Biophysical principles for designing resilient networks of marine protected areas to integrate fisheries, biodiversity and climate change objectives in the Coral Triangle

A Project of the Coral Triangle Support Partnership

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Cover photo: Fishermen in Manus, Papua New Guinea. © J. Tanzer.

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ACRONYMS

CBD	Convention of Biological Diversity
CC	Climate change
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CT	Coral Triangle
CT6	Six countries of the Coral Triangle
CTI	Coral Triangle Initiative
CTI-CFF	Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security
CTMPAS	Coral Triangle Marine Protected Areas System
CTSP	Coral Triangle Support Partnership
EAFM	Ecosystem approach to fisheries management
EAFM REX	Ecosystem approach to fisheries management regional exchange
EBM	Ecosystem based approach to management
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization
FLEP	Fraction of lifetime egg production
IUCN-WCPA	International Union for Conservation of Nature World Commission on Protected Areas
IUU	Illegal, unreported or unregulated
LEP	Lifetime egg production
LMMA	Locally managed marine area
MMA	Marine managed area
MPA	Marine protected area
NOAA	National Oceanic and Atmospheric Administration
NPoA	National Plan of Action
PEMSEA	Partnerships in the Environmental Management for the Seas of East Asia
PNG	Papua New Guinea
PoA	Plan of Action
RPoA	Regional Plan of Action
SST	Sea surface temperature
TNC	The Nature Conservancy
TWG	Technical Working Group
USCTI	United States Coral Triangle Initiative
USAID	United States Agency for International Development
WCPA	World Commission on Protected Areas
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

Introduction

The Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) and its six member countries (CT6) have committed to establishing a Coral Triangle Marine Protected Area System, applying an ecosystem approach to fisheries management, and applying climate change adaptation measures. Developing a robust and practical set of principles to underpin establishment of marine protected area networks that contribute meaningfully to food security, biodiversity conservation and climate change resilience is an important part of contributing to that challenge.

Fisheries are one of the most important ecosystem services benefiting the communities of the Coral Triangle (CT). Overfishing and loss of key habitats is severely undermining the long term sustainability and food security of the region. This trend, if allowed to continue unabated, will result in escalating hardship and economic instability. It will also impact the globally significant marine biodiversity of the region and reduce resilience to climate change and other external impacts. Developing improved methods for applying marine protected areas to contribute to food security and livelihoods is a key challenge for all concerned with managing the fisheries and biodiversity of the CT.

The USAID funded Coral Triangle Support Partnership (CTSP) is a five-year project to provide technical support to the CT6 in achieving their goals. The CTSP is the part of USAID's support to the CTI, along with the US National Oceanic and Atmospheric Administration (NOAA), the US Department of State, and additional contract support through a Program Integrator. One of the primary objectives of the Regional CTI Plan of Action (RPoA) is the establishment of a regional Coral Triangle Marine Protected Area System (CTMPAS) that protects "each major near-shore habitat type within the Coral Triangle Region (e.g. coral reefs, seagrass beds, mangroves, beaches, coastal forests, wetland areas and marine/offshore habitat)". This objective is mirrored in each CT country's National Plan of Action (NPoA). In line with the RPoA and NPoA, CTSP's support for the CTMPAS focuses upon the nearshore habitats of the CT.

Biophysical principles are presented in this report to help nearshore marine protected area networks achieve fisheries sustainability, biodiversity conservation and ecosystem resilience in the face of climate change. These principles can be considered rules-of-thumb to help guide decision making. In the past, such principles and associated rules-of-thumb have focused on only one or two of these objectives – not all three simultaneously.

Effective management of marine resources that achieves resilience and sustainable production requires careful application of a wide range of tools and methods, which includes marine protected areas. Management interventions are likely to be most effective if they are applied as part of an ecosystem-based approach. Marine protected areas, in their various forms can, if well designed and effectively implemented, play a significant role in achieving sustainable use at multiple scales.

The principles developed in this report are designed to contribute to a larger process that includes implementing networks of marine protected areas in ways that complement human uses and values and align with local legal, political and institutional requirements. All of these factors play into an overarching requirement: to achieve fisheries or any other benefits, management actions must be complied with. It is beyond the scope of this report to set out essential political, governance and socio-economic principles to guide marine protected area network design processes; its purpose is to identify biophysical principles. Realistic implementation of any marine protected area network would require that these biophysical principles be coupled with well-developed guidelines dealing with the local human contextual factors.

Marine protected areas, in this report, are defined as any clearly-delineated, managed marine area that contributes to protection of natural resources in some manner. They include, but are not limited to: no-take areas; community-based protected areas; area-based restrictions upon gear, species, size, and take of a particular sex of species or access.

Networks of marine protected areas, for the purposes of this report, refer to a collection of individual marine protected areas that are ecologically connected. For the same amount of spatial coverage, networks of marine protected areas can potentially deliver most of the benefits of individual marine protected areas but with, potentially, less cost due to greater flexibility and diversity in size, shape, distribution and location options. Because of their flexibility in design and application, marine protected area networks are particularly suited to addressing multiple objectives within various contexts.

Theoretically, multiple local or sub-national networks within adjacent ecosystems, ecoregions or seascapes can be scaled up into regional networks by ensuring adjacent networks are ecologically connected as per the principles herein. Such scaling-up has already been planned for parts of the CT (e.g. Sulu-Sulawesi Marine Ecoregion, Lesser Sunda Marine Ecoregion, Bird's Head Seascape and others). An early objective for each country is to contribute at least one well-designed and effectively managed marine protected area network that contributes to an overall CT marine protected area system. These principles will help with these and future scaling up efforts.

In developing biophysical principles to guide the design of networks of marine protected areas, many information gaps were found regarding, for example, the ideal design, the CT ecosystems, and how the socio-political, economic and natural environments currently operate and will change. These uncertainties are not unique to the CT but apply globally. Thus, the principles are designed to embrace this uncertainty including the spreading of risk. Their implementation requires refinement through use of local knowledge (for example target species life histories and habitat use), community uses and values. It also requires an adaptive management system, which managers can use to improve protection as more information becomes available.

Biophysical Principles for Designing Resilient Networks of Marine Protected Areas to Integrate Fisheries, Biodiversity and Climate Change Objectives in the Coral Triangle

Biophysical principles for designing resilient networks of marine protected areas to integrate fisheries, biodiversity and climate change objectives in the CT are provided in the table below. The main rationale for each principle is also provided. These principles each contribute to five broad categories that relate to resilient marine protected area network design: 1) risk spreading; 2) protecting critical areas; 3) incorporating connectivity; 4) threat reduction; and 5) sustainable use.

Many of the principles traditionally proposed as necessary to provide adequate protection of biodiversity are also applicable to the design of marine protected areas to enhance resilience in the face of climate change and to support sustainable fisheries. This is because, although a good deal of previous work on design principles focused on fisheries species, the results apply to unfished species as well. The main differences between principles for the different goals of sustainable fisheries, biodiversity conservation and climate change resilience are that:

- For fisheries goals, individual marine protected areas should be smaller to allow for spillover, to maintain access to more areas yet protect examples of all habitats, to enable flexibility to fishers needs;
- For fisheries goals, marine protected area shapes should allow for more spillover of, especially, adult fished species, but also larval and juvenile fished species;
- For biodiversity goals, some special, unique, isolated etc. sites that contain species and ecosystem functions not commonly found elsewhere are more important to include;
- For biodiversity and climate change goals, no-take areas are more important, as the more holistic conservation benefits far outweigh those of other types of protection;
- For biodiversity and climate change goals, longer-term protection is more important because this will allow the full range of species and ecosystem functions to be restored and maintained in an ongoing manner;
- For climate change goals, climate change "resistant" sites should be prioritized;
- For climate change goals, emphasis should be placed on building connectivity among source *refugia* and susceptible sink reefs to enhance recovery; and
- For climate change goals, emphasis should be placed on including at least three widely separated replicates of all major habitat types into networks to spread risk.

Currently, nowhere in the CT has enough information (or resources to obtain the information) to enable comprehensive implementation of all the principles presented in the table below. Everywhere in the CT there will be enough information to implement some of the principles. The more sparse the information, the more important is the application of the principles regarding prohibition of destructive activities, minimum amount of protection (representing each habitat where known) and replication (refer to principles 1 through 3 below). Even where information is sparse, 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 including large scale catastrophes. In addition, recommendations about minimum size requirements, spacing of marine protected areas and critical habitats, where known, are also often implementable with lower levels of information (principles 4, 7 and 8 below).

Besides limits in knowledge, there are often socio-economic, cultural, political and other reasons that prevent full application of all the principles. When required to compromise, the authors' experience suggests, in the absence of local knowledge to guide decisions, prioritize the principles in the order in the table.

Threat reduction	**Principle 1. Prohibit destructive activities throughout the managed area.** Prohibit as many destructive activities as possible, for example, blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, night spearing (refer also to Principle no. 6 below). **Rationale**. Coastal habitats and their values are vulnerable to destructive activities which can decrease the health and productivity of the ecosystem and consequently, all species (including targeted fish species) living within it. Destructive activities also decrease ecosystem resilience to other impacts.
Connectivity	**Principle 2. Represent 30 percent (or at least 20 percent) of each habitat within no-take areas.** Represent the range of types of coral reefs, seagrass, mudflats, algal beds, soft seabed communities, rocky shores, coastal forests, beaches, mangroves, other wetlands and other habitats in no-take areas. If the only protection offered is no-take areas, then the proportion of no-take areas needs to be higher (40 percent); if additional effective protection is offered (e.g. input/ output controls[1], other spatial controls) then apply 30 percent (or at least 20 percent) no-take areas[2]. **Rationale.** Protection of all fish habitats, all plants and animals and of entire ecosystem health, integrity and resilience can be achieved only if adequate examples of every habitat are included in no-take areas. To ensure achievement of fisheries objectives in areas where fishing has been intense, and of biodiversity conservation and ecosystem resilience where any local stressors have (or have had) impacts, no-take areas should encompass at least 30 percent of the management area. Lesser levels (but not less than 10 percent) can apply in areas with historically low fishing pressure. If aiming to protect species with lower reproductive output or delayed maturation (e.g. sharks or some groupers) more area will be required.

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[1] For example, adequate and effective restrictions on type and quantity of gear, effort, and capacity; limits on catch or landings; limits on sizes; limiting catch of a given sex, or animals in a particular stage of the breeding cycle; regulating discards; daily bag or possession limits.

[2] While this percentage of no-take area coverage is a goal to strive for, the reality in the CT countries is that dense populations of resource users make it difficult to achieve. Thus, opportunistic placement of no-take areas is often the default approach which provides varying percentages of area within no-take areas. While not ideal, working within and around the local context for interventions that are feasible and acceptable is often the bottom-line.

Risk spreading	**Principle 3. Replicate protection of habitats.** Include at least three widely-separated replicates of every habitat within a protected area network, ideally, in no-take areas. (See also Principle 8 on spacing) **Rationale**. Replication of protection minimizes risk that all examples of a habitat will be adversely impacted by the same disturbance. If some protected habitat areas survive an impact, then they can act as a source of larvae for recovery of other areas. Replication also helps enhance representation of biological heterogeneity within habitats that are less understood.
Critical areas	**Principle 4. Ensure that no-take areas include critical habitats.** Include important aggregation sites (e.g. spawning, feeding, breeding grounds), juvenile fish habitat areas, and larval sources. **Rationale.** When animals aggregate they are particularly vulnerable and, often, the reasons they aggregate are crucial to the maintenance of the population. Therefore the main sites where animals aggregate must be protected to help maintain and restore natural balances of populations in communities.
Sustainable use	**Principle 5. No-take areas, prohibitions on destructive fishing gear, other fishing gear and access limits should be in place for the long-term, preferably permanently.** **Rationale.** Long-term protection allows the entire range of species and habitats to recover and maintain natural ecosystem health and associated fishery benefits. Some benefits can be realized in the shorter term (1 to 5 years), especially if fishing pressure has not been heavy. However, 20 to 40 years protection allows heavily fished species and longer-lived targeted predator species (e.g. shark, other coral reef predators) the opportunity to grow to maturity and thereby increase in biomass and then contribute more, and more robust, eggs to stock recruitment and regeneration. This time period also allows for maintaining these ecosystem and fishery productivity benefits. In heavily fished situations, shorter term protection may fail to achieve fisheries, biodiversity and ecosystem resilience objectives. Necessary duration of protection may also be influenced by the life history characteristics of the species of interest. If no-take status reverts to open access in heavily fished areas, the benefits of improved ecosystem function and increased biomass of fishery species can be quickly lost. Thus, no-take areas should be maintained as long as possible. Seasonal closures have an inherent (i.e. seasonal) temporal timeframe, and other temporal closures will be applied for reasons that will have their own temporal requirements.

Connectivity	**Principle 6. Create a multiple use marine protected area that is as large as possible.**[3] Include as much as possible of the coastal ecosystem within a legal or otherwise formalized, multiple-use management boundary. **Rationale**. To apply an ecosystem approach to fisheries management, to maximise the range of biodiversity and habitats protected, to mitigate against any risks, including climate change impacts, the best advice is to include all of the ecosystem within a multiple-use marine protected area. The different levels and types of protection offered within a multiple-use area can offer synergistic benefits, as seen within ecosystem based fisheries management.
Connectivity	**Principle 7. Apply minimum and a variety of sizes to protected areas within the network.** **7.a. For no-take areas**: If no additional effective protection is in place (e.g. no fisheries input/output controls for wide ranging species: refer to Principle 2), a mixture of small (a minimum of 0.4 km^2 or 40 ha) and large (e.g. 4 to 20 km across) no-take areas is required to achieve biodiversity, climate change and fisheries objectives. If there is additional protection for wider ranging species, then networks of small no-take areas can achieve most objectives, particularly regarding fisheries management (subject to implementing Principle 2). Ideal sizes to use will depend on movement patterns of the species of key importance in any situation. **7.b. For temporal closures** of any kind: should be, at minimum, the entire area of site plus a 100 m buffer (or 40 ha minimum if these details are unknown). **Rationale for 7(a) and 7(b):** To help build resilience into fisheries as well as ecosystem health, and to contribute meaningfully to biodiversity protection, the minimum recommended size for all goals is larger (e.g. 10 to 20 km across) than for fisheries alone (e.g. 0.1-0.2 km^2 or 10 to 20 ha). For resilience and biodiversity conservation, larger areas should be protected. Some consider ~4 to 6 km or more to be the minimum diameter to be viable in terms of containing larval dispersal distances of most species (as well as adult movement); but others have found smaller effective dispersal distances. Of course, using networks of protected areas is one way to increase connectivity between sites without matching the size of each site with adult and larval movement patterns. The recommended minimum size here assumes: a network of no-take areas; and the application of principle 2 across those no-take areas. Where larval dispersal patterns and/or adult movement patterns of particular target species are known, this information can inform decisions about ideal sizes of protected areas. Mackerel and other near-shore pelagic species, for example, will need much larger marine protected areas, as their ocean neighborhoods are larger. **7.c. For zones with gear restrictions**: as large an area as possible, up to the entire marine managed area and all areas where gear interferes with threatened species. **7.d. For zones with access restrictions**: as appropriate throughout the marine managed area. **Rationale for 7(c) and 7(d).** Gear and access restrictions can be used, in addition to no-take areas (long-term and temporal), to minimize impacts upon habitats and species.

[3] This may also be known as a marine managed area or a multiple use marine park.

Connectivity

Principle 8. Separate no-take areas by 1 to 20 km apart (with a mode of ~1 to 10 km). Apply a variety of spacing of individual no-take areas throughout the entire management area. Inshore no-take areas should be located closer together (≥1 km apart) than offshore no-take areas (~20 km apart).

Principle 8. cont. Spacing of other long-term protected areas either not applicable OR same as for no-take areas.
Other types of protected areas (e.g. spatial gear or access restrictions) might be quite large in extent throughout the management area (see Principle 7), so it might not be logical to have specified "distances" between them.

Risk spreading

However, if other permanent protected areas are isolated "islands" of protection, then the same spacing rules should apply as to no-take areas.

Rationale. Connectivity between protected areas is important for maintaining diversity, fish stocks, and especially important for maintaining ecosystem resilience. Adult movement is generally at a smaller scale than larval movement. Recent studies are showing huge variability in larval dispersal distances and lower dispersal distances than previously thought (e.g. 100 m to 1 km to 30 km). Mackerel and other nearshore pelagic species may need marine protected areas spaced further apart as their ocean neighborhoods are larger.

Because the CT is the center of marine biodiversity and has multi-species coastal fisheries, there are likely, commensurate diversity in adult movement ranges and larval dispersal distances in species of interest. For these reasons, varying the spacing of no-take areas between 1 to 20 km apart is useful.

Spacing at the higher end of the range (20 km apart) helps with risk spreading and capturing the range of biodiversity. If spacing is less than 20 km, these benefits may still occur. See also principle 3, replication.

Where local knowledge exists on connectivity of locally important species, it should be used to inform this principle on spacing.

Sustainable use

Principle 9. Include an additional 15 percent in shorter-term no-take protection within the network. For example, seasonal, rotational or other temporally variable zones.

Rationale. Shorter term spatial management tools should be applied in addition to the minimum level of no-take protected areas; these can help address particular fisheries needs where targeted stocks need to be restored or recovered. Rotational closures, seasonal closures and most other temporal closures can be beneficial for fisheries (e.g. protecting critical areas at critical times if not included in long-term no-take areas; allowing limited fisheries access at culturally important times). However, they are usually less useful for conserving biodiversity or building resilience where part of the aim is to build and maintain healthy, natural communities and sustain ecosystem services.

These areas may also function as a partial insurance factor[4] by enhancing overall ecosystem resilience against catastrophes such as cyclones, oil spills.

[4] Partial because the best available science refers to no-take areas.

Sustainable use	**Principle 10. Have a mixture of protected area boundaries: both within habitats and at habitat edges.** The relative mix of boundary locations will depend upon management priorities, local knowledge and the geography and resources of a site. **Rationale**. To build resilience to external impacts, it is best to retain the integrity of any protected area as much as possible by locating boundaries at habitat edges to limit adult spillover. However, to encourage fisheries benefits, some boundaries should be located in the middle of fish habitats.
Sustainable use	**Principle 11. Have protected areas in more square or circular shapes.** Use square or circular shapes subject to considerations of compliance (including use of landmarks). **Rationale.** These shapes allow for limited adult spillover which helps maintain the integrity of the protected areas and, therefore, the sustainability of their contribution to fisheries, biodiversity and ecosystem resilience.
Threat reduction	**Principle 12. Minimize external threats.** All else being equal, choose areas for protection that have been, and are likely to continue to be, subject to lower levels of damaging impacts (e.g. areas with higher water quality; no mining; no shipping activity; areas where fishing is likely to be regulated and managed and existing, functional protected areas). **Rationale.** To optimize protection of areas that are less likely to be exposed to local threats and most likely to recover, it is wise to avoid areas that have been or are likely to be damaged from threats including damaging human uses. From a resilience point of view, these areas are also more likely to be in better condition. Therefore they will be more resilient to external threats such as climate change and contribute more and more quickly to overall ecosystem health and fisheries productivity. It takes time for marine protected areas to improve ecosystem health. It is usually advantageous to include existing functional marine protected areas within a new network.
Critical areas	**Principle 13. Include resilient sites in the network.** Protected areas should include areas that are most likely to survive climate change impacts as indicated by either previous survival or conditions that make them more likely to resist, recover or migrate from impacts. **Rationale.** Areas with historically variable sea surface temperature and ocean carbonate chemistry (e.g. aragonite saturation levels) levels appear likely to withstand changes in those parameters similar to areas known to have withstood such environmental changes in the past. Networks should also include coastal habitats (e.g. mangroves which have adjacent, low-lying inland areas that they can expand into as sea level rises).
	Principle 14. Include special or unique sites in the network. Protected areas should include sites that are important for: rare or threatened species (e.g. turtle nesting sites); rare or threatened habitats; being highly biodiverse and especially those at risk; endemic species or habitats and also isolated sites. **Rationale.** Inclusion of these sites within no-take or other protected areas can help ensure all

	examples of the biodiversity and processes of the ecosystem are protected. Being comprehensive in this way increases the chance that all the crucial parts of the system are also able to contribute to ecosystem health and resilience.
Connectivity	**Principle 15. Locate more protection upstream of currents**. If currents are known and consistent, then a greater number of the protected areas, especially no-take areas, should be located towards the upstream end of the management area. If currents are not known, or not constant, then this principle does not apply and protection should be distributed evenly throughout the management boundaries (subject to the principles 7 and 8 on size and spacing). **Rationale.** Protected areas, especially no-take areas, could become a source of larvae contributing disproportionately more to population recruitment. To the degree that currents influence larval dispersal, they will influence genetic connectivity and population recruitment more in locations downstream of protected areas. In this way, one can maximize the likely population "return" per unit area protected and optimize the return to natural population levels which are genetically connected. Information about specific target species larval movements can also inform this principle.

Application of the principles provided in this report will only work if those implementing the marine protected area network have clear, locally relevant, management objectives and align those objectives with the appropriate principles. As the report shows, each set of management objectives require slightly different principles, and local needs may identify different priorities than those indicated above. Local knowledge is crucial to inform prioritization, application and adjustment of these principles.

There is no single method or approach that is able to manage the wide range of pressures and threats to sustainable use. Solutions rest in flexible adoption of integrated management built on sound governance frameworks which are responsive to local needs and aspirations.

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PREFACE

Commitments under the Coral Triangle Initiative

In 2007, the six countries of the Coral Triangle (CT6) [5] established the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF[6]). Eighteen months later, the CT6 approved a Regional CTI Plan of Action (RPoA[7]:) that includes five goals. There are aspects of all five goals to which resilient networks of marine protected areas could, potentially, contribute. In summary, the parts of the RPoA which pertain to marine protected areas are:

- Goal 1. Priority seascapes designated and effectively managed. Target 2. Marine and coastal resources are being sustainably managed and are contributing to environmentally sustainable development benefitting coastal communities and broader economies (marine protected areas can, and to date have been, part of management planning efforts [e.g. Grantham and Possingham 2011, Wilson et al. 2011]).
- Goal 2. Ecosystem approach to management of fisheries (EAFM) and other marine resources fully applied. Marine protected areas are an essential tool to achieve effective EAFM, while EAFM is an effective framework for implementing marine protected areas, thereby enhancing their contribution to broader ecosystem resilience.
- **Goal 3.** Target 1 Region-wide Coral Triangle Marine Protected Area System (CTMPAS) in place and fully functional that includes three actions: 1) jointly establish overall goals, objectives, principles and operational design elements for a CTMPAS centred around priority marine protected area networks; 2) complete and endorse a comprehensive map of marine protected area networks to be included in CTMPAS; and 3) build capacity for effective management of the CTMPAS.
- Goal 4. Climate change adaptation measures achieved. Target 1: Region-wide early action plan for climate change adaptation for the nearshore[8] marine and coastal environment and small island ecosystems developed and implemented. This includes the need to maintain biological diversity and ecosystem services: two outcomes that marine protected areas are well suited to achieve, particularly if designed for resilience to climate change and buffered by EAFM.
- Goal 5. Threatened species status improving via Conservation Action Plans which could include marine protected areas.

Therefore, a critical step in achieving the goals of the Regional and the six National CTI Plans of Action (RPoA, NPoAs) will be to implement resilient networks of marine protected areas that

[5] Indonesia, Philippines, Malaysia, Timor Leste, Papua New Guinea and the Solomon Islands (see cover page).
[6] www.cti-secretariat.net
[7] www.cti-secretariat.net/about-cti/plan-of-actions
[8] Nearshore refers to marine habitats relatively near the shoreline. This includes those areas with habitats that are contiguous with the coastline (which we have called inshore habitats) and deeper water pelagic habitats further from shore but not yet oceanic environments. These deeper, but still nearshore habitats that are not adjacent to the coastline, we term offshore for the purposes of this report.

are specifically designed to integrate fisheries, biodiversity and climate change resilience objectives within an ecosystem-based management framework.

Project description

Given the sign-off of the six member countries' Prime Ministers and Presidents to the CTI, these leaders have committed to establishing a CTMPAS, to applying an ecosystem approach to fisheries management, protection of threatened species and to building climate change resilience in their ecosystems. A critical step in that process will be designing resilient networks of marine protected areas that integrate biodiversity, fisheries and climate change objectives within an ecosystem based management framework.

The USAID Coral Triangle Support Partnership (CTSP) is focussed on supporting country priorities for regional action. One of the many country suggestions for support at a regional scale is to provide assistance for large-scale planning of resilient marine protected area networks. In 2011, the CTSP funded a project "Providing technical support for integrating fisheries, biodiversity and climate change objectives into resilient marine protected area network design in the Coral Triangle".

In this project, the CTSP will provide technical support to assist the CT6 in establishing resilient marine protected area networks that are designed to help achieve biodiversity conservation and fisheries sustainability objectives in the face of climate change and within an ecosystem-based management framework.

Specifically, this project will deliver several key objectives that support each other to achieve the project goal within the context of the CT countries in coordination with CTI partners. The project objectives are to:

1. Identify a set of principles which will enable marine protected area network design to incorporate fisheries sustainability outcomes in the CT at various spatial scales.
2. Identify a set of principles which will enable marine protected area network design to incorporate considerations for adaptation to climate change at various spatial scales.
3. Document a clear assessment of CT6 priorities for marine protected area network design at the local, national and regional scales of implementation, with a focus on USCTI priority geographies and integration sites.
4. Document CT6 requirements for assistance with respect to marine protected area network design and evaluate against available capacity of partners and expert stakeholders.
5. Integrate and support an information system (e.g. CT Atlas) that will support the CT6 by providing a source of information relevant for resilient marine protected area network design and tracking of progress; and
6. Facilitate the provision of expert and technical support for the countries in their efforts to design marine protected networks in a manner that develops in-country capacity.

This report implements the first of three project strategies:

Strategy 1: Integrating climate change and fisheries objectives into resilient marine protected area network design principles within an ecosystem-based management framework

Strategy 2: Conducting a scoping study to determine what technical assistance is required by the CT6 for resilient marine protected area network design, in the CT and how this can be effectively provided.

Strategy 3: Providing technical assistance for resilient marine protected area network design and information management support through CT atlas.

In implementing Strategy 1, this report contributes to objectives (1) and (2) of the project by reviewing literature and accessing key workshop outcomes to identify principles that will enable marine protected area network design to incorporate fisheries sustainability outcomes and considerations for resilience to climate change and other threats (for Terms of Reference see Attachment 1).

1 INTRODUCTION

1.1 Purpose

The purpose of this report and the biophysical design principles presented is to inform plans and opportunities to establish, or improve upon, marine protected area networks so that they more directly address the issues of food security, livelihoods and long term sustainability of marine and coastal resource use in the Coral Triangle (CT). The design principles are intended to be user friendly and largely implementable despite the information constraints of many parts of the CT.

1.2 Context

The marine and coastal resources of the CT provide benefits to 360 million residents of the CT6, as well as millions outside the region (Coral Triangle Secretariat 2009). Collectively the resources supply about 10 percent of the world's marine capture fisheries (Williams and Staples 2010, Sea Around Us Project 2011). Most of this production is sourced from Indonesia, the Philippines and Malaysia (Williams and Staples 2010). These three countries of the CT6 are among the top 20 countries in the world in terms of marine capture fisheries production. Eighty percent of Southeast Asian fish are exported to developed countries (Williams and Staples 2010).

In all the CT6 countries, the consumption of protein from fish as a percentage of total animal protein is among the highest in the world (i.e. over 30 percent) and increasing[9]. Burke et al. (2011) rate the Philippines and Solomon Islands as among those countries in the world that are most highly socially and economically dependent on their coral reef systems, including for food and livelihoods; all other CT countries are rated as highly dependent. This conforms with findings elsewhere (Gillett 2010).

In addition to the important fisheries of the CT, it is also the global center of marine biodiversity (Green and Mous 2008, Barber 2009, Veron et al. 2009). Naturally, the two features of important and productive fish stocks and marine biodiversity are not mutually exclusive. Fish form part of the biodiversity of the CT and the broader biological communities and ecosystem supports the fisheries resources (Green and Mous 2008, Bell et al. 2010). And both fish diversity and, therefore biodiversity more broadly, have been documented to decline due to fishing pressure in the CT (Coral Triangle Secretariat 2009, Lavides et al. 2010, Nanola Jr et al. 2010). Recent work has shown how declines in fish stocks or in general, biodiversity, negatively impact ecosystem function of coral reefs (Sweatman 2008, Mora et al. 2011); a finding that would apply to coral reef systems in the CT.

[9] http://www.unep.org/dewa/vitalwater/jpg/0319-2-fish-protein-EN.jpg

Much of the coastal area of Southeast Asia is overfished and no substantial stocks remain to be exploited (Stobutzki et al. 2006, Williams and Staples 2010). Many of the fished shark species, for example, have been listed as threatened by IUCN (Field et al. 2009). The total catch has continued to increase due to increasing effort, but there has been a large shift in catch with increasing proportions of small, low value/"trash" fish taken, including juveniles of many sought-after species (Williams and Staples 2010). Total catch trajectories may be about to stabilize or trend downwards, and catch per unit effort has declined significantly (Williams and Staples 2010; e.g. Figure 1).

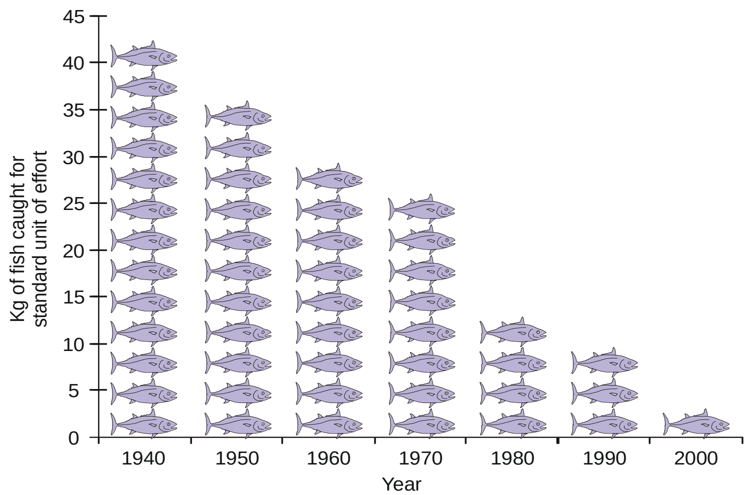

Figure 1**. Trend of catch per unit of effort for fishers using hook-and-line from six provinces in the Philippines** (Green et al. 2003)**.**

In the Pacific, Gillett (2010) has found that, in general, the coastal fishery resources are heavily fished and often show signs of overexploitation, especially in areas close to population centers or providing fishery products in demand by the rapidly-growing Asian economies (see also Gillett and Cartwright 2010). Many parts of the Solomon Islands and Papua New Guinea (PNG) are not yet subject to such heavy pressures due to low population and land-based alternatives for livelihoods and food. However, many other areas, even within these countries, are heavily exploited and the international demand for product (e.g. live reef fish fishery, bêche-de-mer) and population growth will increase pressures into the future (Preston 2009, Gillett and Cartwright 2010). These findings are supported when looking at more detailed fishing trends and other information on fished stocks per individual CT country[10] (Williams 2007, Lavides et al. 2010, Nanola Jr et al. 2010).

Part of the overfishing problem lies with illegal, unreported or unregulated (IUU) fishing which, globally, is estimated to account for 18 to 30 percent of catch (Pauly et al 2003 in Metuzals et al.

[10] http://www.seaaroundus.org/eez/

2010; Agnew et al. 2008, Mills et al. 2011). In the CTI region, IUU estimates are greater. For example, Agnew et al (2008) estimate IUU at 34 percent in the central Western Pacific (which include PNG and Solomon Islands), and in Indonesia's Arafura Sea IUU catches were estimated to be 50 to 100 times greater than reported (Nurhakim et al 2008, Metuzals et al. 2010). While these data refer also to illegal tuna fishing, they include, for example, unregulated and under- or un-reporting of coastal fisheries catches. Gillett (2010) states that the estimation of the production of coastal fisheries by government fishery officers in about half of the Pacific Island countries is largely guesswork; the focus is more on the income producing tuna fisheries. Typically, government fisheries agencies give low priority to estimating the amount of coastal catches despite the importance of these fisheries to local communities (Gillett 2010). For example, extrapolating from 36 case studies that included Philippines, Indonesia and Malaysia, estimates are that marine small-scale fisheries directly provide employment for over 47 million people (an order of magnitude greater than large-scale marine fisheries at 8.6 million; Mills et al. 2011).

Another part of the overfishing problem is destructive fishing practices which, while often illegal in CT countries, still occur and have negative environmental, social and economic impacts (Mous et al. 2000, Pet-Soude et al. 2000, Cesar et al. 2003)[11]. These data are coupled with the fact that fisheries in Indonesia, the Philippines and Malaysia have developed too rapidly for marine resource conservation practitioners to keep pace (Williams and Staples 2010). Fisheries managers in the Pacific are also starting to face these kinds of challenges (Gillett 2010).

In addition, the CT region is also vulnerable to climate change impacts. If unchecked, it is estimated that the impacts of climate change upon the CT will ultimately undermine and destroy ecosystems and livelihoods (Hoegh-Guldberg et al. 2009, Bell et al. 2011). Already very high increases in sea temperature have been measured in the northern part of the CT (Hoegh-Guldberg et al. 2009). Ocean acidity will also rise and rainfall patterns will change (Hoegh-Guldberg et al. 2009, Bell et al. 2011). Yusuf and Francisco (2010) provided information on the vulnerability of Southeast Asian countries, regions, districts, provinces to climate change impacts and found all regions of the Philippines, West and South Sumatra, West and East Java to be among the most vulnerable. However, very few regions within any of the CT countries achieved low ratings in terms of exposure to climate-related hazards (tropical cyclones, sea level rise, floods, etc; Yusuf and Francisco 2010).

Bell et al. (2010) consider that alterations to water temperature, depth of the surface mixed layer and currents occurring as a result of changes in climate are having significant effects on the distribution of both oceanic and coastal fish (see also Bell et al. 2011). The main patterns that have emerged are: 1) expanded distributions of warm water fish species towards the poles and; 2) latitudinal shifts in areas where species occur and contracted distributions of species adapted to cooler waters (Bell et al. 2010, Bell et al. 2011). These issues are discussed in more detail in Section 4.

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[11] See also http://www.agc.gov.my/Akta/Vol.%207/Act%20317.pdf; the Fisheries Law (Law 31/2004) Indonesia, Philippine's Republic Act 8550 http://www.lawphil.net/statutes/repacts/ra1998/ra_8550_1998.html and http://www.fao.org/docrep/010/ag115e/AG115E05.htm)

Other, more local, pressures also threaten the marine environment of the CT, including impacts on water quality from watersheds, coastal development and tourism impacts (Burke et al. 2011; Figure 3, Figure 5).

