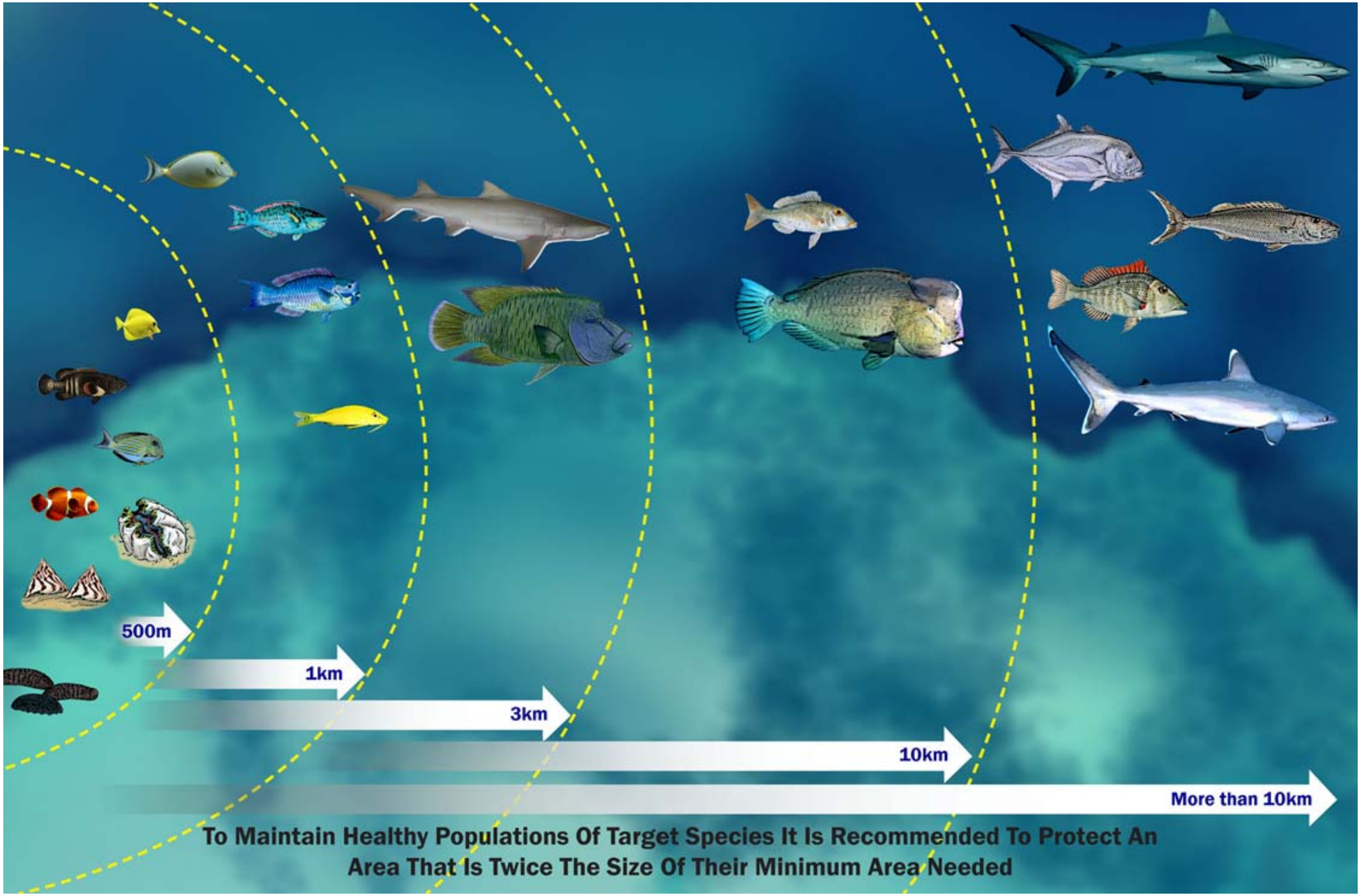

Figure 8. Different fish species have home ranges of different sizes (above), so they need different sized marine reserves.

