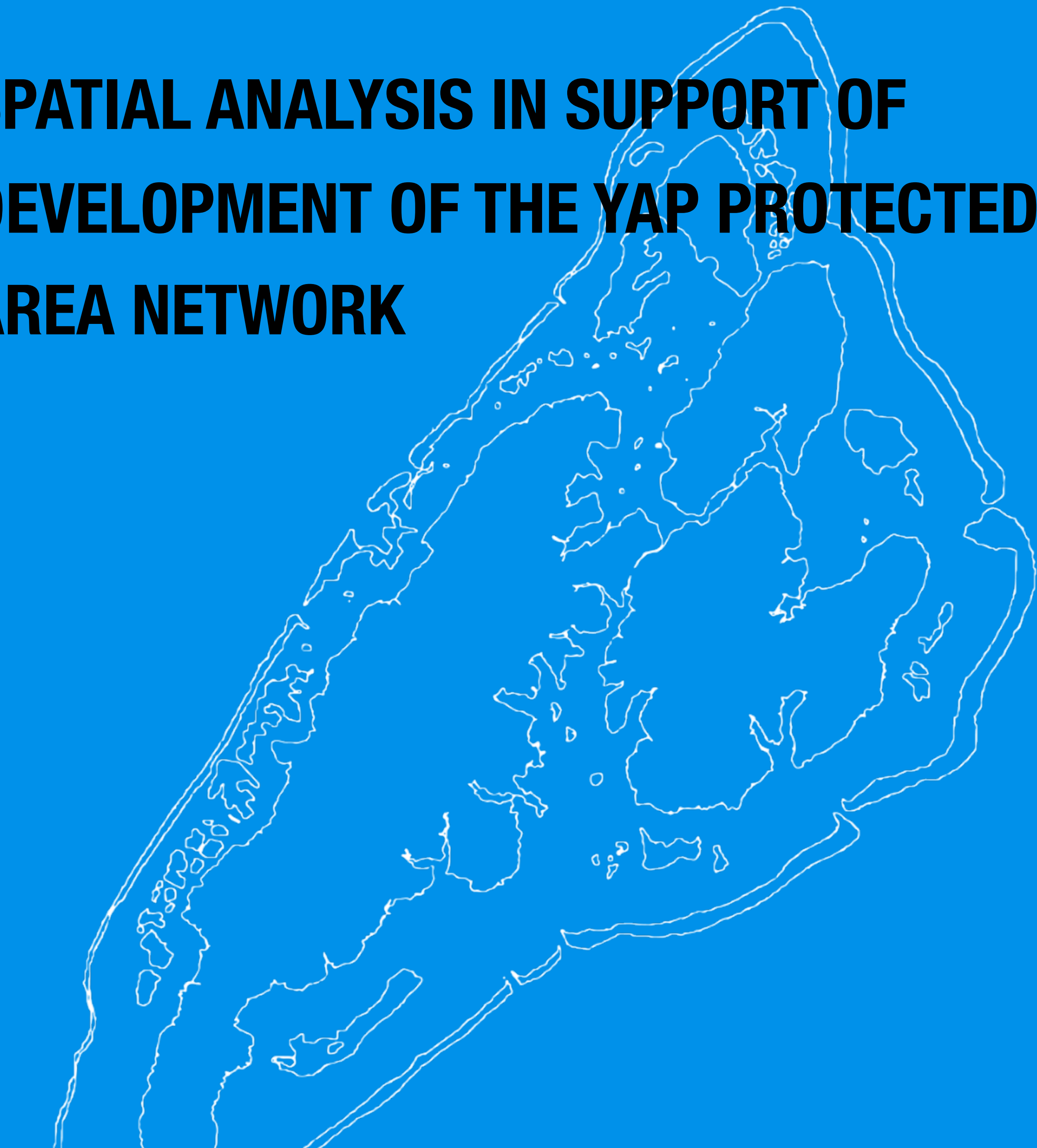
SPATIAL ANALYSIS IN SUPPORT OF DEVELOPMENT OF THE YAP PROTECTED AREA NETWORK



Technical report prepared for The Nature Conservancy

February 2016

Spatial analysis in support of development of the Yap Protected Area Network. Technical report prepared for The Nature Conservancy, February 2016.

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Executive Summary

This report presents methods and results of the following spatial analyses to support the future development of Yaps' protected area network:

1. *Gap analysis of Yap's existing protected area network*
    1.1. *with respect to representation targets specified by the Micronesia challenge*
    1.2. *in terms of adequacy for protecting key fish species*
2. *Spatial conservation prioritization to identify indicative priority areas for conservation, accounting for community interest in undertaking management*

The outputs from these analyses may be used by The Nature Conservancy, Yap Community Action Program, and other state-level actors to assess progress towards state- and regional-level objectives for the Yap protected area network (PAN), and to identify priority areas to extend existing or establish new protected areas. Outputs may also be shared with community organizations to convey the benefits of a state-level PAN, and to provide rationale for why particular areas might be considered as conservation priorities.

The report also contains a synthesis of scientific literature on ecological requirements and management options for key fish species:

3. *Synthesis of ecological requirements and management options for key fish species, to produce:*
    3.1. *a summary of general principles for marine protected area design as they might be implemented in Yap*
    3.2. *species-specific management strategies for key fish species*

This information may be shared with Yapese communities, traditional leaders, and government to assist with the selection of ecologically adequate and culturally appropriate fisheries management strategies.

At present, 12% of Yap's near shore marine area and 0.6% of it's terrestrial area are protected within the PAN. Atoll reefs are afforded greater protection than those surrounding Yap Proper. Representation gaps suggest that additional protected areas or other effective area-based management needs to be designated.

Most of the protected atoll reefs are on Ngulu; if benefits from management are required on other atolls, additional conservation areas may be required there. Around Yap proper, enclosed lagoon reefs (blue holes), passes, and seagrass meadows are underrepresented and should be prioritized as additional sites are added to the PAN. Many species of fisheries or cultural importance utilise mangroves, seagrass beds and lagoon reefs, either as nursery habitats, or during daily foraging movements. Where it is not possible to create MPAs that include contiguous habitat from fringing mangroves to the outer reef slope, establishing smaller MPAs on nursery habitats will benefit management of those species, and may also improve the effectiveness of existing MPAs on nearby coral reefs.

The relatively small size of existing MPAs means that many species will not be adequately protected within their boundaries. Improving protection for species with larger home ranges will require either making some MPAs larger, or alternative management measure for those species, such as catch, size, gear or effort restrictions, or seasonal catch and/or sale bans.

In line with the vision and scope for Yap's PAN (page 8), primacy should be given to local objectives when developing the PAN. The situation analyses for conservation primary targets (pages 9-12) indicate that local objectives include ensuring food security and good health for current and future generations, maintaining cultural practices and traditions associated with nature and natural resources, and sustaining income for local communities.

Towards achieving these goals, this report provides guidance on how to design individual MPAs to ensure they are adequate to protect fish species that have important fisheries and cultural values, and how to locate MPAs in a network to maximise the benefits of small MPAs that minimise negative impacts on fisheries-dependent livelihoods.

It is likely that in developing the PAN to achieve local objectives for natural resource sustainability, area-based representation targets specified by the Micronesia Challenge can be achieved incidentally. However, the situation analyses also highlight the need for complementary management strategies in addition to protected areas. For example re-enforced laws for pollution and dredging, and seasonal restrictions on hunting.

Spatial priorities for new conservation areas are indicated on pages 40-48. However, the location of protected areas and selection of complementary management strategies must be determined by the local communities themselves, informed by their knowledge of the condition of their natural resources and their resource use requirements.

Maintaining cultural practices associated with natural resources is an important local objective for the development of the Yap Protected Area Network.

Introduction

Background

Yap is the Westernmost of the four constituent states of the Federated States of Micronesia (FSM). Yap State consists of a cluster of four high islands connected by mangroves (collectively known as 'Yap proper') and a number of low atolls and islets (collectively referred to as the 'outer islands'), spread 600 miles to the East and South into the tropical western Pacific. In 2010, the population of Yap State was 11,400, with 7,400 residing on Yap proper, and the remainder distributed among the inhabited outer islands of Woleai, Ulithi, Ifalik, Satawal, Lamotrek, Fais, Faraulep, Eauripik, Elato, and Ngulu.

The land area of Yap proper is c. 11,000 ha. Approximately one third of this area is upland forest, with the remaining vegetation comprising tree garden and taro patch agroforest, secondary vegetation, savanna, and mangroves. The island group is surrounded by a single, continuous reef system, 20 miles long and up to 8 miles wide. The reef flat exhibits a broad pattern of zonation: extensive seagrass meadows give way to a predominantly sandy zone with scattered algae and corals that extends out to the barrier reef. Enclosed lagoons (also known as blue holes) located on the reef flat are remnants of a once extensive lagoon system which has been filled in by sedimentation and constructional processes (Tsuda et al 1978). These lagoons contain well developed coral communities and are the principal areas where large fishes congregate within the reef flat system (Tsuda et al 1978). The outer barrier reef is split by eight channels, three of which lead to deep embayments.

Most of the outer atolls contain a number of small islands, only some of which are inhabited. The total land area of the outer islands is only 1,900 ha. Mangrove forests are absent from the outer islands, where marine ecosystems comprise open ocean, reef, and lagoon areas (the latter absent from the raised islands of Satawal and Fais).

Yap's Constitution recognizes traditional rights and ownership of natural resources and areas, and any resource management must be accepted by local communities and approved by the Council of Chiefs (Tafileichig & Inoue, 2001). Traditional systems of marine resource ownership and regulation are complex, and tenure and use rights systems vary between Yap proper and the outer islands, and among the outer islands (Smith, 1991). In general, the inshore waters of each village are within the jurisdiction of the village, and outsiders are prohibited from exploiting resources within that area (Smith, 1991). This places constraints on the extent of spatial management that can be implemented, and on the spatial mobility of fishers in response to spatial management.

The Yapese recognize that culture and natural resources are fully intertwined, and that a healthy environment is the foundation of a healthy culture. Nevertheless, some traditional systems of resource management have been eroded, and need to be reinforced to cope with new threats (Smith, 1991). Improved fishing technology, growing infrastructure on land and increased reliance upon a cash economy represent threats that are not readily addressed by traditional management in place (Houk et al., 2012). For example, the introduction of underwater flashlights means that nighttime spearfishing is now common (Kronen & Tafileichig, 2008). Whilst reef fisheries still have primary subsistence importance, there is an increasing market demand for reef fish, and some fishers sell some or all of their catch either locally or off-island. At the same time, growth of the cash economy has lessened the time available to employ traditional and more time-consuming fishing techniques, and to participate in controlling fishing activity at the community's reef (Kronen & Tafileichig, 2008).

Vision and scope for a Yap State protected area network

In November 2016, The Nature Conservancy (TNC) and Yap Community Action Program (Yap CAP) convened a workshop to discuss the need to refine the design of Yap's Protected Area Network (PAN). During this workshop, participants agreed upon a vision, scope, and goals for Yap's PAN.