Globally, on a comparative level, the combination of local and global pressures on coral reefs is highest in Southeast Asia where nearly 95 percent are threatened, and about 50 percent are in the high or very high threat category (Burke et al. 2011; Figure 2). Indonesia, home to the second largest area of coral reefs in the world, has the largest area of threatened reef, followed by the Philippines (Burke et al. 2011). Overfishing and destructive fishing drive much of threat in this region (Williams and Staples 2010, Burke et al. 2011; Figure 3).

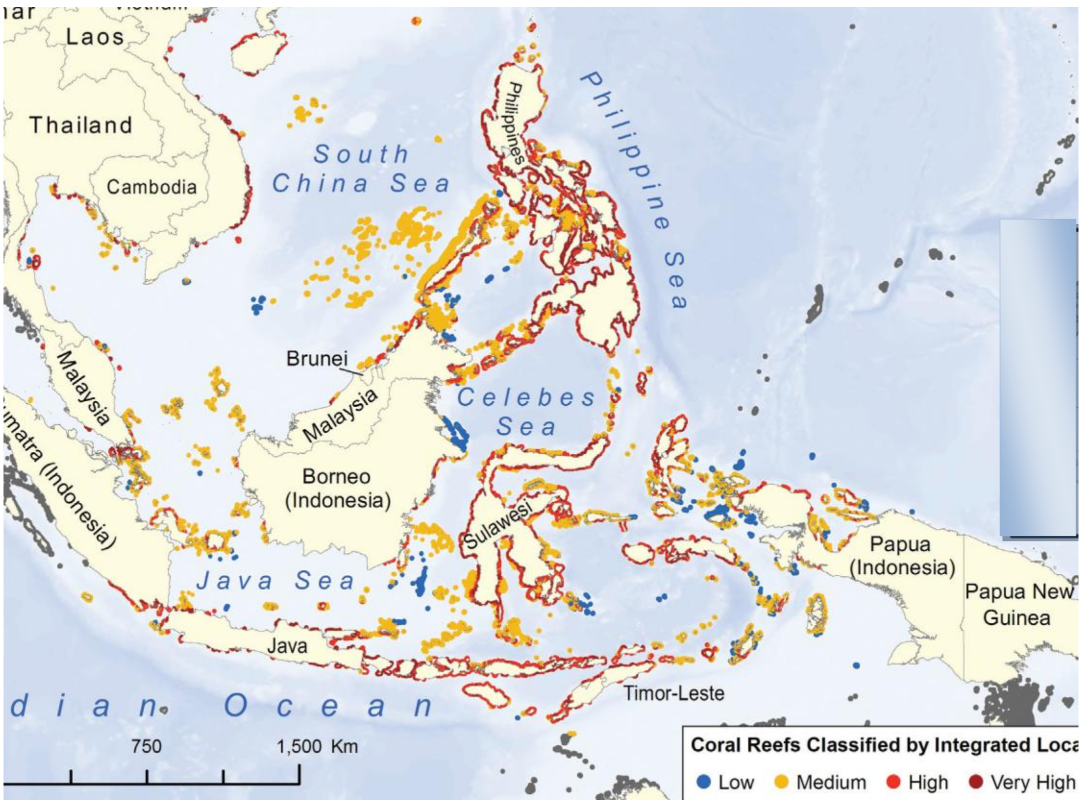

Figure 2. Coral reefs at risk in Southeast Asia classified by integrated local threats level. (Burke et al. 2011).

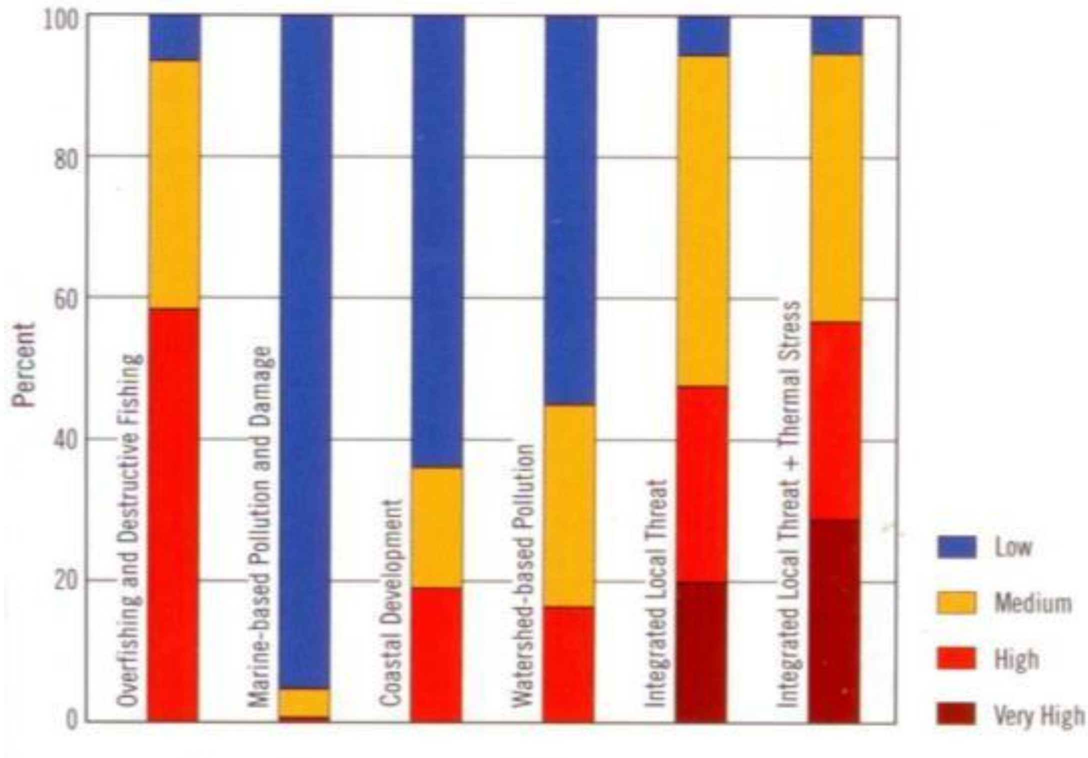

Figure 3. Reefs at risk in southeast Asia.
(Burke et al. 2011)

Even in the Pacific, on average almost 50 percent of reefs are currently considered threatened, with about 20 percent rated as high or very highly threatened especially reefs associated with high islands and areas of higher population such as in Melanesia (Burke et al. 2011; Figure 4, Figure 5). With the inclusion of thermal stress, the percentage of threatened reefs increases to more than 65 percent (Burke et al. 2011; Figure 5). This is the environmental and human context within which marine protected area networks are being created under the umbrella of the CTI. The development of guiding principles for marine protected area network design in this report has occurred with a poignant awareness of this challenging marine resource management context.

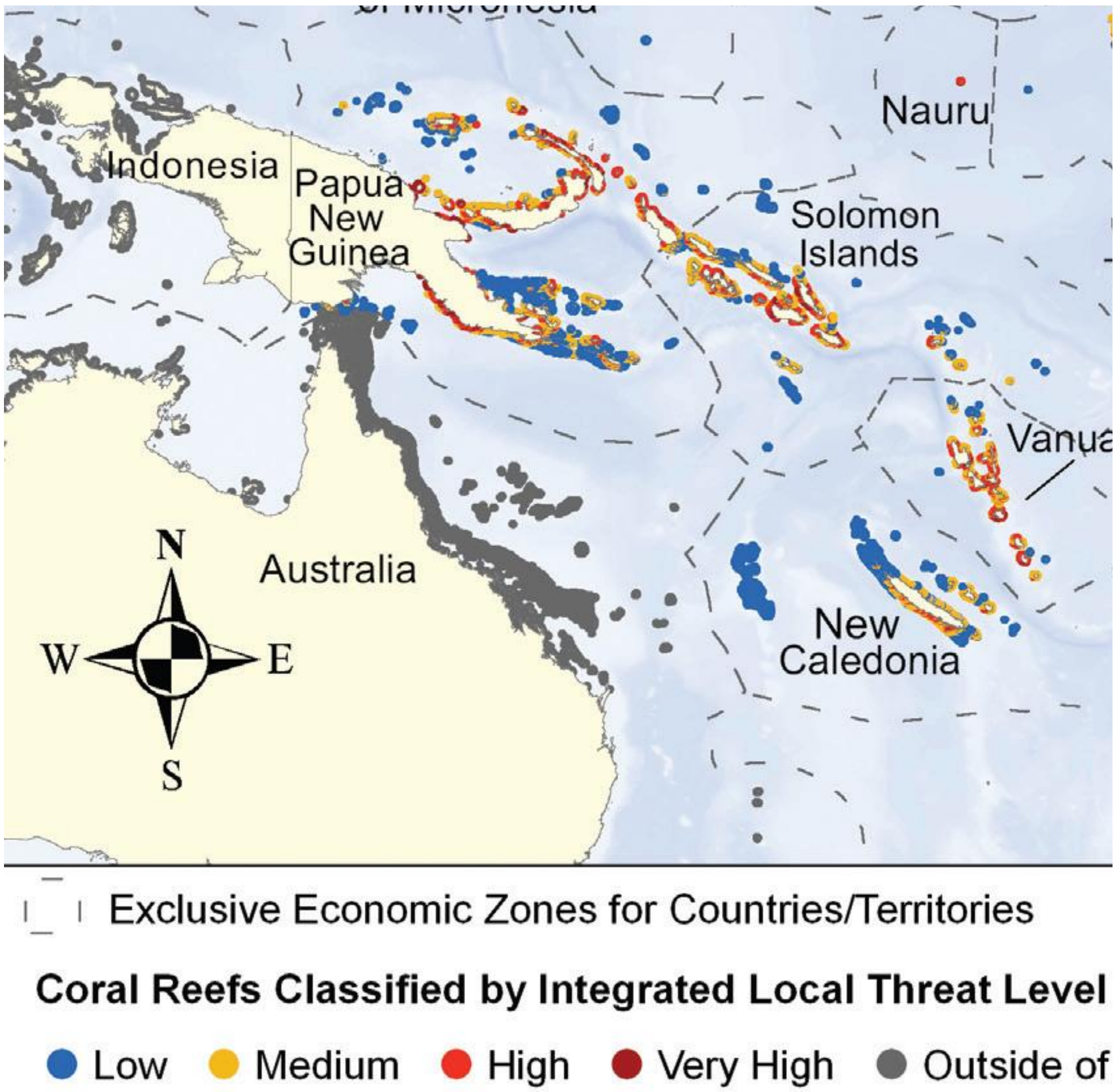

Figure 4. Reefs at risk in the south-western Pacific.
(Burke et al. 2011)

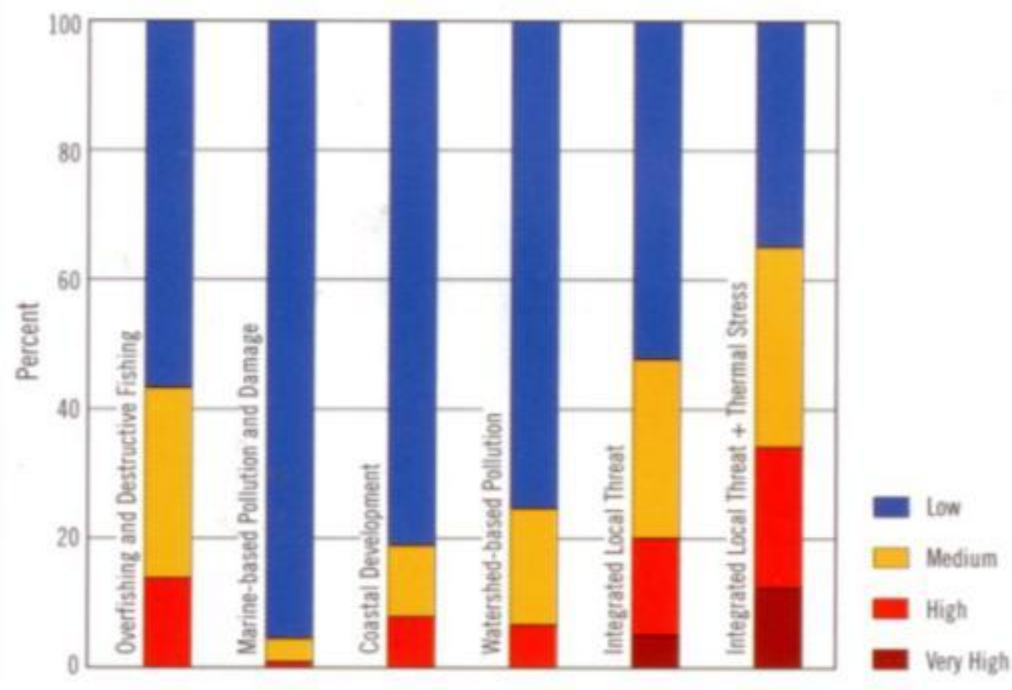

Figure 5. Reefs at risk in the Pacific.
(Burke et al. 2011)

1.3 Biophysical design principles are one part of the process

The biophysical design principles discussed in this report are only one part of the process of establishing marine protected area networks. The other parts of the process address equally important socio-economic, political and governance issues. Other documents provide information and guidance about the broader process one might adopt to implement marine protected areas, which can include networks, and this process is not discussed here (Kelleher 1999, Salm et al. 2001, COREMAP II Ministry of Marine Affairs and Fisheries 2006, White et al. 2006, Alino et al. 2008a, Govan et al. 2008, IUCN-WCPA 2008, Alino et al. 2011).

The principles suggested here, when considered, will be implemented in a tailored manner, ideally by local communities and governments, and will need to accommodate local social, economic, cultural, institutional and political real world factors. This should help lead to marine protected area networks that are effective, in terms of fisheries and other benefits. Despite the limited scope of this work, it is hoped that the biophysical principles will help inform decisions to achieve the best possible outcomes.

1.4 Marine protected area network objectives in the CTI National Plans of Action

Within the Regional and National CTI PoAs, marine protected areas and marine protected area networks are relevant in two ways: 1) they are mentioned specifically as tools to use and there are goals, targets, and 2) objectives or other outcomes of the plans which either explicitly or implicitly can be contributed to by establishment of one or more marine protected areas either in an ecologically connected network or notError! Bookmark not defined.. Many of the objectives n the NPoAs that would benefit from the application of a range of management tools include well designed and implemented marine protected areas. We assessed which of the objectives in the NPoAs that marine protected areas could contribute.

A distinction exists between goals, objectives, and outcomes, as opposed to tools or outputs. For example, statements of values, concerns, preferences, tools, processes and means which contribute to achievement of end-objectives are not, themselves, objectives (Keeney 1988). The separation of means and ends is important because the degree to which any mechanism or tool (like marine protected areas) can achieve any stated objective may be variable (Pitz and Riedel 1984). For example, implementing marine protected areas might be presented as an objective when it might be one of the means to another objective, such as, maximizing resilience a coral reef community, which a raft of management tools can contribute.

More specifically, to optimize the design of a network of marine protected areas, one must first be clear as to the objectives to which marine protected areas are required to contribute. The design must follow the objectives, and the objectives must be developed in concert with community and user engagement.

The preface discusses relevant CT-wide commitments and objectives, in the RPoA, as they pertain to the use of marine protected areas (Coral Triangle Secretariat 2009). Here we combine that information with information from the National CTI Plans of Action to determine, across all these plans: the stated goals and objectives (outcomes) that the CT6 have committed to that are relevant to marine protected areas, marine protected area networks and marine protected area network design.

Objectives stated in the Regional and National CTI PoAs which marine protected area networks could contribute towards are important because the biophysical design principles developed in this report are tailored to contribute to the achievement of those stated objectives.

1.4.1 Shared national CTI goals and objectives that pertain to use of marine protected area networks

For the purposes of this report, the focus is on the common goals, objectives and outcomes that a marine protected area network can contribute towards that the CT6 share. In some cases, NPoAs provide more detail, for example, in the meaning of "habitat". Where this has occurred, it has been assumed that the NPoAs which were silent on the detail would encompass similar aspirations. Where more specific objectives are not identified in the NPoAs, they may be provided in other, more detailed planning or implementation documents not reviewed here.

Reviewing the summary of the relevant components of the CTI NPoAs, we found that the main shared, overlapping CTI objectives that marine protected area networks could contribute to are, in no particular order:

- Increase long-term benefit to human well-being (of current and future coastal communities especially) of the use of marine resources including:
    - Income/employment
    - Livelihoods including diversification
    - Food security
    - Poverty reduction
    - Via eco-tourism[12]
    - Environmentally sustainable development/economic growth
    - Sustaining the full range of marine ecosystem goods and services
    - Resolution of tenure and resource-use conflicts
- Sustainable use of marine resources including:
    - Coastal fisheries[13]
    - Live reef fish fishery
    - Reef-based ornamental fishery
    - Tuna fishery[14]
    - Small pelagic fishery
- Improved quality of marine and coastal resources:
    - Better habitat condition
        - Coral reefs
        - Mangrove forests
        - Seagrass beds
        - Beach and/or coastal forests
        - Wetlands
        - Marine/offshore habitats
        - Mudflats
        - Algal beds
        - Rocky coasts
    - Better condition of fish resources
        - Increased tonnage of landings
        - Increased average size of landed fish by species
        - Viable population levels
        - Healthy spawning aggregations
        - High recruitment
    - Conservation of biodiversity
    - Better functioning of marine and coastal ecosystems including:

[12] While most NPoAs referred to tourism, this does not mean that it is intended to be initiated everywhere.

[13] We can assume this includes use of local species as well as harvested and collected species (e.g. bêche-de-mer, trochus, lobster, crabs, shellfish).

[14] If spawning, feeding or juvenile grounds for tuna are within the coastal inshore pelagic habitat, then a coastal MPA network could contribute to their protection.

        - Greater productivity
        - Sustaining the full range of marine ecosystem goods and services
        - Ecological processes
    - Improved status (e.g. Population, distribution, diversity and economic value) of:
        - Sharks, rays and other cartilaginous fishes
        - Threatened fish (e.g. Napoleon wrasse)
        - Corals
        - Sea turtles
        - Seabirds
        - Marine mammals
        - Crocodile
        - Other species on the IUCN Red List
        - Other identified species
- Address local and global threats to marine resources:
    - Mitigation of effects of fishing in an ecosystem including:
        - Excessive exploitation
        - By-catch
        - Discards
        - Destructive fishing practices (e.g. use of dynamite, noxious substances, destructive gear)
        - Protection of juvenile/nursery areas
        - Discarded fishing gear
    - Mitigation of effects of tourism
- Reduce vulnerability of coastal and marine resources to:
    - Climate change impacts including through
        - Protecting refugia to reseed affected areas
        - Reduction of non-climate stressors
        - Application of climate change resilience principles to marine protected area network design
    - Other external and local threats

(DEC and the NFA 2009, National Secretariat of the CTI-CFF Indonesia 2009, Republic of Philippines 2009, Republic of Timor Leste 2009, Solomon Islands CTI NCC 2009, DEC and the NFA 2010).

All the NPoAs (and the regional CTI PoA) refer to marine protected areas as encompassing a range of types of protection either explicitly or through their discussions of the need to "zone" the marine protected area or to have a zoning plan for the marine protected area. Some refer explicitly to local marine managed areas (LMMAs) as being a type of marine protected area.

The NPoAs contain much detail regarding how marine protected areas should be implemented with regard to governance, community-based management, local tenure, geographic priorities, collection and use of information, legislation, linkages to other CTI goals and other national programs, planning processes, targets, etc. These are not discussed here.

In addition, the Regional and National PoAs recognize that marine protected areas are not the only management tool that can contribute to the objectives listed above. And all the CTI PoAs refer to the need for a broader management framework, in this case EAFM, within which any marine protected areas would sit.

1.5 Scope

Biophysically, nearshore coastal habitats are different to deeper oceanic environments (Costello 2009). The Regional CTI PoA refers to a CTMPAS that protects "each major near-shore habitat type within the Coral Triangle Region (e.g. coral reefs, seagrass beds, mangroves, beach forests, wetland areas and marine/offshore habitat"; Coral Triangle Secretariat 2009). For these reasons, the design principles presented in this report applies most readily to the near-shore habitats of the CT.

This report does not address the myriad of extremely important and, usually, highly situation-specific social, political, economic, institutional, management feasibility and cultural factors that should be considered in designing networks of protected areas. These are discussed in other works and the authors direct you to these (White et al. 2006, IUCN-WCPA 2008, Ehler and Douvere 2009, Agardy 2010, Alino et al. 2011). Other work has developed socio-economic guiding principles but more for the particular geographies where they were applied (e.g.Fernandes et al. 2005, Green et al. 2007, Gleason et al. 2010, Lipsett-Moore et al. 2010, Wilson et al. 2011). Broadly, many of the socio-economic principles concern complementing human uses and values. The way that translates into on-the-water principles will vary at each location and require case-by-case assessment, ideally in collaboration with the local communities (IUCN-WCPA 2008).

The scope of this work is limited in the degree to which the literature is reviewed. The purpose of this report is to deliver useful, clear biophysical marine protected area network design principles and to justify the bases and rationales of those principles. The literature has been reviewed to inform the development and provide the reasoning behind the principles. The intent is not to deliver a comprehensive review of all work conducted on every aspect of marine protected area design. Thus there is heavy reliance on recent reviews and recent research. The review is also limited to literature written in English. We also note that relatively few scientific papers focus on areas such as the CT (Fisher et al. 2010). However, the literature accessed includes not only peer reviewed scientific papers but grey literature. The scope of information accessed to incorporate climate change factors into marine protected area design was limited by the terms of reference of the project, mainly to a workshop held for this purpose in 2010 (Attachment 1; TNC 2011, McLeod et al. submitted).

This work is limited also by the fact that much of what is understood about real world design and functioning of networks of marine protected areas is known by practitioners in the CT who do not write publically accessible documents. More information may also be known to scientists who have not yet disclosed their knowledge in peer-reviewed papers. This kind of knowledge is not captured in this report.

Threatened species considerations were not part of the terms of reference for this report however the authors have attempted to include these factors in an *ad hoc* manner, where practicable.

For definitions used in this report please refer to the Glossary and Attachment 2.

1.6 Target audience

The primary audience for this work is tropical marine resource managers in CT6 and beyond. It is intended to be useful and understandable background for busy decision-makers who may have neither the time nor access to information to synthesize available literature. This may include government policy-makers, who have responsibility over real on-the-water decisions, conservation planners or community leaders. We expect these practitioners to focus on the bottom-line of this report (Executive Summary and Section 5).

1.7 Marine protected area networks within a broader management framework

Marine protected areas and marine protected area networks cannot function as effectively, or in some cases, at all, outside of a broader management framework (NRC 2001, Jones et al. 2007, Ehler and Douvere 2009, Agardy 2010, Agardy et al. 2011b, Alino et al. 2011). In particular, fishery-related objectives cannot be met nearly as well by marine protected areas compared with marine protected areas in concert with other management tools, for example, effort and output controls on fishing, gear modifications (e.g. to enhance selectivity), controls on gear to limit habitat damage (see definition in Attachment 2;. FAO 2003, Coral Triangle Secretariat 2009, DEC and the NFA 2009, National Secretariat of the CTI-CFF Indonesia 2009, Republic of Philippines 2009, Republic of Timor Leste 2009, Solomon Islands CTI NCC 2009, DEC and the NFA 2010, FAO 2010) set within a broader management framework (Russ 2002, Hilborn et al. 2004, Kaiser 2005, Licuanan et al. 2006, Armada et al. 2009, Christie et al. 2009a, Rice and Ridgeway 2010, Pomeroy and Andrew 2011). Some efforts have been directed to management frameworks that support small-scale fisheries in the developing world, such as those in the CT (Foale et al. 2008, Smith et al. 2010, Andrew and Evans 2011, Evans and Andrew 2011).

The CTI Regional and National Plans of Action are committing to an Ecosystem Approach to Fisheries Management (EAFM). All the CT countries have adopted the FAO definition of EAFM; this management approach offers a functional framework within which marine protected areas and, indeed, marine protected area networks have a role along with other management tools (as discussed above).

1.8 How marine protected area networks can benefit coastal communities and marine ecosystems

This report is not intended to evaluate the benefits and costs of marine protected areas; rather, this work focuses on design principles to optimize multi-objective benefits that marine spatial zones can deliver. A brief overview of some of the benefits and costs of marine protected areas is provided to inform our decision-making about how best to develop biophysical design principles for marine protected areas and networks.

Most of the literature refers to effects of no-take marine protected areas. No-take marine protected areas can benefit fish within the protected area, biodiversity conservation and the ecosystem more generally (Ward et al. 2001, Russ 2002, Lubchenco et al. 2003, Lester et al. 2009). Particular benefits within a no-take could include positive impacts upon:

FISHING MORTALITY (direct short-term benefits; realized immediately)
- Eliminate mortality to targeted species and size/age classes
- Eliminate by-catch mortality
- Eliminate incidental mortality directly caused by fishing gear/practices
- Eliminate indirect mortality caused by the damage/destruction of habitats caused by fishing gear/practices
- Eliminate indirect mortality caused by fishing mortality of prey species

POPULATION SIZE (direct short- to medium-term benefits)
- Increase abundance, density and/or biomass of the focal species
- Increase abundance and/or density spawning individuals, or spawning biomass, of the focal species

POPULATION STRUCTURE (direct short- to medium-term benefits)
- Increase mean size/age of individuals of the targeted species
- Restore/maintain 'natural' size/age structure in reserve populations

REPRODUCTION (direct short- to medium-term benefits)
- Increase potential and actual reproductive output
- Protect portion of the stock's spawning biomass
- Enhance settlement/recruitment

HABITAT QUALITY (secondary medium- to long-term benefits)
- Protect and allows recovery of 'natural' habitat characteristics
- Increase biodiversity
- Protect against loss of keystone species, and cascading or indirect effects of fishing
- on community structure
- Re-establish 'natural' community composition, trophic structure, food webs, and ecosystem processes

- Improve amenities and resources for other non-fisheries sectors of society

(Roberts and Hawkins 2000, NRC 2001, Ward et al. 2001, Evans and Russ 2004, Williamson et al. 2004, Russ et al. 2008, Lester et al. 2009).

Benefits of no-take marine protected areas beyond their boundaries, mainly upon harvested species and the associated fisheries could include:

SPILLOVER OF ADULTS/JUVENILES (direct medium-term benefits)

- Result in net emigration of juveniles and adults from reserves
- Increase catches of larger, more valuable individuals near reserves
- Increase abundance of trophy-sized fish near reserves

LARVAL EXPORT (direct medium-term benefits)

- Result in net export of eggs and/or larvae to fished areas
- Enhance recruitment to fisheries (i.e. fished stocks) outside reserves
- More robust larvae exported from larger females

FISHERIES (indirect medium to long-term benefits)

- Increased catches, fisheries yields, profits
- Decreased variability in catches, fisheries yields, profits
- Reduce conflict between fisheries/fishers
- Reduce conflict between different users
- Maintain diversity of fishing opportunities
- Sustain fisheries for vulnerable species
- Increase likelihood that existing fishing effort levels are sustainable
- Increase long-term stability of fisheries

(McCormick 1998, Ward et al. 1999, Pet and Mous 2002, Gell and Roberts 2003, McCormick 2003, Palumbi 2004, Alcala and Russ 2006, Farrell and Botsford 2006, Fogarty and Botsford 2007, McCormick and Gagliano 2008, Jones et al. 2009, Maliao et al. 2009, Pelc et al. 2009, Shanks 2009, Babcock et al. 2010, FAO 2010, Halpern et al. 2010, Kompas et al. 2010, Pelc et al. 2010).

Fishery benefits of no-take areas that are not restricted to inside or outside the area's boundaries could include:

POPULATION (direct medium- to long-term benefits)

- Increase size of stock available to fisheries
- Possibly permit increased fishing mortality
- Have greater success than traditional controls at maintaining sustainable fisheries
- Reduce overfishing of vulnerable species
- Protect species vulnerable to overfishing
- Protect from incidental mortality on spawning or nursery grounds
- Protect/buffer against stock collapse, or serious decline, from overfishing

- Protect/buffer from natural recruitment failure
- Improve probability and rate of recovery after serious decline or collapse
- Reduce variance in stock size and, therefore, in fisheries yield
- Improve prospect of long-term sustainability of stocks
- Improve predictability of recruitment under environmental uncertainty
- Reduce impacts of variation/extremes in natural conditions on stocks/fisheries

GENETIC STRUCTURE (indirect, mostly long-term benefits)

- Protect genetic diversity of focal species
- Reduce risk of loss of genetic information from gene pool
- Reduce effects of fishing selection
- Select for beneficial behavioural changes

ECOSYSTEM (secondary, mostly long-term benefits)

- Reduce risk of disruption of ecosystem structure and function

MANAGEMENT (tertiary, short- to long-term benefits)

- Simplify regulations making compliance enforcement easier
- Avoid difficulties of observing and enforcing size and gear regulations
- Allow violations to be more easily detected
- Reduce need for data collection to support management
- Provide resource protection without detailed stock/system data
- Protect against management failure (precautionary approach)
- Provide a basis for rebuilding stock (bet-hedging strategy)
- Provide areas for study of natural/anthropogenic processes in absence of fishing mortality/effects
- Provide sites with minimal disturbance for study of effects of fishing, natural/anthropogenic environmental pressures, and/or harvest strategies

(Ward et al. 2001, Pet and Mous 2002, Russ 2002, Palumbi 2004, FAO 2010, Kompas et al. 2010, Alino et al. 2011, Hamilton et al. 2011, Pomeroy 2011, Sadovy and Clua 2011).

Where industries exist that depend on a healthy-looking marine environment with many fish (e.g. marine tourism), no-take areas can directly contribute to maintenance and enhancement of economic benefits derived from no-take marine protected areas (Carr and Mendelsohn 2003, White et al. 2006, IUCN-WCPA 2008).

Temporary (including seasonal) or rotational no-take areas could also have fisheries benefits in terms of increasing fish density inside and outside the no-take areas, although these areas are not necessarily beneficial to maintenance of biodiversity on a broad scale (FAO 2003, Cinner et al. 2005b, Game et al. 2009).

Other types of marine protected areas can limit particular types of gear such as bottom trawling, purse seining, gillnetting, dynamite or blast fishing, fishing using noxious chemicals or can limit effort, by-catch and habitat impact in some ways (e.g. excluding non-local fishers or limiting the amount of gear permitted to be used per person in an area; FAO 2003, Great Barrier Reef Marine Park Authority 2004, Govan et al. 2008, WCPA - Marine 2010). These have also been shown to have positive impacts upon the marine environment and the stocks (Poiner et al. 1998, Tanzer pers. comm., Fox and Caldwell 2006, Hutchings et al. 2008).

Marine protected areas that restrict access/take in some way incur management costs and, potentially, short or even long term costs to local fishers (Balmford et al. 2004, FAO 2010, Grafton et al. 2010a, Ban et al. 2011). If some, or all, extractive activities from an area of ocean are removed, there is less area available to the fishers and, potentially, effort previously applied within a new marine park could be displaced to outside the no-take area (Hilborn et al. 2004). This could concentrate fishing effort to some degree and may increase damage to adjacent habitats, target species and non-target species (Grafton et al. 2010a). Fishers may therefore experience a decline in catch per unit effort or, even, catch overall leading to a potential loss in profit (Ward et al. 2001, IUCN-WCPA 2008). Fishing communities may have limited and complex spatial structure and limited mobility (Hilborn et al. 2004). No-take areas, especially in isolation from other management efforts, may cause hardship to fishing communities, shorten fishing seasons and/or force fishers to travel much farther to unfamiliar grounds, increasing risk to the smaller vessels and to people (Grafton et al. 2010a).

There are also costs associated with a lack of management action when a risk to the sustainability of the marine resources in question exists (Cesar et al. 2003, CI 2008). Generally, costs and benefits become more difficult to measure the longer the time frame of the assessment. However as a general rule, the benefits will accrue over the longer term, as it takes time for a newly implemented marine protected area to produce optimum ecological and socio-economic benefits, especially in terms of larger longer-lived species (Cesar 2000).

Whether the benefits of marine protected areas to fisheries outweigh the costs will depend on many factors including human population growth, distance to market, compliance (which is linked, among other things, to governance arrangements), design features of the marine protected area(s) and the surrounding management environment (Russ and Alcala 1996, Cinner et al. 2005b, FAO 2006, McClanahan et al. 2006, IUCN-WCPA 2008, Christie et al. 2009b, FAO 2010).

1.9 Why networks of marine protected areas?

For nearly all marine species, individual marine reserves provide small benefits in terms of species maintenance because the size of the areas are usually small compared to the geographic extent and home range of the species it is aiming to sustain (Roberts et al 2001 in Skilbred et al. 2006, Gaines et al. 2010; see also Sections 2.2.1 to 2.2.4). One solution is to scale up (e.g. the Papahanuamokuakea National Monument that covers almost 360,000 km^2), however such solutions are socially, economically and politically difficult along heavily populated coastal areas, such as those of much of the CT (Gaines et al. 2010).

Alternatively, networks of multiple marine protected areas can have larger impacts, including benefits, that are greater than the sum of the individual parts (Halpern et al 2001 in Skilbred et al. 2006, Gaines et al. 2010, Alino et al. 2011). The benefits can include helping to increase fish biomass and population size (Crowder et al. 2000), increase profits (Costello and Polasky 2008), optimize harvest (Neubert 2003), hedge against uncertainty (Lauck et al 1998 in (Ward et al. 2001), improve stock resilience to external impacts upon fish stocks (Stephansson and Rosenberg 2005 in FAO 2010), protect different life stages, protect larger and/or more migratory species (FAO 2010).

In short, for the same amount of spatial coverage, networks of marine protected areas can deliver most of the benefits of individual marine protected areas as well or better, but with potentially less costs due to greater flexibility and diversity in size, shape, distribution and location options (IUCN-WCPA 2008).

1.10 How can systematic biophysical design of protected area networks help?

In the real world, successful selection and implementation of protected areas is the product of a complex suite of factors that are usually not biological nor predictable (Knight and Cowling 2007). Instead, drivers are economic, availability of resources, organizational and institutional capacity, political willingness, tenure and governance, corruption, donors and others (Foale and Manele 2004, Knight and Cowling 2007, Christie et al. 2009b, Mogina 2010).

Current efforts, including this one, are aimed to inform opportunistic (and planned) spatial marine conservation initiatives with the best biophysical guidance available, while acknowledging the limitations of doing that alone. Noss et al (2002 in Pressey and Bottrill 2008) refer to this combination of pragmatic realities and best available science as informed opportunism. Lipsett-Moore et al. (2010) and Game et al. (2011) provide a good example of how to couple systematic planning with political and social opportunity, with the case of the Province of Choiseul in the Solomon Islands. Work in Choiseul reconciles community-driven conservation opportunities with a systematic and representation-based approach to prioritization and led to implementation of one land and one marine protected area for each of the twelve wards of the island (Lipsett-Moore et al. 2010, Game et al. 2011).