Principle 8: Separate marine reserves by 1 to 20 km

Distance between MPAs, particularly marine reserves, is important because it influences the degree to which populations are connected through adult, juvenile and larval movement.[42] This connectivity among populations helps maintain fish stocks, diversity and build ecosystem resilience by ensuring that marine reserves are mutually replenishing to facilitate recovery after disturbance.[40, 51, 70] Since the larvae of most species tend to move longer distances than adults and juveniles, reserves should be spaced to allow connectivity through larval dispersal and to maximize recruitment subsidy to fished areas.[17, 4, 7, 41, 58, 28, 47, 53, 23]

Recent studies for a range of species (including key fisheries species), have shown that while some larvae move long distances (10s to 100s of km), many stay close to home (10s to 100s of m).[71, 42, 70] So varying the spacing of marine reserves from 1-20 km apart (with a mode of 1 to 10 km) will accommodate the larval dispersal patterns of most species.[34, 41, 70] Spacing at the higher end of the range also helps with risk spreading, and capturing spatial variation in species composition within habitats (see Principle 3, Figure 5).

Principle 9: Include an additional 15% of key habitats in shorter term marine reserves.

Shorter term spatial management tools, such as seasonal, rotational, periodically harvested or other temporally variable marine reserves, should be used in addition to the minimum level of long term marine reserves (see Principles 2 and 5). These can help address particular fisheries needs (e.g. where stocks need to be protected or restored).


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▲ **Traditionally managed tabu areas in Papua New Guinea are periodically fished after periods of closure. While harvests can be bountiful when the area is open to fishing, the benefits of the closure are quickly lost if harvests aren't carefully managed.**

These shorter term reserves 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; and by stockpiling resources that can be harvested to raise cash or harvest food for important community events.[24, 49] However, they are usually less useful for conserving biodiversity or building ecosystem resilience, where the aim is to build and maintain healthy, natural communities and sustain ecosystem services (see Principle 5).[43] These areas may also function as a partial insurance factor by enhancing overall ecosystem resilience against catastrophes such as cyclones, oil spills, etc.[6]

Principle 10: Locate MPA boundaries both within habitats and at habitat edges.

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 MPA (Figure 9). However, if some adult movement is required to fished areas outside the MPA, some boundaries should also be located within habitat types.[28] Therefore, to achieve all these objectives simultaneously, boundaries should be located both within habitats and at habitat edges (see Figure 10), depending on management priorities, local knowledge and the geography of a site.

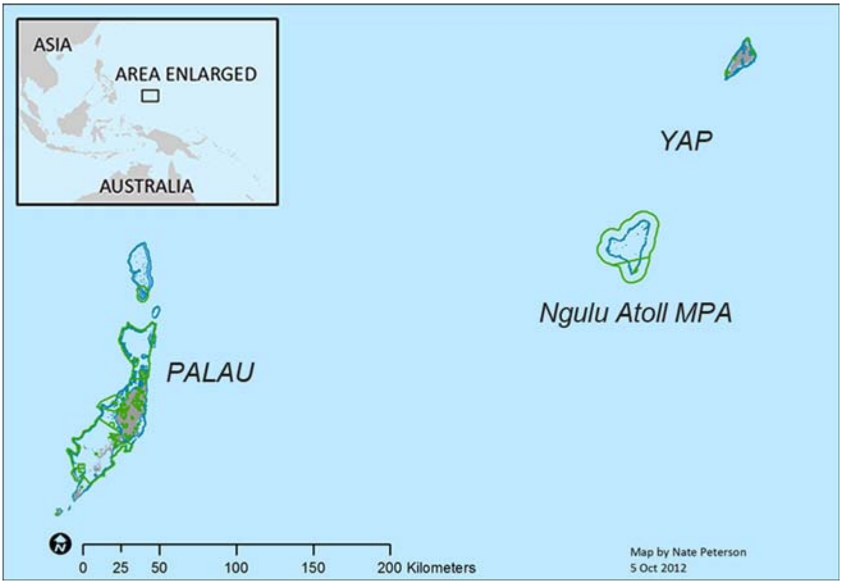

Figure 9. Ngulu Marine Protected Area in Yap includes the entire coral reef ecosystem (©Nate Peterson TNC).