Participants discussed and agreed on the scope of a State-Wide PAN that will:

- include the whole of Yap State, including the outer islands
- include both marine and terrestrial environments
- focus first on achieving local objectives, but also consider how these can feed into the Micronesia Challenge and other international objectives
- include protected areas and other management strategies, including traditional resource management
- have have clear roles and responsibilities for implementing the PAN
- include a workable and realistic management plan that integrates local knowledge and best practices informed by science

Key Challenges to be addressed

1. *Overfishing of reef fish and invertebrates caused by replacement of traditional fishing practices with modern methods lowers access to local food supply and income for local communities, with negative impacts on Yapese culture and health.*
2. *Land development is leading to the destruction of forests and mangroves which threatens food security and local cultural practice, and negatively impacts on nursery habitat for fish species.*

Roles and responsibilities for implementing the Yap PAN

Communities (traditional leaders and councils) will first and foremost take responsibility for implementation. Yap State and FSM agencies will provide support, for example by creating and enforcing laws that support community-led management actions. NGOs will provide technical support for planning and implementation, and donors will provide funding for management activities.

Conservation primary targets

Conservation primary targets are species of concern, habitats or ecological processes that are chosen to represent and encompass the full suite of biodiversity in the project area. They are the basis for setting goals, carrying out conservation actions, and measuring conservation effectiveness. The following features were identified as primary conservation targets for the Yap PAN:

- **Corals**
- **Bumphead parrotfish and humphead wrasse**
- **Marine invertebrates** (e.g. trochus, clam, sea cucumber)
- **Turtles**
- **Mangroves**
- **Forests**
- **Fruit bats**

Corals

Primary threats to coral reef habitats in Yap come from poor development practices (e.g. dredging and coastal development), pollution, and coral bleaching caused by climate change. Coral reefs provide many important ecosystem services to Yapese communities, and their degradation will negatively impact on food security, income and culture. In addition, coral reefs provide a protective environment for seagrass beds and mangroves by buffering oceanic waves and currents; thus loss of coral reefs can lead to further coastal erosion and ecosystem loss.

Whilst bleaching cannot be prevented through local management actions, establishing a state wide protected area network that includes example of different coral reef habitat types and considers resilience principles can help to reduce local threats to reefs, improving the likelihood that they can resist or recover from climate change impacts.

Action to reduce direct threats by reviewing, improving and enforcing laws for pollution and dredging should also be considered.

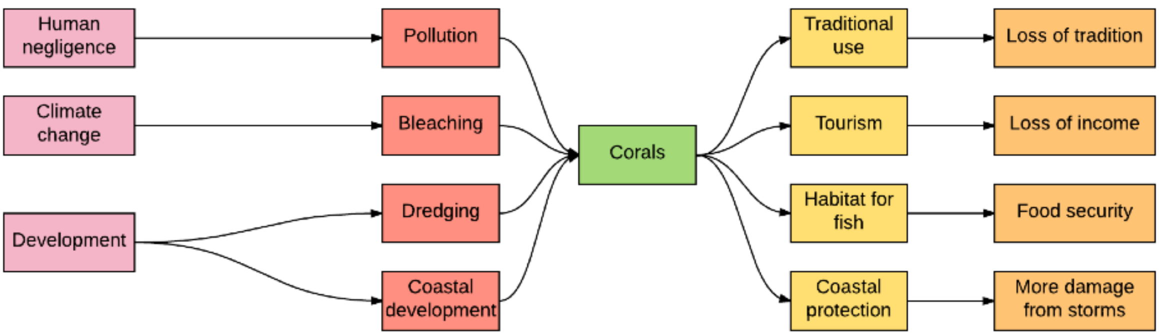


Figure 1. Situation analysis for corals

Reef fish and marine invertebrates (e.g. trochus, clam, sea cucumber)

Primary threats to reef fish and marine invertebrate populations in Yap come from overfishing and habitat loss. Reef fish and marine invertebrates underpin the food security and livelihoods of Yapese communities engaged in commercial and subsistence fisheries. Some species also have important traditional uses, and healthy, diverse marine communities attract tourists to the islands. Marine invertebrates also help to maintain good water quality in the lagoon. Decline in populations of reef fish and invertebrates will negatively impact on people's health and income, and may lead to loss of traditional practices. Conversely, increases in fish populations will enhance food security and will mean people don't have to travel os far to catch enough to feed their families.

No-take marine conservation areas are one of the most effective tools available to communities to address threats from overfishing. Conservation areas should be designed to ensure that they are adequate to protect the species that communities consider most important. Communities are only able to enforce their own areas and need support from chiefs and the government to prosecute between-community violations.

Spatial constraints on communities' ability to establish marine conservation areas means that additional fisheries management will be required (particularly for those species with large home ranges that are unable to be protected within community managed marine areas). These strategies might include gear restrictions, size and species restrictions on catch, and limits or bans on sale of some species. Reducing pressure on reef fisheries by promoting alternative fishing grounds and/or facilitating the use of alternative fishing gears that target pelagic species is another possible approach.

To address threats from habitat loss, increasing protection for mangrove forests (which promote the development of reefs by interrupting freshwater discharge and acting as sinks for pollutants and also provide nursery habitat for many species) should be a priority. Ensuring that land development is conducted in a way that minimizes erosion and sedimentation is also critical.

Figure 2. Situation analyses for reef fish and marine invertebrates

Turtles

Primary threats to turtles in Yap come from overharvesting, marine pollution and erosion of nesting beaches. Turtles have cultural importance as a food source in Yap, and also attract tourists. Decline in turtle populations will have negative impacts on food security (particularly in the outer islands), culture and income.

Due to the long-distance migrations undertaken by turtles, spatial management (e.g. within marine managed areas) for these species should focus on protecting nesting sites.

Policies which could help to protect turtles in Yap include:

- Reintroducing traditional regulations on turtle catch and egg consumption
- Prohibiting sales of turtles and eggs to the main island
- Regulating the use of long lines, which threaten turtles through by-catch
- Enforcing the ban on plastic bags

Challenges in enforcing these regulations arise because communities own their resources and may have few alternative sources of income. Communities and the government will need to work together to design and enforce regulations that prevent over harvesting without excessive negative impacts on livelihoods.

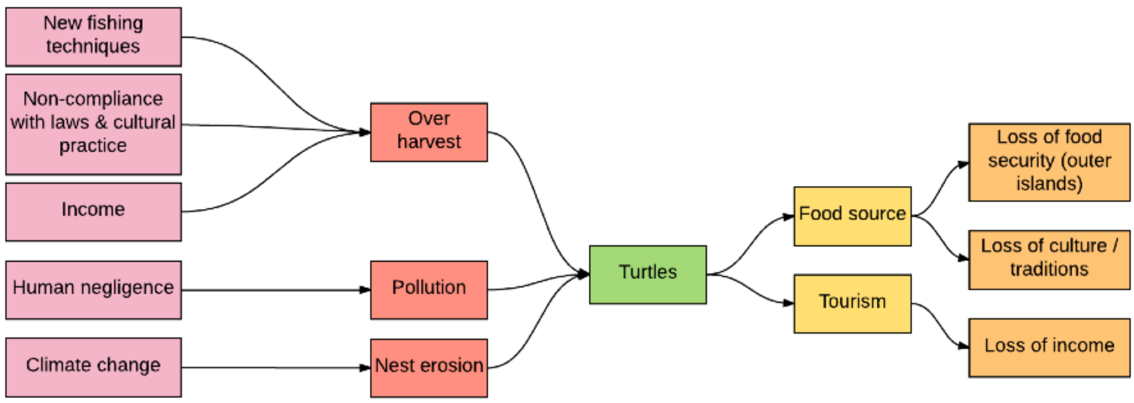


Figure 3. Situation analysis for turtles

Mangroves

Mangroves in Yap are directly threatened by habitat destruction from both anthropogenic and natural causes. Whilst typhoon damage is difficult or impossible to manage, actions can be taken to reduce threats from human activities on mangroves.

Establishing protected areas will allow for some intact mangrove communities to remain. Priority areas for strict protection should include areas with old growth mangroves (these need to be identified), and might also include areas where mangroves may provide important nursery habitat for juvenile reef fishes.

Traditional practices which imposed limits on who could harvest different species and prevented clear cutting are may no longer be sufficient, given high demand for mangrove wood. In areas where cutting is allowed, this could be managed with rotational periods of cutting and re-vegetation to ensure that the resource is sustained.

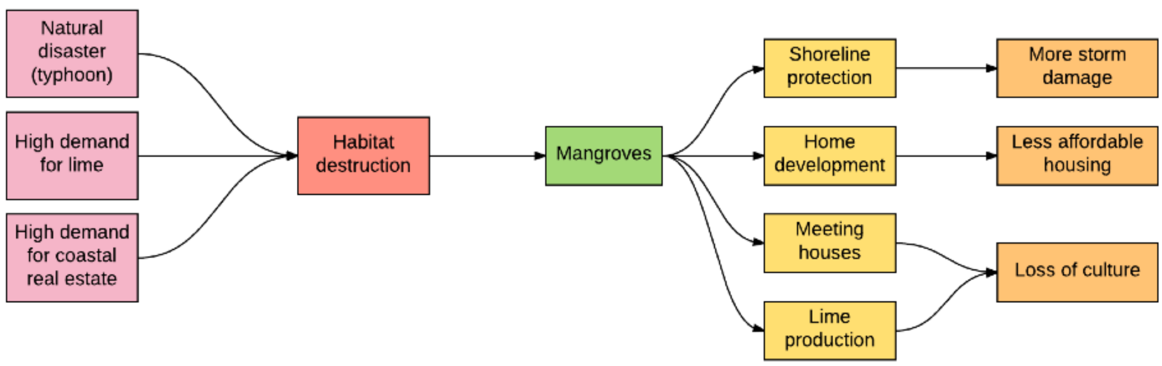


Figure 4. Situation analysis for mangroves

Forests and fruit bats

Forest resources in Yap are threatened under pressure from direct exploitation to meet increased need for lumber, and from invasive species and natural disasters. Healthier forests and vegetation will provide an increase in fruit yielding trees, allowing for a revival in the use of medicinal plants and a healthier diet for Yapese people. Well managed forest resources will also provide a sustainable source of lumber.

At present, Yap does not have any terrestrial protected areas. If conservation areas are established, these should focus on forest areas that provide important habitat for food resources (including fruit bats). These areas could allow harvest of fruits and bats to continue but prohibit no cutting. It was also noted that the number of new canoes being built could be limited to reduce pressure on forest resources.

Fruit bats are a traditional food source in Yap, and are primarily threatened by unsustainable levels of hunting. However, they also provide an important ecosystem service in seed dispersal. Existing laws allow hunting only for traditional purposes, but these regulations need to be strengthened and enforced. This might be best achieved through action by the chiefs to reactivate and enforce traditional practice.

Additional management strategies that might be considered are to establish protected areas and regulations to prevent hunting at roost sites, or to establish a seasonal hunting period (allowing for hunting when customary needs are greatest e.g. Yap Day).