There are also a multitude of management activities which can contribute to biodiversity, fisheries and climate change objectives that do not involve a spatial dimension. These include input and output controls on fisheries, stopping of illegal fishing, enforcement of existing legislation, reduction of water pollution, protection of wetlands and mangroves monitoring, education and awareness raising, capacity building, community participation, etc. (Armada et al. 2009, Christie et al. 2009a). These activities are important in providing effective marine resource management outcomes.

2 DESIGN PRINCIPLES FOR ACHIEVING FISHERIES OBJECTIVES

2.1 Fisheries objectives

An ecosystem approach to fisheries management has been adopted and defined by the CT6 in accordance with the UN FAO definition[15] (see Attachment 2).

Marine protected areas, especially within an EAFM framework, could contribute to some of the fisheries-related objectives as identified in the National and Regional CTI PoAs (Section 1.4.1), for example:

- Increase long-term benefit to human well-being (of current and future coastal communities especially) of the use of marine resources including
    - Income/employment
    - Livelihoods including diversification
    - Food security
    - Poverty reduction
    - Environmentally sustainable development/economic growth
    - Sustaining the full range of marine ecosystem goods and services
    - Resolution of tenure ad resource-use conflicts
- Sustainable use of marine resources including
    - Coastal fisheries[13]
    - Live reef fish fishery
    - Reef-based ornamental fishery
    - Tuna fishery[16]
    - Small pelagic fishery
- Improved quality of marine and coastal resources
    - Better condition of fish resources
        - Increased tonnage of landings
        - Increased average size of landed fish by species
        - Viable population levels
        - Healthy spawning aggregations
        - High recruitment
- An ecosystem approach to fisheries management includes broader considerations of ecosystem health and habitat condition (see Attachment 2). In this way, marine protected areas can contribute to EAFM by contributing to:
- Improved quality of marine and coastal resources
    - Better habitat condition
        - Coral reefs

[15] See also http://www.fao.org/fishery/mpas/en

[16] If spawning or juvenile grounds for tuna are within the coastal inshore pelagic habitat, then a coastal MPA network could contribute to their protection.

        - Mangrove forests
        - Seagrass beds
        - Beach and/or coastal forests
        - Wetlands
        - Marine/offshore habitats
        - Mudflats
        - Algal beds
        - Rocky coasts
    - Conservation of biodiversity
    - Better functioning of marine and coastal ecosystems including
        - Greater productivity
        - Sustaining the full range of marine ecosystem goods and services
        - Ecological processes
    - Improved status (e.g. population, distribution, diversity and economic value) of:
        - Sharks, rays and other cartilaginous fishes
        - Threatened fish (e.g. Napoleon wrasse)
- Address local and global threats to marine resources
    - Mitigation of effects of fishing in an ecosystem including:
        - Excessive exploitation
        - By-catch
        - Discards
        - Destructive fishing practices (e.g. use of dynamite, noxious substances, destructive gear)
        - Protection of juvenile/nursery areas
        - Discarded fishing gear

Section 2 derives biophysical design principles for different types of marine protected areas that contribute to achieving the objectives listed above.

2.2 Literature review and lessons learned

The vast majority of fishers in the CT and elsewhere are involved in small-scale fisheries (Pomeroy and Andrew 2011). These fisheries are difficult to categorize, but mainly occur nearshore, with local fishers who fish in relatively small boats with relatively low technology and on a daily basis (Pomeroy and Andrew 2011). These fisheries have been occurring for generations (Cinner 2005, Cinner and Aswani 2007). In that time, permanent or temporary no-take areas (or managed areas restricting access or gear) have been part of the traditional management of the fished stocks (Cinner et al. 2005a, Cinner et al. 2005b, IUCN-WCPA 2008, Game et al. 2009, TNC et al. 2010, Grantham and Possingham 2011). Sometimes no-take areas have been implemented to help sustain fish stocks; otherwise they have been implemented to enhance stocks to make exploitation easier (Foale and Manele 2004, Cinner and Aswani 2007). In either case, they form part of known and familiar traditional management practices (Cinner and Aswani 2007, IUCN-WCPA 2008, Wilson et al. 2011).

For these fisheries, there is limited or no formal, quantified information on catch or effort (Pomeroy and Andrew 2011). Therefore, any management method used in small-scale fisheries must require limited scientifically collected data or be able to use local knowledge and be simple and cost effective (Preston 2009, Pomeroy 2011). However, most small-scale coastal fisheries are complex; they usually involve multiple gears, multiple species, open access, seasonal fluctuations in capacity and effort and interactions between small-scale and large-scale fleets (Crowder et al. 2000, Pomeroy 2011). These factors often limit the usefulness of many available approaches to measurement of fishing capacity and results in estimates (when they exist) that are subject to some uncertainty (Pomeroy 2011).

The desired response to the uncertainty in small-scale fisheries is in "living with uncertainty" by acknowledging the sheer gaps in human knowledge and understanding of these natural and human systems. (Charles 2007 in McConney and Charles 2010) exemplifies failures to do this.

Today, conventional fisheries managers are looking beyond single objective, single species and limited management toolboxes to manage fisheries better, especially in multi-gear, multi-species and data-poor fisheries (Pomeroy and Andrew 2011, Salomon et al. 2011). EAFM provides an overarching basis for management within which marine protected area can have a role (FAO 2003; Attachment 2). Spatial fisheries management options have long been used for sustainability purposes in fisheries around the world and have included seasonal or permanent spawning closures, closures to protect nursery areas, breeding areas, fish aggregation sites and habitat protection areas (FAO 2003, 2006, 2010). Under IUCN Guidelines, spatial closures intended to ensure sustainability as a priority (versus intended to maximize yield) can be considered marine protected areas (WCPA - Marine 2010).

Marine protected areas (of all kinds) in developing countries seem to work when combined with traditional tenure systems and other fisheries management tools (e.g. EAFM), for example in parts of the Asia-Pacific, such as the Philippines (Pomeroy et al 2001 in McConney and Charles 2010). As part of a broader management program, marine protected area networks can be attractive to small-scale fishers because benefits can derive from much smaller sized individual protected areas, which also impose less of a burden on the fishing community (IUCN-WCPA 2008). But if, or how, they assist in replenishing nearby fisheries depends significantly on technical design and compliance (Russ and Alcala 1996, McConney and Charles 2010). For these reasons, and others, there is seen to be a role for marine protected area networks within the mix of resource management tools (including EAFM) to address tropical, small-scale fisheries management objectives in countries, like the CT6 (Preston 2009, Pomeroy 2011).

Unfortunately, most of the research into designing networks of marine protected areas is focused upon only no-take areas, and this limits the utility of this literature review. Marine resource managers including fisheries managers have, however, a suite of types of spatial management regimes at their disposal (most of which can be called marine protected areas; WCPA - Marine 2010). EAFM, which is being pursued in the CT, promotes an ecosystem-wide, holistic approach to fisheries management which includes consideration of different types of permanent and/or temporary marine protected areas (FAO 2003, 2010; Attachment 2). These will be discussed below.

This section (2) and the following sections, (3 and 4), are organized into sub-headings that explore different aspects of marine protected area network design followed by a final heading within which all this information is used to define biophysical operational principles to guide decisions on design, in this case, for fisheries objectives.

2.2.1 Why a network for fisheries?

There is general consensus that marine protected area networks are more desirable than individual marine protected areas (Skilbred et al. 2006). A network of marine protected areas has been identified as a desired outcome of all the CTI NPoA as well as other national plans (Philippine Republic Act 7586 "National Integrated Protected Areas System" Act 1992, Philippine Marine Sanctuary Strategy, COREMAP II Ministry of Marine Affairs and Fisheries 2006). While one marine protected area, particularly a no-take area, can be important in helping to stabilize or enhance adult marine populations locally, if they are too small it is possible they cannot sustain the population of interest (Gaines et al. 2010). If there is only a single no-take area, then it will likely need to be at least as large as the average dispersal distance (and adult home range) for the each of the species of interest to generate benefits in terms of protection of each species (Gaines et al. 2010). Larval and adult movement of target species can be large enough that this may require reserves of tens to hundreds of kilometers wide (Shanks 2009, Gaines et al. 2010). Few reserves are this large (Gaines et al. 2010). Large no-take areas particularly can be socio-economically unacceptable and therefore unviable in terms of implementation especially in small-scale fisheries (IUCN-WCPA 2008). For these reasons, a connected network of smaller no-take marine protected areas can provide many of the benefits of a larger area without as many of the socio-economic and political hurdles to implementation (IUCN-WCPA 2008; see Sections 2.2.2 to 2.2.4).

In addition, within a network, if a natural or human disturbance damages or destroys a single protected area, there is still a likelihood that the objectives of the management action can still be attained due to the remaining marine protected areas (NRC 2001, Gaines et al. 2010). Thus networks offer a greater level of insurance against disasters, which are a common feature in most marine environments (Allison et al. 2003, Gaines et al. 2010).

Because of the redundancy or replication inherent in an ecologically connected network of marine protected areas, survival of parts of the network after a disaster mean that a network can also contribute to replenishment of areas of the ecosystem that are damaged (Gaines et al. 2010). This can include replenishment of damaged protected areas within the network or other parts of the damaged ecosystem.

Networks are also effective because they can better encompass a range of marine habitats than a single marine protected area. This is important because marine species tend to segregate by habitat and often use different habitats during different life stages (Roberts et al. 2003a). Therefore, placing protected areas in examples of all major marine habitat types is important for meeting fisheries and conservation goals (Gaines et al. 2010). Networks can achieve this without including swaths of marine ecosystem covering tens or hundreds of kilometers within no take areas (Gaines et al. 2010).

2.2.2 Proportion of a region to include in a marine protected area network

2.2.2.1 Research

Fisheries rely on abundant and persistent populations (Gaines et al. 2010). Many of the models exploring optimal percentages of ecosystems to protect in marine protected areas either (a) presume that the fishing effort outside protected area boundaries is so high that the external fish stock cannot contribute to replenishment of target species within marine protected area boundaries; or (b) find that marine protected areas are most useful, in terms of contributing to fisheries objectives, when fishing pressure is high (Botsford et al. 2009b). These models also presume that the marine protected areas are no-take areas (Botsford et al. 2009b). Section 1.2 discussed the fact that near-shore fisheries throughout much of the CT are either fully mature or over exploited with often inadequate fisheries management. Thus, the modelling work applies well to these parts of the CT situation.

A population, including a fish population, can be maintained if each individual reproduces enough to replace itself in the next generation (Botsford et al. 2009b). However, for most marine populations, the number of eggs or larvae required to produce one reproductive offspring that survives the larval and early juvenile stage is poorly known (Botsford et al. 2009b). Because of these difficulties in establishing the actual minimum threshold value of lifetime egg production (LEP) for each species, marine ecologists concerned with fisheries have expressed LEP as a fraction of the unfished, pristine value (fraction of lifetime egg production, or FLEP), and examined empirical information to determine a general safe value of that parameter (Mace and Sissenwine 1993, Gerber et al. 2003, Botsford et al. 2009b). Meta-analyses suggest that keeping FLEP above 35 percent ensures adequate replacement over a range of species (Gerber et al. 2003, Botsford et al. 2009a). This has been otherwise referred to at the level the population must remain at, compared to unfished stock levels, to achieve Maximum Sustainable Yield (Clark 1990, Myers, Brown and Barrowman 1999, Ralston 2002 in FAO 2010). This recommendation has incorporated data showing examples of fisheries collapse when FLEP is below: 35 percent (Clark 1991); 30 percent (Mace and Sissenwine1993); 40 percent (Clark 1993, Mace 1994); 55-60 percent (Dorn 2002, for rockfishes; all in Botsford 2010).

For marine protected areas to contribute to fisheries outside their boundaries, they must first be able to sustain target species within their boundaries (Hastings and Botsford 2006). This requires one of two things: (1) individual marine protected areas with a diameter greater than the average dispersal distance of the species of interest (Botsford et al. 2009a); or (2) if the marine protected area is smaller than the average larval dispersal distance, then species will persist only if a certain fraction (~35 percent) of the coastline is covered with connected marine protected areas (Fogarty and Botsford 2007). This fraction is the same as the FLEP required for a single, non-spatial population of that species to persist (~35 percent; Botsford et al 2001, 2008 in Botsford et al. 2009b). For species characterized by delayed maturation and low reproductive output, the required fraction may be considerably higher (Fogarty and Botsford 2007).

Table 1. Additional recommendations for amounts of area to protect in no-take marine protected areas

Suggested percent no-take	Details	Reference
~30 percent of reef area	To achieve fisheries (and conservation) objectives in the CT	(Jones et al. 2008)
20 percent	Generic advice	(Roberts and Hawkins 2000, NRC 2001, Roberts et al. 2003b)
30-50 percent	Generic advice — The larval replenishment offered by no-take areas is most effective for more depleted fisheries.	(Friedlander et al. 2003, Halpern and Warner 2003)
10 to 50 percent	Needed to sustain fisheries outside these reserves — exact amount varies depending on the objectives considered.	(Gell and Roberts 2003, Kaiser 2005, in Skilbred et al. 2006)
8 to 80 percent	Depends on the fishery — there is not one figure that will suit all species perfectly in terms of maximising yield.	(NRC 2001)
21-40 percent	Summaries of data for reef fish only	(NRC 2001)

The biological basis for any of these numbers have not been empirically tested in relation to specific habitats (Sale et al. 2005).

2.2.2.2 Other marine protected area zones

The discussion above is mainly restricted to no-take areas and recommendations for target species of interest. Other kinds of marine protected areas which allow take of target species can contribute to both maintenance of the fishery and EAFM objectives by reducing impacts on habitat, reducing impacts on by-catch and limiting access or gear (FAO 2010). There is general advice that all types of management of any fishery should extend throughout the spatial extent of the habitat of the fished stocks using, ideally, an EAFM framework (FAO 2003). Beyond this, we could find no advice as to proportions of this area that should be included in other types of marine protected area zones or categories. Despite this, some managers have implemented multiple-use zoning within their marine parks as indicated below.

2.2.2.3 Examples

Sites being implemented

Percentage targets for no-take areas, or marine protected areas, have been implemented in a few cases. For Karimunjawa National Park and Wakatobi Marine National Park in Indonesia, 100 percent of both parks are zoned for protection to some degree, including 0.4 percent and 3.16 percent in no-take areas respectively (Green et al. 2009b, Green et al. 2011). In the Philippines, in the Southeast of Cebu, a network of 22 marine protected areas exists that include about 6 percent of reef habitat in no-take areas with surrounding buffer zones which allow hook and line fishing only (Green et al. 2009b, Green et al. 2011). In the Verde Passage, about 1.5 percent of the 1.4 million hectares is included in marine protected areas (an increase of 1,500 percent since 2006; CI - Philippines 2007, CI 2010). Tubbataha Reefs National Park and World Heritage Site is the largest marine park in the Philippines (968.3 km^2) and is 100 percent no-take (Green et al. 2009b, Green et al. 2011). In the Solomon Islands, for Choiseul Province, a target of 10 percent of the original extent of each ecosystem type is included in protected areas (20 percent when considering climate change; Lipsett-Moore et al. 2010).

In the Channel Islands, off California, USA, 30 to 50 percent of each habitat in each biogeographic region was recommended to be included no-take marine protected areas (Airame et al. 2003). The Scientific Advisory Panel for the Channel Islands process estimated that this would conserve 80 percent of the species of concern (Airame et al. 2003). In 2004, 21 percent of the Channel Islands National Marine Sanctuary was included in 11 marine reserves distributed among the 5 islands comprising the island group (Airame and Ugoretz 2008).

On the Great Barrier Reef, in 2004, at least 20 percent of every bioregion (33 percent overall) was included in a network of no-take areas where the remaining area of marine park (encompassing most of the Great Barrier Reef ecosystem) is included in other categories of marine protected area (Great Barrier Reef Marine Park Authority 2004, Fernandes et al. 2005).

North central California, USA, recently implemented a network of marine protected areas using scientific advice that led to 20 percent of the region in marine protected areas, including 11 percent being no-take areas and much of the remainder allowing limited take of selected species only (Gleason et al. 2010).

Planned intervention

The CTI Regional and some NPoA state ultimate targets of 20 percent of each major near-shore habitat type within the CT region within no-take areas, plus a much larger amount in some form of designated protected status (Coral Triangle Secretariat 2009, DEC and the NFA 2009, Republic of Philippines 2009). Interim no-take area targets for 2020 have been set in some cases (e.g. Philippines 10 percent with ultimate targets of 20 percent; Republic of Philippines 2009). For the Solomon Islands, the target is 50 percent of Solomon Island coastal, watershed and inshore area under improved management through Community-Based Resource Management and Integrated Coastal Management approaches by 2015 (Solomon Islands CTI NCC 2009).

Indonesia's CTI NPoA aims for 20 million hectares of marine protected areas by 2020 (National Secretariat of the CTI-CFF Indonesia 2009).

In PNG, a planning process for Kimbe Bay used a target of 20 percent of each habitat and recommended that a total of 45 percent of coastal part of the planning area (<200 m deep) be included in marine protected areas (Green et al. 2007). In Timor Leste and Indonesia, the scientific design for the Lesser Sunda ecoregion of the CTI includes 20 percent in marine protected areas of each of the near-shore shallow habitats and for the deep sea yet near-shore habitats the targets varied from 5 to 100 percent depending on the conservation feature to be protected (Wilson 2006). The draft Indonesian Grand Strategy for Marine Conservation Area Networks also calls for at least a core of 20 percent no-take within each Marine Conservation Area (COREMAP II Ministry of Marine Affairs and Fisheries 2006). In Indonesia, further, examples include Berau Marine Conservation Area, which is planning to include 8 percent of its entire area in no-take marine protected areas (Green et al. 2009b). The systematic planning for the Sulu-Sulawesi Marine Ecoregion includes the establishment of functional integrated networks of marine protected areas within priority conservation areas, although planning does not involve numeric marine protected area spatial targets (Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003).

Other suggestions for the proportion of a region to protect within a marine protected area have been provided: ten percent is committed to by CBD party states (UNEP-WCMC 2008); 5 to 20 or 30 percent of critical habitat per planning area (Govan et al. 2008, Lowry et al. 2009); 30 to 70 percent averaging 30 to 40 percent (Pet and Mous 2002, The Ecology Centre The University of Queensland 2009); 4 to 66 percent for Tabina in the Philippines, for demersal and pelagic fish, respectively (Licuanan et al. 2006); 18 to 30 percent depending on the target species in the Florida Keys (Dahlgren and Sobel 2000 in Licuanan et al. 2006); 31 to 48 percent for the Seaflower marine protected area in the Caribbean (Friedlander et al. 2003).

Other studies provide general advice about the appropriate proportion to include in marine protected areas but stop short of suggesting any amounts (Roberts et al. 2003a, Roberts et al. 2003b, IUCN-WCPA 2008, Sale et al. 2010).

Given the extremely wide variety of species exploited in the Philippines and the broader CT (e.g. 350 species in Bolinao, NW Philippines; McManus et al 1992 in Licuanan et al. 2006; Sea Around Us Project[17]), it is unlikely that sufficient data will be available to allow for each species to be modelled to determine ideal levels of protection in each case (Licuanan et al. 2006).

One way forward is to implement the advice most likely to apply to the majority of species of interest; another may be to group fished species into taxa with similar life histories and patterns of habitat use and determine the different requirements per group of taxa. This report largely

[17] www.seaaroundus.org

adopts the former approach. The latter avenue was explored at an inaugural Marine Conservation Think Tank, held in Auckland, New Zealand December, 2011.

2.2.3 How big should the individual protected areas be within a network?

2.2.3.1 Research

If one is implementing a single marine protected area, especially a no-take area, where there is little other effective marine resource management, to ensure maintenance of the target species, the size of the marine protected area should be at least as large as the average dispersal distance of the larvae (and home range of adults) to ensure persistence of the population within its boundaries (Hastings and Botsford 2006). Where local information on target species dispersal distances and adult home ranges exist, it can be used to describe ideal marine protected area sizes for those species.

To date, known dispersal distances vary from a few hundred meters to hundreds of kilometers or even greater (Shanks 2009). Shanks (2009) hypothesise four functional types of larval dispersers:

1. Organisms with propagule durations of less than half a day that disperse in the order of meters to tens of meters. These are mainly colonial organisms (e.g. some corals, ascidians, bryozoans, algae);
2. Organisms with propagule durations of greater than or equal to half day to greater than 30 days, but with dispersal distances of less than 1 km. Species in this group appear to be inhabitants of shallow coastal environments, such as ornamental and other smaller coral reef fishes (Jones et al. 1999, Almany et al. 2007, Jones et al. 2010b);
3. Organisms with propagule durations of more than one week, and some dispersal distances greater than 20 km and adults that inhabit shallow coastal waters which include higher order coral reef fishes (Jones et al. 2010b); and
4. Species with long propagule durations (greater than one month), long dispersal distances (greater than 20 km), and adults that inhabit the waters over the continental shelf. There is the least amount of data for this group.

These kinds of data have led to advice that, to ensure persistence, individual no-take areas should be 4 to 6 km in diameter for short distance dispersers, which are many of the coral reef species (Shanks et al. 2003). As the size of an individual no-take area increases, longer distance dispersers meet the replacement criterion, and their catch exceeds that of the shorter-distance dispersers because of the greater area of spillover (Fogarty and Botsford 2007). There is advice that at least some individual marine protected areas should be relatively large (from several to tens of km alongshore length) to better accommodate mobile adult fish (Palumbi 2004, Botsford et al. 2009a, Gaines et al. 2010).

Other modelling studies have found that recruitment benefits outside boundaries are positive for no-take areas from 1, 5, 10 to 100 km in diameter, and that the benefits increase with the size of no-take area (Pelc et al. 2010, Pelc 2011).

However, if one is relying upon a network of no-take areas to help maintain stocks of fished species within and outside the marine protected area, then the individual size of each area can be much smaller (Gaines et al. 2010). Palumbi (2004) suggests a variation in reserve sizes (1 to 100 km in diameter) to accommodate the large variance in dispersal distances across taxa. Subject to considerations of the overall proportion of a habitat range with no-take areas (Section 2.2.2) and distances between the no-take areas (Section 2.2.4), other work suggests that individual marine protected areas can be small and still effective in terms of contributing to fisheries objectives (Russ and Alcala 1996, Steneck 2006, Fogarty and Botsford 2007, Jones et al. 2008, Lester et al. 2009). In some cases, including only ~0.1 km^2 of reef habitat in no-take areas is sufficient (Russ and Alcala 1996, Lester et al. 2009).

The latest coral reef studies show that small no-take areas (from 0.77 km^2 to 4.23 km^2 or 77 to 423 ha) containing even smaller areas of coral reef habitat (from 0.11 km^2 to 0.77 km^2 or 11 to 77 ha) can also be demographically connected, via larval dispersal to themselves (self-recruitment), to other no-take areas, and to the fished reef habitat outside the no-take areas (Jones et al. 2010b, unpublished data Great Barrier Reef Marine Park Authority, Williamson 2011). These data are for targeted reef fish species (e.g. coral trout, *Plectropomus maculatus* and stripy snapper, *Lutjanus carponotatus;* Jones et al. 2010b). Work in New Ireland, PNG, has confirmed these results: small no-take marine protected areas of around 0.5 km^2 or less (in this case protecting spawning sites of *Plectropomus aereolatus*) can help protect fish spawning biomass (Hamilton pers. comm.) This is also due to the connectivity between protected spawning sites, as well as the unprotected sites outside the no-take areas (Hamilton pers. comm.)

Other factors lend weight to the need for a minimum sized no-take area: species interactions, if considered important (and with ecosystem-based fisheries management they are considered important) increase the likely required minimum size (Baskett et al. 2007). This is more likely to be true for long-distance dispersers, top predators, specialists and inferior colonisers (Baskett et al. 2007).

The persistence and increased health of small no-take areas has been well explored (Halpern 2003, Alcala and Russ 2006, Lester et al. 2009, Maliao et al. 2009). The fact that it is possible that these small no-take areas contribute positively to local coral reef fisheries has also been shown (Alcala and Russ 2006). The evidence of larval demographic connectivity to other areas beyond the boundaries of even small marine protected area boundaries is new and supports a large body of theory (Palumbi 2004, Hamilton pers. comm., Jones et al. 2010b, Sale et al. 2010).

The literature reviewed shows the utility of small no-take marine protected areas; not just large ones.

Single large or several small protected areas

For fisheries, to maximize recruitment beyond boundaries, several small protected areas are likely to be better than a single large area of the same size (Hastings and Botsford 2003). This may be more accurate if there are high levels of local retention, which latest studies are revealing for nearshore coastal environments including coral reefs (Jones et al. 2007, Shanks 2009, Jones et al. 2010b).

Where habitat is discontinuous, the optimal reserve size to ensure larval retention may be constrained by the size of habitat patches (Palumbi 2004).

Overall, current research suggests either a range of sizes of marine protected areas (0.2 to 100 km in diameter) or a system of medium-sized marine protected areas would be most effective for fisheries (Halpern and Warner 2003, Palumbi 2004, Jones et al. 2007, Jones et al. 2008). Although, Halpern and Warner (2003) consider reserves of 10 to 100 km to be moderately sized.

2.2.3.2 Examples

Sites being implementation

The way local resource tenure systems can shape conservation outcomes has been identified as one of the top 100 questions of conservation importance (Sutherland et al 2009 in Weeks et al. 2010b). Within many coastal communities of the CT6, local tenure arrangements impact resource management options and decisions including size of marine protected areas (Cinner and Aswani 2007, Govan 2009, Weeks et al. 2010b). This means that the size of many marine protected areas have been, and are likely to continue to be, linked to the size of local tenure areas which are variable (from less than 1 to 5 km longshore extent to an offshore extent of 5 to 15 km; Johannes 2002, Aswani 2005, Weeks et al. 2010b).

A prime example of small no-take areas, albeit not in a marine protected area network, that has been shown to contribute to fisheries are Sumilon and Apo no-take areas in the Philippines. The two marine protected areas are 0.375 km^2 (37.5 ha, containing 25 percent of the coral reef of the island Sumilon) and 0.22 km^2 (22.5 ha, containing 10 percent of the coral reef of Apo island; Alcala and Russ 2006). Sumilon Island is also included in a broader initiative in SE Cebu encompassing 1,250 km^2 of water, including an inter-municipal integrated coastal management partnership. The area has 22 no-take marine protected areas with an average size of 0.14 km^2 (14 ha) and totalling an area of 3 km^2 (which is 6 percent of the reef habitat in the area; Green et al. 2009b). The entire Tubbataha Reefs Natural Park and World Heritage Site, also in the Philippines, is a 968 km^2 no-take area (Green et al. 2009b). In the Philippines overall, of the 852 marine protected areas with known area, 35 percent are less than 10 ha in size, and 48 percent are within 11 to 100 ha (Arceo et al. 2009). This is significant since, in 2000, 93 percent of the 311 marine protected areas with known area were less than 10 ha in size (Alino et al 2000 in Arceo et al. 2009). In the Solomon Islands, marine managed areas average 11 km^2 (1100 ha) in size, and in PNG they average 23 km^2 (2300 ha); these include multi-use areas and no-take areas (Govan 2009). No-take areas in PNG vary from 0.012 to 6.5 km^2 (1.2 to 650 ha), and in Solomon Islands from 0.001 to 157.8 km^2 (0.1 to 157 800 ha; Govan 2009).

Kurimunjawa National Park in western Indonesia is 1,106 km^2, of which 1,101 km^2 is sea. The entire area is zoned for some level of protection, including four no-take areas summing to an area of 445 km^2 (of which one comprises over half the total area; Green et al. 2009b). Wakatobi Marine National Park, Indonesia, is 13,900 km^2 and is a multiple-use marine protected area with 439 km^2 in no-take areas, varying in size from 365 km^2 to 13 $km^{2.}$ (Green et al. 2009b). The seven new marine protected areas in Raja Ampat, northwest Papua, Indonesia, encompass about 45 percent of the shallow-water coastal ecosystems of the Raja Ampat Corridor (CI 2011). Overall, Indonesia has 100 marine conservation areas which vary enormously in size. For example, just the 30 District Marine Conservation Areas range from 200 to 1,271,749 ha (2 to 12,717.49 km^2; Mulyana and Dermawan 2008).

Scientific advice given to the California Department of Fish and Game for California was "to best protect adult populations, based on adult neighbourhood sizes[18] and movement patterns, marine protected areas should have an alongshore extent of at least 5 to 10 km of coastline, and preferably 10 to 20 km. Larger marine protected areas would be required to fully protect marine birds, mammals, and migratory fish". And many of the no-take areas, especially when combined with other protected zones fulfilled these criteria when implemented in 2009 (Carr et al. 2010, Gleason et al. 2010).

On the Great Barrier Reef, scientific recommendations were for each no-take areas to be 10 or 20 km across at some point (Fernandes et al. 2005). Just less than half the 146 no-take areas implemented conformed to these requirements, and a large number of the individual areas were relatively small especially in more heavily used areas (e.g. 0.77 km^2, 1.47 km^2; Fernandes et al. 2005, unpublished data Great Barrier Reef Marine Park Authority). Data collected to date show these no-take areas are working in that both numbers and biomass of key target species have increased significantly. This is also likely influenced by the inclusion of at least 20 percent of locally available reef habitat within them (Fernandes et al. 2005, Russ et al. 2008, Jones et al. 2010b, Williamson 2011).

Planned intervention

Berau Marine Conservation Area in Indonesia is 12,000 km^2, and plans are to zone the entire area for different levels of protection, including no-take areas of a minimum size of 1.5 to 20 km^2 (Green et al. 2009b).

White et al (2006) advise that to help maintain coral reef fisheries, no-take areas should be at least 0.1 to 0.2 km^2 (10 to 20 ha). Ten hectares no-take areas have been reported in the past to show increases in the size and number of prized fish species in the Caribbean (Roberts and Hawkins 1997 in Roberts and Hawkins 2000). And Friedlander et al (2003) recommended a minimum size of 10 km^2 for no-take areas to be located in Seaflower Biosphere Reserve, now declared as a 65,000 km^2 multiple use marine protected area (Howard 2006). Govan et al (2008) recommend at least a 1 km longshore area of at least 100 m wide as a minimum size for an LMMA. IUCN-WCPA (2008) recommends marine protected areas that are 10 to 20 km across at their minimum dimension.

Advice on factors to consider when determining appropriate sizes of marine protected areas can also be found elsewhere and offer suggestions on size varying from 10 ha to 450 ha up to, an admittedly unrealistic, minimum diameter of 175 or 390 km, if truly aiming for a diameter at least 1.5 times the dispersal distance of larvae of the entire suite of resident species (NRC 2001,

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[18] A neighborhood, in this sense, centers on a set of parents and is an area that is large enough to retain them (i.e. includes the adult range) and most of the offspring of those parents. An "adult" neighbourhood refers only to adult movements and range (Palumbi 2004).

Salm et al. 2001, Roberts et al. 2003a, Roberts et al. 2003b, Shanks 2009, FAO 2010, USAID Program Integrator 2010).

2.2.4 How far apart should individual marine protected areas be within a network?

Research into the question about spacing of marine protected areas is, again, entirely focused upon no-take areas. We will explore this body of work, but also attempt to discuss implications for other levels of marine protection.

2.2.4.1 Ecosystem connectivity

There are different types of marine connectivity: ontogenetic connectivity between different habitats (where different life stages use different habitats); connections between the land and the sea; diurnal, tidal or other regular movements of adults between habitats; connections between different locations of the same habitat because of larval dispersal and recruitment patterns (Sale et al. 2010). All types of connectivity are important to ecosystem functioning including the distribution and abundance of plants and animals (Lindenmayer et al. 2008). It has been argued that strong connectivity within an ecosystem, and between no-take protected areas, helps populations to recover from disturbances through the links between populations, processes or food webs (e.g. Mumby and Hastings 2008, Sale et al. 2010).

In this section we explore the implications of larval connectivity on marine protected area network design. In Section 2.2.6 implications of other types of connectivity on design are discussed.

2.2.4.2 Research

The distance between marine protected areas is important because it determines, in part, the degree to which stocks of the same species are connected to each other (Sale et al. 2010). There are different types of connectivity between adjacent marine protected areas. Inside protected areas, adults can move into adjacent areas (Halpern et al. 2010). Data show that these distances, for mainly sedentary or mobile (versus high mobile species)[19], are in the order of 600 to 800 m, assuming that "fishing the line" of the marine protected area boundary does not preclude the movement (Halpern et al. 2010).

Ontogenetic connectivity exists, for example, when different life stages of a species use different habitats within an ecosystem (Jones et al. 2010a). If protection is offered to the entire suite of habitats used by a species throughout its life, and the protected areas are located close enough to each other to allow access to individuals moving between them, then multiple marine protected areas can offer holistic (in terms of life stages) protection to the species involved (Sale et al. 2010). Individuals can also use different habitats on a daily basis (e.g. day and night) so could

[19] As defined by Fishbase: www.fishbase.org

also potentially benefit from appropriately spaced protected areas that include different habitats (Sale et al. 2010).

The larval connectivity pertaining to spacing of marine protected areas is called population connectivity and has two forms: 1) genetic connectivity and; 2) demographic (or ecological) connectivity (Sale et al. 2010). Genetic connectivity refers to the amount of gene flow occurring among populations over generations and determines the genetic differences among those populations. A very low level of gene transfer (one or two individuals per generation) can be enough to result in genetically similar populations (Sale et al. 2010). At much higher rates of larval connectivity, population demographics such as recruitment can be positively impacted and so influence population growth (Sale et al. 2010). This is termed demographic connectivity and is of most concern to fisheries managers as it can involve the greatest contribution to sustaining or enhancing fished stocks (Ward and Hegerl 2003, FAO 2010).

Both types of population connectivity between spatially separated populations located in separate marine protected areas matter because they can help:

- maintain or build the overall population within a region;
- the regional population as a whole withstand external impacts within any one part of its range;
- maintain adequate gene flow throughout the extent of the population; and
- replenish depleted areas of the population (Sale et al. 2010).

Optimal spacing of marine reserves in a network is strongly influenced by the spatial scale of movement of the target species (Palumbi 2004, Gaines et al. 2010). In particular, the scales of larval movement can determine the distances between marine protected areas that allow for demographic connectivity (Botsford et al. 2003, Palumbi 2004, Kaplan and Botsford 2005, Botsford et al. 2009a, Shanks 2009, Gaines et al. 2010). If each protected area can enhance the rate of population growth in the other areas (by being adequately connected), then this population synergy potentially can result in increased numbers both within protected areas and outside (Neubert 2003, Gaines et al. 2010).