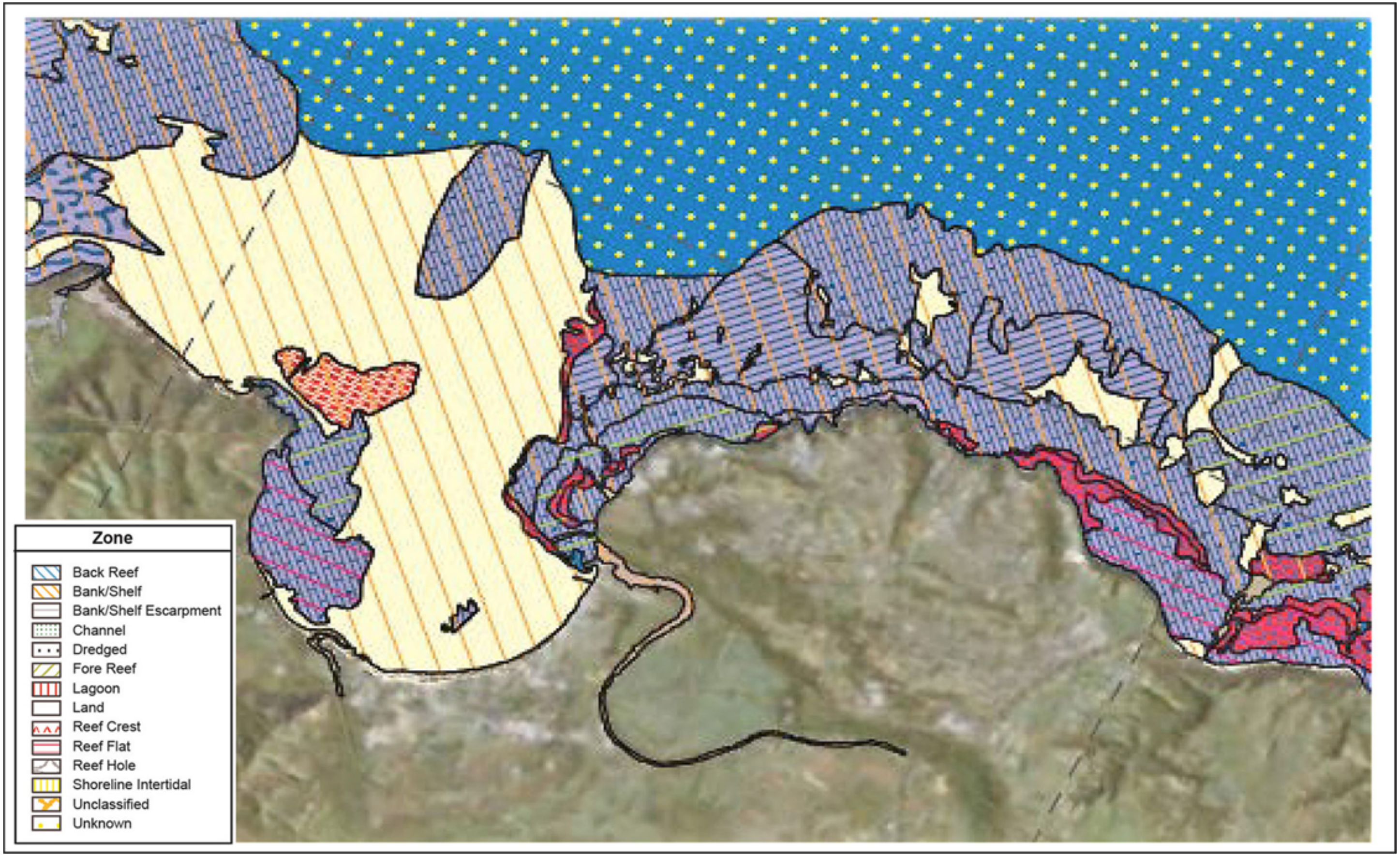

Figure 10. Benthic habitat maps, such as this one from Hawai'i, can be used to locate MPA boundaries both within habitats and at habitat edges. (Map © NOAA)

Principle 11: Have MPAs in more square or circular shapes.

These compact shapes limit adult spillover more than other shapes (e.g. long rectangles or triangles), which helps maintain the integrity of the protected areas and, therefore, the sustainability of their contribution to biodiversity protection, fisheries production and and ecosystem resilience.[40, 51] Other factors, such as the use of natural landmarks, should also be considered if they will facilitate compliance.

Principle 12: Minimize and avoid local threats.

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 human uses (Figure 2); and choose areas for protection that have been, and are likely to be, subjected to lower levels of damaging impacts (Figure 1). These areas are likely to be more resilient to climate change and contribute more, and more quickly, to ecosystem health and fisheries productivity.[50] Since it takes time for MPAs to improve ecosystem health, it is usually advantageous to include existing effective MPAs within a network.[65, 40, 33]

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▲ **Local threats, such as runoff from poor land use practices, causing pollution, should be minimized or avoided.**

Principle 13: Include resilient sites in marine reserves.