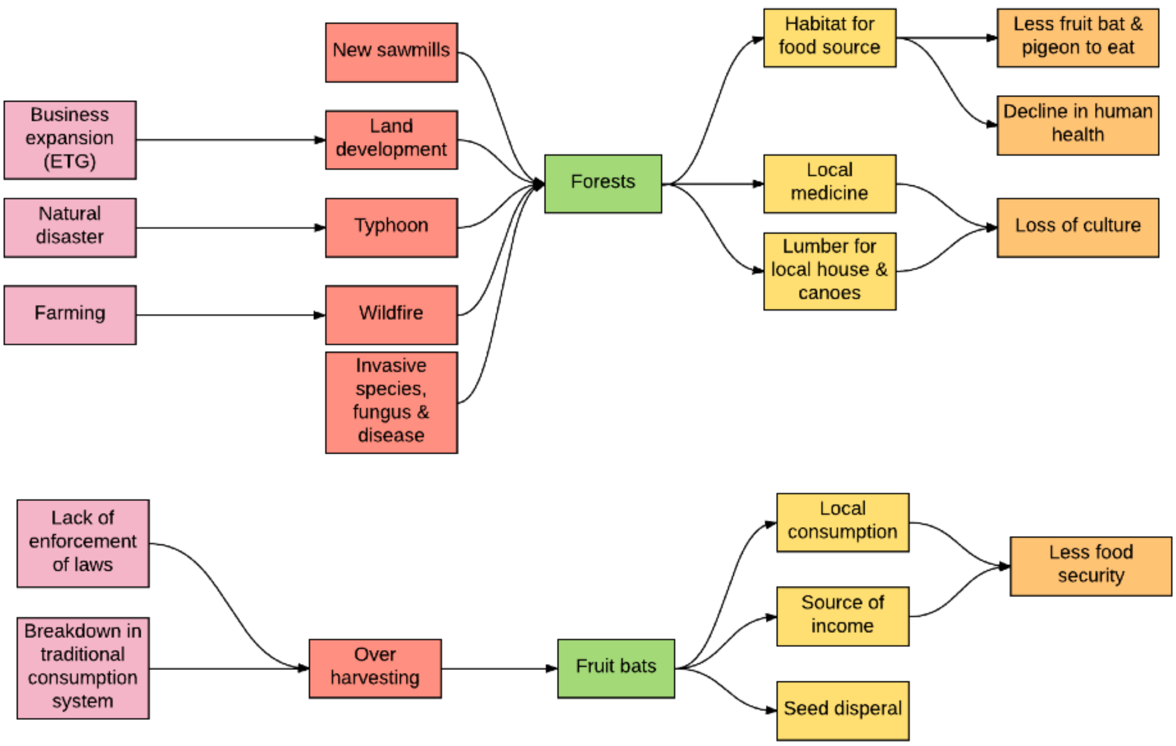


Figure 5. Situation analyses for forests and fruit bats

Gap analysis of Yap's existing marine and terrestrial protected area network

At its simplest, a gap analysis is an assessment of the extent to which a protected area system meets conservation objectives. The "gaps" are the difference between where the protected area network is now, and where we would like it to be. Gap analysis considers three different types of "gaps" in the protected area network:

Representation gaps: either no representations of a particular species or habitat type in any protected area, or not enough examples of the species or ecosystem represented to ensure long-term protection.

Ecological gaps: while the species or habitat type occurs in the protected area system, occurrence is either of inadequate ecological condition, or the protected area(s) fail to address species' movements or specific ecological conditions needed for long-term survival or ecosystem functioning.

Management gaps: protected areas exist but management regimes (management objectives, governance types, or management effectiveness) do not provide full security for particular species or ecosystems given local conditions.

Existing protected areas

During the November 2016 PAN workshop, participants agreed that membership of the Yap State PAN requires that a protected area has a community-endorsed management plan in place. The locations and boundaries of existing protected areas in Yap State are shown in Figure 6.

Conservation features

Marine habitat information (Figures 7 and 9) was based on the Millennium Coral Reef Mapping Project data (IMaRS-USF & IRD, 2005). Seagrass habitat was inferred from habitats classified as "diffuse fringing non-reef" in the Millennium Coral Reef dataset, validated for the western lagoon of Yap Proper in Houk et al. (2013).

Representation targets

Representation targets have been set out by the Micronesia Challenge, which aims to effectively conserve at least 30% of near-shore marine resources and 20% of terrestrial resources across Micronesia by 2020. This ambitious challenge far exceeds current goals set by international conventions and treaties; for example, the Aichi Biodiversity Targets set out by the Convention of Biological Diversity state that: "by 2020, at least 17 per cent of terrestrial and inland water areas, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures".

To ensure adequate and unbiased protection for different ecosystem and habitats types, representation targets should be applied to the different habitat types present (e.g. Figures 7, 8 & 9), rather than to marine and terrestrial areas overall.

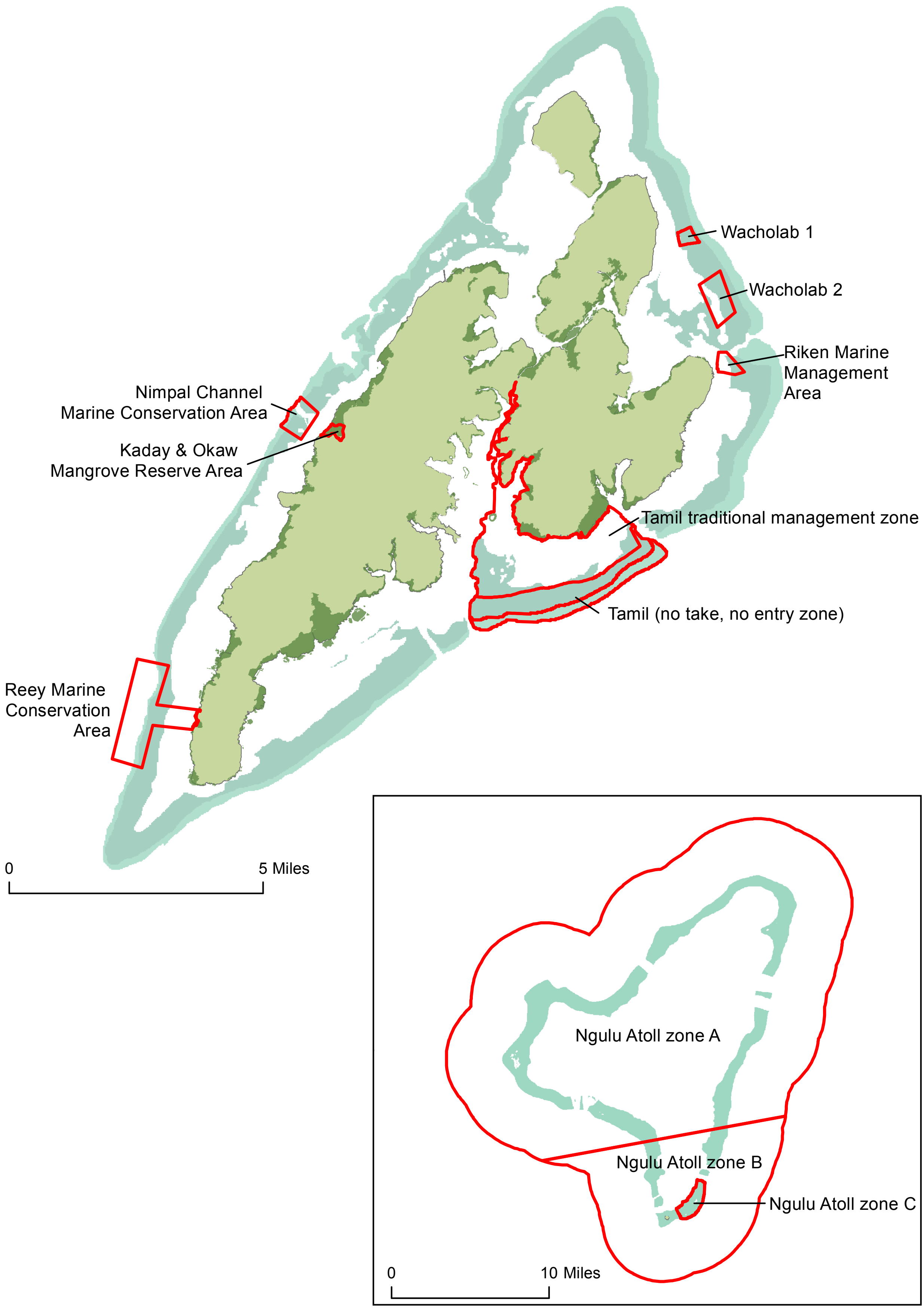


Figure 6. Existing protected areas in Yap State

(Note that some spatial management has also been implemented on Ulithi, but the boundaries are not yet known)