Shanks (2009) gathered data on the larval dispersal of 67 tropical and temperate marine species (including algae, invertebrates and fishes), and found it to vary from less than 1 m to 500 km. On average, actual dispersal distances are significantly less than potential distances as might be indicated by larval (propagule) duration (Botsford et al. 2009b, Shanks 2009). For example, some fish larvae, with a life of 10 to 48 days, might only travel 100 to 500 m (Jones et al. 1999, Almany et al. 2007), while others travel up to about 50 km (Shanks 2009). For some coral trout and snapper larvae, with a duration of 28 to 42 days, have been shown to travel from 100 to 500 m up to ~30 km (Jones et al. 2010b). Recent work in Manus, PNG, confirms that larval dispersal distances of ~1 to 30 km (and adult movements from ~1 to 10 km) are common for the coral trout, *Plectropomus aereolatus* (Hamilton pers. comm.). This confirms that spacing of no-take areas from at least 1 to 30 km apart can be effective in terms of demographic connectivity for this species (Hamilton pers. comm.). The latter pieces of work are particularly interesting from a fisheries management point of view as these larval characteristics would allow for self-recruitment within a relatively small protected area, as well as larval spillover to outside a protected area.

In the CT, many species can be important in the small-scale, nearshore fisheries that matter to coastal communities (Nanola Jr et al. 2010). Each species will have its own life history characteristics and behaviours that impact upon, for example, larval dispersal distances and, therefore, what spacing of marine protected areas would be effective for it (Shanks 2009).

Data are not available on larval dispersal distances for all the species of importance to coastal CT communities and if they were, they would likely be different for different species (Jones et al. 2007). The possibility of grouping taxa with similar life histories and habitat requirements to consider common marine protected area network design needs per group was explored at the inaugural Marine Conservation Think Tank in Auckland, New Zealand in December 2011.

This lack of information is not unique to the CT, and scientists have consolidated existing information into advice about optimal spacing of marine protected areas given the uncertainty (Sale et al. 2010). Sale et al (2010) suggest locating no-take marine protected areas 10 to 30 km apart. Gaines et al (2010) recommend 10 to 100 km distance between protected areas. The lower-than-expected dispersal distances found for larvae suggest that the distances between adjacent marine protected areas need to be less (Jones et al. 2007). Shanks et al. (2003) recommend a spacing of 10 to 20 km for species with typical pelagic larval durations to promote connectivity among adjacent reserves.

At high fishing rates and small reserve sizes, variable reserve placement have a positive local effect on catch and recruitment when several reserves were located close to each other (Kaplan and Botsford 2005). Variable reserve spacing can offer additional protection to overfished populations (Kaplan and Botsford 2005). Palumbi (2004), Halpern and Warner (2003) and Roberts et al (2003) also argue for variation in spacing (10 to 200 km; Palumbi 2004), but the reasoning is to reflect the likely variation in the dispersal abilities of numerous species of target fish and invertebrates.

Where habitat is discontinuous, the optimal spacing of marine protected areas to ensure larval connectivity may be constrained by the spacing of habitat patches (Palumbi 2004).

2.2.4.3 Examples

Sites being implemented

As with the issue of size of marine protected area (Section 2.2.3.2), for many coastal communities of the CT6, local tenure impacts upon options and decisions for spacing of marine protected areas (Cinner and Aswani 2007, Govan 2009, Weeks et al. 2010b). Some larger-scale conservation efforts are exploring the inclusion of one marine protected area within each area under local community tenure (e.g. Solomon Islands; Lipsett-Moore et al. 2010). Others are also aiming to spread the costs and benefits of multiple (potentially networks of) marine protected areas across local communities' tenure areas (e.g. Philippines, Indonesia, Timor Leste, PNG, Solomon Islands; Govan 2009, Green et al. 2009a, Weeks et al. 2010b, Grantham and

Possingham 2011, Wilson et al. 2011). In terms of spacing of marine protected areas within a region of interest, this has translated to spreading the location of marine protected areas across the units of area under local tenure.
This means that spacing of any marine protected areas (as per size) has been, and is likely to continue to be linked to the size of local tenure areas and other governance and jurisdictional boundaries (Johannes 2002, Aswani 2005, Weeks et al. 2010b).

In the Philippines, SE Cebu, individual marine protected areas are located at a distance of less than 1 km to less than 10 km apart, as this matches local government area boundaries (IUCN-WCPA 2008, Green et al. 2009b). In Wakatobi Marine National Park, Indonesia, no-take areas were located within the larger marine park using rules of thumb for larval dispersal and are between 10 to 20 km apart (Green et al. 2009b). In Raja Ampat, however, the seven marine protected areas declared in 2007, are located from 12 km to ~50 km to just over 100 km apart (CI 2011, Grantham and Possingham 2011). In the Verde Island Passage there are approximately 70 marine protected areas separated by distances of less than 1 km and up to ~10 km apart at most (Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) 2009, CI 2010). Larval dispersal was explicitly considered, through application of rules of thumb, in the most recent zoning plan for Karimunjawa National Park, Indonesia leading to protection zones from less than 1 km to ~10 km apart (Green et al. 2009b).

From elsewhere in the world, we can see that desired distances between marine protected areas (or no-take zones) were sometimes not specified in detail (e.g. Great Barrier Reef Marine Park, Airame et al. 2003, Fernandes et al. 2005). In the case of the Great Barrier Reef, a huge variety of distances between no-take zones (from a few km to tens of km) was implemented in 2004[20]. In the Channel Islands off California, USA, scientists recommended no more than 50 to 100 km between marine protected areas which was then implemented successfully (National Marine Sanctuary Program 2007). The recent marine protected area planning process in north central California implemented scientific recommendations of distances between areas of 50 to 100 km in 2009 (Gleason et al. 2010).

Planned intervention

In Berau Marine Conservation Area, Indonesia, no-take zones within a larger conservation area were proposed to be 500 m to 40 km from each other (Green et al. 2009b). Green et al (2007) proposed that marine protected areas for Kimbe Bay, PNG, be located 2 to 35 km apart, and with only one separated by more than 15 km to the next nearest area. For the Lesser Sunda Marine Ecoregion, Wilson et al (2011) designed a network of multiple-use marine protected areas (including existing marine protected areas and areas of interest) of 100 to 200 km distance between individual areas to maintain genetic connectivity.

IUCN-WCPA (2008) suggests a spacing of 10 to 20 km, up to 50 to 100 km between individual marine protected areas and recommends variable spacing, as opposed to even spacing. Jones et

[20] www.gbrmpa.gov.au; accessed 5/18/11

al (2008) also advocate varying distance between no-take marine protected areas for the CT, in particular.

2.2.5 What shape should individual marine protected areas be within a network?

Two factors inform decisions about the ideal shape of any marine protected area: 1) the concept of edge effects; and 2) the need to facilitate compliance with simple boundaries identifiable by landmarks or, in some cases, with simple coordinates (Friedlander et al. 2003, Govan et al. 2008, IUCN-WCPA 2008). Coordinate-based boundaries are probably less useful in locations where compasses or GPSs are not commonly used.

The more edge a reserve has, the faster it will export or spillover larvae, especially adults relative to the total protected area (Roberts et al. 2001). For fisheries objectives, the marine protected area should maximize the "edge effect" by using shapes that have a great deal of edge per unit volume (Halpern and Warner 2003). Marine protected areas that are rectangular will offer a large edge per unit volume (compared to a circle; White et al. 2006). In theory, a rectangle can also offer a relatively simple border to enhance compliance (IUCN-WCPA 2008).

Real-world examples show some success in creating marine protected areas, or zones within them, with simple boundaries (mainly using straight lines, squares or rectangles) for compliance purposes (e.g. Karimunjawa National Park, Indonesia; Tubbataha Reefs Natural Park and World Heritage Site, Philippines; Raja Ampat, Indonesia; Great Barrier Reef Marine Park, Australia; north central California, USA; Green et al. 2009b, Gleason et al. 2010, Grantham and Possingham 2011, GBRMPA 2011). The logic of using simple and identifiable boundaries that align with known landmarks has been applied often in the creation of marine protected areas in the CT, but very little has been documented about the application of this design principle.

The authors could find no references of real world examples of implementing specific shapes of marine protected areas with the stated purpose of enhancing spillover, despite the few written examples identified having shapes that do just that (as discussed above).

There are also new planning processes underway that are aiming to support implementation of simply shaped marine protected areas to foster compliance, as opposed to edge-effects (e.g. Kimbe Bay, PNG; Lesser Sunda Ecoregion, Indonesia and Timor Leste; Green et al. 2009a, Wilson et al. 2011).

2.2.6 Where should the marine protected areas be located?

For fisheries, biophysical factors to consider in terms of location of marine protected areas in a network include:

- Representation of the diversity of fish habitats within the region of interest
- Different but contiguous fish habitats, where possible
- Spawning and other types of aggregation sites
- Juvenile and nursery areas

- Breeding areas
- Migration routes
- Movement of currents
- Larval source areas
- Existing uses and threats, and
- Marine protected area boundaries within habitats to encourage spillover

(NRC 2001, Roberts et al. 2003a, White et al. 2006, IUCN-WCPA 2008, Mumby and Hastings 2008, Lowry et al. 2009, Gaines et al. 2010, Sale et al. 2010, Secretariat of the Pacific Community 2010).

These factors are considered in more detail below. Many other socio-economic, political and governance factors will also influence the location of any marine protected areas (e.g. tenure or jurisdictional boundaries; enforcement; complementing human uses and values). These are not within the scope of this report.

2.2.6.1 Represent the diversity of fish habitats and contiguous habitats

The tropical coastal small-scale fisheries in the CT target multiple species, and some of these species use different coastal habitats (Gaines et al. 2010, McConney and Charles 2010, Pomeroy and Andrew 2011, Sea Around Us Project 2011). In addition, different life stages of the same species may use different habitats (Ward et al. 2001, Palumbi 2004, Gaines et al. 2010, Sale et al. 2010). Because the number of species that are important in any of the CT nearshore fisheries may be large (Nanola Jr et al. 2010, Sea Around Us Project 2011), there is an extremely high likelihood that every coastal habitat will be important for at least one of the target species at some stage in their life. Some studies have found that, to maintain the connectivity of the habitats for different species, it is also important to protect different but adjacent fish habitats within a marine protected area (Mumby and Hastings 2008, Mamauag et al. 2009, Jones et al. 2010a; see Section 2.2.4.2).

For these reasons, it is important to try to protect adequate examples of all coastal habitats within a region (ideally multiple, contiguous habitats also from inshore to offshore) in marine protected areas (Palumbi 2004, IUCN-WCPA 2008, Lowry et al. 2009, Gaines et al. 2010) including within the CT (Jones et al. 2008). Where biological data area inadequate, geomorphological data, or even more simple surrogates, could be used to help define habitats (Roff and Taylor 2000, P. Alino pers.comm., Roff et al. 2003, Kerrigan et al. 2011). Simple surrogates may include: depth, distance from shore, hard seabed substrates (e.g. coral reefs) versus soft seabeds, areas under river influences, current type and geographic spacing. Representing the range of habitats is similar to taking a system-wide approach to designing a network of marine protected areas – which aligns well with an ecosystem approach to fisheries management (Christie et al. 2009a, McCook et al. 2009).

This conforms with CT6 intentions stated in CTI Regional and National PoAs (e.g. Coral Triangle Secretariat 2009, DEC and the NFA 2009, Republic of Philippines 2009) and other linked planning processes in the region (e.g. Indonesia's draft Grand Strategy Marine Conservation Area Networks; Kimbe Bay, PNG; Lesser Sunda, Indonesia and Timor Leste;

Choiseul, Solomon Islands; Berau Marine Conservation Area, Indonesia; Sulu-Sulawesi Marine Ecoregion, Malaysia, Philippines and Indonesia; Raja Ampat, Indonesia; and advice about the LMMA process; Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, COREMAP II Ministry of Marine Affairs and Fisheries 2006, Govan et al. 2008, Green et al. 2009a, Green et al. 2009b, Lipsett-Moore et al. 2010, Grantham and Possingham 2011, Wilson et al. 2011).

Many places in the CT are, or have already, implemented marine protected areas or networks that encompass a diversity of coastal habitats (e.g. Raja Ampat, Indonesia; Choiseul, Solomon Islands; Berau Marine Conservation Area and Wakatobi Marine National Park in Indonesia; SE Cebu Network and Tubbataha Reefs Natural Park in the Philippines; Green et al. 2009b, Lipsett-Moore et al. 2010, Grantham and Possingham 2011).

2.2.6.2 Include critical habitats

Spawning and other types of aggregation sites, juvenile and nursery areas, breeding and foraging areas and migration routes between these sites are all important locations for fished species and, at some of these locations, gathered individuals are disproportionately vulnerable to impacts, such as fishing, often leading to stock decline (Lowry et al. 2009, Sale et al. 2010, Sadovy and Clua 2011). Reef fish are particularly well known to aggregate for spawning, including fish found in the CT such as grouper, snapper, coral trout, wrasse and bass[21]. What many of these types of ontogenetically critical sites share is the seasonal, and sometime predictable, nature of their importance (Sadovy and Clua 2011).

For these reasons, scientific advice is to protect all sites that are important to critical life stages of targeted species (FAO 2006, IUCN-WCPA 2008, FAO 2009, Lowry et al. 2009, Sale et al. 2010, Sadovy and Clua 2011). This type of reasoning for marine area protection has, in part, been applied for decades, if not hundreds of years, in different locations in the CT (Cinner and Aswani 2007). In particular, documented examples include protection of spawning aggregations in New Ireland, PNG and spawning aggregations in Wakatobi Marine National Park, Indonesia (Green et al. 2009b, Hamilton et al. 2011).

Other planning processes in the CT are taking into account critical habitats (e.g. Indonesia's draft Grand Strategy Marine Conservation Area Networks; Berau Marine Conservation Area, Indonesia; Kimbe Bay, PNG; Lesser Sunda Marine Ecoregion, Timor Leste, Indonesia; Sulu-Sulawesi Marine Ecoregion, Malaysia, Indonesia, Philippines; Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, COREMAP II Ministry of Marine Affairs and Fisheries 2006, Green et al. 2009a, Green et al. 2009b, Wilson et al. 2011).

[21] http://www.scrfa.org/, accessed 5/24/11

Once again, given the diversity of target species in the nearshore CT environments (Nanola Jr et al. 2010, Sea Around Us Project 2011), it is likely that many locations within coastal habitats will be used, at some time, for some aspect of the lifecycle of at least one fished species. Comprehensive data on all sites that are important for all stages of the life cycle of all species targeted within CT small-scale coastal fisheries are absent. Where locals do have this information, it can be used to prioritize locating protected areas to accord with the local fishery specific objectives of the marine protected area. Where this information is not available, protecting examples of every habitat is recommended.

2.2.6.3 Accommodate currents and larval source areas

Sometimes information is available about the areas within a region that are a source of larval recruitment and which are sinks (Sale et al. 2010). Sink populations are those that fail to replenish themselves and are stocked by dispersing surplus from other populations, which serve as sources (Sale et al. 2010). It is likely that few populations can be permanently labelled as sources or sinks (Sale et al. 2010). However, Sale et al (2010) suggest that source populations should be considered more important and should be considered the priority for protection in marine protected areas. Protecting a source population can help compensate for harvest lost from a no-take marine protected area, depending on the life history and demography of the species of interest (Hart and Sissenwine 2009, Kaplan 2009, White 2009 in Gaines et al. 2010).

Others agree that protection of source populations in marine protected areas should be a priority (Allison et al. 1998, Ward et al. 2001, Jones et al. 2007, IUCN-WCPA 2008, McCook et al. 2009, Gaines et al. 2010) including in the CT context (Jones et al. 2008). It is particularly important for fisheries to protect the source populations as opposed to displacement of fishing into source areas (Crowder et al. 2000).

Interestingly, Gaines et al (2010) consider that for fisheries, it is important to protect the greatest sources and sinks, as well as intermediary areas to account for heterogeneity in larval dispersal. This view is particularly relevant in multi-species fisheries, which are data poor (in terms of knowledge of the location of sources and sinks), as is the case in most tropical, developing country small-scale coastal fisheries (Pomeroy and Andrew 2011). The implications of the advice from Gaines et al (2003) is that protecting replicate examples of every habitat type is likely to account for heterogeneity of larval source and sink sites – which is useful to know for data poor situations. Obviously, where local knowledge can identify larval sources, this information should inform marine protected area design.

Currents can influence the direction and degree to which larvae from any source are dispersed (Gaines et al. 2003, Palumbi 2004) although perhaps not as influential on the distances travelled as originally thought (Cowen et al. 2007, Shanks 2009; Section 2.2.4). Nonetheless, larvae released are more likely to move down current, and factoring such potential movements into reserve design can be important (Gaines et al. 2003, Sale et al. 2010). Therefore, within the management area being considered, potential source areas which are at the downstream end of the management boundary may be less likely to contribute to larval recruitment within the management area than sources located at the upstream end of the management area (Gaines et al. 2003).

It has been broadly agreed that consideration of oceanographic processes and currents is important in marine protected area design and that, in particular, protected areas should be located upstream of unidirectional currents (Crowder et al. 2000, White et al. 2006, IUCN-WCPA 2008, Lowry et al. 2009, FAO 2010, Sale et al. 2010). However, if currents and oceanic processes are complex, or reversible or unknown, then an even spread of marine protected areas throughout the management area is recommended (IUCN-WCPA 2008; see Section 2.2.4).

In the CT, protection has been afforded to some sites identified as larval sources, including considerations to currents and other water movements (e.g. Tubbataha Reefs Natural Park[22]); some areas (Calamianes and Tawi-Tawi) within the Philippines, USAID FISH Project (Fisheries Improved for Sustainable Harvest, FISH, Project 2010).

In CT planning processes, the issue of prevailing currents and sources versus sinks of larval recruitment is being considered (e.g. Lesser-Sunda Marine Ecoregion, Timor Leste, Indonesia; Sulu-Sulawesi Marine Ecoregion, Malaysia, Philippines, Indonesia; Kimbe Bay, PNG; Tun Sakaran Marine Park, Malaysia; Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, Wood 2006, Green et al. 2009a, Wilson et al. 2011).

2.2.6.4 Consider existing uses and threats

This discussion assumes that marine protected areas are being considered for areas that are used for fisheries and other purposes and have suffered impacts from those anthropogenic uses. In this way, the marine protected areas will be contributing to restoration and rehabilitation of habitats, fisheries and biodiversity. Beyond this, however, there will always be difference in the degree to which areas have been damaged, and this has implications on decisions about where to locate them.

Proposals for locations of new marine protected areas should factor in existing and future uses and threats, such as existing protected areas and other existing management frameworks, existing fishing areas, existing tourism uses, mining activities, the threat of climate change (this is discussed more in Section 4), shipping, marine and adjacent land tenures, adjacent land use, catchment quality and consequent inbound water quality (Kelleher 1999, Jameson et al. 2002, Cinner et al. 2005c, Armada et al. 2009, FAO 2009, Lowry et al. 2009, McConney and Charles 2010, Agardy et al. 2011b). From a biophysical design point of view, factoring in existing and potential future uses and threats helps achieve two purposes:

1. Increase the likelihood of survival of protected areas from impacts of external threats by, where possible, locating them to minimising the probability or degree of impact(s); and
2. Encourage compliance due to complementarity with existing uses

(Jameson et al. 2002, Allison et al. 2003, Roberts et al. 2003a, IUCN-WCPA 2008, The Ecology Centre The University of Queensland 2009, Sale et al. 2010).

[22] www.tubbatahareefs.org, accessed 5/25/11

In addition, (Smith and Wilen 2003, and Sanchirico 2004; both in Gaines et al. 2010) recommend that if the local fishery has been over-exploited, then locate no-take marine protected areas near ports and other heavily fished areas to foster rehabilitation of the fishery and also early spillover success. They also suggest that if the fishery is not over-exploited and spillover effects are not expected, then place no-take areas further from port to minimize displacement (Gaines et al. 2010).

Accounting for existing and potential future uses and threats intertwines planning for networks of marine protected areas with broader planning frameworks such as marine spatial planning, ocean zoning or ecosystem-based fisheries management (Ehler and Douvere 2009, Agardy 2010, FAO 2010).

Designing marine protected areas with consideration of existing uses and threats is common, especially with regard to fishing uses, albeit more often to minimize conflict than to avoid degraded habitats (Ward et al. 2001, White et al. 2006). Complementing fishing uses and other uses and threats occurred, for example, with Karimunjawa National Park, Indonesia; SE Cebu, Philippines; the Great Barrier Reef Marine Park, Australia; as well as in California, USA (Great Barrier Reef Marine Park Authority 2004, Green et al. 2009b, Gleason et al. 2010).

Some documented examples of accounting for existing uses and threats in planning include the Lesser Sunda Marine Ecoregion, Timor Leste and Indonesia; Kimbe Bay, PNG; Raja Ampat, Indonesia; Berau Marine Conservation Area, Indonesia (Green et al. 2007, Green et al. 2009b, Grantham and Possingham 2011, Wilson et al. 2011).

2.2.6.5 Use local knowledge

The general principles about placement of marine protected areas will often be informed by detailed species and taxa specific information that local resource users have about fishes and information about human use patterns within any local area (Johannes 1998, Aswani and Lauer 2006).

2.2.7 The importance of replication

The three most important reasons to replicate representation of habitats within a network of marine protected areas are:

1. Several smaller marine protected areas, especially no-take areas, are more likely to deliver greater benefits to areas available to fishing than one large area (Allison et al. 1998, Gaines et al. 2010);
2. To provide insurance against human or natural disturbances in the hope that some of the protected areas will escape damage and be a source of replenishment for impacted protected and other adjacent areas (Nilsson 1998 in Kelleher 1999, Ward et al. 2001, Gaines et al. 2010); and
3. To manage for the uncertainty associated with habitat heterogeneity. Habitat diversity and complexity is often poorly understood, and replication of protected areas increases the likelihood that all aspects of all habitats and communities are represented within any network

of protected areas (Crowder et al. 2000, Roberts et al. 2003a, FAO 2010, NRC 2001, IUCN-WCPA 2008).

Another reason to replicate marine protected areas within habitats is to support adaptive management. This occurs by providing enough replicates and, therefore, analytical power for studies on marine protected area effectiveness, such as changes in populations and communities inside and outside marine protected areas (Hilborn et al. 2004, IUCN-WCPA 2008).

The design criterion of replication is being, and has been, applied both explicitly and implicitly in the CT and beyond. For example, it has been applied in the Verde Passage, SE Cebu and elsewhere in the Philippines, where adjacent municipalities have included coastal habitats within marine protected areas. In 2007, the Raja Ampat government declared six additional (seven total) marine protected areas within its jurisdiction. In Choiseul, Solomon Islands, three to five replicates were suggested and largely implemented, and also in the Great Barrier Reef, California Channel Islands and North-Central California. (Fernandes et al. 2005, National Marine Sanctuary Program 2007, Green et al. 2009b, CI 2010, Fisheries Improved for Sustainable Harvest (FISH) Project 2010, Gleason et al. 2010, Lipsett-Moore et al. 2010, Grantham and Possingham 2011).

Currently, PNG and Solomon Islands have 166 and 127 marine managed areas of which some may serve as replicates; this function of the sites has not been explored (Govan 2009). Similarly, Indonesia has 100 marine conservation areas, some of which may function as replicates of each other (Mulyana and Dermawan 2008).

Replicate marine protected areas are also planned for: Kimbe Bay, PNG; in the more detailed planning of Raja Ampat; in the Lesser Sunda marine ecoregion; in the broader Sulu-Sulawesi marine ecoregion and elsewhere (Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, Green et al. 2007, Grantham and Possingham 2011, Wilson et al. 2011).

2.2.8 Type of protection possible within the marine protected area network

Many types and levels of protection can be offered within marine protected areas and are discussed in Attachment 2. That discussion is not repeated, but the types of protection that could be useful to achieving fisheries objectives are presented here.

2.2.8.1 No-take areas

Much of the research and advice discussed above pertains either explicitly or implicitly to no-take areas (e.g. Lubchenco et al. 2003, Jones et al. 2007, Gaines et al. 2010, Sale et al. 2010). Gaines et al. (2010) state that "When a fishery is being overexploited or when environmental or management uncertainty exists then *no-take areas* benefit fisheries across a greater set of species" (Hart 2006, Stefansson and Rosenberg 2005, Grafton et al 2005). Therefore, in the CT, no-take area should be one of the types of protection offered within a marine protected area network designed to achieve fisheries objectives.

2.2.8.2 Seasonal no-take areas

In theory, some of the seasonal and ontogenetic habitat and site uses by fished species could be protected with temporary no-take areas such as seasonal or other temporal closures (NRC 2001, Hilborn et al. 2004, Fogarty and Botsford 2007, IUCN-WCPA 2008). Seasonal closures (e.g. for spawning) are well known management tools in many traditional societies in the CT and elsewhere (Cinner and Aswani 2007, FAO 2010). Another approach to use is "open" fishing seasons, where a specified area is available for fishing only during a designated time of year (FAO 2010). Seasonal no-take areas have been identified at tools of potential use within the context of the CTI (e.g. DEC and the NFA 2009, Republic of Philippines 2009, TNC et al. 2010).

Seasonal no-take areas require knowledge of which target species are the most important (and assumptions that this will remain constant) and about their temporal habitat, site or migratory requirements (and assumptions that this will also remain constant; IUCN-WCPA 2008, Sadovy and Clua 2011). It assumes that the current target species are the most desirable, and that no "fishing down the line" (no change to a lower value target species over time due to overfishing of the preferred species) has occurred (Pauly 2010). Seasonal no-take areas assume that there are few target species so that only a few seasonal closures are required to be useful to the fisheries; otherwise the implementation of multiple different seasonal closures to protected different stages of different species becomes unfeasible.

2.2.8.3 Other temporal closures

Long-term, but not permanent, closures can have significant and positive impacts upon fished (and other) species in the CT, for example in remote, low population communities with well-defined tenure rights and local management (Cinner et al. 2005a, Cinner et al. 2005b, McClanahan et al. 2006). They might be put in place to align with: a particular (non-seasonal) lifecycle phase of a locally important species; a local feast; a death; replenishment of over-fished species; when school fees are due; or a range of other reasons (Cinner and Aswani 2007). They can potentially help maintain stocks or even help to recover or restore stocks of targeted fish species. In one example, reefs are opened to fishing for 2 to 3 hours, three times per year (Cinner et al. 2005a). Often the rate of exploitation upon opening of the protected area has a significant, long-term and extremely detrimental effects on fished populations, especially longer-lived species (Russell 1998, Foale and Manele 2004, McClanahan et al. 2006). The impacts of short periods of fishing can, for example, remove stocks that have taken up to a decade to build (Russell 1998, Russ 2002, Russ and Alcala 2004, McClannahan 2000, McClanahan and Graham 2005 in Cinner et al. 2005b).

Temporary closures, which are mobile in space and time, have also been considered useful in ecosystem-based fisheries management, in terms of reducing unwanted by-catch at least cost to the fishers (Grantham et al. 2008). However, the benefits of this approach need to be weighed against the potential confusion and costs of implementing a spatially and temporally variable spatial management regime (Grantham et al. 2008).

2.2.8.4 Rotational closures

Rotational closures involve the relocation of no-take areas from one (or one set) of location(s) to another at set times (Game et al. 2009, Kaplan et al. 2010, Kompas et al. 2010). Rotational no-take areas are well known to both conventional and traditional fisheries resource users and managers (Cinner and Aswani 2007, FAO 2010, Kaplan et al. 2010), and are now a tool within the broader ecosystem management toolbox (NRC 2001, IUCN-WCPA 2008). They are receiving more attention due to the political realities associated with permanent no-take areas and can also potentially deliver fisheries benefits (Game et al. 2009). Fisheries benefits can be realized with rotational closures, though potentially at the cost of ecosystem benefits (Chu et al 2008 in Kompas et al. 2010). Some argue that this requires the rotational periods to be at least long enough to be commensurate with the life history of the species being protected so that there can be an increase in biomass (and eggs) per recruit (Botsford et al. 1993 in Kaplan et al. 2010). With this provision, fisheries benefits would be realized even if effort is fully redistributed outside closure areas (Hart 2003 in Kaplan et al. 2010). Longer rotational period reduces the dependence of results on fishing effort, limiting the impact of overfishing (Kaplan et al. 2010). In fact, some data are showing that short-term (annual) rotational closures can be ineffective at contributing to fished stocks, but rather that stocks, and average size of fish, have been shown to continue to decline when rotational closures are in place despite recovery of the stocks during periods of closure (Williams et al. 2006).

2.2.8.5 Gear restrictions

Another type of marine protected area (or spatial fisheries management tool) is one that restricts the amount or type of fishing gear permitted to be used within it (FAO 2010). Already, within the CT, fishing with destructive fishing gear is prohibited in most areas (e.g. fishing using cyanide or dynamite), although it often still occurs (Cesar 2000, FAO 2011; see also the Fisheries Law [Law 31/2004] Indonesia, Fisheries Law Malaysia[23], Philippine's Republic Act 8550[24] and FAO Country Fisheries Law[25]). Gear restrictions are often perceived as more beneficial than implementation of no-take areas (McClanahan et al. 2009, Pomeroy 2011) and can help improve catch in, some instances, but may not necessarily contribute to broader goals of an ecosystem approach to fisheries management (Cinner et al. 2005a). Unfortunately, in many small-scale coastal fisheries, gear restrictions have been found to be ineffective for the same reason other effort controls have been ineffective: poor fisheries management overall (Pomeroy 2011).

2.2.8.6 Access restrictions

Marine protected areas, as well as other spatial tools (e.g. local government boundaries in the Philippines; White et al. 2006), can be used to restrict fishing access to reduce negative impacts on resources and enhance sustainability (Guidetti and Claudet 2009, McConney and Charles 2010, Stephenson and Lane 2010, Pomeroy 2011). The restrictions may apply to favor local versus "outside" fishers (Pauly 2010). This sometimes occurs in the case of LMMAs – the

[23] http://www.agc.gov.my/Akta/Vol.%207/Act%20317.pdf
[24] http://www.lawphil.net/statutes/repacts/ra1998/ra_8550_1998.html
[25] http://www.fao.org/docrep/010/ag115e/AG115E05.htm

boundaries of which often align with local tenure systems (Govan 2009). In PNG and the Solomons, approximately 97 percent and 87 percent of land tenure is estimated to reside under customary tenure which may be amenable to these kinds of controls (Govan 2009, Weeks et al. 2010b).

An alternative form of limiting access could be through licenses, allowing some users access to particular spatial areas or zones (as promoted in the FISH project in the Philippines; Christie et al. 2007); such access could be conditional upon, for example, ongoing demonstration of ecologically sustainable practices (e.g. Guidetti and Claudet 2009; for another example see Australian Government Department of Sustainability, Environment, Water, Population and Communities[26]).

2.2.8.7 No-go areas

From a fisheries point of view, the benefits of a no-go area include:-

- Easier enforcement, which provides more certainty of compliance to no fishing regulations (enforcement is simpler if access is not allowed within an area); and
- Relatively "pristine" reference data for assessment of impacts of all uses, not just fishing.

These may seem to be relatively minor benefits until one considers the Great Barrier Reef Marine Park finding significant differences in shark populations within no-take versus no-go zones (Robbins et al. 2006). These studies found no significant difference between no-take areas and fished areas for sharks on the Great Barrier Reef, and an order of magnitude more sharks in areas that allowed no access (except for research with a permit; Robbins et al. 2006). It is very likely these findings point to an amount of illegal fishing in the no take areas as compared to the no-go areas[27].

Furthermore, non-extractive uses of coral reefs (e.g. diving) have been found to have negative impacts on habitat with likely limits to sustainable use (Hawkins et al. 1993, Harriett et al. 1997). Thus, having the ability to ensure effectiveness of any protection established can be useful, and no-go areas can help with this effort.

2.2.8.8 Relationship to IUCN categories of marine protected areas

The WCPA – Marine (2010) is working on a draft document that describes a standardized list of different levels of protection that could be offered within any marine protected area. This list complies with the IUCN categories of protected areas (Dudley 2008) and is discussed further in Attachment 2.

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[26] http://www.environment.gov.au/coasts/fisheries/ accessed 31/5/11

[27] Enforcement activities on the Great Barrier Reef have, while this study was being conducted, been reviewed and improved (Bishop 2009).

2.2.8.9 Applying multiple use zoning within marine protected areas

One way to reap the entire range of different fisheries (and other) benefits from different types of marine zoning is to include many different levels of protection within one, usually larger, marine park (Kelleher 1999, Christie et al. 2007, Alino et al. 2008c, IUCN-WCPA 2008, The Ecology Centre The University of Queensland 2009). This approach also allows for greater flexibility in accommodating human uses and values, and also helps mitigate against the failure of any one type of zoning being chosen to achieve all the desired objectives (Agardy 1997, Great Barrier Reef Marine Park Authority 2004, National Marine Sanctuary Program 2007, Green et al. 2009b, Agostini et al. 2010, Gleason et al. 2010, Grantham and Possingham 2011). This way of using marine protected areas is consistent with an ecosystem approach to fisheries management (Christie et al. 2007, IUCN-WCPA 2008).

Multiple-use zoning is being planned or applied in the CT in many places (e.g. Berau Marine Conservation Area, Karimunjawa National Park, Wakatobi Marine National Park, Raja Ampat, Indonesia; SE Cebu Network, Lanuza Bay, Calamianes, Tawi-Tawi, Danajon Bank, Philippines; Tun Mustapha Park, Tun Sakaran Marine Park, Malaysia). Use of LMMAs (e.g. in PNG and Solomon Islands) often allows for different types and levels of use and access (Wood 2006, Govan et al. 2008, Govan 2009, Green et al. 2009b, Armada 2011, Grantham and Possingham 2011, Jumin et al. 2011).

2.2.9 Duration of protection to offer within the marine protected area network

Different types of protection may require different durations of protection.

Seasonal closures that protect known aggregation sites (for spawning or other reasons) or protect habitats used by vulnerable life stages of target species can help maintain or even improve fished stocks (IUCN-WCPA 2008, Sadovy and Clua 2011). This assumes the areas used and the seasons/life histories are known to ensure protection of the correct sites at the right times for all the species of interest. It also assumes that temporary protection at these sites/times can be effectively enforced.

For no-take areas that protect a sub-set of the overall stock of target species, the longer the areas are protected, on average, the larger the individuals within them will become. Also the more of them leads to greater likelihoods of adult spillover, greater numbers of larvae being produced, and higher rates of larval survival due to larger egg size (Russ and Alcala 1996, 2004, Russ et al. 2005, Evans et al. 2008, IUCN-WCPA 2008, Lester et al. 2009, Maliao et al. 2009). Testing of a model explicitly exploring the ideal length of no-take protection for two fished species (one fish and a scallop) found that if: 1) fish mortality is greater than maximum sustainable yield, 2) the level of protection in no-take areas is low (e.g. ~10 percent), and 3) there is a low spawning biomass, then long-term protection is best (Hart 2006)

.