Resilient sites (refugia) for key habitats and species (Figure 11) should be included in MPAs, preferably marine reserves, because they are likely to be important for maintaining biodiversity in the face of climate change.[75, 40, 51] They include areas most likely to withstand climate change impacts such as: those known to have withstood environmental changes (or extremes) in the past; areas with historically variable sea surface temperature and ocean carbonate chemistry, which may be more likely to withstand changes in those parameters in future; and coastal habitats (e.g. mangroves, turtle nesting areas) which have adjacent, low-lying inland areas without infrastructure that they can expand into as sea levels rise.[75, 40, 51] Refugia may also provide fisheries benefits, since habitat loss is a major threat to tropical coastal fisheries in the face of climate change.[10]

Principle 14: Include special or unique sites in marine reserves.

Previous principles may lead to overlooking some sites that are special and/or unique, such as 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.[41, 40, 71] Inclusion of these sites within MPAs can help ensure all examples of the biodiversity and ecosystem processes are protected.[40] These sites may also play critical roles that contribute to ecosystem health and resilience.[41, 51, 40] Isolated areas may require special protection (e.g. Ngulu Atoll in Yap: Figure 9) since they are particularly vulnerable to disturbance because they may take longer to recover based on larval transport from other areas.

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Habitats that are important for rare, threatened and endemic species such as sea turtles or the Banggai Cardinalfish should be protected in marine reserves.

Figure 11. Some sites are more resilient and should be included in marine reserves including: mangroves that have space to move inland with rising sea levels (1); and ecosystems that have resisted or recovered from damage (e.g. coral bleaching) in the past (2) or have characteristics that indicate they are more likely to survive impacts in the future (e.g. heat-tolerant corals that may be more resistant to coral bleaching) (3).

▲ **Isolated areas, such as this atoll in the Marshall Islands, are particularly vulnerable to disturbance, and should be protected in marine reserves.**

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Principle 15: Locate more protection upstream.

MPAs, especially marine reserves, can become a source of larvae contributing disproportionately more to population recruitment.[28, 71, 36] To the degree that currents influence larval dispersal, MPAs will contribute disproportionately more to genetic connectivity and population recruitment of locations down-current.[40, 51, 71]

If connectivity patterns are unknown, and currents are known, strong, and consistent (Figure 12), then a greater number of the protected areas, especially marine reserves, should be located towards the upstream end of the management area.[40, 51, 71] If currents are not known or not consistent, then this principle does not apply. In all instances, marine reserves should be distributed subject to Principles 7 and 8 regarding size and spacing.