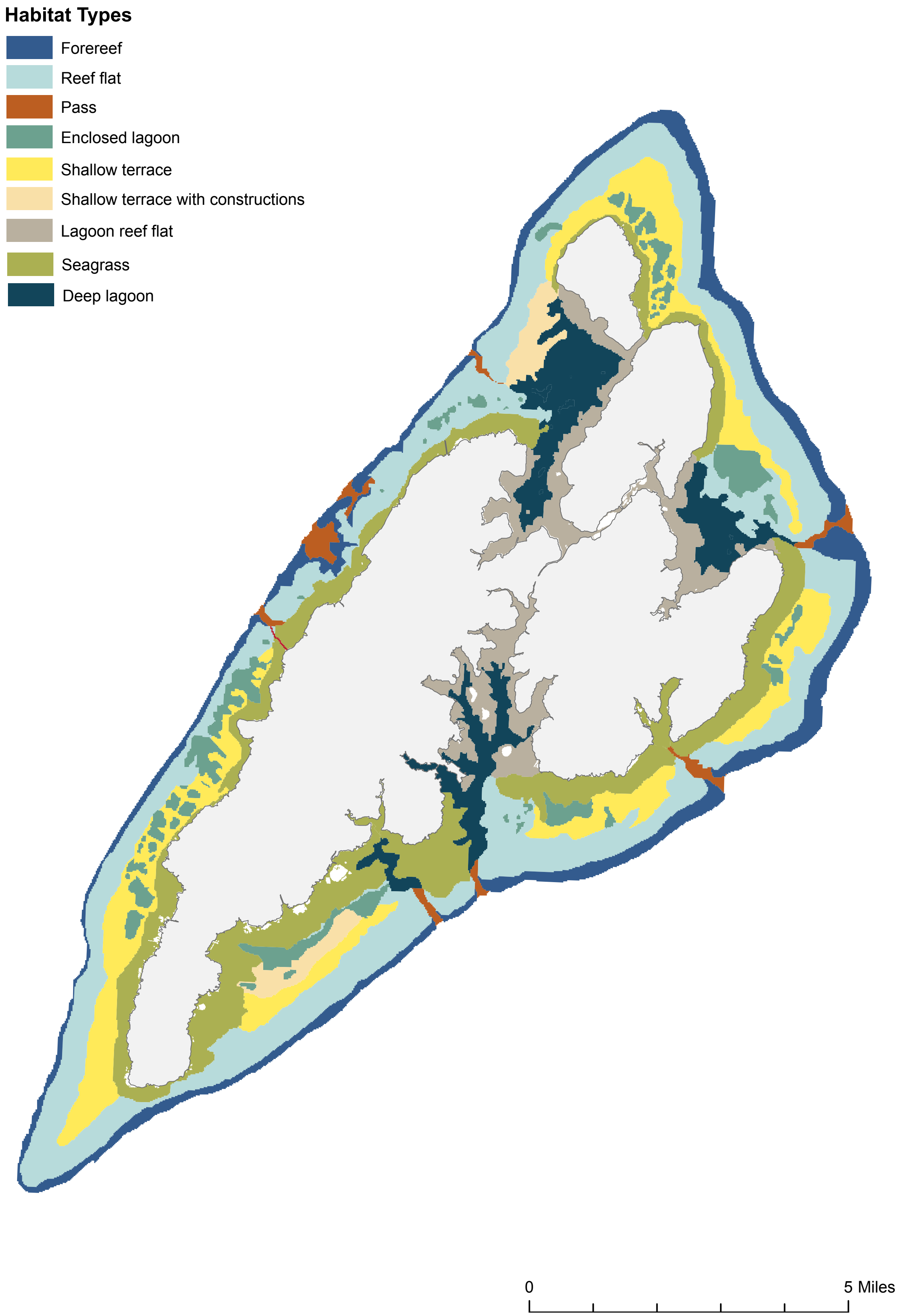


Figure 7. Marine habitat types on Yap proper

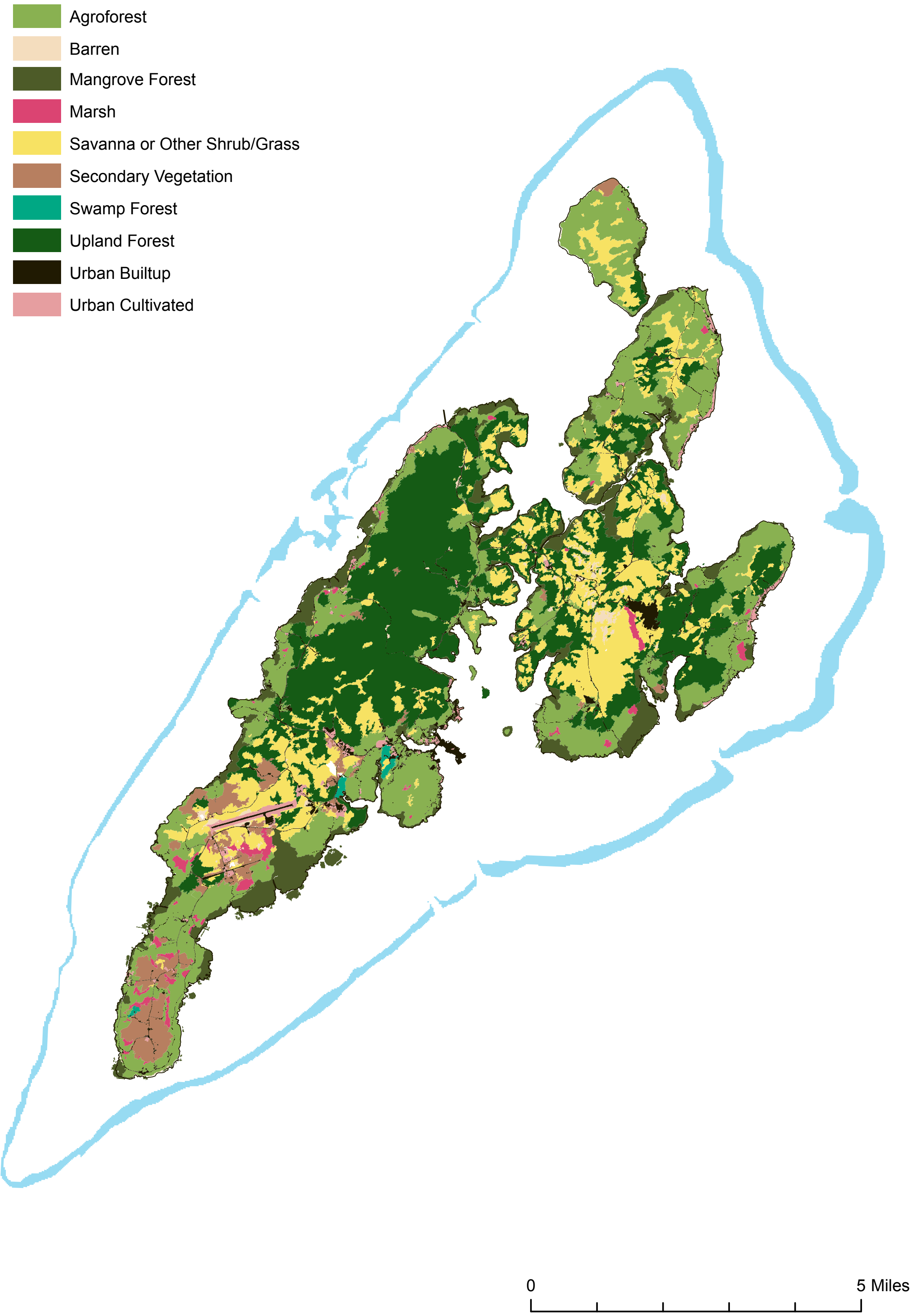


Figure 8. Terrestrial habitat types on Yap proper

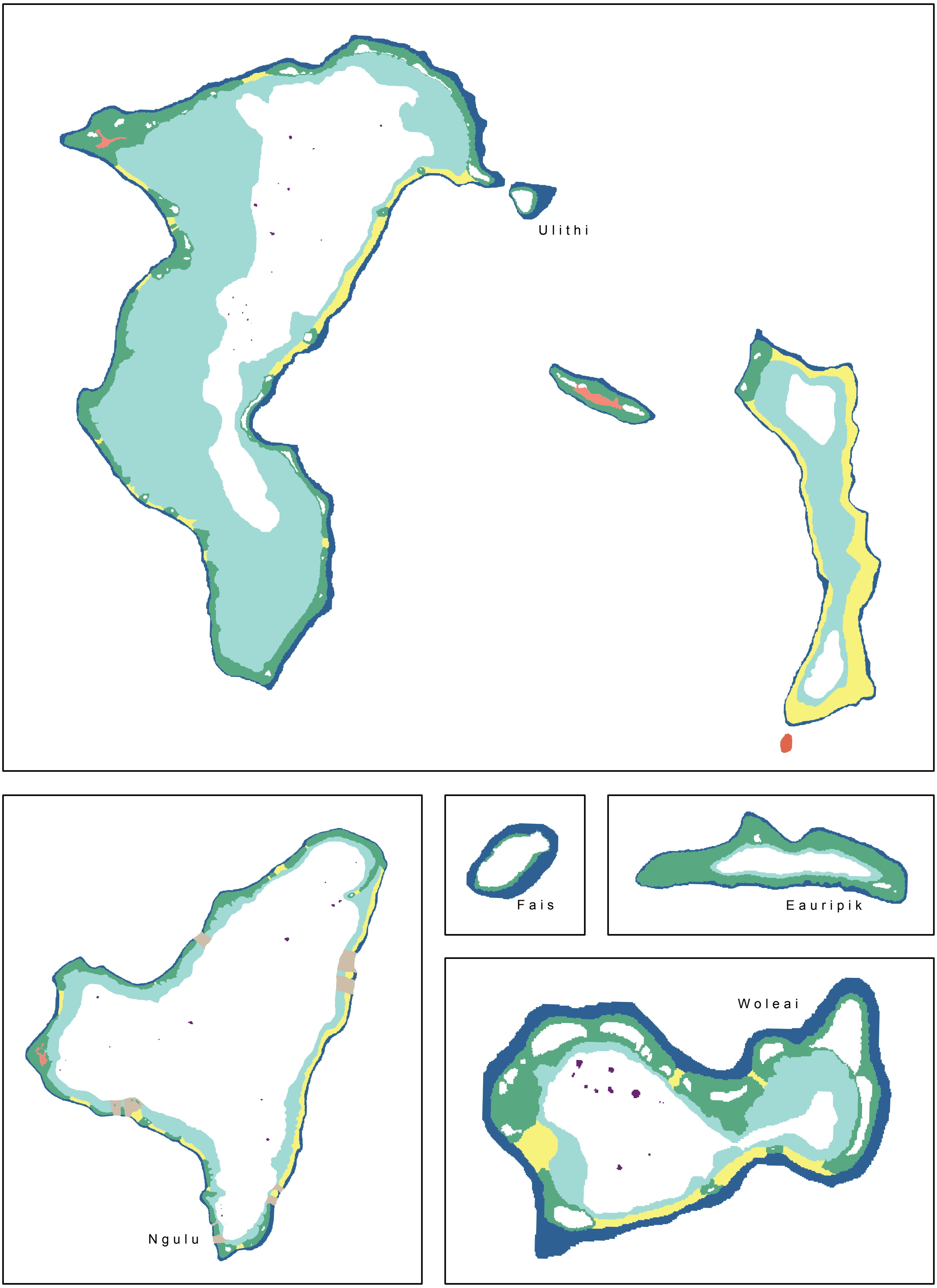


Figure 9. Marine habitat types on Yap's outer islands

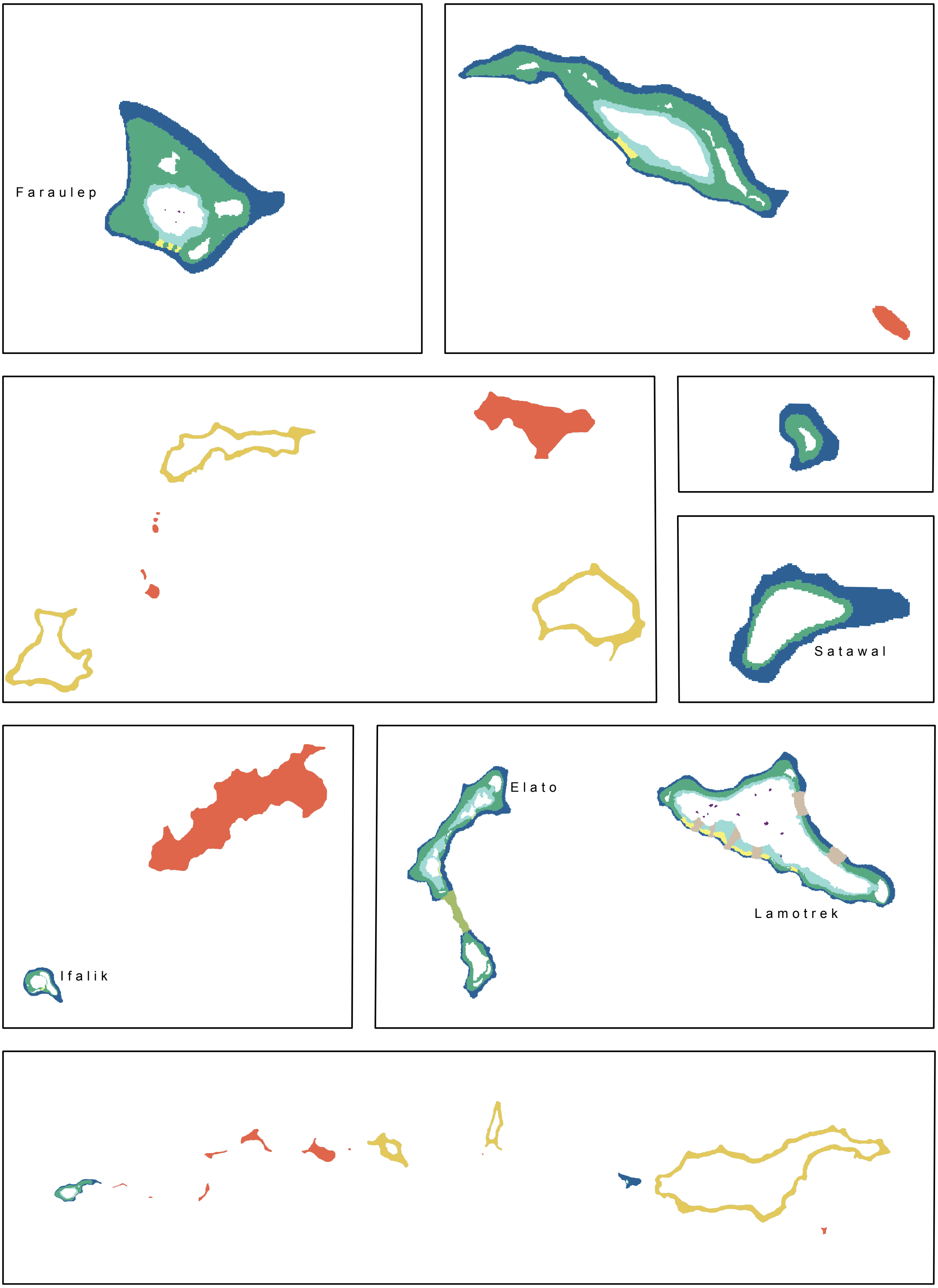


Figure 9 continued.

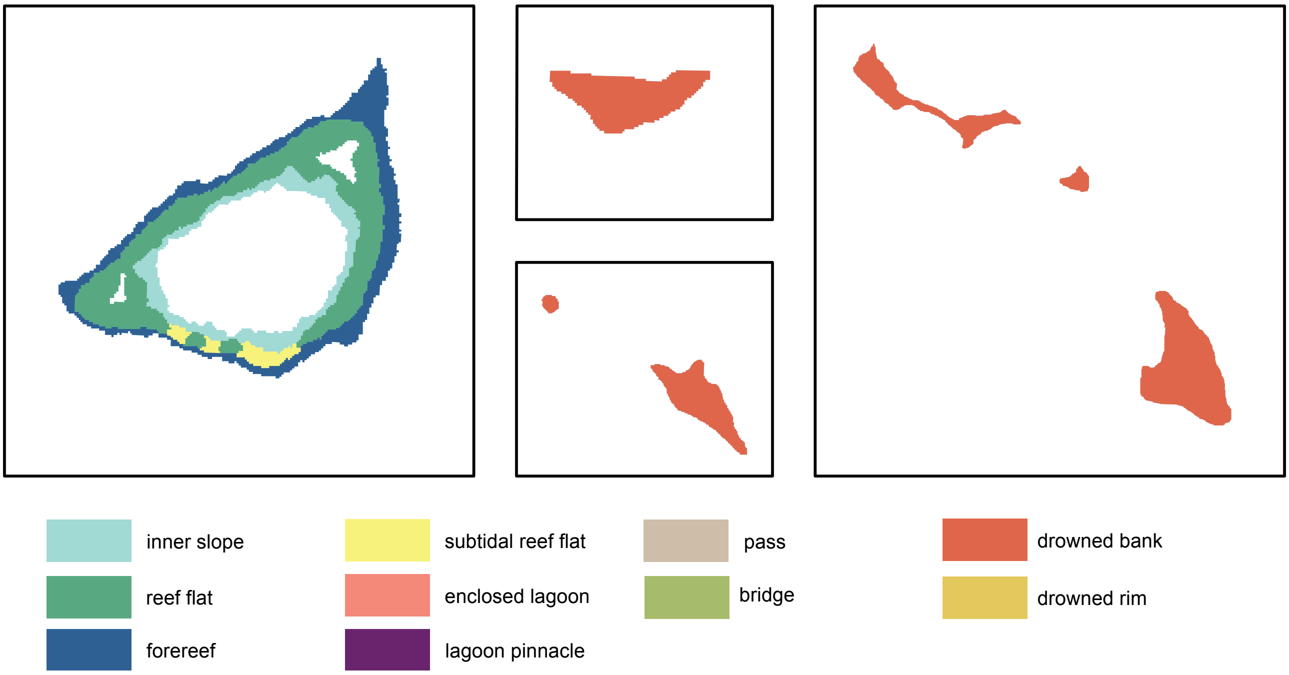


Figure 9 continued.

Representation gaps

At present, 12% of Yap's near shore marine area and 0.6% of it's terrestrial area are protected within the PAN (Table 1 and Figures 10 & 11).

This falls short of the targets laid out in the Micronesia Challenge. Yap has a lower percentage of marine and terrestrial areas protected than in Pohnpei state. However, it should be noted that Yap's existing protected areas have greater management effectiveness than those in Pohnpei (attested by ecological monitoring results)[1]. Protected area extent should not be considered as a sole (or ultimately a reliable) indicator of conservation effectiveness.

Nevertheless, to ensure the future sustainability of Yap's natural resources, it is likely that additional protected areas, or other effective area-based management, will be required. The placement of additional protected areas should consider how well different habitat types are represented within the PAN at present. If we look at individual habitat types, the extent to which they are represented within the PAN is highly variable (Table 1 and Figure 10).

Key Messages:

- Atoll reefs are afforded greater protection (16%) than the island reefs surrounding Yap Proper (13% protected). Although bank reefs are not currently protected, this will be difficult to achieve considering that they are remote from inhabited islands.

1 An MPA effectiveness assessment tool has been developed for Micronesia modeled after the Indonesian MPAME tool. This allows for enhanced understanding of management effectiveness of existing MPA sites to be taken into consideration of the PAN design, regarding whether sites are appropriate of state goals and objectives based on management level and conservation effectiveness.

- Some atoll habitat types are sufficiently protected, with > 40% of their total extent within protected areas. However, most of this area is within the Ngulu MPA. Additional protection on other atolls will be required to observe management benefits there.
- All habitat types surrounding Yap Proper have < 20% of their extent within protected areas. This is below the 20 - 40% recognized as best scientific practice.
- Of particular concern, enclosed lagoon reefs (blue holes) and passes have < 10% protection, and only 12% of seagrass is protected. These representation gaps suggest that additional protected areas need to be designated around Yap proper.
- Terrestrial protection in Yap lags behind marine management efforts, though one protected area has been proposed. Given the relatively small land area in Yap, management targets towards particular species and ecological communities of conservation interest might be more appropriate than strict protected areas.

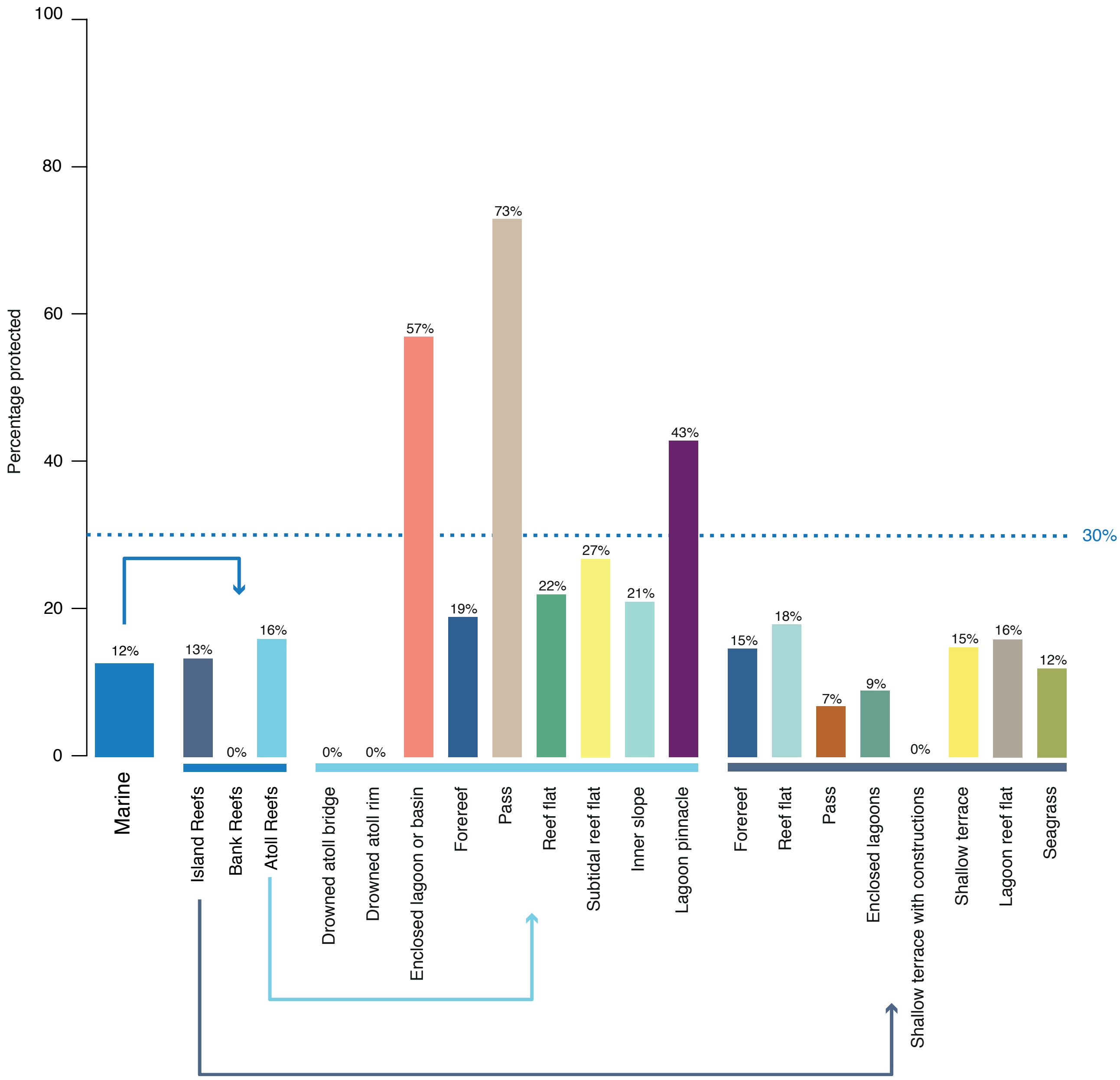


Figure 10. Representation gap analysis of terrestrial habitat types in Yap's protected area network