In many situations in the CT, these three criteria will apply (see Section 1.2). For these reasons, and for reasons of enhancing compliance through simplicity of rules, permanent no-take areas are advocated by many as part of the spatial management toolbox (NRC 2001, Gaines et al. 2010).

Rotational closures can have equal amounts of time available to fishing as to protection from fishing. Annual rotations of fishing closures have not worked in Hawai'i as the level of decline in fished stocks during the year of fishing is greater than the level of enhancement of fished stocks during the year of protection (Williams et al. 2006). Other studies have shown that previously fished stocks, after many years of protection, can be reduced to pre-protection levels within matters of weeks to a year after long-term protection is removed (Russell 1998, Russ and Alcala 2004). Kaplan et al (2010) suggest that fisheries benefits can be realized with rotational closures if the rotational periods are long enough to be commensurate with the life history of the species being protected so that there can be an increase biomass (and eggs) per recruit (Botsford et al 1993 in Kaplan et al. 2010; see also Section 2.2.8.4).

Temporary closures may be more flexible allowing for the possibility of longer periods of protection than the periods of access to fishers thus enabling ongoing contribution to the fished stocks (e.g. in Ahus Island, PNG; Cinner et al. 2005a). Combining knowledge of the life histories of target species (as suggested above) with knowledge of the speed of decline in protected stocks once available to fishing could lead to a combination of temporary closures with fishing periods that could benefit fisheries. For longer lived taxa (e.g. some sharks and groupers), it may take up to one decade or more for new recruits to reach maturity and contribute to recruitment in the population (Frisk et al. 2005)

Areas zoned to restrict certain gears can be permanent or temporary with consideration of the specific goals of the area under management, the species of matter and compliance considerations. For any no-go or no-access areas to achieve long-term and enduring fisheries benefits, for even the long-lived species, they should be permanent (Robbins et al. 2006).

Any chosen level of protection can, in theory, be applied for any period of time and with any pattern of change. The more complicated any changes to protection (both in time and type), the more difficult for people to understand and comply (Ward et al. 2001, McClanahan et al. 2006, Bishop 2009). However, the benefits are often more flexibility to human uses and values and thus a greater willingness to comply (Cinner et al. 2005a, Cinner et al. 2005b, McClanahan et al. 2006, McConney and Charles 2010). Some studies advocate community partnerships in the process of establishing (any variety and combination of) marine protected areas coupled with long-term protection to ensure the full economic, social and biological benefits can accrue (IUCN-WCPA 2008).

2.2.9.1 How long is long-term protection?

No-take areas can only benefit fisheries if all the targeted fish species have time to grow, so there is increased biomass, and then time to reproduce, so there is increased egg production and recruitment (Claudet et al. 2008, Molloy et al. 2009, Kaplan et al. 2010, Selig and Bruno 2010). To maximize benefits, the newly recruited fish to the stock within the no-take area should also have time to grow to reproductive size and then, in turn reproduce – thus contributing further to enhancing fished stocks. Sharks are prime target species in the CT and can be long-lived (commonly ~10 years to maturity; Frisk et al 2005, Field et al. 2009, White and Kyne 2010). Where there has been significant fishing effort, the remaining standing stock may also take several generations to recover (e.g. Russ and Alcala 2004, Russ et al. 2005, Molloy et al. 2009).

This is especially true for the larger, predatory coral reef fishes which can take 20 to 40 years (Russ and Alcala 1996, Russ and Alcala 2010). Claudet et al (2008) also discovered no asymptote when looking at increases in density of targeted fishes in the many marine protected areas studied (the oldest being 33 years old; see also Claudet et al. 2010). To restore entire ecosystems, through allowing enough time for the trophic cascade effects of protection to be fully realized, takes even longer than the time for target species to recover (Graham et al. 2003, Babcock et al. 2010).

This information must be coupled with the fact that the fisheries (and other) benefits of even long-term no-take areas can be removed by short periods of fishing (Russell 1998, Russ and Alcala 2003, Mapstone et al. 2004, Williams et al. 2006).

To accommodate these factors, in the case of the CT,

long-term protection should be in place for ~ 20-40 years, preferably permanently.

Note, however, that some of the benefits of the no-take areas are likely to start accruing after only 3 to 5 years or sooner, especially if effective management of fisheries occurs outside no-take areas (Russ and Alcala 1996, Evans and Russ 2004, Russ et al. 2005, Russ et al. 2008).

2.2.10 Adaptive management

Adaptive management means monitoring and evaluating to test the effectiveness of the management actions and improving them over time (Salafsky et al 2001 in IUCN-WCPA 2008; D'Agrosa et al. 2007, Parks 2011). In fisheries management, including the use of marine protected areas, there is much uncertainty, both in terms of current knowledge and in terms of changes in the situation being managed (Grafton and Kompas 2005, Parks 2011). Adaptive management is a mechanism whereby the network of marine protected areas can be refined in response to increases in information or a changing environment (Grafton and Kompas 2005). It requires that the management regime established is flexible enough to accommodate any changes (IUCN-WCPA 2008) and robust enough to ensure that the flexibility is not abused to erode management effectiveness.

Any improvements in a management regime, however, must be balanced against the requirement that any management efforts usually require a lengthy period of time before results materialize (see Section 2.2.9). This type of adaptive management is not new and is already being applied within the CT in Indonesia, Solomon Islands, Philippines, and elsewhere (Green, Meneses et al 2009; Aswani, Albert et al 2007).

2.2.11 Scaling up

The ecosystem approach to fisheries management, as agreed by the CT6, calls for an ecosystem-wide framework for management using “ecologically meaningful boundaries” (FAO 2003). Ecologically meaningful boundaries are rarely at the small scale of many coastal communities of the CT. Rather, ecosystems are defined as habitats and their associated communities of species who interact, more or less, as a functional unit (Jax 2006 in Costello 2009). They are connected through their use of space, food or other resources at the same time, although they will exchange materials and individuals organisms with external ecosystems (Costello 2009). Most local tenure and jurisdictional arrangements do not support broader (ecosystem-wide) management approaches for implementing marine protected areas or other management tools (Agardy 2010, Mills et al. 2010).

Providing guidance to overcome the socio-political challenges to addressing institutional, legal, government and other governance hurdles to "scaling up" to regional networks of marine protected areas is beyond the scope of the report (but see IUCN-WCPA 2008, Weeks et al. 2009, Agardy 2010, Weeks et al. 2010b). Here the discussion explores the biophysical aspects of scaling up.

2.2.11.1 Scaling down and up

Biophysically, to scale up networks of marine protected areas, especially in the coastal environment of the CT so that they are functionally connected requires a combination of two approaches (Mills et al. 2010). One is to bring the broad scale biogeographic overview of the CT to the lowest scale possible. The other is multiplication (or replication) of small-scale marine protected areas into networks throughout the lower-scale geographies (Weeks et al. 2009, Pomeroy et al. 2010). These smaller-scale groups of marine protected areas must conform to, at least, the spacing requirements discussed above to ensure they form functionally connected networks (Section 2.2.4).

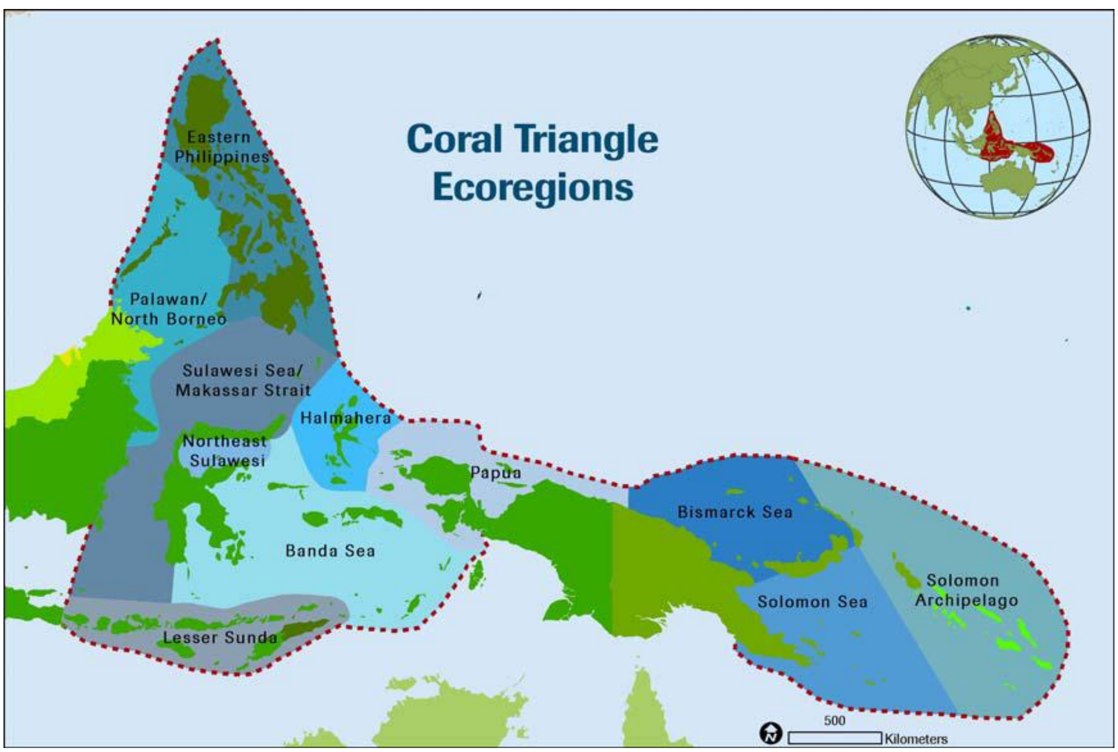

Figure 6. Eleven ecoregions of the Coral Triangle.
(Green and Mous 2008)

To elaborate on the "scaling down", consider the eleven ecoregions defined for the CT by Green and Mous (2008), or the phylogeographic management units defined by Carpenter et al. (2010; Figure 6 and Figure 7). These ecoregions or management units have divided the CT into slightly more "workable" geographies that could, potentially, support marine resource management at that scale, including implementation of functional networks of marine protected areas (e.g. Lesser Sunda, Timor Leste and Indonesia; Bismarck Solomon Seas Ecoregion, PNG, Solomon Islands and Indonesia; Sulu-Sulawesi Marine Ecoregion, Malaysia, Indonesia and Philippines; Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, Wilson and Hitipeuw 2004, CI 2010, Wilson et al. 2011).

Figure 7. Coral Triangle management units based upon phylogeographic breaks. (Carpenter, Barber et al 2010).

Biophysically, 32 finer-scaled seascapes have been defined within ecoregions as well (Green and Mous 2008). These finer-scaled geographies are closer, in size, to a scale at which marine resource management can be implemented, via combining local action with higher level government support. Some work has been done at this scale (e.g. in Bird's Head, Indonesia; TNC et al. 2010, CI 2011).

Within these, even smaller scaled bio-geographic systems have been defined, potentially "ecosystems' within which coordination, collaboration or simply multiplication of efforts can, or are, leading to networks of protected areas (e.g. Raja Ampat, Indonesia; Bohol, Verde Passage, Cagayan Ridge, SE Cebu, Philippines; Kimbe Bay, PNG; Choiseul, Solomon Islands; Alcala and Russ 2006, CI - Philippines 2007, Green et al. 2007, Green et al. 2009b, CI 2010, Lipsett-Moore et al. 2010, Grantham and Possingham 2011, Wilson et al. 2011).

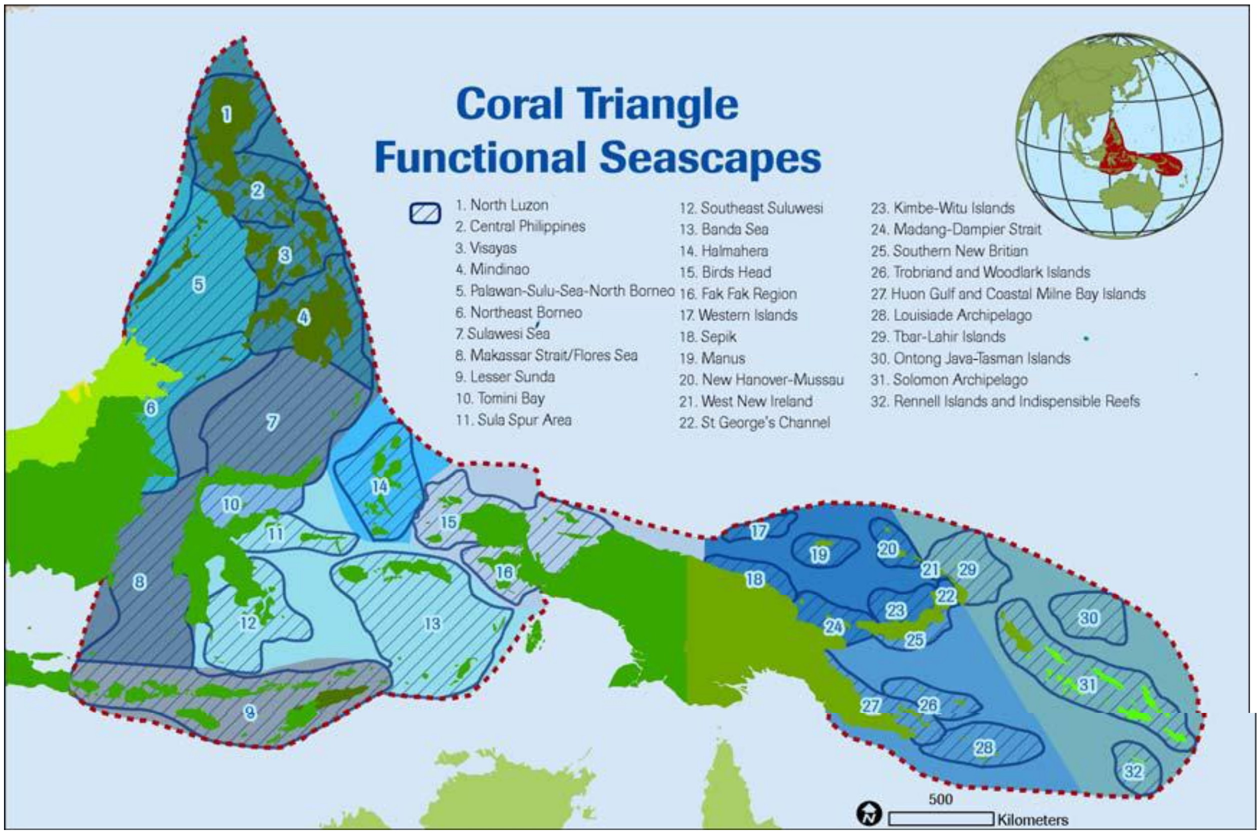

Figure 8. Functional seascapes of the Coral Triangle.
(Green and Mous 2008)

In some cases, the "scaling down" of the size of geography within which to work has been an instance of local communities "scaling up" from the small marine areas under their jurisdiction by collaborating with each other and coordinating with higher level government authorities (e.g. Bohol, SE Cebu, Verde Passage, Philippines; Choiseul , Solomon Islands; Alcala and Russ 2006, Green et al. 2009b, Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) 2009, Lipsett-Moore et al. 2010). Some work is being done to inform these efforts by modelling regional scale connectivity (Melbourne-Thomas et al. 2011). This community-based approach to "scaling up" is a key dimension of the use of LMMAs, which are a well-known tool in the Solomon Islands and Papua New Guinea[28] (Govan et al. 2008, Govan 2009) and are increasingly being used elsewhere (e.g. Eastern Indonesia).

[28] www.lmmanetwork.org, accessed 6/4/11

The Regional CTI PoA calls for a CT marine protected area system which implies networks of protected areas beyond most tenure and other jurisdictional boundaries. Currently, the focus of each country is to contribute at least one well-designed and effectively managed marine protected area network towards an overall CT marine protected area system. This might require some combination of scaling up and down while applying the principles suggested in this report.

2.2.11.2 Multiple use marine parks to help scale up

One tool that is only partly being applied to assist in scaling up marine protected areas is multiple-use marine parks or multiple-use marine protected areas. While multiple zoning within marine protected areas (or marine parks) is well known (see Section 2.2.8) their utility in potentially scaling up to larger scale and functional networks of marine protected areas has not often been explicitly discussed.

The advantage of large and multi-zoned marine parks is that small-scale zoning issues can be addressed with less risk to fisheries objectives if couched within a larger, more ecologically holistic framework (Agardy 1997, Kelleher 1999, Great Barrier Reef Marine Park Authority 2004). The disadvantage, in the CT and elsewhere, is the multiple layers and sectors of higher-level government that may need to be engaged to provide an adequate legislative framework for an ecosystem-wide approach to marine protected areas (IUCN-WCPA 2008, Christie et al. 2009a, Agardy 2010).

2.3 Guiding principles

Here we use all of the information presented above to offer biophysical guiding principles to apply if one is only interested in fisheries objectives, albeit within an ecosystem approach to fisheries management.

Table 2. Biophysical design principles for a resilient marine protected area network for fisheries

	Principle	Detail	Rationale
1	Create a multiple-use marine managed area that is as large as possible[3].	Include as much as possible of the coastal ecosystem within a legal or otherwise formalised or functional management boundary.	For an ecosystem approach to fisheries management the entire ecosystem should, as far as possible, be managed as one unit within which different levels of protection can apply (FAO 2003, Christie et al. 2009a; see Sections 2.2.1, 2.2.8.9 and 2.2.11).
2	Prohibit destructive activities throughout the managed area.	Communities and managers must decide which activities will not be allowed within their coastal marine managed area at all (e.g. blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, night spearing).	Coastal habitats and their associated values are vulnerable to destructive activities, some of which may be conducted by people coming in from outside which brings no benefit to the local communities but impacts their livelihood (Hall 1999, Cesar 2000, Cesar et al. 2003, FAO 2003, Metuzals et al. 2010, FAO 2011).
3	Represent at least 20 percent but best 35 percent of each habitat within no-take areas[2].	Represent the range of types of coral reefs, seagrasses, mudflats, algal beds, soft seabed, rocky shores, coastal forests, beaches, mangroves, other wetlands in no-take areas. Protect different contiguous habitats within no-take areas where possible. If there is little or no other management in place, then include ~35 percent of the management area in long-term no-take areas.	Different fished species use different habitats sometimes at different times of the day or at different life stages; therefore it is important to offer refuges of each kind of habitat. If possible, do this where they are contiguous (Palumbi 2004, IUCN-WCPA 2008, Lowry et al. 2009, Gaines et al. 2010, Jones et al. 2010a; see Section 2.2.6.1). This recommended amount of no-take protection is the minimum required to help contribute to fisheries especially where mortality is, or has been, greater than maximum sustainable yield (e.g. Gerber et al. 2003, Halpern and Warner 2003, Fogarty and Botsford 2007, Botsford et al. 2009a, Botsford et al. 2009b; see also Section 2.2.2). If aiming to protect species with lower reproductive output or delayed maturation (e.g. sharks or some groupers) more area will be

		If other kinds of effective fisheries management is in place[29] or if other types of spatial protection (e.g. rotational, seasonal or other temporal closures) encompass ~15 percent of the area then have at least 20 percent in long-term no-take areas.	required; in areas with lower fishing pressure, less area may be required but not less than 10 percent (Fogarty and Botsford 2007).
4	Implement gear and/or access restrictions in other parts of the marine managed area (that are not no-take areas).	If gears are used that impact too heavily on the fished stocks, other species or habitats, then it's use should be limited in type, volume and/or spatially restricted. If the volume or type of fishers accessing the managed area is having excessive impacts upon fished stocks, other species or habitats, their access to the area should be restricted.	To help ensure the sustainability of the fished stocks, to address particular fisheries needs where targeted stocks need to be restored or recovered and to minimize impacts upon the environment and other species, gear and access restrictions should apply within the managed area in addition to no-take areas and temporal closures (FAO 2003, 2010).
5	Ensure that no-take areas (or seasonal closures) include critical habitat sites of fished species at critical times.	Include important aggregation sites (e.g. spawning, feeding, breeding grounds, migration corridors) and juvenile habitat areas of fished species in long-term or seasonal no-take areas. Larval sources should be in long-term no-take areas.	When animals aggregate they are particularly vulnerable to fishing and, often, the reasons they are aggregating are crucial to the maintenance of the stock. Therefore the main aggregation sites must be protected to help maintain or rebuild fished stocks (Sadovy and Clua 2011; see Sections 2.2.6.2 and 2.2.6.3).

[29] For example, adequate and effective restrictions on type and quantity of gear, effort, and capacity; limits on catch or landings; limits on sizes; limiting catch of a given sex, or animals in a particular stage of the breeding cycle; regulating discards; daily bag or possession limits.

6	Apply minimum and a variety of sizes to protected areas.	No-take areas inshore[4] should be a minimum of 0.2 km^2 (20 ha; e.g. 500 m from shore to deep water x ~400 m longshore length); offshore no-take areas (i.e. outside 500 m) should be a minimum of 2 km longshore length and 3 km offshore width; ideally offshore areas should be 10 to 20 km in diameter. Beyond these minimums, vary the sizes as much as possible. Temporal closures of any kind should include, at minimum, the entire area of site of interest plus a 100 m buffer area (or 20 ha minimum if these details are unknown). Gear restrictions: as large an area as possible up to the entire marine managed area. Access restrictions: as appropriate throughout the marine managed area.	The larger the area protected the more likely to encompass the mean larval dispersal distance of all targeted species as well as adult ocean neighborhoods (Palumbi 2004, Hastings and Botsford 2006, Shanks 2009). For this reason some recommend ~3 to 20 km in longshore extent or more (Halpern and Warner 2003, Gaines et al. 2010). However no-take areas around 0.2 km^2 (20 ha) have been found to bring benefits to nearshore fisheries (Roberts and Hawkins 2000, Alcala and Russ 2006, Lester et al. 2009, Jones et al. 2010b) and allow for more spillover (Hastings and Botsford 2003). *These minimum sizes have only been shown to work when coupled with 20 to 30 percent of reef area in a network of no-take areas.* Where larval dispersal patterns and/or adult movement patterns of target species are known, this can inform decisions about the ideal size of protected areas. Mackerel and other nearshore pelagic species, for example, would benefit more from larger areas of protection due to their larger ocean neighborhoods (Palumbi 2004; see Section 2.2.3). Gear and access restrictions have particular fisheries purposes for which communities and managers must decide the spatial extent within which to implement these controls. The fish stocks will respond best to the greatest spatial extent of protection offered – and should, at least, include adult neighborhoods of target species.

7	Separate no-take areas by 1 to 20 km (with a mode of ~1 to 10 km apart). Spacing of other long-term protected areas either not applicable or same as for no-take areas.	Apply a variety of spacing of individual no-take areas throughout the entire management area. Inshore no-take areas should be located closer together (≥1km apart) than the more offshore no-take areas (~20 km apart). Other types of protected areas (e.g. spatial access or gear restrictions) might be quite large in extent throughout the management area (see Principle 6) and so it might not make sense to have specified "distances" between them. However, if other permanent protected areas are isolated "islands" of protection, then the same spacing rules should apply as to no-take areas.	Data are showing both huge variability in larval dispersal distances and lower dispersal distances than previously thought (e.g. 100 m to 1 km to 30 km; Pelc et al. 2009, Shanks 2009, Jones et al. 2010b). And adult movements are generally at a smaller scale than larval movements (Palumbi 2004). Given the multi-species nature of inshore CT fisheries with, likely, commensurate variety in larval dispersal and adult movement patterns, varying the spacing between no-take areas 1 to 20 km apart is also useful. Where more details about ocean neighborhoods are known for locally fished species, this information can be used to refine this recommendation about spacing. See also Section 2.2.4.
8	Have protected areas in rectangular or triangular shapes.	Use more rectangular or triangular shapes (versus square or circular shapes) subject to considerations of compliance (including use of landmarks).	These shapes enhance spillover (White et al. 2006; Section 2.2.5).
9	Have boundaries within habitats.	Place protected area boundaries well within each habitat being protected.	Adult spillover will be enhanced if individuals traversing the same habitat move from protected to non-protected areas (Gaines et al. 2010; see Section 2.2.6).
10	Locate more protection upstream of currents.	If currents are known and consistent, then a greater number of the protected areas, especially no-take areas, should be located towards the upstream end of the management area. If currents are not	Protected areas, especially no-take areas, could become a source of larvae contributing disproportionately more to population recruitment (Gaines et al. 2003). The degree that currents influence larval dispersal will influence genetic connectivity and population recruitment much more in

		known or not constant, then this principle does not apply and protection should be distributed evenly throughout the management boundaries (subject to the principles on size and spacing).	locations downstream of protected areas thus maximising fish population "return" per unit area protected (Sale et al. 2010; see Section 2.2.6.3).
11	Minimize external threats.	All else being equal, choose areas that have been, and are likely to continue to be, subjected to lower levels of damaging impacts (e.g. areas with high water quality; no mining; no shipping; areas where fishing is likely to be regulated and managed; and existing functional marine protected areas). For over-exploited species, locate no-take areas near fishing villages/ports and other heavily fished areas. If fisheries are not over-exploited, then locate the no-take areas away from fishing villages/ports.	To optimize protection of areas that are more likely to survive other threats, recover and be complied with, aim to avoid areas which have been, or are likely to be, most damaged from external threats or human uses (see Section 2.2.6.4). It takes time for marine protected areas to deliver fishery benefits. Therefore it is usually advantageous to include existing marine protected areas within a new network (IUCN-WCPA 2008, Green et al. 2009b). By locating no-take areas near heavily fished areas, once spillover effects start to be realised they will immediately benefit local fishers (Gaines et al 2010). If fisheries are not over-exploited, then locate the no-take areas away from fishing villages/ports to minimize displacement of fishing effort.
12	Replicate protection of habitats.	Include at least three replicates (up to five) of every habitat within a protected area network, ideally in no-take area.	Replication of protection allows for risk minimisation in the event of extreme events because surviving protected areas can function as larval sources to help restore impacted areas. Replication also helps enhance representation of habitat diversity or biological heterogeneity that we do not know about (IUCN-WCPA 2008, Gaines et al. 2010; Section 2.2.7).
13	No-take areas, areas with prohibitions on destructive gear, other gear and access limits		No-take areas can, after 1 to 5 years, start to show some benefits (Russ and Alcala 1996, Ward et al. 2001, Russ et al. 2008, Hamilton et al. 2011; Section 1.8). However, in heavily fished situations, shorter term protection may fail to achieve

	should be in place for the long-term (i.e. at least 20 to 40 years). Rotational closures' duration should, at least, match the generation time of the target species.		fisheries objectives by not allowing enough time for remaining stocks to grow and reproduce to the degree where they can positively impact stocks outside the protected area (Russ and Alcala 1996, 2004, Hart 2006, Russ and Alcala 2010). Longer term protection is also important for fished species with delayed maturation (e.g. shark and some grouper). Long-term protection allows the full range of species and habitats to recover and associated fisheries benefits to accrue and be sustained (IUCN-WCPA 2008). If no-take status reverts back to open access in heavily fished areas, the benefits of improved ecosystem function and increased biomass of fishery species can be quickly lost (Russell 1998, Williams et al. 2006). Thus, no-take areas should be maintained in no-take status as long as possible. Where there is local knowledge about target species life-histories, this can inform decisions about duration of protection. See Section 2.2.9. Fisheries benefits can be realised with rotational closures if the rotational periods are long enough to be commensurate with the life history of the species being protected so that there can be an increase biomass (and eggs) per recruit (Kaplan et al. 2010; see Section 2.2.9). Seasonal closures have an inherent (i.e. seasonal) temporal timeframe and other temporal closures will be applied for reasons that will have their own temporal requirements.

2.3.1 More uncertainty leads to less flexibility

The less information there is available about the multiple species targeted in the CT inshore and coastal fisheries, the less flexibility there is around the choice of level and type of protection to offer. For example, if critical habitat areas and times of spawning for targeted fish species are not known, if their responses to various access restrictions or gear restrictions area unknown, if the effectiveness of existing fisheries management is unknown (or poor), then it will be more important to include ~35 percent of the area in long-term (versus seasonal or other) no-take areas so that the overall level of protection can lead to a positive impact on the fish stock and, hence, the fishery (Section 2.2.2).

2.3.2 Prioritising the principles

As discussed (Section 1.3), it is quite likely that there will be conflicts between some of these principles and equally important socio-economic, political, institutional and cultural considerations. There may be a requirement for managers to prioritize the biophysical principles to implement. Local needs, context and objectives should drive the prioritization of implementing the biophysical principles. Sometimes, however, these decisions will benefit from additional guidance.

The authors have been unable to find literature that prioritizes principles such as those given above, despite many of them have been presented and even used elsewhere (see Sections 2.2.2.3, 2.2.3.2, 2.2.4.3 and 2.2.6). Our experience leads us to recommend that, in the absence of other drivers for prioritizing principles, removal of all destructive fishing practices from within the boundaries of the multiple use marine managed area is the first priority (Principle 2 in Table 2).

We know of one example where external experts have prioritized 11 biophysical design principles for marine protected area networks, and they gave priority to ensuring minimum levels of no-take protection per biological region (or bioregion; Coles et al. 2001). In this case, the Great Barrier Reef Marine Park, destructive activities were already banned (Great Barrier Reef Marine Park Act 1975). For those seeking further advice on priorities, the authors recommend the same priority to managers in the CT:

> *ensure minimum levels of no-take areas (per habitat where known) within the management area under consideration* (Principle 3 in Table 2).

In addition, we recommend prioritizing:

- replication of no-take areas (Principle 12 above), and
- inclusion of critical habitats within no-take areas (Principle 5 in Table 2).

3 DESIGN PRINCIPLES FOR ACHIEVING BIODIVERSITY OBJECTIVES

3.1 Biodiversity objectives

Marine protected areas could contribute to some of the biodiversity-related objectives identified in the National and Regional CTI PoAs (Section 1.4.1) for example:

Increase long-term benefit to human well-being (of current and future coastal communities especially) of the use of marine resources including:

- Sustaining the full range of marine ecosystem goods and services
- Improved quality of marine and coastal resources
    - Better habitat condition
        - Coral reefs
        - Mangrove forests
        - Seagrass beds
        - Beach and/or coastal forests
        - Wetlands
        - Marine/offshore habitats
        - Mudflats
        - Algal beds
        - Rocky coasts
    - Conservation of biodiversity
    - Better functioning of marine and coastal ecosystems including
        - Greater productivity
        - Sustaining the full range of marine ecosystem goods and services
        - Ecological processes
    - Improved status (e.g. Population, distribution, diversity and economic value) of:
        - Sharks, rays and other cartilaginous fishes
        - Threatened fish (e.g. Napoleon wrasse)
        - Corals
        - Sea turtles
        - Seabirds
        - Marine mammals
        - Crocodile
        - Other species on the IUCN Red List
        - Other identified species
- Address local and global threats to marine resources
    - Mitigation of effects of fishing in an ecosystem including:
        - Excessive exploitation
        - By-catch
        - Discards

        - Destructive fishing practices (e.g. use of dynamite, noxious substances, destructive gear)
        - Protection of juvenile/nursery areas
        - Discarded fishing gear
    - Mitigation of effects of tourism
- Reduce vulnerability of coastal and marine resources to
    - External and local threats

Comparing these objectives with those that the CT6 have identified which relate to an ecosystem approach to fisheries management, one sees a vast overlap (see Section 2.1). Many of the objectives are the same. This is not surprising for a couple of reasons: species targeted by fisheries comprise part of the biodiversity of the marine environment therefore, in some ways, biodiversity objectives must overlap with fisheries objectives (Nichols et al. 2010); and the ecosystem approach to fisheries management must, by definition, include objectives that are broader than those to do only and directly with fished species (FAO 2003).

3.2 Literature review and lessons learned

The literature reviewed in Section 2.2 that pertains to the proportion, spacing and replication of marine protected areas is the best available and, although mostly refers mainly to models, data and experiences that include explicit consideration of fished species and fisheries, the conclusions and recommendations are the same for the protection of biodiversity more generally (Halpern and Warner 2003, Gaines et al. 2010). Salm and Clark (1984) offer advice that pertains to maintenance of coral species diversity in particular (suggesting a minimum size of a marine protected area as 300 ha). This advice falls within the parameters discussed for other taxa in Section 2.2.3.

Threatened species

Threatened species are defined as those on the IUCN Red List of Threatened Species of listed under CITES and includes threatened cetaceans, turtles, groupers, threatened wrasses, and elasmobranches (Coral Triangle Secretariat 2009). Some of these species are also fished, and therefore considered under Section 2. Beyond this, advice and experience exists regarding what proportion and spacing marine protected areas should have that explicitly addresses other threatened species; this discussion is beyond the scope of this report (see

Attachment **1**). Where some clear and useful advice, knowledge or experiences with threatened species and marine protected areas are known to the authors, this information will be included in an *ad hoc* basis (for example, see Hoyt 2005, Hamann et al. 2008).

For example, it is considered that the recommended spacing of marine protected areas for fisheries, and biodiversity more generally, are too close to accommodate the migration patterns and/or ocean neighborhoods of most marine mammals, turtles, seabirds and many oceanic sharks and other large pelagic fish (e.g. tuna; Palumbi 2004, Carr et al. 2010, Gaines et al. 2010).

3.2.1 How big should individual marine protected areas be within a network?

If the CT6 biodiversity objectives as listed in Section 3.1 were the priority, then best available scientific advice is to make any marine protected areas larger than one would for fisheries purposes (Halpern and Warner 2003, Gaines et al. 2010). Any choice in size of marine protected area will support some species and not others, depending on the adult range and larval dispersal distance. The larger the area protected, the more species' ocean neighborhoods will be accommodated, and therefore the more biodiversity will be protected (Palumbi 2004, Gaines et al. 2010; Section 3.2.3).

It should be noted that the Census of Coral Reef Ecosystems suggests that about 600,000 to nine million marine species of plants and animals inhabit coral reef-related ecosystems (Plaisance et al. 2011). Most of these species are from phyla such as Mollusca, Porifera, Cnidaria, Arthropoda, Echinodermata, Platyhelminthes, Nematoda, Annelida or are plants. Many of these, although not all, have relatively small ocean neighborhoods, according to the very limited research conducted on such species (Shanks 2009). Coral and Chordata, which comprise fish and megafauna, are a small percentage of the biodiversity of coral reefs (Plaisance et al. 2011). Of these, the large-bodied and/or wide-ranging pelagic fish species, turtles and mammals comprise an even smaller proportion of the total coral reef biodiversity. This small proportion of coral reef ecosystem-associated animals often have large ocean neighborhoods, although this may exclude some taxa such as many groupers (Williams et al. 2004) and perhaps even one or two of the nearshore pelagic species (e.g. Spanish mackerel and longtail tuna; Stapley et al. 2004). Animals with a large ocean neighborhood may only benefit from very large no-take marine protected areas, no-take areas that protect key habitats, seasonal no-take marine protected areas that protect the animals at key times (e.g. spawning or migration sites) or very large managed areas within which controls on take apply (Limpus and Chatto 2004, Saalfeld and Marsh 2004, Freon et al. 2005).