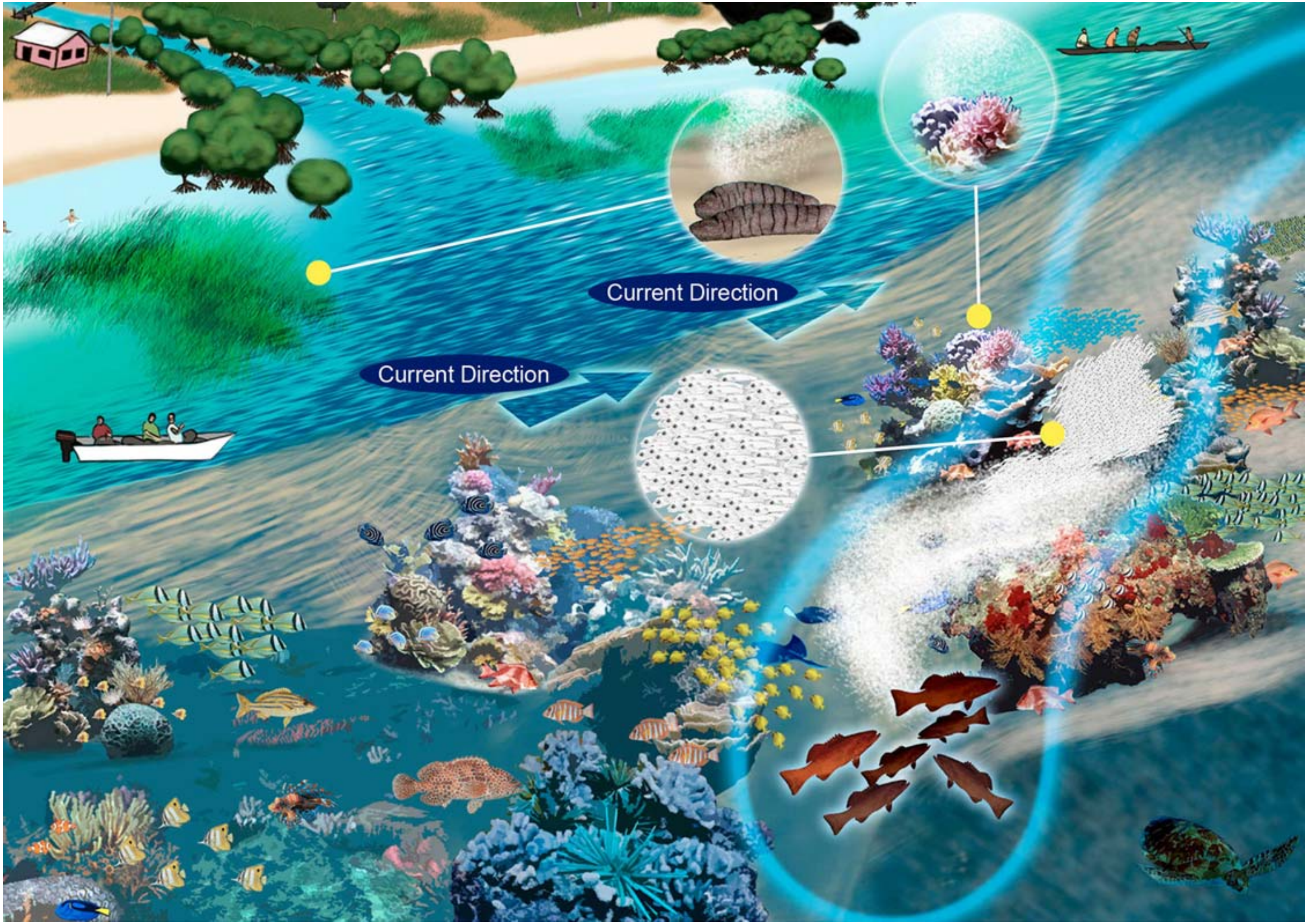

Figure 12. If currents are known, strong and consistent, more protection should be located upstream in a management area.

Summary

This document contains 15 principles to guide spatial planning for designing and establishing networks of marine protected areas. Full application of the principles presented will help achieve the multiple objectives of marine biodiversity conservation, fisheries management associated with tropical near shore habitats, and the incorporation of climate change considerations to build long term resilience of the management area. While this Guide does not integrate the important social, economic and political considerations for effective, long term and sustainable MPA networks, for the first time multiple objectives are accommodated and shown to be mostly complementary to each other for basic marine resource management strategies. It is recommended that to the extent a planning and implementation context supports the application of these principles, that they be prioritized in the order they are presented. Adaptive management planning will be essential to move towards the full application of the 15 principles.

GLOSSARY

Connectivity is the demographic linking of local populations through dispersal of pelagic larvae and movement of juveniles or adults.[42] There are different types of connectivity including: connectivity among populations in the same habitat in different locations; connectivity among marine habitats (e.g. where species use different habitats at different stages in their life history); and connectivity between the land and the sea.

An **ecosystem approach to fisheries** strives to balance diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions, and applying an integrated approach to fisheries within ecologically meaningful boundaries.[21, 22]

Ecosystem-based management is a management approach that recognizes ecosystems and their rich mix of elements, including humans, which interact with each other in important ways. Management options are applied to each resource sector in a holistic and integrated manner that accounts for all aspects of the ecosystem.

The home range is the area in which an individual fish spends most of its time, and engages in most of its routine activities, such as foraging and resting.[46]

Marine protected areas are defined as any clearly-delineated, managed marine area that contributes to protection of natural resources in some manner.[19] Marine reserves are one type of marine protected area where extraction of resources is not permitted. [40]

Marine protected area networks in this Guide refers to a group of individual marine protected areas that are ecologically connected.[40] For contexts other than biophysical, MPA networks can include social and governance networks of MPAs.

Resilience is defined as the ability of an ecosystem to maintain key functions and processes in the face of (human or natural) stresses or pressures, either by resisting or adapting to change.[57, 74]

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Understanding and incorporating biological and physical processes in spatial planning provides the foundation for marine conservation and fisheries management. This short, succinct guide provides 15 principles for designing marine protected area networks that are based on the best available biophysical information regarding tropical marine ecosystems. The Guide is intended to be useful for busy decision-makers, who may not have access to the increasing amount of research literature regarding this issue. These principles should be used in combination with important social, economic and political considerations in marine spatial planning.

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