Table 1. Gap analysis of Yap's protected area network

Habitat type	*Total area (ha)*	*Representation target*	*Percentage protected in existing PAs*
Marine	**131245**	**30%**	**12.46%**
Yap Proper Reefs	15260	30%	13.41%
Forereef	1717.25	30%	14.69%
Reef flat	4572	30%	18.31%
Pass	222	30%	7.18%
Enclosed lagoons	746	30%	10.46%
Shallow terrace with constructions	334	30%	0%
Shallow terrace	2003	30%	14.54%
Lagoon reef flat	1217	30%	16.48%
Seagrass	3046	30%	11.64%
Atoll Reefs	89388	30%	16.01%
Drowned atoll bridge	135	30%	0%
Drowned atoll rim	25441	30%	0%
Atoll enclosed lagoon or basin	105	30%	57.38%
Atoll Forereef	9394	30%	19.07%
Atoll Pass	1277	30%	73.86%
Atoll Reef flat	14473	30%	21.92%
Atoll Subtidal reef flat	5234	30%	26.57%
Atoll Inner slope	32866	30%	20.99%
Atoll Lagoon pinnacle	91.58	30%	43.18%
Terrestrial	**13483.60**	**20%**	**0.57%**
Mangrove Forest	42	30%	1.87%
Atoll land	30	20%	1.44%
Marsh	134	20%	0.00%
Savanna	1766	20%	0.00%
Swamp Forest	27	20%	0.00%
Upland Forest	3336	20%	0.00%

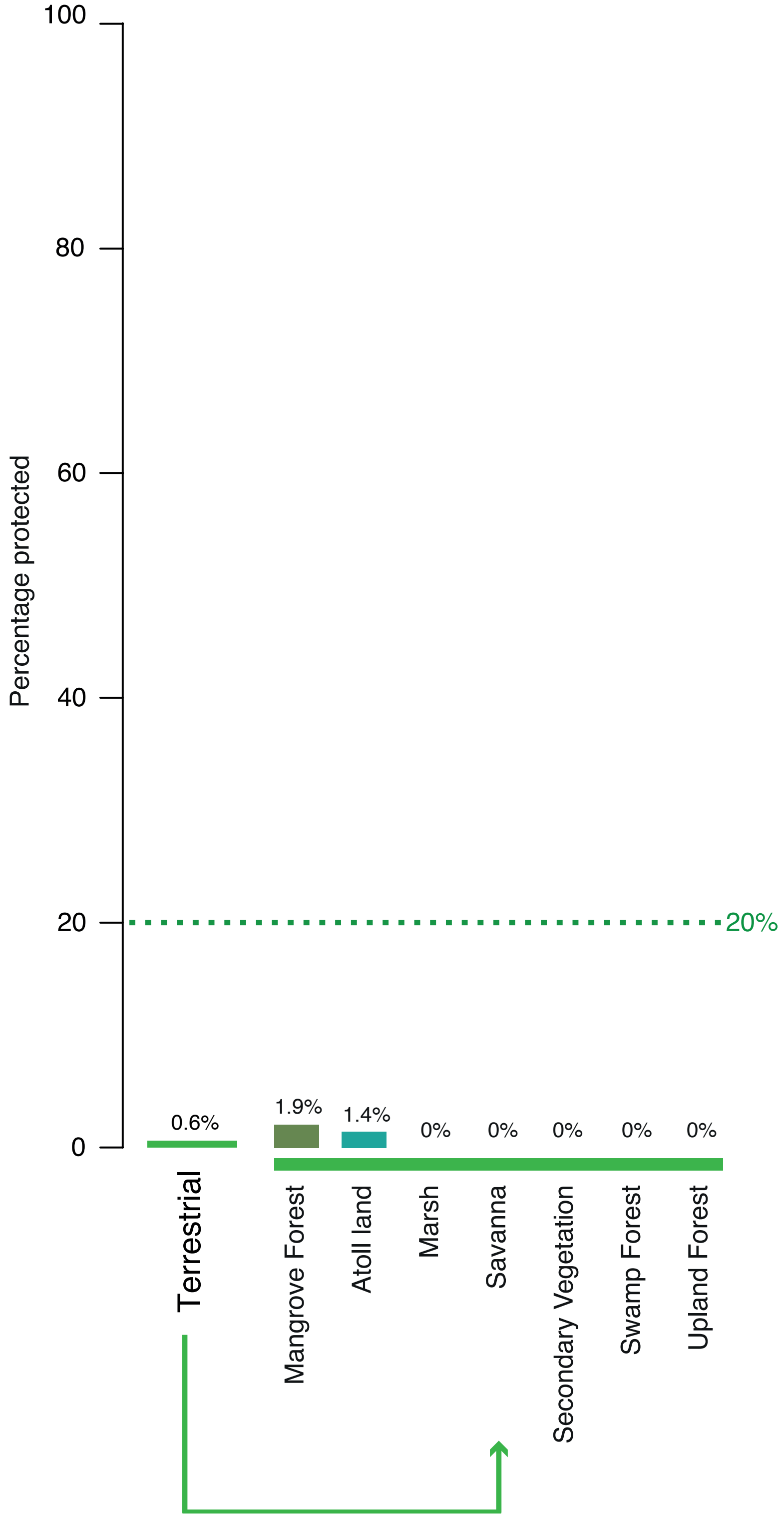


Figure 11. Representation gap analysis of terrestrial habitat types in Yap's protected area network

Ecological gaps

Ecological gaps assess the adequacy of protected areas to ensure the persistence of the features they are designed to protect; for example: do protected areas contain the habitat types that the species requires and are they large enough to encompass their daily movement? This analysis focuses on the adequacy of Yap's marine protected areas in terms protecting key fishery species.

To sustain target species within their boundaries, marine protected areas should be more than twice the size of the home range of focal species (in all directions), should include habitats that are critical to the life history of focal species (e.g. home ranges, nursery grounds, migration corridors and spawning aggregations), and be located to accommodate movement patterns among these (Green et al., 2015). This will ensure that the protected area includes the entire home range of at least one individual, and will likely include many more where individuals have overlapping ranges (Green et al., 2015).

Key fishery species of interest are listed in Table 2, along with the recommended minimum MPA size to protect that species.

To calculate the effective size of existing MPAs in Yap, the ArcGIS Minimum Bounding Geometry tool was used to calculate the shortest distance between any two vertices of the convex hull of the MPA polygon.

Comparison with the size of MPAs in Yap (Figure 12) highlights that many MPAs are too small to protect all species of interest.

Key Messages:

- Only species with very small home ranges, such as ***Cephalopholis argus*** and ***Ctenochaetus striatus*** are likely to be well protected in all existing MPAs.
- Improving protection for species with larger home ranges will require either making some MPAs larger, or alternative management measure for those species, such as catch, size, gear or effort restrictions, or seasonal catch and/or sale bans.
- It is important to note that minimum size recommendations should apply to the habitat types that species use. Clearly, if a protected area has both a marine and terrestrial component, the parts on land will not be included in the fishes home range! Some marine habitats are also inhospitable to some species, for example many reef fish species will not cross open areas of deep lagoon between reefs.
- Some species require larger protected areas where the habitat is patchy. For example, steephead parrotfish (***Chlorurus microrhinos***) have a home range of 0.2 miles on continuous fringing reef, but move an average of 1.25 miles each day on patchy reef habitat.
- Some species utilize different habitat types for foraging and resting, or at different stages throughout their life history, performing ontogenetic migrations between nursery, juvenile and adult habitats. For example, rabbitfish (Siganidae) have been found to be more abundant on reefs close to mangroves (Olds et al., 2013) and Bumphead parrotfish (***Bolbometopon muricatum***) requires shallow mangrove areas and seagrass meadows for nursery areas. MPAs with good habitat connectivity (i.e. they contain mangrove, and coral reef habitats within their boundaries, or are within close proximity to these) are likely to provide better protection for these species.

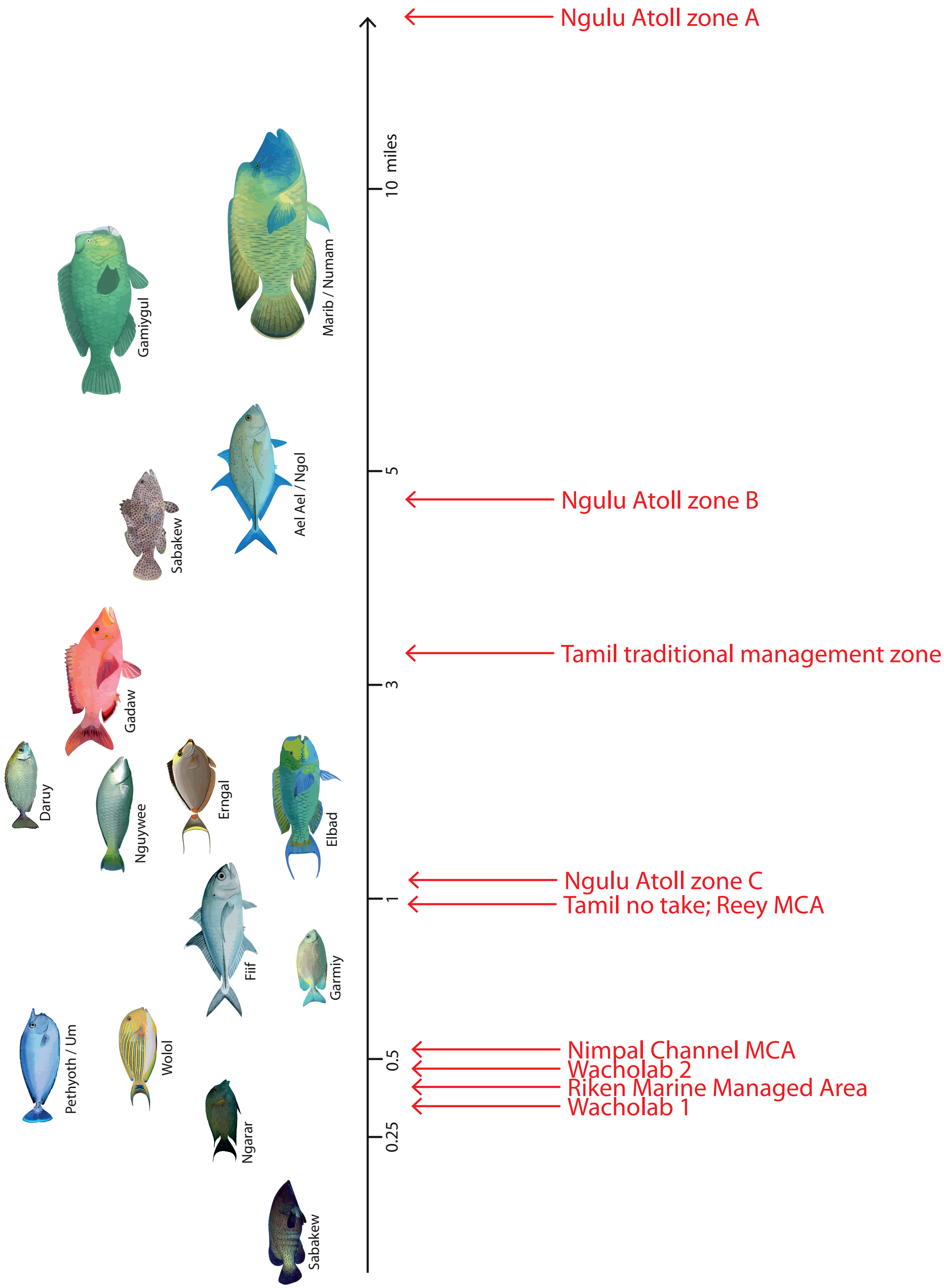


Figure 12. Home range movements of key fish species and effective sizes of existing marine protected areas in Yap