To accommodate these larger animals, some suggest no-take marine protected areas that are several to tens of kilometers in alongshore length and extend offshore to encompass depth-related movement of adults (Palumbi 2004, Botsford et al. 2009a, Gaines et al. 2010). Knowledge on larval dispersal distances means that the ideal no-take marine protected area size should be at least once to twice the diameter of the larval dispersal distance; a size of many to tens of kilometers alongshore conforms with this ideal for many of the larger species with, potentially, greater larval dispersal distances (Section 3.2.3.; Almany et al. 2007, Pelc et al. 2009, Shanks 2009, Gaines et al. 2010, Jones et al. 2010b, Pelc et al. 2010).

Larger marine protected areas also help reduce the amount of adult spillover by reducing the edge per unit of area protected thus increasing the maintenance of biomass within the protected area (Gaines et al. 2010).

3.2.2 What shape should individual marine protected areas be within a network?

For fisheries, it is important to facilitate adult spillover, as well as persistence of the stock within the protected area. For biodiversity purposes it is best to reduce spillover (Halpern and Warner

2003, Gaines et al. 2010). Therefore, it is important to consider the ratio of edge habitat versus core interior habitat. Edges of marine protected areas are often extensively fished, and therefore do not offer the same refuge to fish species as core interior protected areas offer (Halpern and Warner 2003; Willis et al. 2003 in IUCN-WCPA 2008). Shapes that might help minimize spillover include squares or circles (although the latter may be difficult to enforce) rather than rectangles or triangles (White et al. 2006).

3.2.3 Where should the marine protected areas be located?

The criteria discussed for locating marine protected areas for fisheries (Section 2.2.6) apply to objectives to do with protection of biodiversity as well. There are additional criteria that could be applied if biodiversity conservation was the priority.

Marine protected area sites that optimize biodiversity conservation should be areas that:

- Are relatively natural, that is, in relatively good condition;
- Have high diversity of species and/or ecosystems;
- Include important habitats for vulnerable/threatened species;
- Include existing marine protected areas where biodiversity benefits have already accrued;
- Are vulnerable to disturbance or destruction and contain rich resources or rich biodiversity;
- Protect isolated populations/sites;
- Include rare ecosystems, habitats or biogeographies (either through natural limits to their extent or human-caused reduction of natural extent);
- Are unique sites

(Agardy 1997, Kelleher 1999, Salm et al. 2001, White et al. 2006, Jones et al. 2007, IUCN-WCPA 2008, Lowry et al. 2009, Sale et al. 2010).

For biodiversity conservation, to reduce loss of biomass from the protected area which, in turn, maximizes the integrity of the natural community within the protected area, spillover of adult fished stocks should be minimized (Lowe et al 2003, Popple and Hunte 2005 in Gaines et al. 2010). To help with this, whole biological units/habitats should be included within a marine protected area where possible, rather than setting boundaries through the middle of habitats (Lowe et al 2003, Popple and Hunte 2005 in Gaines et al. 2010).

In the CT, there are many examples of how some of these criteria have been addressed (Kelleher 1999, Dobbs et al. 2007, Dobbs et al. 2008, IUCN-WCPA 2008, Green et al. 2009a, Green et al. 2009b, Lipsett-Moore et al. 2010, Grantham and Possingham 2011, Wilson et al. 2011). Documented examples include protection of turtle and seabird nesting sites in Wakatobi Marine National Park, Indonesia; seabird breeding and nesting sites, hawksbill and green sea turtle nesting sites at Tubbataha Reefs Natural Park[30]; (Green et al. 2009b, Hamilton et al. 2011). There are also suggestions by some to close areas to fishing in locations where by-catch of, or interactions with, threatened species is high (Grantham et al. 2008).

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[30] www.tubbatahareefs.org, accessed 5/25/11

3.2.4 Type of protection to offer within the marine protected area network

No-go (no access) marine protected areas are the best type of protection to ensure conservation of all aspects of biodiversity. If humans cannot access a site their impacts will be minimized and compliance to the no access rule is relatively easy to enforce as entry into the area is not permitted (see Section 2.2.8.7). This type of protection is unlikely to be feasible in many situations (IUCN-WCPA 2008).

However, no-take areas can also be extremely effective in protecting biodiversity (Hollingworth 1999, Roberts and Hawkins 2000, NRC 2001, Lubchenco et al. 2003, Lester et al. 2009, Sale et al. 2010). Other kinds of protection that allow some types and levels of fishing offer less protection to the entire community because they allow ongoing impacts on targeted species, by-catch, discards, cascading effects of the fishing through the community, impacts (e.g. of anchors, lost lines or nets) on the habitat or even explicit damage to the habitat through damaging fishing practices (e.g. trawling; Hall 1999, Hollingworth 1999, Ward et al. 2001).

Socio-economically, multiple-use zoning within the ecosystem-wide marine protected area are required when prioritizing biodiversity protection and need to be consistent with an ecosystem-based approach to marine resource management (McLeod et al. 2005).

3.2.5 Duration of protection to offer within the marine protected area network

For biodiversity conservation objectives, permanent protection is best. Permanent protection provides time for the marine community to recover from human impacts as well as optimizes the long-term, permanent potential biodiversity benefits beyond the protected area boundaries (IUCN-WCPA 2008). Where populations, especially of longer-lived species with slow reproductive rates, have been severely depleted any level of recovery may take a very long period of time (up to decades); in other instances some populations may recover more quickly (Roberts and Hawkins 2000, Evans and Russ 2004, Russ and Alcala 2004, Alcala and Russ 2006, Hart 2006). Returning to a natural balance under such scenarios is unlikely to occur quickly.

3.3 Guiding principles

For biodiversity conservation only, the accurate but trivial "solution" in terms of biophysical design principles is to include the entire ecosystem within a permanent no-take marine protected area. Such a solution is socio-economically undesirable and relatively non-implementable and has, therefore, rarely been fully applied. An alternative, more feasible set of principles is provided in Table 3. Note that some of the justifications for the principles are the same as that for the fisheries principles. This is because much of the science informing the definition of biophysical design principles is the same for fisheries and biodiversity. Areas where the principles provided below differ from those in the previous fisheries chapter (Section 2.3) are highlighted in yellow.

Table 3. Biophysical principles to design a marine protected area network for biodiversity conservation. Highlighted portions of the table indicate different advice than what applies to fisheries objectives.

	Principle	Detail	Rationale
1	Create a multiple use marine protected area that is as large as possible[3].	Include as much as possible of the coastal ecosystem within a legal or otherwise formalized management boundary.	To maximize protection of the full range of biodiversity it is best to include the entire ecosystem, with all the component habitats and species within a broader managed area (McLeod et al. 2005; see Sections 2.2.1, 2.2.8.9, 2.2.11).
2	Prohibit destructive activities.	To protect the entire range of biodiversity, destructive activities should be prohibited (e.g. blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, night spearing).	Coastal habitats and their associated biodiversity are vulnerable to destructive activities, some of which may be conducted by people coming in from outside which brings no benefit to the local communities but impacts their ecosystem (Hall 1999, Cesar 2000, Cesar et al. 2003, FAO 2003, IUCN-WCPA 2008, Metuzals et al. 2010, FAO 2011).
3	Represent at least 35 percent of each habitat within no-take areas[2].	Represent the range of types of coral reefs, seagrasses, mudflats, algal beds, soft seabed, rocky shores, coastal forests, beaches, mangroves, other wetlands.	The full range of biodiversity can only be protected if examples of every habitat are included in no-take protected areas (Palumbi 2004, IUCN-WCPA 2008, Lowry et al. 2009, Gaines et al. 2010; see Sections 2.2.6.1 and 3.2.3). Rotational closures, seasonal closures and most other temporal closures can be beneficial for fisheries but are less useful for protecting biodiversity where part of the aim is to build and retain examples of natural communities. Therefore protection of biodiversity is best served by no-take areas (Roberts and Hawkins 2000, NRC 2001) of which a minimum of around 35 percent is recommended for most species. This excludes most threatened species which require larger amounts of protected areas due to their delayed maturation and

			lower fecundity. (e.g. Halpern and Warner 2003, Fogarty and Botsford 2007, Botsford et al. 2009a, Botsford et al. 2009b; see Section 2.2.2)
4	Ensure that no-take areas include critical habitat sites.	Include important: aggregation sites (e.g. spawning, feeding, breeding grounds); juvenile habitat areas; larval sources; turtle nesting areas; migration corridors.	When animals aggregate they are particularly vulnerable and, often, the reasons they are aggregating are crucial to the maintenance of the population therefore the any sites where animals group together or aggregate must be protected (Sadovy and Clua 2011; see Sections 2.2.6.2, 2.2.6.3 and 3.2.3).
5	Apply minimum and a variety of sizes to protected areas within the network.	No-take areas inshore[4] should be a minimum of 5 km in alongshore length; the width should span the entire depth profile if possible (at least 5 km); further offshore, a minimum diameter of ~20 km should apply to no-take areas. Beyond these minimums, vary the sizes. Gear restrictions should apply to as large an area as possible up to the entire marine managed area and to all areas where gear interferes with threatened species. Access restrictions: as appropriate throughout the marine managed area.	For biodiversity purposes, the larger the area protected the better as this will accommodate more species' adult range (Halpern and Warner 2003, Hastings and Botsford 2006, Shanks 2009). Gaines et al (2010) advocate several to tens of km in longshore length for no-take areas for biodiversity protection (and fisheries). Palumbi (2004) identifies that mackerel and other near- but not inshore pelagic species may need even larger areas. Shanks (2009) and others consider ~4 to 6 km in size to be a viable minimum; all advocate a variety of sizes but with these sizes being the minimum. See Sections 2.2.3 and 3.2.1. Gear and access restrictions should be used, in addition to no-take areas, to minimize impacts upon habitats and species.
6	Separate no-take areas by 1 to 20 km (with a mode of ~1 to 10 km apart).	Apply a variety of spacing of individual no-take areas (from 1 to 20 km apart) throughout the entire management area. Inshore no-take areas should be located closer together (≥1 km apart)	Recent studies are showing huge variability in larval dispersal distances and lower dispersal distances than previously thought (e.g. 100 m to 1 km to 30 km; Pelc et al. 2009, Shanks 2009, Jones et al. 2010b).

	Spacing of other long-term protected areas either not applicable OR same as for no-take areas.	than the more offshore no-take areas (~20 km apart). Other types of protected areas (e.g. spatial gear or access restrictions) might be quite large in extent throughout the management area (see Principle 5) and so it might not make sense to have specified "distances" between them. If other permanent protected areas are isolated "islands" of protection, then the same spacing rules should apply as to no-take areas.	Given that the CT is the centre of marine biodiversity, with, likely, commensurate diversity in larval dispersal distances, varying the spacing between no-take areas 1 to 20 km apart is also useful. See Section 2.2.4. Spacing at the higher end of the range (towards 20 km apart) also helps with risk spreading and capturing the range of biodiversity (IUCN-WCPA 2008, McLeod et al. 2009). But if spacing is less than 20 km, these benefits may still occur. See principle 11.
7	Have protected areas in square or circular shapes.	Use more square or circular shapes subject to considerations of compliance (including use of landmarks).	These shapes minimize adult spillover (White et al. 2006; see Sections 2.2.5 and 3.2.2).
8	Place protected area boundaries at habitat edges.	Match the edge of any habitat with the edge of a protected area.	To protect biodiversity from human impacts it is best to retain the integrity of any protected area as much as possible; locating boundaries at habitat edges diminishes adult spillover (Gaines et al 2010).
9	Locate more protection upstream of currents.	If currents are known and consistent, then a greater number of the protected areas, especially no-take areas, should be located towards the upstream end of the management area. If currents are not known or not constant then this principle does not apply and protection should be distributed evenly throughout the management	Protected areas, especially no-take areas, should become a source of larvae contributing disproportionately greater amount to population recruitment (Gaines et al. 2003). The degree that currents influence larval dispersal will influence genetic connectivity and population recruitment much more in locations downstream of protected areas thus maximizing population return per unit area protected (Sale et al. 2010). See Section 2.2.6.3.

		boundaries (subject to the principle on spacing).	
10	Minimize external threats.	All else being equal, choose areas for protection that have been, and are likely to continue to be, subjected to lower levels of damaging impacts (e.g. areas with high water quality; no mining; no shipping; areas where fishing is likely to be regulated and managed; and existing, functional protected areas).	To optimize protection of areas that are more likely to survive other threats, it is wise to avoid areas that have been or are likely to be damaged from external threats or subject to damaging human uses (see Section 2.2.6.4). From a biodiversity conservation point of view, these areas are also more likely to be in better condition, thus better reflect the biodiversity of the area and offer a better basis for restoration. It takes time for marine protected areas to deliver biodiversity conservation benefits. Therefore it is usually advantageous to include existing functional marine protected areas within a new network (IUCN-WCPA 2008, Green et al. 2009b).
11	Replicate protection of habitats.	Include at least three (at best five) replicates of every habitat within no-take areas.	Replication of protection allows for risk minimisation in the event of extreme events so that surviving protected areas can help repopulated impacted areas. Replication helps enhance representation of habitat diversity or biological heterogeneity that we do not know about (IUCN-WCPA 2008, Gaines et al. 2010; see Section 2.2.7).
12	No-take areas, prohibitions on destructive gear, other gear and access limits should be in place for the long-term (i.e. at least 20 to 40 years), preferably permanently.		Long-term protection allows the full range of species and habitats to recover to the point at which natural ecosystem health can be maintained (IUCN-WCPA 2008). In heavily fished situations, shorter term protection may fail to achieve biodiversity objectives (Russ and Alcala 2010). If no-take status reverts back to open access in heavily fished areas, the benefits of improved ecosystem function and increased biomass of fishery species can be quickly lost (Russell 1998, Williams et al. 2006). Thus, no-take areas should be maintained in no-take status as long as possible. See

			Section 2.2.9.
13	Include special sites in no-take areas.	No-take areas should include sites that are important for: rare or threatened species; rare or threatened habitats; being highly biodiverse and especially those at risk; endemic species or habitats and also isolated sites.	Inclusion of these sites within no-take areas can help ensure all examples of the biodiversity and processes of the ecosystem are protected. See Section 3.2.3.
14	Include sites with high fishery: by-catch species interactions in permanent or seasonal no-take areas.		Some areas, perhaps only seasonally, experience disproportionately high levels of interactions between fisheries and threatened species. To diminish these impacts, these areas should be included in the network (Allison et al. 1998, Grantham et al. 2008).

4 DESIGN PRINCIPLES FOR ACHIEVING CLIMATE CHANGE OBJECTIVES

4.1 Climate change objectives

In this section, we look at climate change resilience (refer Glossary, p.111).

Marine protected areas can contribute to the following climate change objectives in the National and Regional CTI PoAs (Section 1.4.1):

Increase long-term benefit to human well-being (of current and future coastal communities especially) of the use of marine resources including:

- Sustaining the full range of marine ecosystem goods and services
- Improved quality of marine and coastal resources
    - Better habitat condition
        - Coral reefs
        - Mangrove forests
        - Seagrass beds
        - Beach and/or coastal forests
        - Wetlands
        - Marine/offshore habitats
        - Mudflats
        - Algal beds
        - Rocky coasts
    - Better functioning of marine and coastal ecosystems including
        - Greater productivity
        - Sustaining the full range of marine ecosystem goods and services
        - Ecological processes
- Reduce vulnerability of coastal and marine resources to
    - Climate change impacts including through
        - Protecting refugia to reseed affected areas
        - Reduction of non-climate stressors
        - Application of climate change resilience principles to marine protected area network design
    - Other external and local threats

Many of these objectives are the same as the objectives identified in the fisheries and biodiversity sections of this report (Sections 2.1 and 3.1). This is a reflection of the fact that these "different" objectives are not unrelated but rather, objectives that relate to building resilience or adapting to climate change are often also objectives that help to enhance fisheries or biodiversity conservation and *vice versa*.

4.2 Lessons learned[31]

Strong resilience can be due to both intrinsic factors, such as biological or ecological characteristics of a species, community or ecosystem (e.g. potential for recruitment success), and extrinsic factors, such as physical features (e.g. current patterns that may favour larval dispersal or an effective management regime; Salm and West 2003). For example, certain environmental factors, such as those that cause cooling of heated surface waters, can ameliorate stress associated with thermal bleaching of corals in tropical systems (Mumby et al 2007 in IUCN-WCPA 2008).

Potential climate and ocean change impacts upon coastal ecosystems may include: increasing sea surface temperatures (SST), sea level rise, ocean acidification, changes to rainfall patterns and intensification of the severity of cyclonic/hurricane events (IPCC 2007, Willis et al. 2008, Hoegh-Guldberg et al. 2009). There are consequent implications of these changes on: the physical structure of habitats; coral bleaching events; all calcifying organisms; species compositions; larval survival and recruitment patterns and success levels; species distributions; species ranges and survival; water quality; mangrove forests; photosynthesis sometimes possibly favouring algal communities (Johnson and Marshall 2007; Hoegh-Guldberg et al 2009, Carpenter et al. 2008, Willis et al. 2008, Munday et al. 2009, Bell et al. 2010, Bell et al. 2011). The implications for fisheries, especially in smaller island geographies, in heavily exploited fisheries and in economies dependent on fisheries (such as many parts of the CT) are significant (Pratchett et al. 2008, Bell et al. 2010, Brander 2010, Bell et al. 2011, Pratchett et al. 2011).

Of course, all of these impacts apply in addition to existing local stressors such as over fishing, destructive fishing, poor water quality, coastal developments, shipping, mining etc. (Marshall and Schuttenberg 2006, Hoegh-Guldberg et al. 2009, Bell et al. 2011).

When designing networks of marine protected areas, enhancing the resilience of coral reef ecosystems to climate change and other external impacts can mean application of some generic strategies for which detailed, specific knowledge is not required (Alino 2011, McLeod et al. submitted). Other strategies for climate change resilience require information about impacts that are likely to be realized in certain locations and why some sites are more susceptible than others (Salm and West 2003, Game et al. 2008a, McLeod et al. 2009, TNC 2011, McLeod et al. submitted). For climate change, models are being used to support decision-making for conservation including for design of marine protected area networks (McLeod et al. submitted). All these factors are discussed in more detail below.

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[31] As defined by the terms of reference of this project (Attachment 1), the majority of the material presented in this section was to have derived from a workshop held in Brisbane in 2010 titled: Integrating climate change vulnerability into conservation planning for tropical marine ecosystems and communities (TNC 2011, McLeod et al. submitted). Where other sources are cited in this section, these are being used in addition to information derived from the workshop.

Looking at implications of consideration of resilience and climate change on marine protected area network design, this project is largely using the outputs of an expert workshop[31] held in 2010 (TNC 2011, McLeod et al. submitted). For the remainder of this chapter, all information presented can be referenced back to the workshop, unless otherwise indicated. Where other references are cited, they are an additional source to the workshop report and associated unpublished manuscript (TNC 2011, McLeod et al. submitted).

4.2.1 Proportion of a region to include in a marine protected area network

In the past, it has been suggested that to offer adequate risk reduction, no-take areas should cover 30 to 60 percent of the management areas (NRC 2001). Allison et al (2003) advocates an additional ~30 percent protection in no-take areas to provide adequate insurance against disturbances. For example, consider the ~35 percent of no-take areas suggested in previous section and multiple it by 1.3 (i.e. 35 percent x 1.3 = 46 percent), which totals ~46 percent of the management area in no-take areas. McLeod et al (2009) provide a general recommendation to include a minimum of 20 to 30 percent of the management area in a marine protected area network (but not necessarily no-take areas) to ensure resilient networks in the context of climate change.

Some efforts in the real world have included an "insurance" factor into designs of marine protected area networks to help build resilience. For example, on the Great Barrier Reef, the minimum recommended levels of protection were significantly exceeded in many areas (i.e. minimum recommendation was 20 percent; overall zoning included 33 percent of management area in no-take zones; Fernandes et al 2005).

Some areas are explicitly accounting for the likely impacts of climate change in terms of proportion of area to protect. For example, in Choiseul, Solomon Islands, communities have decided to double the proposed level of overall protection in response to the threat of climate change impacts and to increase targets to protection of 95 percent for critical habitats (Lipsett-Moore et al 2010).

4.2.2 How big should the individual protected areas be within a network?

McLeod et al (2009) advocate including larger areas within marine protected areas: 10 to-20 km in diameter to help protect the full range of habitat types, the ecological processes that they rely upon and to accommodate self-seeding by short distance dispersers. This is consistent with some advice from other practitioners (TNC 2009; Section 2.2.3).

For Kimbe Bay, PNG, Green et al. (2007) did not specify a minimum size of protected areas but the principles did explicitly identify the need to incorporate patterns of connectivity, which include self-seeding of sites. Consequently, Kimbe Bay's marine protected area network design led to 14 of the 15 areas of interest being greater than 10 km^2. In the Lesser Sunda, climate change connectivity and other principles led to a coastal marine protected area network design where 72 of the 86 areas of interest were larger than 10 km^2 (Wilson et al. 2011).

4.2.3 How far apart should individual marine protected be areas within a network?

McLeod et al (2009) advocate ensuring connectivity between marine protected areas to help build resilience to climate change (to accommodate larval dispersal and movement of juveniles and adults, and support replenishment following disturbance). They suggest locating protected areas less than 15 to 20 km apart, which also matches with other advice (McLeod et al 2009, TNC 2009; Section 2.2.4).

This advice has been used in the implementation or planning for marine protected areas in the CT, in some instances, with particular regard to climate change resilience (Green et al 2007, Green et al 2009, Wilson et al 2011; Section 2.2.4.3).

4.2.4 What shape should individual marine protected areas be within a network?

Use of simple shapes (e.g. squares) which minimize edge effects (and adult spillover) is suggested to support internal integrity of marine protected areas which may then be more resilient to climate change (McLeod et al 2009, TNC 2009).

This is also consistent with advice for protecting biodiversity (Section 3.2.2).

4.2.5 Where should the marine protected areas be located?

The most advice about building resilience to climate and ocean change in marine protected area design pertains to where to locate the protected areas. Some of the advice is generic and the same as provided above (Sections 2.2.6 and 3.2.3). For example, marine protected area networks should include: special and unique sites; critical habitats (e.g. nursery grounds, spawning sites, turtle nesting sites); areas of high biodiversity; examples of every habitat type; larval source areas; areas in upstream locations within the management boundaries; areas that have not suffered as much from local threats and human impacts (Marshall and Schuttenberg 2006, Green et al 2007, McLeod et al 2009, TNC 2009). The implementation of these recommendations is likely to contribute to fisheries, biodiversity as well as resilience and climate change goals.

Some of the advice is particular to climate change (McLeod et al 2009). This advice is about choosing marine protected areas with consideration of locations that are known, or likely, to be either more resistant to (or more able to recovery from) climate and ocean change impacts (Côté and Darling 2010). The aim is to locate protected areas (and networks) where they are most likely to survive climate and ocean change impacts. The longer the likely recovery time, the more important to protect the tolerant sites (Game et al. 2008a). However, if the sites chosen are not politically feasible or knowledge is insufficient to identify these sites, some practitioners advocate a higher overall level of protection to minimize risk (Allison et al. 2003, Game et al. 2008a, Game et al. 2008b).

To achieve climate change resilience, best scientific advice is to choose sites to include in the marine protected area network:

- With lower exposure to thermal stress, such as areas with: cold-water upwellings; adjacent deep water; warmer water being regularly exchanged for cooler water; more exposure to high cloud cover; strong currents; shade (e.g. close to high cliffs; lower chronic and/or acute thermal stress);
- With a variety of temperature regimes (including high and low SSTs and high variability in SSTs) to account for uncertainties in climate impacts and in ecological responses to those impacts;
- That have demonstrated resilience to climate change impacts (e.g. areas that have resisted or recovered from bleaching);
- That enable coastal habitats to migrate inshore as sea level rises (i.e. where coastal development and/or topography does not impede landward migration of habitats);
- That have a natural variety of ocean carbonate chemistry regimes;
- That have biological, physical and/or chemical processes that can alleviate the impacts of ocean acidification (e.g. areas of high water mixing, areas with high biodiversity, areas less vulnerable to other stressors); and
- That builds connectivity among source *refugia* and susceptible sink reefs to enhance recovery.

(Salm and West 2003, Marshall and Schuttenberg 2006, McLeod and Salm 2006, McClanahan et al. 2007, IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, Sale et al. 2010, Oliver and Palumbi 2011, TNC 2011, McLeod et al. submitted).

Unfortunately, there are a lack of tools that provide reliable thermal, sea-level rise, ocean chemistry data at the necessary coverage and spatial resolution (i.e. less than about 16 km^2) to inform conservation planning (McLeod et al. submitted). There are, however, models and data that apply at an ecoregional or country extents within the CT that can, potentially, inform higher-level management decisions (Green and Mous 2008; Peñaflor et al. 2009, McLeod et al. 2010a, McLeod et al. 2010b). McLeod et al. (2010a) assessed the vulnerability of CT countries to sea-level rise and found all the countries to be vulnerable in different ways (for more details see Attachment 3). McLeod et al (2010b) suggest that, in terms of avoiding thermal stress from climate change, the Palawan/North Borneo ecoregion may be a good area for future investment in coral reef conservation, assuming that protection is directed at areas with low risk of thermal stress (Game et al. 2008, McLeod et al 2010b). Coral reef areas in the Solomon Sea and Banda ecoregions may also be good choices according to McLeod et al (2010b), as these areas have moderate mean annual maximum degree heating weeks[32], moderately low local stresses, and lower degree

[32] Degree heating weeks is a measure that combines the intensity and duration of thermal stress in order to predict coral bleaching.

heating week projections by 2100 than surrounding ecoregions. For more details see Attachment 3.

At a finer scale, planners and decision-makers must rely upon local, empirical data to inform their management planning and this is occurring in some areas (e.g. Kimbe Bay, PNG; Lesser Sunda Marine Ecoregion, Indonesia and Timor Leste; Raja Ampat, Indonesia; Green et al. 2007, TNC et al. 2010, Grantham and Possingham 2011, Wilson et al 2011).

One expected impact of increased sea surface temperatures is the latitudinal movement of fish species distributions towards the poles (Bell et al 2010). This would imply that any large scale network of marine protected areas should extend to as broad and as high a latitude as possible (FAO 2006, Gaines et al. 2010).

4.2.6 The importance of replication

From a risk management perspective, building ecosystem resilience includes building redundancy into management actions (e.g. marine protected area networks) so that the management action can still achieve its objectives in the event of a catastrophe (Allison et al 2003, Section 2.2.7). This logic extends also to risks associated with climate change with best advice recommending at least three widely separated replicates of each habitat in marine protected areas (Marshall and Schuttenberg 2006, McLeod et al 2009, TNC 2009). See Section 2.2.4 on spacing.

4.2.7 Type of protection to offer within the marine protected area network

Advice pertaining to climate change resilience is silent on the kind of protection that should be afforded within any network of marine protected areas aside from stating that it should include a high proportion of no-take areas (IUCN-WCPA 2008). More generally, advice on marine protected area design to insure against major disturbances or catastrophes pertains only to no-take areas (e.g. Allison et al 2003).

4.2.8 Duration of protection to offer within the marine protected area network

For resilient networks of marine protected areas, IUCN-WCPA (2008) advocate long-term protection, including in no-take areas. It is safe to assume that this applies to resilience to climate change impacts as well.

4.3 Guiding principles

Overall, the information gathered above, and building on previous sections, leads to a set of biophysical guiding principles that can contribute to building ecosystem resilience including resilience to climate change impacts (Table 4). Again, some of the rationale is the same as for protecting fish stocks and biodiversity because some of the same science informs a range of design principles.

Areas where the principles differ from the principles for fisheries objectives are highlighted in yellow. There are no differences from only the biodiversity objectives. Areas where the principles differ from both fisheries and biodiversity objectives are highlighted grey.

Table 4. Biophysical principles to design a marine protected area network for building climate change resilience
Where the principles differ from the principles for fisheries objectives, they are highlighted in yellow; no differences from biodiversity objectives); where different from both, they are highlighted grey.

	Principle	Detail	Rationale
1	Create as large a multiple use marine protected area possible[3].	Include as much as possible of the coastal ecosystem within a legal or otherwise formalised multiple use management boundary.	To mitigate against any risks, including climate change impacts, best advice is to protect more of the ecosystem than one would otherwise – thus include the whole ecosystem where possible within a broader management framework (Allison et al. 2003, McLeod et al. 2005, McLeod et al. 2009; see Sections 2.2.1, 2.2.8.9, 2.2.11 and 4.2.2).
2	Prohibit destructive activities.	For an ecosystem to be as healthy as possible, to withstand external threats, destructive activities should be prohibited (e.g. blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, night spearing).	Coastal habitats and their associated values are vulnerable to destructive activities, which decrease their resilience to external impacts such as climate change (Hall 1999, Cesar 2000, Cesar et al. 2003, FAO 2003, Marshall and Schuttenberg 2006, IUCN-WCPA 2008, Metuzals et al. 2010, FAO 2011, Pratchett et al. 2011).
3	Represent at least 30 percent of each habitat within no-take areas[2].	Represent the range of types of coral reef, seagrasses, mudflats, algal beds, soft seabed, rocky shores, coastal forests, beaches, mangroves, other wetlands.	Entire ecosystem health, integrity and resilience can only be protected if examples of every habitat are included in protected areas (Palumbi 2004, IUCN-WCPA 2008, Lowry et al. 2009, McLeod et al. 2009, TNC 2009, Gaines et al. 2010; see Sections 2.2.6.1, 3.2.3 and 4.2.5). To build ecosystem resilience, including to climate change, a minimum of around 20 to 30 percent no-take protection is recommended (e.g. ICN-WCPA 2008; McLeod et al 2009) but only the higher end of this range conforms with other advice (e.g. Halpern and Warner 2003, Fogarty and Botsford 2007, Botsford et al. 2009a, Botsford et al. 2009b;

			Sections 2.2.2 and 4.2.1). Rotational closures, seasonal closures and most other temporal closures can be beneficial for fisheries but are less useful for building resilience where part of the aim is to build healthy, natural communities. For building resilience these types of marine protected areas should be applied in addition to no-take areas.
4	Ensure that no-take areas include critical sites.	Include important: aggregation sites (e.g. spawning, feeding, breeding); juvenile fish habitat areas; larval sources; turtle nesting areas; migration corridors.	When animals aggregate they are particularly vulnerable and often the reasons they are aggregating are crucial to the maintenance of the population. Therefore the main sites where animals group together or aggregate must be protected to help restore natural balances of populations in communities (IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, Sadovy and Clua 2011; see Sections 2.2.6.2, 2.2.6.3, 3.2.3 and 4.2.5).
5	Apply minimum and a variety of sizes to protected areas within the network.	No-take areas inshore[4] should be a minimum of 10 to 20 km diameter; further offshore, the minimum diameter of no-take areas should be~20 km. Beyond these minimums, vary the sizes. Gear restrictions should apply to as large an area as possible up to the entire marine managed area and all areas where gear interferes with threatened species.	To ensure resilience to climate change, there is agreement that each no-take marine protected area needs to be larger than for fisheries or biodiversity conservation alone (i.e. 10 to 20 km across); the larger the area protected the better (IUCN-WCPA 2008, McLeod et al. 2009). This is slightly larger than Gaines et al (2010) advocate, which is several to tens of km in longshore length for no-take areas for biodiversity protection (and fisheries). See Sections 2.2.3, 3.2.1. and 4.2.2).. Gear and access restrictions can be used, in addition to no-take areas, to help minimize impacts upon habitats and species.

		Access restrictions should be applied as appropriate throughout the marine managed area.	
6	Separate no-take areas by 1 to 20 km (with a mode of ~1 to 10 km apart). Spacing of other long-term protected areas either not applicable or same as for no-take areas.	Apply a variety of spacing of individual no-take areas (from 1 to 20 km apart) throughout the entire management area. Inshore no-take areas should be located closer together (more towards ≥1 km apart) than the more offshore no-take areas (more toward ~20 km apart). Other types of protected areas (e.g. spatial gear or access restrictions) might be quite large in extent throughout the management area (see Principle 5), so it might not be logical to have specified "distances" between them. If other permanent protected areas are isolated "islands" of protection, then the same spacing rules should apply as to no-take areas.	Connectivity between protected areas is important for climate change resilience (Marshall and Schuttenberg 2006, IUCN-WCPA 2008, TNC 2009, McLeod, Salm et al 2009; Section 4.2.3). Recent studies are showing huge variability in larval dispersal distances and lower dispersal distances than previously thought (e.g. 100 m to 1 km to 30 km; Pelc et al. 2009, Shanks 2009, Jones et al. 2010b). Because the CT is the centre of marine biodiversity, with, likely, commensurate diversity in larval dispersal distances, varying the spacing between no-take areas between 1 to 20 km apart is useful. See Section 2.2.4. Spacing at the higher end of the range (20 km) also helps with risk spreading and capturing the range of biodiversity (IUCN-WCPA 2008, McLeod et al. 2009). But if spacing is less than 20 km, these benefits may still occur. See also principle 11, replication.

7	Have protected areas in square or circular shapes.	Use more square or circular shapes subject to considerations of compliance (including use of landmarks).	These shapes minimize adult spillover (White et al. 2006) which helps enhance the integrity of the protected areas and, therefore, their health and resilience (IUCN-WCPA 2008, McLeod et al 2009; see Sections 2.2.5, 3.2.2 and 4.2.4.
8	Place protected area boundaries at habitat edges.	Match the edge of any habitat with the edge of a protected area.	To build resilience to external impacts it is best to retain the integrity of any protected area as much as possible; locating boundaries at habitat edges diminishes adult spillover (IUCN-WCPA 2008, McLeod et al. 2009, Gaines et al. 2010).
9	Locate more protection upstream of currents.	If currents are known and consistent, then a greater number of the protected areas, especially no-take areas, should be located towards the upstream end of the management area. If currents are not known or not constant, then this principle does not apply, and protection should be distributed evenly throughout the management boundaries (with consideration of the principle on spacing).	Protected areas, especially no-take areas, should become a source of larvae contributing disproportionate amount to population recruitment (Gaines et al. 2003). The degree that currents influence larval dispersal will influence population recruitment much more in locations downstream of protected areas thus maximising population "return" per unit area protected and optimising the return of the ecosystem to natural population levels (Marshall and Schuttenberg 2006, IUCN-WCPA 2008, McLeod et al. 2009, Sale et al. 2010, TNC 2009; see Section 2.2.6.3).
10	Minimize external threats.	Choose areas that have been, and are likely to continue to be, subjected to lower levels of damaging impacts (e.g. areas with high water quality; no mining; no shipping; areas where fishing is likely to be regulated and managed; and existing, functional protected areas).	To optimize protection of areas that are less likely to be exposed to local threats and more likely to recover, it is wise to avoid areas that have been, or are likely to be, damaged from these threats including damaging human uses (see Section 2.2.6.4). From a resilience point of view these areas are also more likely to be in better condition and therefore more resilient to external threats such as climate change and thus contribute more and more quickly to overall ecosystem resilience (Marshall and Schuttenberg 2006, TNC 2009).

			It takes time for marine protected areas to improve ecosystem health. Therefore it is usually advantageous to include existing functional marine protected areas within a new network (IUCN-WCPA 2008, Green et al. 2009b).
11	Replicate protection of habitats.	Include at least three widely separated replicates of every habitat within a protected area network, ideally in no-take areas.	Replication of protection allows for risk minimization in the event of extreme events and helps enhance representation of habitats diversity or biodiversity heterogeneity that are unknown (IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, Gaines et al. 2010). See Sections 2.2.7 and 4.2.6.
12	No-take areas, prohibitions on destructive gear, other gear and access limits should be in place for the long-term (at least 20 to 40 years), preferably permanently.		Long-term protection allows the entire range of species and habitats to recover to the point at which natural ecosystem health is restored and then maintained (IUCN-WCPA 2008). In heavily fished situations, shorter term protection may fail to achieve ecosystem resilience. If no-take status reverts back to open access in heavily fished areas, the benefits of improved ecosystem function and increased biomass of fishery species can be quickly lost (Russell 1998, Williams et al. 2006). Thus, no-take areas should be maintained in no-take status as long as possible. See Sections 3.2.5 and 4.2.8.
13	Include special or unique sites in no-take areas.	No-take areas should include sites: that are important for: rare or threatened species; rare or threatened habitats; being highly biodiverse and especially those at risk; endemic species or habitats and also isolated sites.	Inclusion of these sites within no-take areas can help ensure all examples of the biodiversity and processes of the ecosystem are protected. (Section 3.2.3). This type of comprehensive inclusion increases the chance that all the crucial parts of the system are able to contribute to climate change resilience (IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009).

14	Include resilient sites in no-take areas.	No-take areas should include areas that are most likely to survive climate change impacts due either to previous survival or conditions that will make them more likely to resist, recover or migrate from impacts. Section 4.2.5.	Areas with historically variable sea surface temperature (SST) and ocean carbonate chemistry (e.g. aragonite saturation levels) levels appear likely to withstand changes in those parameters similar to areas known to have withstood such environmental changes in the past (Salm and West 2003, Marshall and Schuttenberg 2006, Mumby 2007 in IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, TNC 2011, McLeod et al. submitted). Networks should also include coastal habitats e.g. mangroves which have adjacent, low-lying inland areas that they can expand into as sea level rises (McLeod and Salm 2006; see Section 4.2.5).

5 BIOPHYSICAL PRINCIPLES FOR DESIGNING RESILIENT NETWORKS OF MARINE PROTECTED AREAS TO ACHIEVE FISHERIES, BIODIVERSITY AND CLIMATE CHANGE OBJECTIVES

5.1 Multiple objectives

There is significant overlap between principles that contribute to larger fisheries goals and objectives that contribute to larger biodiversity conservation goals (compare CT6 objectives list in Sections 2.1 and 3.1). There is also much overlap between those two sets of principles and those that pertain to the goal of building ecosystem resilience, including resilience to climate change impacts (compare Sections 2.1 and 3.1 with Section 4.1).

The overlap is because the overarching goals of an ecosystem approach to fisheries management (see definition in Attachment 2), biodiversity conservation and ecosystem resilience (including resilience to climate change impacts) are very similar along many dimensions. Achievement of many of the specific objectives within any one of the three goals also contributes to achieving the other goals.

5.2 Linking objectives to principles

In establishing any network of marine protected areas, the priorities among different objectives and the details of the objectives (e.g. regarding which species, which fisheries are the priority and what are the fishery targets you are aiming towards) will be essential drivers to the degree and manner in which any biophysical guiding principles are implemented (Pitz and Riedel 1984). Clearly defined and specific marine resource management objectives will be essential to the appropriate, prioritized, local application of the suggested biophysical guiding principles in Table 5 (Section 1.4).

5.3 Lessons learned

From the exploration of the literature (Sections 2, 3 and 4) and from tapping into climate change expertise (TNC 2011, McLeod et al. submitted), we have learned that most of the design principles for marine protected area networks that help achieve fisheries objectives also help achieve biodiversity and resilience objectives and vice-versa. In the case of climate change resilience, Section 4.2.5 offers some specific suggestions for locating marine protected areas in sites that will withstand climate change impacts. But this latter also helps ensure ecosystem survival through climate change, which helps achieve fisheries and biodiversity objectives.

Overall, there is much similarity in the design principles advocated to help achieve all three goals. However, there are some differences, which include the following:

- For fisheries goals, individual marine protected areas should be smaller to allow for more spillover, to maintain access to more areas while still protecting examples of all habitats and to enable flexibility to fishers needs;
- For fisheries goals, marine protected area shapes should allow for more spillover of especially adult fished species but also larval and juvenile fished species;
- For biodiversity goals, some special, unique, isolated sites that contain species and ecosystem functions not commonly found elsewhere are important to include;
- For biodiversity and climate change goals, no-take areas are important as the more holistic conservation benefits far outweigh those of other types of protection;
- For biodiversity and climate change goals, permanent protection is important because this will allow the full range of species and ecosystem functions to be restored and maintained in an ongoing manner;
- For climate change goals, climate change resistant sites should be chosen;
- For climate change goals, emphasis should be placed on building connectivity among source *refugia* and susceptible sink reefs to enhance recovery; and
- For climate change goals, emphasis should be placed on including at least three widely separated replicates of all major habitat types into networks to spread risk.

5.3.1 Applying the precautionary principle

An overarching common theme in much of the discussions above is that there exists inadequate information to be certain of the best management approach to take, including when designing of networks of marine protected areas for fisheries or other objectives (Sale et al. 2005, McCook et al. 2009, Gaines et al. 2010, Grafton et al. 2010b, Osmond et al. 2010, Sale et al. 2010). This is particularly true for small-scale, multi-species fisheries in developing countries (Johannes 1998, McConney and Charles 2010, Pomeroy and Andrew 2011). There are costs of waiting for more information due to the ongoing decline of ecosystems (Johannes 1998, Grantham et al. 2009).

The entire CTI, however, is a response to current (and deteriorating) conditions and is a call to action despite the inadequate information and uncertainty (Coral Triangle Secretariat 2009). All practitioners in the field agree that incomplete information should not be a reason for inaction; rather, the precautionary principle should apply (Johannes 1998, Russ 2002, IUCN-WCPA 2008, the CTI National Plans of Action, Coral Triangle Secretariat 2009, Gaines et al. 2010).

In the context of the considerable uncertainty and lack of understanding associated with fish stocks, natural physical cycles and impacts, fishing effort, ecosystem functioning and with climate change effects, marine protected area networks can provide valuable insurance against long-term overfishing and habitat damage (J. Tanzer, pers. comm).

Even if complete information were available on every species of interest, the likelihood of one set of design principles perfectly serving the needs of all of them would be close to nil; thus we are reduced to using approximations that can be applied across a range of species (Jones et al. 2007, Gaines et al. 2010).

Much of the research and advice discussed above pertains to only one kind of marine protected area: no-take areas (e.g. Lubchenco et al. 2003, Jones et al. 2007, Gaines et al. 2010, Sale et al. 2010). Thus, while there remains some uncertainty about the use of no-take areas in marine protected area network design, there is even less knowledge about combining a range of different levels of protection within marine protected area network design (Gaines et al 2010).

5.4 Recommended and prioritized guiding principles

Factoring all of the information collated and analyzed in Sections 2.2, 3.2, 4.2 through 5.3, we offer the following set of biophysical principles for designing resilient networks of marine protected areas to integrate fisheries, biodiversity and climate change objectives in the CT and elsewhere.

Each community will have local knowledge and values by which to apply their own priorities for and adjustments of the principles. For example, locations where bleaching has destroyed an area or a community values a particularly special or unique area may become priorities in the network design. In the absence of more detailed local information, and as discussed in Section 2.3.2, based upon the experience of the authors, we provide our suggested priority for application of the principles by the order in which they are presented in Table 5. This priority recognizes that all of the principles contribute to all three goals (fisheries, biodiversity and climate change) in some way.

Table 5. Prioritized biophysical principles for designing resilient networks of marine protected areas to integrate fisheries, biodiversity and climate change objectives.

	Principle	Rationale
1	**Prohibit destructive activities throughout the managed area.** Prohibit as many destructive activities as possible, for example, blast fishing, poison fishing, spearfishing on scuba, bottom trawling, long-lining, gill netting, coral mining, fishing on hookah, night spearing. (refer to Principle 6).	Coastal habitats and their values are vulnerable to destructive activities which can decrease the health and productivity of the ecosystem and, consequently, all species (including targeted fish species) living within it. Destructive activities also decrease ecosystem resilience to other impacts (Hall 1999, Cesar 2000, Cesar et al. 2003, FAO 2003, Marshall and Schuttenberg 2006, IUCN-WCPA 2008, Metuzals et al. 2010, FAO 2011, Pratchett et al. 2011).
2	**Represent 30 percent (or, at least, 20 percent) of each habitat within no-take areas[2]** Represent the range of types of coral reefs, seagrass, mudflats, algal beds, soft seabed communities, rocky shores, coastal forests, beaches, mangroves, other wetlands and other habitats in no-take areas. If the only protection offered is no-take areas, then the proportion of no-take areas needs to be higher (e.g. 40 percent); if additional effective protection is offered (e.g. input/ output controls[33], other spatial controls) then apply 30 percent (or, at least, 20 percent) no-take areas.	Protection of all fish habitats, all plants and animals and of entire ecosystem health, integrity and resilience can only be achieved if adequate examples of every habitat are included in no-take areas (Palumbi 2004, IUCN-WCPA 2008, Lowry et al. 2009, McLeod et al. 2009, TNC 2009, Gaines et al. 2010; see Sections 2.2.6.1, 3.2.3 and 4.2.5). To ensure achievement of fisheries objectives in areas where fishing has been heavy, and of biodiversity conservation and ecosystem resilience where any local stressors have (or have had) impacts, no-take areas should encompass at least 30 percent of the management area (e.g. Gerber et al. 2003, Halpern and Warner 2003, Fogarty and Botsford 2007, Botsford et al. 2009a, Botsford et al. 2009b; Sections 2.2.2 and 4.2.1). Lesser levels (but not less than 10 percent) can apply in areas with historically low fishing pressure (Botsford et al. 2001, Botsford et al. 2009b). If aiming to protect species with lower reproductive output or delayed maturation (e.g. sharks or some groupers) more area will be required (Fogarty and Botsford 2007).

[33] For example, adequate and effective restrictions on type and quantity of gear, effort, and capacity; limits on catch or landings; limits on sizes; limiting catch of a given sex, or animals in a particular stage of the breeding cycle; regulating discards; daily bag or possession limits.

3	**Replicate protection of habitats.** Include at least three replicates of every habitat within a protected area network, ideally, in no-take areas. (See Principle 8 on spacing)	Replication of protection minimizes risk that all examples of a habitat will be adversely impacted by the same disturbance. If some protected habitat areas survive an impact they can act as a source of larvae for recovery of other areas. Replication also helps enhance representation of biological heterogeneity within habitats that are not understood. (IUCN-WCPA 2008, McLeod et al. 2009, Gaines et al. 2010; see Sections 2.2.7, 4.2.6).
4	**Ensure that no-take areas include critical habitats.** Include important: aggregation sites (e.g. spawning, feeding, breeding grounds); juvenile fish habitat areas; larval sources.	When animals aggregate, they are particularly vulnerable and often the reasons they are aggregating are crucial to the maintenance of the population. Therefore the main sites where animals group together or aggregate must be protected to help restore natural balances of populations in communities (IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, Sadovy and Clua 2011; see Sections 2.2.6.2, 2.2.6.3, 3.2.3 and 4.2.5).
5	**No-take areas, prohibitions on destructive fishing gear, other fishing gear and access limits should be in place for the long-term, preferably permanently.**	Long-term protection allows the entire range of species and habitats to recover, then maintain, natural ecosystem health and associated fishery benefits (IUCN-WCPA 2008). Some benefits can be realized in the shorter term (1 to 5 years) especially if fishing pressure has not been heavy (Ward et al. 2001, Russ et al. 2008, Hamilton et al. 2011; Section 1.8). However, 20 to 40 years protection allows heavily fished species and the longer-lived targeted predator species (e.g. shark, other coral reef predators) the opportunity to grow to maturity and thereby increase in biomass and then contribute increasingly more, and more robust, eggs to stock recruitment and regeneration (Russ and Alcala 1996, 2004, Frisk et al. 2005, Hart 2006, Kaplan et al. 2010, Russ and Alcala 2010, White and Kyne 2010). Twenty to forty years protection (or, best, permanent protection) allows these fishery and ecosystem benefits to be sustained (Russ and Alcala 1996, 2004, Frisk et al. 2005, Hart 2006, Kaplan et al. 2010, Russ and Alcala 2010, White and Kyne 2010). In heavily fished situations, shorter term protection may fail to achieve fisheries, biodiversity and ecosystem resilience objectives. If no-take status reverts back to open access in heavily fished areas, the benefits of improved ecosystem function and increased biomass of fishery species can be quickly lost (Russell 1998, Williams et al. 2006). Thus, no-take areas should

		be maintained in no-take status as long as possible. Necessary duration of protection may also be influenced by the life history characteristics of the species of interest. See Sections 2.2.9, 3.2.5 and 4.2.8. Seasonal closures have an inherent (i.e. seasonal) temporal timeframe and other temporal closures will be applied for reasons that will have their own temporal requirements.
6	**Create a multiple use marine protected area that is as large as possible.**[34] Include as much as possible of the coastal ecosystem within a legal or otherwise formalised multiple use management boundary.	To apply an ecosystem approach to fisheries management, to maximize the range of biodiversity and habitats protected, to mitigate against any risks, including climate change impacts, the best advice is to include all of the ecosystem within a multiple-use marine managed area that offers a broader management framework (Allison et al. 2003, FAO 2003, McLeod et al. 2005, Christie et al. 2009a, McLeod et al. 2009). The different levels of protection offered within a multiple-use area can offer synergistic benefits, as seen within ecosystem based fisheries management (Link 2010; see Sections 2.2.1, 2.2.8.9, 2.2.11 and 4.2.2).
7	**Apply minimum and a variety of sizes to protected areas within the network.** **No-take areas**: If no additional effective protection is in place (e.g. no fisheries input/output controls for wide ranging species: refer to Principle 2), then a mixture of small (a minimum of 0.4 km^2 or 40 ha) and large (e.g. 4 to 20 km across) no-take areas is required to achieve biodiversity, climate change and fisheries objectives. If there is additional protection for wider ranging	To help build resilience into the fisheries, the ecosystem and to contribute meaningfully to biodiversity protection the minimum recommended size for all goals is much larger (e.g. 10 to 20 km across) than just for fisheries alone (e.g. 0.1 to 0.2 km^2. or 10 to 20 ha ;White et al. 2006); for resilience and biodiversity conservation the larger the area protected the better (Halpern and Warner 2003, IUCN-WCPA 2008, McLeod et al. 2009, Gaines et al. 2010). Shanks (2009) and others consider ~4 to 6 km or more to be the minimum viable diameter in terms of containing larval dispersal distances of most species (as well as adult movement) but others have found smaller effective dispersal distances (e.g. 100 m to 1 km to 30 km;Alcala and Russ 2006, Almany et al. 2007, Lester et al. 2009, Jones et al. 2010b). And, of course, using networks of protected areas is one way to increase connectivity between sites without matching each site's size

[34] This may also be known as a marine managed area or a multiple use marine park

	species, then networks of small no-take areas can achieve most objectives, particularly regarding fisheries management (subject to implementing Principle 2). Exact sizes to use will depend on the movement patterns of the species of key importance in any situation. **Temporal closures** of any kind should include, at minimum the entire area of the site plus a 100 m wide buffer (or 40 ha minimum if these details are unknown) **Gear restrictions**: as large an area as possible up to the entire marine managed area and all areas where gear interferes with threatened species. **Access restrictions**: as appropriate throughout the marine managed area.	with adult and larval movement patterns (IUCN-WCPA 2008, Weeks et al. 2010a). The recommended minimum size here assumes: a network of no-take areas; and the application of principle 2 in terms of amounts of no-take areas. Where larval dispersal patterns and/or adult movement patterns of particular target species are known, this information can also inform decisions about ideal sizes of protected areas. Most mackerel and other near-shore pelagic species, for example, will need much larger marine protected areas as their ocean neighbourhoods are larger (Palumbi 2004; see Sections 2.2.3, 3.2.1. and 4.2.2). Gear and access restrictions can be used, in addition to no-take areas (long-term and temporal), to minimize impacts upon habitats and species.

8	**Separate no-take areas by 1 to 20 km (with a mode of ~1 to 10 km apart).** Apply a variety of spacing of individual no-take areas (from 1 to 20 km apart) throughout the entire management area. Inshore no-take areas should be located closer together (≥1 km apart) than the more offshore no-take areas (~20 km apart). **Spacing of other long-term protected areas either not applicable or same as for no-take areas.** Other types of protected areas (e.g. gear and access restrictions) might be quite large in extent throughout the management area (see Principle 7) and so it might not be logical to have specified "distances" between them. However, if other permanent protected areas are isolated "islands" of protection, then the same spacing rules should apply as to no-take areas.	Connectivity between protected areas is important for maintaining diversity, fish stocks and especially important for maintaining ecosystem resilience (Marshall and Schuttenberg 2006, IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009; see Section 4.2.3). Adult movement is generally at a smaller scale than larval movement (Palumbi 2004). Recent studies are showing huge variability in larval dispersal distances and lower dispersal distances than previously thought (e.g. 100 m to 1 km to 30 km; Almany et al. 2007, Pelc et al. 2009, Shanks 2009, Jones et al. 2010b). Mackerel and other nearshore pelagic species may need marine protected areas spaced further apart as their ocean neighborhoods are larger (Palumbi 2004). Because the CT is the center of marine biodiversity and has multi-species coastal fisheries (Green and Mous 2008, Veron et al. 2009, Nanola Jr et al. 2010) there are, likely, commensurate diversity in adult movement ranges and larval dispersal distances in species of interest. For these reasons, varying the spacing between no-take areas between 1 to 20 km apart is useful (Jones et al. 2007, Jones et al. 2008; see Section 2.2.4). Spacing at the higher end of the range (20 km apart) also helps with risk spreading and capturing the range of biodiversity (IUCN-WCPA 2008, McLeod et al. 2009). But if spacing is less than 20 km, these benefits may still occur. See principle 3 on replication. Where local knowledge exists on connectivity of locally important species, it should be used to inform this principle on spacing.
9	**Include an additional 15 percent in shorter-term no-take protection,** such as seasonal, rotational or other temporally variable zones.	Shorter-term spatial management tools should be applied in addition to the minimum level of no-take protected areas (principle 2). Rotational closures, seasonal closures and most other temporal closures can be beneficial for fisheries (e.g. protecting critical areas at critical times if not included in long-term no-take areas; allowing limited fisheries access at culturally important times) but are usually less useful for conserving biodiversity or building resilience where part of the aim is to build and maintain healthy, natural

		communities and sustain ecosystem services. These areas also function as a partial insurance factor[4] against catastrophes by enhancing overall ecosystem resilience against catastrophes such as cyclones, oil spills (Allison et al. 2003).
10	**Have a mixture of protected area boundaries: both within habitats and at habitat edges.** The relative mix of boundary locations will depend upon management priorities, local knowledge and on what is possible given the geography and resources of a site.	To build resilience to external impacts, it is best to retain the integrity of any protected area as much as possible by locating boundaries at habitat edges to limit adult spillover (IUCN-WCPA 2008, McLeod et al. 2009, Gaines et al. 2010). However, to encourage fisheries benefits, some boundaries should be in the middle of fish habitats (Gaines et al. 2010).
11	**Have protected areas that are more square or circular in shape.** Use more square or circular shapes subject to considerations of compliance (including use of landmarks).	These shapes allow for limited adult spillover (White et al. 2006) which helps maintain the integrity of the protected areas and, therefore, the sustainability of their contribution to fisheries, biodiversity and ecosystem resilience (IUCN-WCPA 2008, McLeod et al. 2009; see Sections 2.2.5, 3.2.2 and 4.2.4).
12	**Minimize external threats.** Choose areas for protection that have been, and are likely to continue to be, subjected to lower levels of damaging impacts (e.g. areas with higher water quality; no mining; no shipping activity; areas where fishing is likely to be regulated and managed; and existing, functional protected areas).	To optimize protection of areas that are less likely to be exposed to local threats and most likely to recover, it is wise to avoid areas that have been or are likely to be damaged from threats including damaging human uses (see Section 2.2.6.4). From a resilience point of view, these areas are also more likely to be in better condition and therefore are more resilient to external threats such as climate change; and thus contribute more, and more quickly, to overall ecosystem health and fisheries productivity (Marshall and Schuttenberg 2006; TNC 2009). It takes time for marine protected areas to improve ecosystem health. Therefore it is usually advantageous to include existing functional marine protected areas within a new network (Russ and Alcala 2004, IUCN-WCPA 2008, Green et al. 2009b)

13	**Include resilient sites in protected areas.** Protected, ideally no-take, areas should include areas that are most likely to survive climate change impacts as indicated by either previous survival or conditions that make them more likely to resist, recover or migrate from impacts. See Section 4.2.5.	Areas with historically variable sea surface temperature (SST) and ocean carbonate chemistry (e.g. aragonite saturation levels) levels appear likely to withstand changes in those parameters similar to areas known to have withstood such environmental changes in the past (Salm and West 2003, Marshall and Schuttenberg 2006, McLeod et al. 2009, TNC 2009, 2011, McLeod et al. submitted; Mumby 2007 in IUCN-WCPA 2008). Networks should also include coastal habitats e.g. mangroves which have adjacent, low-lying inland areas that they can expand into as sea level rises (McLeod and Salm 2006; see Section 4.2.5).
14	**Include special or unique sites in protected areas.** Protected, ideally no-take, areas should include sites that are important for: rare or threatened species (e.g. turtle nesting sites); rare or threatened habitats; being highly biodiverse and especially those at risk; endemic species or habitats and also isolated sites.	Inclusion of these sites within the network can help ensure all examples of the biodiversity and processes of the ecosystem are protected (Section 3.2.3). Being comprehensive in this way increases the chance that all the crucial parts of the system are able to contribute to ecosystem health and resilience (IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009).
15	**Locate more protection upstream of currents.** If currents are known and consistent, then a greater number of the protected areas, especially no-take areas, should be located towards the upstream end of the management area. If currents are not known or not constant then this principle does not apply and protection should be distributed evenly throughout the management boundaries (subject to the principles 7 and 8 on size and spacing).	Protected areas, especially no-take areas, should become a source of larvae contributing disproportionately greater amount to population recruitment (Gaines et al. 2003, Sale et al. 2010). To the degree that currents influence larval dispersal, they will influence genetic connectivity and population recruitment and much more in locations downstream of protected areas. In this way, one can maximize the likely population "return" per unit area protected and optimize the return to natural population levels which are genetically connected (Marshall and Schuttenberg 2006, IUCN-WCPA 2008, McLeod et al. 2009, TNC 2009, Sale et al 2010). Information about specific target species larval movements can also inform this principle. See Section 2.2.6.3.

Incomplete information to implement the recommended principles

Currently, nowhere in the CT has all the information (or resources to obtain the information) required to implement the recommended principles (Alino et al. 2008d). Everywhere in the CT there will be enough information to implement some of the principles. In particular, we know that local communities and fishers will have important knowledge to contribute (Johannes 1998). We do not know what information is available in which locations. For this reason, we include all the principles that might be potentially useful, and leave it to the managers to use existing knowledge to apply them as far as possible given their information constraints.

The less the information, the more important are the recommendations regarding prohibition of destructive activities, minimum amount of protection (per habitat where known) and replication.

These three design principles increase the likelihood of protecting the entire range of unknown species and processes of importance and insure against the impact of unpredictable disturbances and large scale catastrophes. In addition, recommendations about minimum size requirements, spacing of marine protected areas and critical habitats, where known, are also often implementable with lower levels of information (Nilsson 1998 in Kelleher 1999, Coles et al. 2001, NRC 2001, Ward et al. 2001, IUCN-WCPA 2008, Gaines et al. 2010; Section 2.3.2)

Besides being limited by knowledge, as discussed in Sections 1.3, 1.7 and 1.8, there are broader, additional economic, social, institutional, management, political, cultural, resource and time constraints that will influence the degree to which the principles can be applied. When required to compromise for these reasons, we recommend prioritizing the principles in the order presented in the table above while realizing that local traditional use patterns and political jurisdictions can make it difficult to achieve even the first principle completely.

6 CONCLUSIONS

The principles developed in this report (Table 5) are one small, but important, part of a much bigger process that includes implementing many local networks of marine protected areas in ways that complements human uses and values and aligns with local legal, political and institutional requirements. The complementarities are essential for many reasons, not least is to ensure the success of any marine protected areas by ensuring compliance; non-compliance will lead to no fisheries or ecological benefits.

Adjacent and ecologically connected local networks can, theoretically, be scaled-up into regional networks as has been planned for parts of the CT (e.g. Sulu-Sulawesi Marine Ecoregion, Lesser-Sunda Marine Ecoregion, Bird's Head Seascape and elsewhere; Stakeholders of the Sulu-Sulawesi Marine Ecoregion Technical Working Groups of Indonesia Malaysia and the Philippines and the WWF SSME Conservation Program Team 2003, TNC et al. 2010, CI 2011, Wilson et al. 2011; Section 1.3).

Comprehensive networks of marine protected areas will be inadequate to the task of ensuring all fisheries are sustainable, all biodiversity is conserved and CT ecosystems are resilient to ongoing local and external threats, including climate change (Allison et al. 1998, Hilborn et al. 2004, IUCN-WCPA 2008). The CTI, and all practitioners, acknowledge that marine resource management requires a broader, integrated framework, such as ecosystem-based management (Alino et al. 2008b, IUCN-WCPA 2008, Christie et al. 2009a, Coral Triangle Secretariat 2009, DEC and the NFA 2009, Ehler and Douvere 2009, National Secretariat of the CTI-CFF Indonesia 2009, Republic of Philippines 2009, Republic of Timor Leste 2009, Solomon Islands CTI NCC 2009, Agardy 2010, DEC and the NFA 2010, FAO 2010; Attachment 2, see definitions of EAFM, EBM, Section 1.7).

By acknowledging these broader issues and management frameworks, the authors hope that these practical, on-the-water, guiding principles offer at least one sensible foundation upon which CT marine resource managers can move forward in implementing networks of marine protected areas for fisheries, biodiversity and resilience objectives.

7 GLOSSARY

Adaptive capacity is the ability of a system to cope with, or adapt to, environmental variability and change (e.g. including environmental hazards or policy changes). The adaptive capacity of an ecosystem can refer to its intrinsic capacity to resist or adapt to change via physiological and/or behavioural plasticity or evolutionary adaptation (i.e. through natural selection) of the species that make up the system, in part also determined by genetic, species, or ecosystem diversity and ecosystem heterogeneity. Adaptive capacity may also be due to external conditions (e.g. presence of coastal development or natural barriers that limit the ability of a species or ecosystem to move inland in response to sea level rise) or natural processes such as rates of geological uplift or marsh accretion which can reduce the amount of localized sea level rise.

Design principles are biophysical "rules of thumb" or guidelines about sizes, shapes, locations, distributions etc. of spatial marine areas to include in protected area networks.

Ecosystem approach to fisheries management (EAFM). The CTI Regional and National Plans of Action all refer to the FAO definition of EAFM (strictly, FAO refers to an ecosystem approach to fisheries) which is also used in this document:
"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"

Ecosystem-based management, **or EBM**, is a management approach that recognizes ecological systems for what they are: a 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 and each other sector.

Exposure refers to the rate and magnitude of climate and ocean change and the variability that a system (e.g., ecosystem, community, resource, region, sector) experiences. For example, habitats and communities in low-lying coastal areas are likely to have relatively higher exposure to sea level rise.

Locally managed marine areas (LMMAs) can be defined as marine protected areas under the IUCN definition if managers have a primary concern for the sustainability of their ecosystem (including fish stocks) versus an intention to exploit the fisheries without concern as to its sustainability or impacts upon the ecosystem.

Marine protected areas are defined as any clearly-delineated, managed marine area that contributes to protection of natural resources in some manner. No-take areas are one type of marine protected area.

Nearshore habitats (comprising both **inshore** and **offshore habitats**) refer to marine habitats relatively near the shoreline. This includes those areas with habitats that are contiguous with the coastline (which we have referred to as inshore habitats) and deeper water pelagic habitats further from shore but not yet oceanic environments. These deeper, but still nearshore habitats that are not adjacent to the coastline, we term offshore for the purposes of this report.

Networks of marine protected areas, for this report only, refer to a group of individual marine protected areas that are ecologically connected.

Ocean neighborhoods are the area centred on a set of parents that is large enough to retain most of the offspring of those parents and the movement of the parents. If adults move widely, neighborhoods are large and diffuse. If adults are sessile and larvae are restricted in their dispersal, then a neighborhood might be small and distinct.

Resilience, here, 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.

The **sensitivity** of a system is the degree to which it is affected by environmental variability or change. Sensitivity of ecological systems to environmental change typically refers to physiological tolerances to change and or variability in physical or chemical conditions (e.g., temperature, pH).

Vulnerability is defined as the degree to which a system is susceptible to, and unable to cope with, adverse environmental impacts, including climate variability and extremes, and is a function of exposure, sensitivity, and adaptive capacity.

See also Attachment 2.

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Attachment 1. Terms of reference for this report

Introduction and overall scope of work

Design principles for networks of marine protected areas have, in the past, focused on achievement of biodiversity objectives and focussed on no-take marine protected areas. While some consideration has been given to the requirements of fisheries and adaptation to climate change, the level of consideration has often been limited given the purposes for which the networks of no-take s were being designed.

This project aims to provide insight as to how to better tailor marine protected area design principles to accommodate fisheries aims and objectives. It will also incorporate latest thinking on including basic climate change considerations into marine protected area network design.

The scope of this work includes coral reefs, nearshore (coastal) benthic and small pelagic fisheries and other coastal ecosystems that are particularly important to many coastal communities in the CT. Large scale pelagic systems will generally not be included, nor threatened species, which can, hopefully, be included at a later date.

The combined biophysical design considerations and consequent set of revised marine protected area design principles will then be matched with equal efforts to accommodate human uses and values into marine protected area design. The result will build on earlier efforts to lay out a set of design principles for marine protected areas and marine protected area networks (ecological and social) such as, but not limited to IUCN-WCPA (2008).

The document will also address the issues and challenges of going to scale, or scaling up marine protected areas/marine protected area networks to address larger areas and concerns from a fisheries management and biodiversity protection perspective. The document, in addition to dealing with generic issues of marine protected areas and fisheries, will address the context of scaling and linkages specifically within the CT. It will reference the context of the countries and feedback from countries as relevant in the resulting guidelines. This will ensure that the result is linked to the reality of coastal and marine resources management in the CT region.

In this document, marine protected areas are intended to refer to all types of marine protected areas (e.g. marine managed areas (MMAs), local marine managed areas (LMMAs, etc.) and no-take marine protected areas will be referred to, explicitly, as such.

This scope of work has been developed on the basis of information provided by Dr. Alison Green and Dr. Alan White of the Nature Conservancy, and Mr Maurice Knight, Chief of Party for the Coral Triangle Support Partnership (CTSP). Implementation of this project will be responsive to the timing of several workshops in the CT region and the availability of key resource contacts in the countries and partner organizations of the CTSP. In this regard, a very rigid timeline will not be possible so that the final product will be completed in its entirety until important regional meetings have occurred and feedback from the countries and various experts is adequately reflected in the result.

Methods

The project will comprise several steps which are outlined in the table below. The information on duration does not indicate the amount of time that the consultant will spend on the task but rather, the actions that will be required to complete the task given the need to seek input from others, gather information from a variety of sources etc.

Task no.	Task	Detail
1	Canvas expert input	Seek informal input and advice from local experts (e.g. Prof Garry Russ, Prof Geoff Jones) and input from CTI Working Group and other regional experts (facilitated by Project Managers).
2	Literature review	Summarize key literature and knowledge about fisheries objectives and requirements for MPA design. The literature review will also summarize recommendations from a recent climate change workshop[35].
3	Review MPA design principles	Review and revise existing MPA design principles with consideration of fisheries requirements as per the literature review (Task 2). Provide brief justifications for same.
4	Canvas expert opinion	Seek informal input and advice from local experts (e.g. Prof Garry Russ, Prof Geoff Jones) and input from CTI Working Group and other regional experts (facilitated by Project Managers) as to revised principles.
5	Draft report	Provide written report containing full literature review including revised principles and associated, brief, justifications.
6	MPA workshop	Consolidate expert input at CTI Regional Exchange MPA Workshop in April or May 2011 in the Philippines and finalize report after feedback has been received from the CT6 experts as feasible.
7	Review report	CTSP/TNC to provide comment on report.
8	Final report	Respond to comments and finalize report.

Project Deliverables

The deliverables for this project are as follows:

Task no.	**Deliverables**
1	Literature review, and compilation of expert input and draft report outline
2	Consolidated draft report
	Review report
3	Canvas input at Regional Exchange MPA Workshop, Philippines & deliver final report

Project Management and Administration

This project is to be supervised by Dr. Alison Green and Dr. Alan White of the Nature Conservancy, with input from Mr Maurice Knight.

The project will be conducted in a flexible manner and in close consultation with the project manager(s).

Project Extension

The purpose of this proposal extension is three-fold:

1. Extending the original, agreed consultation list from about 21 to over 40 experts with attendant revisions of the project report;
2. Extend the original, agreed information source for the Climate Change chapter of the draft report to include additional sources; and

[35] This project will incorporate recommendations arising from an expert workshop held by TNC in Brisbane, 10-12 May 2010 called "How can climate change models inform conservation planning in the Coral Triangle." The recommendations provide advice in modifying principles for designing resilient networks of MPAs.