Table 2. Key fisheries species of interest, and recommended minimum MPA sizes

English / Scientific name	*Yapese name*	*Fish Movement Information* [a]	*Minimum recommended effective MPA size* [b]
Lined surgeonfish / Acanthurus lineatus	Wolol	Home range <0.3 miles.	0.6 miles
Bumphead parrotfish / Bolbometopon muricatum	Gamiygul	Mean home range <1.5 miles (range up to 4.7 miles)	9.4 miles
Bluefin trevally / Caranx melampygus	Ael Ael / Ngol	Home ranges <3.3 miles. Long-term movements may be up to 62 miles	6.6 miles. NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs
Bigeye trevally / Caranx sexfasciatus	Fiif	Home ranges <0.6 miles. However, ontogenetic shifts can be >1.2 miles, and long term movements of 10 miles recorded.	1.2 miles. NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs
Peacock hind / Cephalopholis argus	Sabakew	Home ranges <0.03 miles. Larger maximum home ranges recorded in this family	0.12 miles
Humphead wrasse / Cheilinus undulatus	Marib / Numam	Adult home ranges in Micronesia range between 1.2 and 6.2 miles	12 miles
Steephead parrotfish / Chlorurus microrhinos	Elbad	Home ranges <1.3 miles. Inter-reef movements may be greater.	2.6 miles. NOTE - MPAs might need to be larger to allow for inter-reef movements in patch reef habitats.
Striated surgeonfish / Ctenochaetus striatus	Ngarar	Home ranges <0.2 miles.	0.4 miles.
Highfin grouper / Epinephelus maculatus	Sabakew	Home ranges 0.4 - 2.5 miles, inter-reef movements up to 3.7 miles.	5 miles. NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs.
Pacific long-nose parrotfish / Hipposcarus longiceps	Nguywee	Pacific long-nose parrotfish / Hipposcarus longiceps	2.4 miles. NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs

Humpback red snapper / Lutjanus gibbus	Gadaw	No data are currently available. The closest proxy to use may be L. rivulatus, where mean long-term movement = 0.6 miles; maximum = 90 miles	3.7 miles (likely to encompass home range for most individuals)
Orangespine unicornfish / Naso lituratus	Erngal	Home ranges <1.3 miles	2.6 miles
Bluespine unicornfish / Naso unicornis	Pethyoth / Um	Home ranges <0.3 miles	0.6 miles
Mottled spinefoot / Siganus fuscescens	Daruy	Home ranges <1.3 miles.	2.6 miles
Golden-lined spinefoot / Siganus lineatus	Garmiy	Mean home range = 0.4 miles.	0.8 miles.

[a] From Green et al 2015. Where no empirical data are available, substituted from species of same family, similar size and behavior.

[b] Based on 2 x home range movement of species.

Sabakew (*Cephalopholis argus*) has a small home range, and thus is adequately protected within existing MPAs in Yap. Photo © Take Sinclair-Taylor.

Synthesis of ecological requirements & management options for key fish species

Summary of general principles for resilient marine protected area design

Well-designed and effectively managed MPAs can play a significant role in achieving sustainable use of marine resources at multiple scales. Scaling up from individual MPAs to a state-wide MPA network will facilitate the protection of species and habitats in addition to the maintenance of ecological processes, structure, and function. Comprehensive design principles for marine protected areas are available elsewhere, e.g. http://www.reefresilience.org/coral-reefs/resilient-mpa-design/. This section contains an overview of design principles for marine protected areas, with specific guidance for implementation in Yap.

Principle 1: Effective management, including providing community benefits and reducing threats, is the core of resilience-based strategies

- Ensure no-take areas are in place for the long-term, preferably permanently
- Minimize and reduce stressors
- Embed MPAs in broader management frameworks

Whilst MPAs can protect against negative effects of overfishing of reef fish and invertebrates, they cannot reduce threats from poor land management practices. Degradation and destruction of forests and mangroves negatively impacts on downstream habitats, and was identified as a key challenge to be addressed by the Yap PAN. Doing so will improve the effectiveness of existing MPAs.

To protect coral reef habitats outside of protected areas, participants at the 2016 PAN workshop recommended that laws for pollution and dredging should be reviewed, improved, and better enforced.

Principle 2: Representation of the full suite of marine habitat types helps ensure that key elements of biodiversity will be represented in the network

- Represent 20–40% of each major habitat (i.e., each type of coral reef, mangrove, and seagrass community) in marine reserves
- Replicate protection of each major habitat within at least three widely separated marine reserves

Reef fish surveys conducted in Yap (Houk et al., 2012) have found that there are distinct coral and fish assemblages present on lagoon reefs (blue holes), channel reefs and outer reefs. Whilst fish biomass is greater on outer reefs, back reef habitats provide critical nursery habitats for many fish species. Thus, it is important to make sure that all of these reef types are adequately represented within Yap's PAN.

Mangroves on the west coast of Yap proper are dominated by Sonneratia alba and Bruguiera gymnorrhiza, whereas those on the east coast are predominately Rhizophora species (MacKenzie et al., 2011). These differences are caused by different exposure to tropical storms, which impact the windward east coast. As different mangrove communities provide different habitat for fish and invertebrate species it is important to include both east and west coast mangroves in the PAN. This might be achieved by extending management in Tamil, or protecting mangroves in Rull.

Principle 3: Protect critical areas that can serve as reliable sources of larvae for replenishment and preservation of ecological function

- Ensure that no-take areas include critical habitats
- Include special or unique sites in the MPA network (e.g. turtle nesting sites)
- Include resilient sites in the MPA network

Houk et al. (2012) found greater densities of juvenile Cheilinus undulatus on enclosed lagoons (also referred to as blue holes) located on the reef flats of Yap proper, pointing to their potential importance as juvenile habitat. These critical areas are currently underrepresented in the PAN: <10% of lagoon reefs are within MPAs.

Fishers usually have some local knowledge of the location of reef fish spawning aggregation sites. These should also be considered as critical areas and prioritized for inclusion in the Yap State PAN.

On the outer islands, turtle nesting beaches have been identified and these should be protected.

Principle 4: Maintenance of ecological connectivity among and between habitats

- Apply minimum sizes to marine reserves, depending on which species require protection and how far they move
- Space marine reserves 1–15 km apart, with smaller reserves closer together.
- Ensure that MPAs are located in habitats that focal species use.

Assessment of the adequacy of existing MPAs in Yap (Figure 12) indicates that only species with small home ranges are adequately protected within all MPAs. Given the difficulty of establishing large MPAs, MPAs should be placed to protect critical areas, and alternative fisheries management strategies should be employed to protect species with larger home ranges. Examples of these are included on pages 30-35.

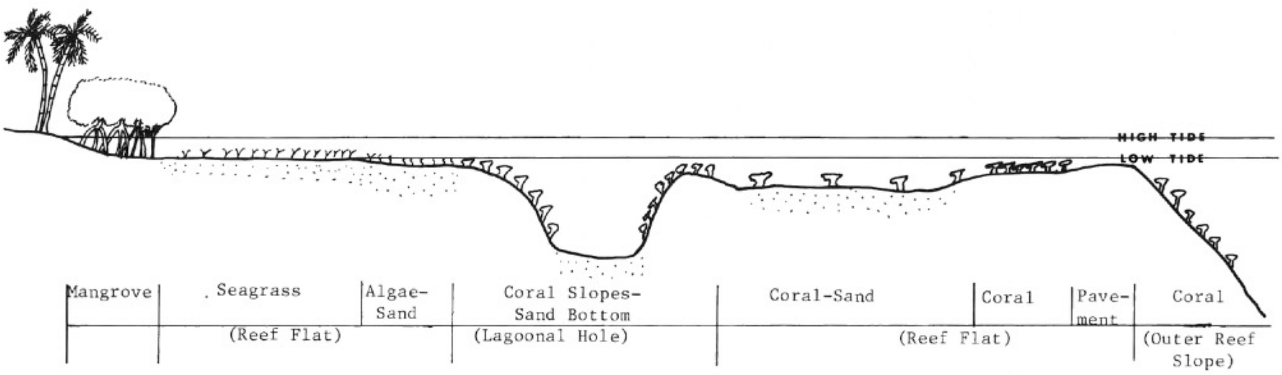


Figure 13. Cross section of Yap lagoon, adapted from Tsuda *et al. (*1978)

Ideally, marine conservation areas would encompass all habitats from mangroves to the outer reef slope.

It is likely that all of the reefs surrounding Yap proper are well connected via larval dispersal (dispersal distance in coral reef fishes tend to be in the range of 3-9 miles). Without a hydrodynamic model to predict larval connectivity between the outer islands, it is difficult to take larval connectivity into account in placing MPAs. Establishing a state-wide network of marine protected areas will improve the likelihood that MPAs can act to replenish one another through larval exchange.

'Seascape connectivity' describes the connections between adjacent habitat types within a seascape, e.g. mangroves, seagrass beds, reef flats and the reef slope. These connections are essential for many reef fish species which use multiple habitat types every day, or during different stages of their lives. For example, bumphead parrotfish and other species perform ontogenetic migrations between habitat types, using mangroves and seagrass beds as nursery habitats, living on fringing and lagoon reefs as juveniles before finally moving to seaward reefs as adults. Other species, such as snappers, forage on seagrass beds and sand flats during the day, and shelter on reefs at night. To maintain seascape connectivity, MPAs would ideally extend from the coastline (including mangroves) out to the edge of the reef slope. Where this is not possible, MPAs in the network should be located to protect different habitat types (see page 38).

Principle 5: Identification and consideration of social, cultural, economic and governance aspects of coastal communities in design and management

As determined at the PAN workshop in Nov 2016, communities (traditional leaders and councils) will first and foremost take responsibility for implementation of managed areas, with Yap State and FSM agencies will provide support, for example by creating and enforcing laws that support community-led management actions. Community involvement in all aspects of MPA design, implementation and management will ensure that relevant social, cultural, economic and governance considerations are taken into account.

Species-specific management strategies for key fish species

The next section contains a synthesis of ecological information (habitat preferences and movement patterns) for key fish species, and how this can be interpreted to identify to options for implementing management to improve the status of these species in Yap.

Bumphead Parrotfish

Gamiygul | *Bolbometopon muricatum*

The bumphead parrotfish is the largest member of the parrotfishes, growing to a maximum total length of 1.3 m and weighing up to 46 kg. The species has been estimated to reach 40 years of age.

Adults are primarily olive to blue green or grey in color with the anterior region near the head being yellow to pink in coloration. Adult bumphead parrotfish are easily recognized by the prominent bulbous bump on their forehead. Juveniles (<50cm) are greenish brown in color, with 2-3 vertical rows of white spots along their flank.