3. Pursuing further input to, and garnering support for, the messages of the report at a face-to-face meeting where key EAFM TWG players from countries are present and via TNC communications on the report at an upcoming EAFM REX.

Extending consultations and literature sources

Consultations around the draft report are important for two reasons: 1) to optimize the quality of the report itself and; 2) to ensure its relevance (and acceptability) to CT6 marine resource managers, including fisheries managers. For these reasons, broader consultations than originally envisaged have been determined to be crucial. These consultations enable a widening of the dialogue on the usefulness of integrating across fisheries, biodiversity and climate change divides.

To bolster these discussions, it is important that the Climate Change (CC) section of the report is robust. To build a more robust CC section requires accessing more information sources than originally agreed (originally, it was agreed that a dedicated CC Workshop in Brisbane in 2010 would be an adequate data source).

Provision of additional time to the consultant to address these issues will achieve:

- A higher quality report due to
  - More extensive expert input; and
  - A slight broadening of the information base used in the CC section of the report to enhance its robustness;
- A broader dialogue across the CT about integrating fisheries with biodiversity and climate change into marine protected area network design; and
- Greater uptake of the report once finalized.

Target EAFM expert input

It is recognized that electronic and telephonic means of communication are limited mechanisms by which to gain meaningful dialogue and input in the CT setting. Face-to-face meetings are significantly more productive in garnering the ideas, suggestions and insights of key CT players. To ensure the utility of the draft report on marine protected area network design principles it requires substantial input from and acceptance of, especially, fisheries managers.

Two opportunities have presented themselves to secure this input. It is possible for the TNC lead staff member on Ecosystem Approach to Fisheries Management (EAFM; Dr. Andrew Smith) to present the report to an EAFM regional exchange in Sabah, Malaysia in September 2011. He will pursue input on behalf of the project authors and direct input and comments back to the report's primary author.

In addition, the report's primary author can participate in the upcoming CTSP CTI EAFM Technical Working Group meeting (TWG) in Jakarta, Indonesia. The intention is for the author to set up meetings with key fisheries parties, at this week-long meeting, to discuss the contents of the draft report and seek feedback.

Responding to input from the EAFM REX and attendance of the draft report's senior author at the EAFM REX will achieve:

- An improved and more useful report;

- An improved understanding, on the part of the intended audience of the report, of the purpose and intent of the report;
- Greater ownership of the report outputs (namely the design principles); and
- Wider distribution of the final report to practitioners in the field.

The scope of this work, therefore, entails the senior author of the draft marine protected area network design report responding to feedback from the EAFM REX and TWG and travelling to and from Jakarta at the time of the EAFM TWG to elicit, especially, in-country (i.e. CT6) fisheries expertise into and support for the report.

Methods

Extending consultations and literature sources

The contractor will increase the number of electronic communications with CT stakeholders from about 21 to over 40 as directed by the project supervisors. This consultation will lead to commensurate input from these people and the consultant will revise the draft report accordingly.

The contractor will enhance the Climate Change section by accessing additional literature and rewriting that section, and associated parts of the report, accordingly.

The methods for this part of the proposal are as follows:

Task no.	Deliverable	Delivery date
1.	List of additional Climate Change (CC) literature	3rd Oct 2011
2.	Revised CC chapter	10th Oct 2011
3.	Revised report including other relevant parts of the report for consistency with revised CC chapter	17th Oct 2011
4.	Additional electronic communications with over 20 additional key CT players	Ongoing

Target EAFM expert input

The contractor will seek additional input to and wider circulation of the draft report on marine protected area network design principles to achieve fisheries, biodiversity and climate change objectives at the EAFM TWG in Jakarta, Indonesia and from experts at the EAFM REX (to be attended by Dr Smith of TNC).

This input will be integrated into the final report in addition to the input already solicited as part of the original contract (TNC Contract Ref: AP/Regional Marine/ETOC013111).

The final report will then be delivered to all parties identified through the EAFM TWG in addition to those already identified and contacted per email, skype, telephone and personally at the MPA ME REX as well as via other *fora*.

Implementation of this project will be responsive to the timing of the EAFM TWG. Therefore, a very rigid timeline will not be possible so that the final product will be completed in its entirety after the EAFM TWG has occurred and feedback from the various experts attending that meeting has been adequately reflected in the resulting report.

The methods for this part of the project are as follows:

Task no.	Deliverable	Delivery date
1.	Preparation of powerpoint and support material for Dr Andrew Smith ahead of the EAFM REX in September	By 16 September 2011
2.	List of proposed meetings at EAFM TWG	1 week prior to EAFM TWG
3.	Participation in and summary minute of meeting outcomes	1 week post-EAFM TWG
4.	Maintain communications with EAFM TWG members as necessary	Ongoing after TWG meeting
5.	Updated MPA design report based upon input from EAFM REX and TWG	3 weeks post EAFM TWG
6.	Distribution of final report to all interested parties	1 week post-final approval by project team

Attachment 2. Justification and explanation of definitions used in this report

Are marine protected areas really just no-take areas?

Marine protected areas are not just no-take areas; they encompass a range of types of protection (Alino et al. 2008c).

The FAO define a marine protected area as a protected marine intertidal or subtidal area, within territorial waters, EEZs or in the high seas, set aside by law or other effective means, together with its overlying water and associated flora, fauna, historical and cultural features. It provides degrees of preservation and protection for important marine biodiversity and resources, a particular habitat (e.g. a mangrove or a reef) or species, or sub-population (e.g. spawners or juveniles) depending on the degree of use permitted. In marine protected areas, activities (e.g. of scientific, educational, recreational, extractive nature, including fishing) are strictly regulated and could be prohibited. FAO defines a no-take marine protected areas as one kind of marine protected area[36].

A marine protected area is included in IUCN's definition of protected area which is "A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values."(Dudley 2008). IUCN/WCPA (1994 in Sale et al. 2010) explicitly defined a marine protected area as a means to protect part or all of the enclosed environment. Protected areas are distinguished from other kinds of marine spatial zoning in that they have nature conservation as a primary rather than a secondary aim (WCPA - Marine 2010). The category VI protected areas explicitly have the sustainable use of natural resources as a *means* to achieve nature conservation (Dudley 2008). In this way, then, any clearly defined, managed area that contributes to protection of natural resources in some way is a marine protected area.

> *The Regional CTI Plan of Action and the National CTI PoAs refer to MPAs as including "the broad range of marine protected area categories: strictly protected, multiple use, government managed, locally managed marine areas (LMMAs), etc. The "total marine area" targets will include the full range of marine protected area use categories from strict protection to sustainable resource use areas*. (Coral Triangle Secretariat 2009)

[36] http://www.fao.org/fi/glossary/; accessed 5/8/11

Within different CT countries, marine protected areas will have different legal definitions that will be important for the CTI. For example, in the Decree of the Government of the Republic of Indonesia No. 60/2007 regarding fishery resource conservation (Article 1) various types of marine protected areas are defined:

"A Fishery Conservation[37] Area refers to a water area, which is protected and managed through use of a zoning system, to create sustainable management of fishery resources and their environment.

An Aquatic National Park refers to an aquatic conservation area, with its original ecosystem, established for the purpose of education and scientific research as well as activities supportive to sustainable fishery management, aquatic tourism and leisure.

An Aquatic Protected Area refers to an aquatic conservation area, with characteristic features, established for the purpose of protecting the diversity of fish species and leisure.

An Aquatic Tourism Park refers to an aquatic conservation area created for the purpose of aquatic tourism activities and leisure.

A Fishery Protected Area refers to a specific aquatic area, be it fresh, brackish or sea water, with specific condition and features, serving as a nursery ground/feeding ground for a specific species of fish, established to serve as a protected area."

These kinds of definitions, agreements and laws create a broad definition of marine protected areas which can be categorized into different levels of protection (WCPA - Marine 2010). Here we summarize the draft definitions of marine protected areas being considered for use by IUCN (Dudley 2008, WCPA - Marine 2010).

[37] Fisheries conservation is defined to include "sustainable use of aquatic biodiversity" and fishery resource conservation is defined to include "ecosystem conservation".

Table 6. Summary of draft IUCN WCPA-Marine categories for Marine Protected Areas (adapted from: Dudley 2008, WCPA - Marine 2010)

Category	Description: primary objective
Ia	Strict nature reserve: To conserve regionally, nationally or globally outstanding ecosystems, species (occurrences or aggregations) and/ or geodiversity features: these attributes will have been formed mostly or entirely by non-human forces and will be degraded or destroyed when subjected to all but very light human impact.
Ib	Wilderness area: To protect the long-term ecological integrity of natural areas that are undisturbed by significant human activity, free of modern infrastructure and where natural forces and processes predominate, so that current and future generations have the opportunity to experience such areas.
II	National Park: To protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation.
III	Natural monument or feature: To protect specific outstanding natural features and their associated biodiversity and habitats
IV	Habitat/species managed area: To maintain, conserve and restore species and habitats
V	Protected seascape: To protect and sustain important landscapes/seascapes and the associated nature conservation and other values created by interactions with humans through traditional management practices
VI	Protected area with sustainable use of natural resources: To protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial

Table 7 indicates which activities could be permitted within the various categories of marine protected areas. Note that categories V and VI allow for fishing. Fishing/collecting may be permissible in category IV marine protected areas where the resource use does not compromise the ecological/species management objectives of the site. Traditional fishing and collection in accordance with cultural tradition and use is suggested to be allowed in all categories of marine protected areas In all cases, management of marine protected areas, irrespective of the category, should ensure that any resource extraction is ecologically sustainable (WCPA - Marine 2010).

Carefully managed mining affecting a small part of a marine protected area may be permissible depending in national legislation relating to mining in protected areas generally or in a specific marine protected area but these areas should be assigned as Category V or IV. When applying a category to a single protected area, the primary objective of the category should apply to at least three quarters of the protected area. The remaining 25 percent of land or water within a protected area can be managed for other purposes as long as these are compatible with the primary objective of the protected area (WCPA - Marine 2010).

Zoning is usually a management tool not generally identified by a separate category, but different zones in larger protected areas can have their own category, if the zones: 1) are clearly mapped; 2) are recognized by legal or other effective means; and 3) have distinct and unambiguous management aims that can be assigned to a particular protected area category (WCPA - Marine 2010).

Table 7. Draft matrix of IUCN categories & activities that may be permitted in a Marine Protected Area (WCPA - Marine 2010)

Activities that may be permitted in a Marine Protected Area	Ia	Ib	II	III	IV	V	VI
Habitation	N	N*	N*	N*	N*	Y	N*
Waste discharge	N	N	N	N	N	Y	Y
Mining (oil, gas, sand, gravel, coral)	N	N	N	N	N	Y	Y
Commercial fishing/collection	N	N	N	N	*	Y	Y
Recreational fishing/collection	N	N	N	N	*	Y	Y
Aquaculture	N	N	N	N	*	Y	Y
Works (e.g. harbours, ports, dredging)	N	N	N	N	*	Y	Y
Research: extractive	N	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons (e.g. beach replenishment, fish aggregation, artificial reefs)	N	N	N*	N*	Y	Y	Y
Problem wildlife management (e.g. shark control programmes)	N	N	Y*	Y*	Y*	Y	Y
Shipping	N	N	Y*	Y*	Y	Y	Y
Commercial tourism	N	N	Y	Y	Y	Y	Y
Non-extractive recreation (e.g. diving)	N	Y	Y	Y	Y	Y	Y
Traditional fishing/collection in accordance with cultural tradition and use	Y*	Y	Y	Y	Y	Y	Y
Non-extractive traditional use	Y*	Y	Y	Y	Y	Y	Y
Research: non-extractive	Y*	Y	Y	Y	Y	Y	Y
Restoration/enhancement for conservation (e.g. invasive species control, coral reintroduction)	Y*	Y*	Y	Y	Y	Y	Y

Key: N = No
Y = Yes
* = Variable
N* = Generally no, unless special circumstance apply
Y* = No alternative exists and therefore special approval is needed

Locally Managed Marine Areas

Govan et al (2008) define an LMMA as "an area of near-shore waters and coastal resources that is largely or wholly managed at a local level by the coastal communities, land-owning groups, partner organizations, and/or collaborative government representatives who reside or are based in the immediate area."

WCPA-Marine (2010) have an analogous Indigenous and Community Conserved Areas which is defined by IUCN as: "natural and/or modified ecosystems containing significant biodiversity values, ecological functions and benefits, and cultural values voluntarily conserved by indigenous peoples and local communities both sedentary and mobile – through customary laws or other effective means".

The revised definition of a protected area and associated principles in the 2008 IUCN Guidelines stipulate that to be a protected area means giving priority to biodiversity; other values may be present at the same level of importance but in the event of conflict biodiversity values must be the most important (Dudley 2008).

We interpret this to mean that LMMAs can be marine protected areas under IUCN guidelines as long as managers have a primary concern for the sustainability of their ecosystem including fish stocks versus an intention to exploit the fisheries without concern as to its sustainability or impacts upon the ecosystem. IUCN-WCPA Marine (2010) advises that areas set aside purely to maintain fishing stocks, particularly on a temporary basis, should not usually be counted as a protected area (although they certainly represent good fishery management). But, as Dudley (2008) states, "it is up to individual countries to determine what they describe as a protected area."

What are marine protected area networks

A marine protected area network has been referred to as a collection of "individual marine protected areas operating cooperatively and synergistically, at various spatial scales, and with a range of protection levels, in order to fulfil ecological aims more effectively and comprehensively than individual sites could alone"(IUCN-WCPA 2008). This means the marine protected areas must be ecologically connected, must be interacting in some way (NRC 2001). Networks of marine protected areas, for the purposes of this report, refer to a collection of individual marine protected areas that are ecologically connected (WCPA/IUCN 2007). They can be connected through larval dispersal or adult movement of marine organisms (Palumbi 2004). For example, larvae may be released at one marine protected area site and move to another marine protected area or adults may move from one marine protected area to another (Palumbi 2004). A group of marine protected areas may be connected in this way for some species but not for others or, for any one species, they may be connected via larval movement but not via adult movement (Jones et al. 2007). In addition, it may be that organisms at different life stages use different habitats and, if marine protected areas are in those different habitats, it may lead to a connection between them through ontogenetic movement patterns (Gaines et al. 2010).

Larval connectivity between marine protected areas may be classified as population/demographic or genetic connectivity. Population or demographic connectivity refers to the degree to which larvae from marine protected areas contribute to maintenance of fish populations either outside the marine protected area or within other nearby marine protected areas (Palumbi 2003). This type of connectivity seems to be at the scale from less than 1 km to perhaps over 20 km (Botsford et al. 2009b, Shanks 2009). Genetic connectivity is usually expressed over much larger spatial scales (from 100s to 1000s to 10,000s of km) and over evolutionary timeframes where a relatively small level of larval success can influence patterns of genetic diversity in populations (Palumbi 2004). This ecological connectivity is important in considerations of reserve design and is discussed in more detail in Sections 2, 3 and 4.

Networks of marine protected areas can also refer to learning networks and collectives of governance and administrative arrangements that pertain to multiple marine protected areas (White et al. 2006, IUCN-WCPA 2008). These social networks can be very important in terms of enhancing management effectiveness (White et al. 2006, IUCN-WCPA 2008), however, are beyond the scope of this report.

Resilience

Resilience, here, 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" (Holling 1973 and Nystrom and Folke 2001 in McLeod et al. 2009; Holling et al 1995 and Nystrom and Folke 2001 in Marshall and Schuttenberg 2006). That is, a system can transform and adapt to change while still maintaining the same function, structure, identity and feedbacks (Folke et al. 2010). This definition incorporates two different processes: resistance and recovery (Côté and Darling 2010).

For coral reef ecosystems, resilience is the capacity to adapt to change and to maintain the dominance of hard corals and/or morphological diversity (Marshall and Schuttenberg 2006). It includes the ability of the entire suite of faunal and floral meta-populations to persist despite external impacts and threats (Botsford et al. 2009b).

Figure 9. Different levels of resilience of natural communities and consequent responses to disturbance events.
(IUCN-WCPA 2008)

The idea of building marine ecosystem resilience is much older than the "resilience" terminology, as indicated by work conducted approximately ten years ago (Lubchenco et al. 2003). "Resilience" was not mentioned, rather, discussions were around the maintenance of ecosystem structure and function in the event of environmental disturbances, management failures or other human impacts (NCEAS and the American Association for the Advancement of the Sciences 2001, Lubchenco et al. 2003, National Fisheries Conservation Center 2004). These ideas conform very well with current ideas of building or maintaining ecosystem resilience.

Marine protected areas and marine protected area networks have been identified as tools to help build marine ecosystem resilience (Lubchenco et al. 2003, Hughes et al. 2010). This is because heavy or over-fishing can reduce ecosystem resilience and marine protected areas help can mitigate those impacts (Lubchenco et al. 2003, Hughes et al. 2010). Therefore, considerations of resilience are important in marine protected area network design, particularly in the face of global climate change (IUCN-WCPA 2008, McLeod et al. 2009). If a marine protected area or marine protected area network is resilient, then it can rebound from, or withstand, environmental fluctuations or unexpected catastrophes and support populations which can potentially replenish other damaged populations (Salm and West 2003). The implications of consideration of ecosystem resilience in the design of marine protected area networks are discussed further in Sections 2, 3 and 4.

Ecosystem Approach to Fisheries Management (EAFM)

The CTI Regional and National PoAs all refer to the FAO definition of an Ecosystem Approach to Fisheries which is also used in this document to define EAFM:

> "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" (FAO 2003).

The CTI Regional and National Plans of Action (and FAO) further state the purpose of an ecosystem approach to fisheries is:

> "to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems (FAO 2003)."

Technically, then, an ecosystem approach to fisheries (as per FAO) encompasses the planning and development of the fishery as well as the management; the CTI is more focussed on the management aspects of the fishery (Coral Triangle Secretariat 2009, Link 2010).

An ecosystem approach to fisheries, including their management, recognizes that fisheries have the potential to alter the structure, biodiversity and productivity of marine ecosystems, and natural resources should not be allowed to decrease below their level of maximum productivity

(FAO 2003). Therefore, fisheries management under EAFM should respect the following principles (amongst others):

- fisheries should be managed to limit their impact on the ecosystem to the extent possible;
- ecological relationships between harvested, dependent and associated species should be maintained;
- management measures should be compatible across the entire distribution of the resource (across jurisdictions and management plans); and
- the precautionary approach should be applied because the knowledge on ecosystems is incomplete (FAO 2003).

Pacific Island fisheries agencies have already decided to implement an ecosystem approach to fisheries management with communities and have initiatives on this approach underway (Smith et al. 2010).

Within the CTI Regional and National Plans of Action and within FAO's definition of EAFM, marine protected areas of various types are acknowledged to have an important role. These factors are discussed in more detail in Section 2.

Ecosystem-based management

The overarching framework for management in the CTI is proposed to be ecosystem-based management. Ecosystem-based management, or EBM, is an approach that goes beyond examining single issues, species, or ecosystem functions in isolation (Alino et al. 2008b, Agardy et al. 2011a). Instead it recognizes ecological systems for what they are: a rich mix of elements, including humans, that interact with each other in important ways (Agardy et al. 2011a). And the geographic framework for management is the entire ecosystem (Link 2010). Management options are applied to each resource sector in an holistic and integrated manner that accounts for all aspects of the ecosystem and each other sector (Link 2010). EBM encompasses all the subordinate CTI goals to do with marine protected areas, EAFM, climate change adaptation measures and threatened species.

According to Agardy et al (2011a), Alino et al. (2008) and Christie et al. (2007), instead of focusing on fisheries, this framework calls for an integrated, comprehensive approach to management of all human activities in the ocean (see also McLeod et al. 2005, de la Mare 2004, Browman and Stergiou 2005 in Christie et al. 2007). The approach has been trialled, conceptually, with marine capture fisheries (Lack 2004) and, to a degree in Australia's EEZ however, this latter excludes fisheries management (Christie et al. 2007, Australian Government Department of Sustainability, Environment, Water, Population and Communities 2011). Ecosystem-based management, arguably, aligns favourably with calls for marine spatial planning (Ehler and Douvere 2009) and ocean zoning (Agardy 2010) both of which consider the multiple use Great Barrier Reef Marine Park as a case study (see also Section 1.7).

One value of this broader approach to marine resource management is that a multi-faceted, more comprehensive approach is likely to be more robust to the considerable uncertainty and lack of understanding that exists in managing marine environments anywhere, including the CT (Agardy 2010, Tanzer pers. comm.)

What are design principles?

In this report, design principles are biophysical "rules of thumb" or guidelines about sizes, shapes, locations, distributions etc. of spatial marine areas to include in protected area networks (IUCN-WCPA 2008, FAO 2009, Carr et al. 2010, Gaines et al. 2010). The rules of thumb presented here are those that are most likely to help achieve the stated marine resource management objectives as defined in the Regional and National CTI PoAs and discussed in the Preface and Section 1.4. They include advice about zoning to apply to the marine protected areas.

The design principles in this report are intended to provide one of the bases from which managers can then determine, locally, what might work best in their particular situation. The aim is that the biophysical design principles will help managers identify many different potential options for functioning networks of marine protected areas - any set of which can help achieve stated fisheries, biodiversity, resilience and climate change objectives (Roberts et al. 2003b). The various options for protection can then be assessed (and accepted or rejected) based upon social, political, economic, cultural and management feasibility; Roberts et al. 2003b).

The guiding principles are intended to help design networks of marine protected areas that are likely to work better, in terms of the suite of desired CTI goals and objectives, than if chosen based on other more narrowly focused priorities.

As already mentioned, other non-biological reasons may lead to deviation from biophysical design principles (Knight and Cowling 2007). This is inevitable and has occurred in almost all instances where design criteria were used to guide decision-making. Even in the Great Barrier Reef Marine Park, only two out of eleven biophysical design principles tailored to the needs of the Great Barrier Reef ecosystem were adhered to completely due to socio-economic and political factors (Fernandes et al. 2005, Tanzer pers. comm.)

Attachment 3. Areas of high and low vulnerability to climate change stressors in the Coral Triangle, and recommendations for marine protected area network design.

This information is summarized from McLeod et al 2010a,b. Please see the original document for more information and original references.

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3.a. Vulnerability to sea level rise

The following four main sea-level rise impacts are assessed in ecological, social and economic terms over the twenty-first century: 1) coastal wetland change, 2) increased coastal flooding, 3) increased coastal erosion, and 4) saltwater intrusion into estuaries and deltas. The results suggest that sea-level rise will significantly affect coastal regions and habitats in the CT countries, but the impacts will differ across the region in terms of people flooded annually, coastal wetland change and loss, and damage and adaptation costs (McLeod et al 2010a).

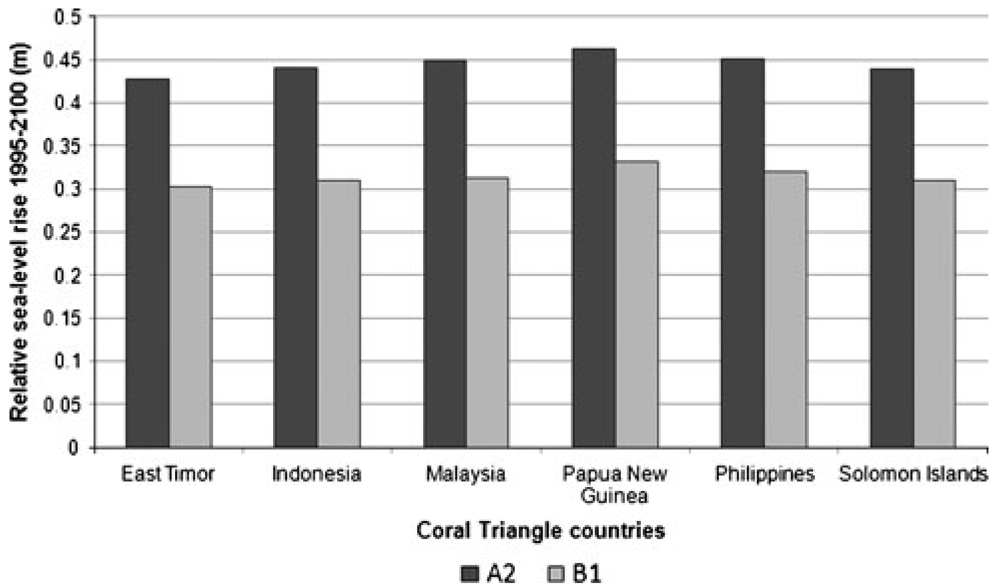

Figure 10. Average relative sea-level rise (m) 1995–2100 for Coral Triangle countries under IPCC A2 and B1 scenarios.

Indonesia is projected to be most affected by coastal flooding, with nearly 5.9 million people expected to experience flooding annually in 2100, assuming no adaptation. However, if adaptation is considered, this number is significantly reduced.

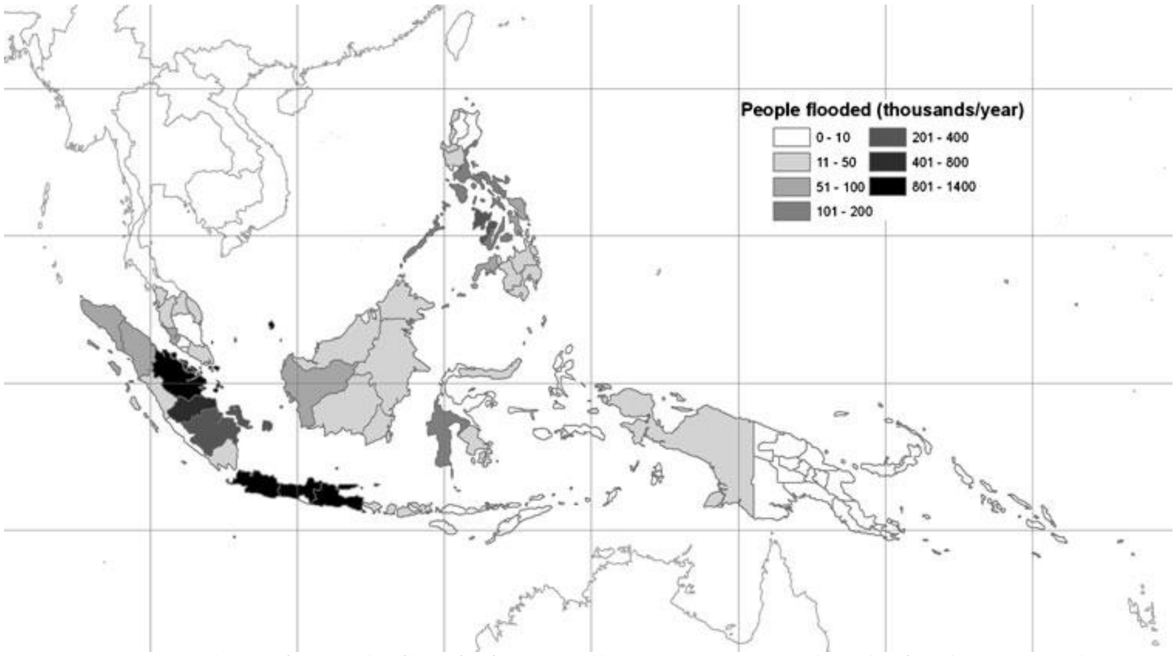

Figure 11. Number of people flooded annually in 2100 at the level of sub-national administrative units under the A2 scenario without adaptation

By the end of the century, coastal wetland loss is most significant for Indonesia in terms of total area lost, but the Solomon Islands are projected to experience the greatest relative loss of coastal wetlands.

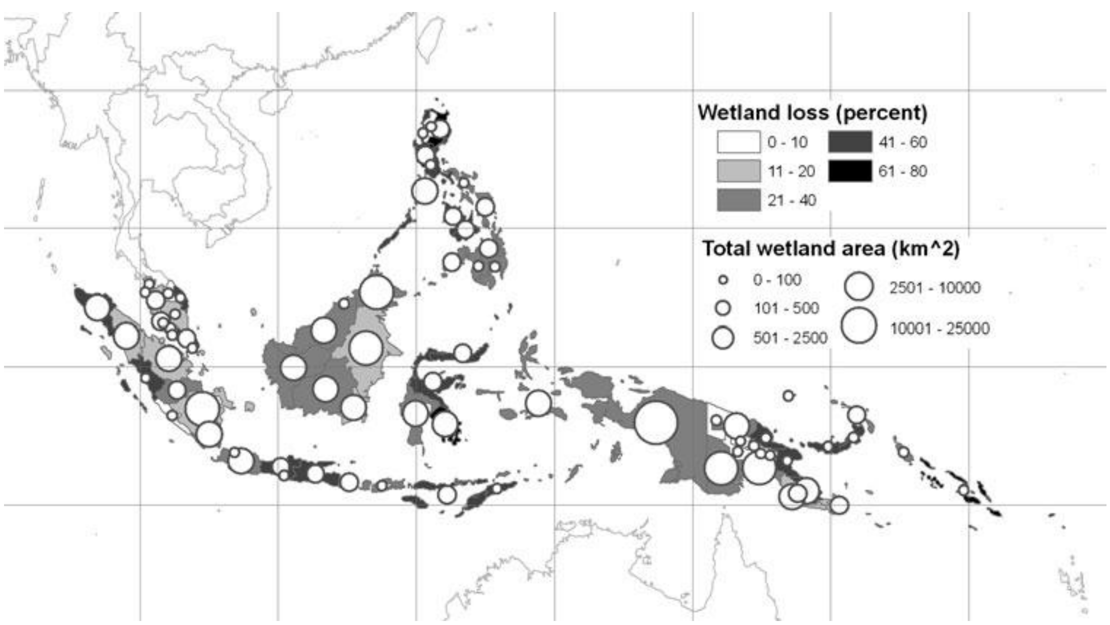

Figure 12. Coastal wetland area in 2100 and wetland loss relative to 2010 at the level of sub-national administrative units under the IPCC A2 scenario without adaptation

Damage costs associated with sea-level rise are highest in the Philippines (US $6.5 billion/year) and lowest in the Solomon Islands (US $70,000/year). Adaptation is estimated to reduce damage costs significantly, in particular for the Philippines, Indonesia, and Malaysia (between 68 and 99 percent).

3.b. Vulnerability to rising sea surface temperatures

McLeod et al 2010b provides an assessment of past and future climatic stress, thermal variability, and anthropogenic impacts in the CT at the ecoregional level, thus incorporating both local (e.g., pollution, development, and overfishing) and global threats (increasing SSTs). It offers specific management recommendations for marine protected area networks based on the levels of vulnerability to thermal and local stress that are repeated here.

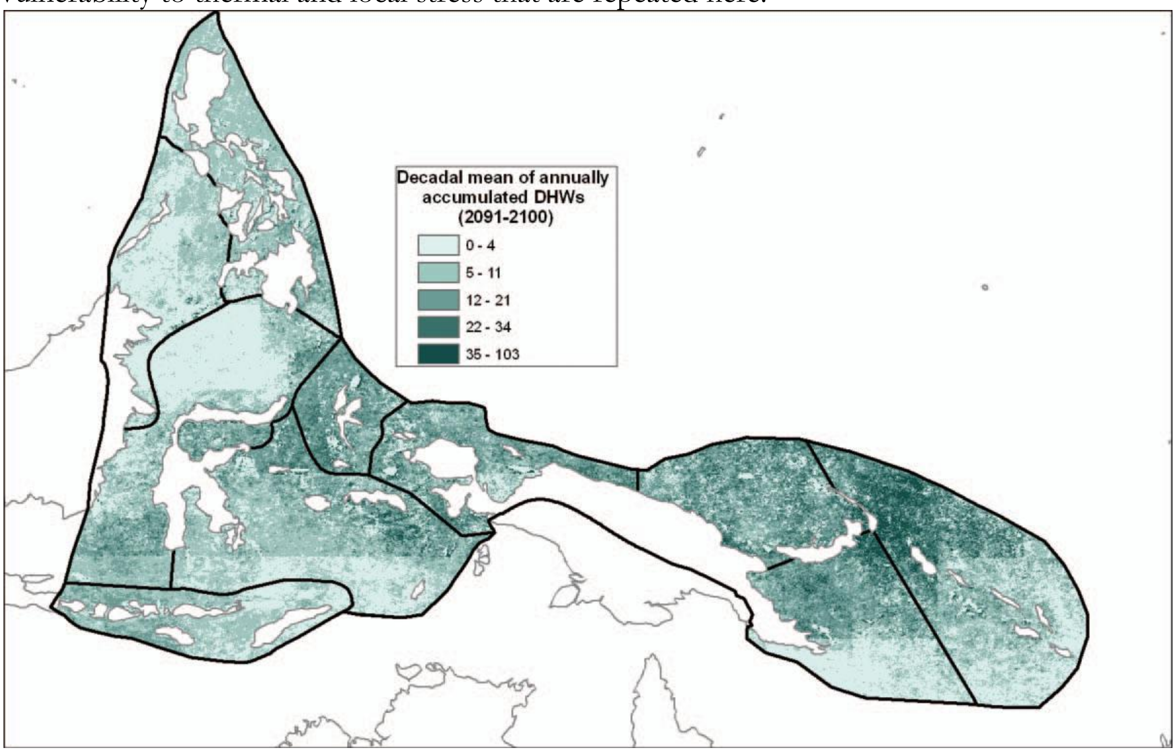

Figure 13. Projected decadal mean (2091–2100) of annually accumulated Degree Heating Weeks (DHW) for the Coral Triangle based on coupled general circulation models

3.c. Recommendations for Marine Protected Area Network Design

Regions with relatively low vulnerability to thermal stress and local stress (e.g. Palawan/North Borneo, Solomon Sea) should be prioritized for implementation of resilient marine protected area networks if they are reinforced by management strategies that address human impacts outside of marine protected areas (e.g., overfishing reduction of runoff from poor land use practices). Areas with low vulnerability to both thermal and local stresses should be considered good candidates for new marine protected area establishment.

In reef areas with moderately high vulnerability to thermal stress and local impacts (e.g., Northeast Sulawesi, Sulawesi Sea/Makassar), it is critical to reduce local stresses through effective management and rigorously apply principles for designing resilient networks of marine protected areas. Strategies that facilitate coral reef recovery following bleaching events are likely to include the maintenance of herbivores, water quality and access to coral recruits, which is often a function of the proximity of damaged reefs to healthy coral populations. Such strategies should consider restoration of damaged areas in high priority reef areas, especially when these are important to facilitate connectivity among marine protected areas in the network. It is also important to monitor the cumulative effects of multiple stressors, both local and climatic, in these areas.

In regions with high vulnerability to thermal stress, but low vulnerability to human activities (e.g., Bismarck Sea, Halmahera, Solomon Archipelago), management strategies should focus on the rigorous application of resilience principles to marine protected area network design, especially the identification and protection of bleaching resistant coral communities.