With their fused teeth, bumphead parrotfish scrape coral to feed on plant growth and the very small plants (zooxanthellae) living within the coral. The role of bumphead parrotfish in bioerosion and sand generation is of notable importance, making them a key component of the coral reef ecosystem. Their feeding activity also prevents coral becoming smothered by algae.

Habitats

Three habitat types are important to bumphead parrotfish:

1. Juveniles recruit to shallow, low-energy, **lagoonal areas** with either plumose algal beds, **seagrass**, **mangroves**, or high relief coral formations. These “nursery” habitats are essential - bumphead parrotfish are not found in regions where mangroves are absent (including Yap’s outer islands).
2. During the day, adults are found primarily on **shallow barrier and fringing reefs**, in the high-energy environment of the **forereef**, crest, and adjacent areas. Spawning occurs throughout the year in aggregations on reef fronts and passes.
3. At night, adults sleep in **sheltered areas of the reef**, either in caves or in some instances on the reef top in shallow water.

Movement Patterns

Bumphead parrotfish movement patterns are distinct between day and night. Day time movement patterns are characterized by groups of individuals foraging among forereef, reef flat, reef pass, and clear outer lagoon habitats. At dusk, schools of parrotfish move to nocturnal resting sites found among sheltered forereef and lagoonal habitats. Bumphead parrotfish remain motionless while resting and use caves, passages, and other protected habitat features as refuge during the night. Adult bumphead parrotfish may range up to 4 miles from their nocturnal resting sites.

Key Threats

The primary threats to bumphead parrotfish are loss and/or degradation of juvenile habitat, and overharvesting of adults.

Juvenile bumphead parrotfish require nursery habitat including mangrove swamps, seagrass beds and coral reef lagoons. These nearshore, shallow water areas are especially vulnerable to pollution, modification, and impacts from coastal development. In contrast to juvenile habitat, adult habitat loss and/or degradation is not a high priority concern.

Bumphead parrotfish are highly prized throughout their range, and are harvested primarily by spearfishing. The large adult size of bumphead parrotfish, diurnal feeding behavior and nocturnal resting behavior make them especially vulnerable to harvest. Fishers often spearfish at night to target schools sleeping in shallow water on reef fronts and passes. There are numerous reports of major reductions in the abundances and catch rates of *B. muricatum* shortly after the introduction of night spearfishing.

Management Options for Bumphead Parrotfish

- *Restrictions on spearfishing:* either prohibiting spearfishing altogether; prohibiting fishing with lights (limiting night spearfishing); or prohibiting fishing with SCUBA. There are local regulations banning spearfishing on some islands within Yap state.
- *Prohibition of take or sale:* the most effective management option would be a species-level restriction on sales in local markets. In Pohnpei sale of bumphead parrotfish is banned; whilst customary use is permitted, traditional leaders have decided not to accept bumphead parrotfish until populations recover.
- *Protection of mangroves:* prohibition on mangrove harvest and/or sale; inclusion of mangroves in protected areas; and sustainable harvest and/or restoration requirements. Shallow lagoon areas identified as nursery habitat for bumphead parrotfish should be carefully protected.
- *Community-managed no-take areas:* given the large home range size of adults of this species, this would require a no-take area > 9 miles. Thus, no-take areas might be more useful for protecting juvenile habitats.
- There is no basis for spawning season closures as a management option for this species. It is also unlikely that catch or size limits would be useful for managing bumphead parrotfish.

The most effective actions to improve the status of bumphead parrotfish populations are to:

- **Ban night-time spearfishing**
- **Protect shallow lagoon areas and mangroves used as nursery habitat within no-take areas**

References: Aswani & Hamilton, 2004; Kobayashi et al., 2011; Sadovy de Mitcheson & Colin, 2012; Information Sheets for Fishing Communities #4 Parrotfish (Scaridae), produced by SPC (www.spc.int) in collaboration with the LMMA Network (www.lmmanetwork.org).

Dusky Rabbitfish

Daruy | *Siganus fuscescens* (and other rabbitfish)

Siganus fuscescens has an olive green or brown body, with a silvery belly and small spots. When frightened, they display a mottled color and project their venomous spines. In Micronesia, rabbitfish have long supported subsistence and, more recently, modest commercial fisheries.

Habitats

Siganus fuscescens inhabits **lagoons**, **coastal reefs**, and **shallow seagrass beds**. During the day, adults and juveniles feed on seagrasses and often school with juvenile parrotfishes, surgeon fishes, and goatfishes.

Several studies have found that juveniles also use **mangroves** as a nursery area, and *S. fuscescens* has been found to be more abundant on reefs close to mangroves. Adults roam the seagrass flats during high tide and retreat to deep lagoon waters as the tide ebbs.

Movement Patterns

Home range sizes for schools of ***S. fuscescens*** in the Philippines were estimated to be less than 1 mile, with a resulting recommended marine protected area of 2 miles. Larger fish were found to be more active and have a larger home range area. Since few large individuals were surveyed in the Philippines, home range estimates should be considered an underestimate for this species.

S. fuscescens is known for forming large "pre-spawning aggregations", in which fish congregate as groups in inshore areas and then migrate together across the reef to spawn on the outer reef later in the afternoon or early evening.

Key Threats

1. Rabbitfish are especially vulnerable to night-time spearfishing, as they are unresponsive and lying sideways on the bottom of seagrass beds.
2. Rabbitfish are often caught as they gather in large groups and move from inshore areas to spawning aggregation sites. The timing of these spawning migrations is well known by fishers. Fishing spawning aggregations is destructive, as these breeding fish are responsible for producing small fish, many of which will grow and be available to be caught in future years.

3. Rabbitfish are vulnerable to loss or degradation of seagrass habitats which they inhabit and feed upon.

Management Options for Dusky Rabbitfish

- *S. fuscescens* is a good candidate for protection within community-managed no-take areas, as they have a small home range size, and populations can recover quickly once protected. Note however that while well designed and managed no-take areas will allow fish numbers to increase, they will not protect the fish during their spawning migrations and at their aggregation sites unless other measures are taken.
- Some fishing communities have implemented a ban on night-time spearfishing, as rabbitfish are especially vulnerable when sleeping in seagrass.
- Minimum size limits have been applied in many Pacific Island countries, but these are difficult to enforce over a large coastline with many fishing communities. Catch limits have also been applied, but are usually inappropriate in community fisheries unless the catch is to be sold.
- In some areas the banning of gill nets by fishing communities has protected against the overharvesting of rabbitfish on their spawning migrations and in their spawning aggregations. However, the permanent banning of gill net fishing may be unreasonable as adult rabbitfish are difficult to catch by other methods. An alternative is to restrict the use of small-mesh gill nets by imposing a minimum mesh-size.

Fishers usually have some local knowledge of the timing and location of spawning aggregations and this information makes the following management options possible:

- a ban on fishing during the peak of the spawning season (this may require several short closures at monthly intervals, as some species appear to aggregate around the period of the new moon).
- a ban on fishing in areas (sites) where spawning aggregations occur.

The most effective actions a community can take to improve the status of rabbitfish populations are to:

- **Ban fishing of spawning aggregations**
- **Restrict mesh-sizes in nets**
- **Protect seagrass beds in no-take areas**

References: Bellefleur, 1997; Mellin et al., 2007; Olds et al. 2012, Kitalong, 2012; Honda et al., 2013; Davis et al., 2014. Information Sheets for Fishing Communities #2 Rabbitfish (Siganidae), produced by SPC (www.spc.int) in collaboration with the LMMA Network (www.lmmanetwork.org)

Orangespine Unicornfish & Bluespine Unicornfish

Erngal | *Naso lituratus* & Um | *Naso unicornis*

Naso is a genus of fish in the surgeonfish family, Acanthuridae. Fish of this genus are known commonly as unicornfishes because of a bony horn projecting from the head in front of the eyes.

In addition to their cultural and commercial importance as food fishes, these species have a key ecological function on coral reefs. ***N. lituratus*** and ***N. unicornis*** play a disproportionately important role removing established brown macroalgae, which are often the dominant algal group involved in phase-shifts from coral-dominated to algal-dominated reef systems.

Habitats

The orangespine unicornfish and bluespine unicornfish are common in a variety of coral reef habitats, where they feed primarily on large fleshy macroalgae. Both species prefer structurally complex areas which provide refuge holes. *N. lituratus* are found in areas of coral, rock, or rubble of **lagoon and seaward reefs**. *N. unicornis* inhabit **channels**, moats, **lagoon and seaward reefs** with strong surge.

Underwater visual census results suggested that bluespine unicornfish undergo ontogenetic habitat shifts from shallow, sheltered areas of the reef to deeper, more exposed habitats (Meyer & Holland 2005).

Movement Patterns

Both ***N. lituratus*** and ***N. unicornis*** display strong site attachment, with relatively small home ranges. Home ranges for Naso unicornis in Micronesia are <0.3 miles and for ***N. lituratu***s are <1.3 miles. However, home ranges can vary by an order of magnitude between locations (for example they are much larger in Guam than in Hawaii), and larger individuals on continuous barrier reefs can cover much larger distances, e.g. 5–7.5 miles in Pohnpei.

Two types of daily movement patterns have been identified: “commuters” make daily crepuscular migrations over several hundred meters between night-time refuge holes and foraging areas, while “forayers” undertake multiple brief excursions from refuge holes to local foraging areas (10–40 m away).

Key Threats

The primary threats to unicornfish are from unsustainable fishing practices, and life-history characteristics which make them vulnerable to overexploitation. Both species form large aggregations, which despite being short-lived, allow fisherman to obtain large catches at predictable times and places. Habitat specificity, slow growth and extended longevity all increase their vulnerability to overfishing.

Unicornfishes are a highly desirable food fish in Micronesia, and this has led to overexploitation. It has been estimated that 61% of ***N. lituratus*** and 73% of ***N. unicornis*** caught in FSM are immature (Houk et al., 2012a).

Management Options for Unicornfishes

- Both species are ideal candidates for protection within community-managed no-take areas. These should be designed to ensure that no-take areas are at least twice the size of each species' home range (i.e., 2.6 miles across for ***N. lituratus*** or 0.6 miles across for ***N. unicornis***), and ideally should use natural boundaries such as sandy areas. Evidence from no-take areas in Fiji and Philippines has shown positive effects on both population density and individual size of these species. While strong site-attachment can reduce adult spillover from reserves, increased juvenile recruitment to local fishing areas will still benefit local fishermen.
- As both unicornfish species are predominantly harvested via spearfishing, size limits could theoretically be established. Minimum size limits have been imposed in some countries, including in Pohnpei. However, not only are these limits difficult to enforce, but they may not offer adequate protection. Minimum size limits can be set to ensure that individuals reach maturation before capture, however maximum size limits might also be required to protect the largest and thus most fecund and functionally important individuals.
- Periodic closures and sales bans are another potential management option for unicornfish, however these are difficult to implement effectively, due to uncertainty around spawning months. For example, ***N. lituratus*** peaked through March–November in Guam, and April in Pohnpei, while N. unicornis spawning was limited through May–October in Guam, and in Pohnpei reproductively active individuals were found in all months except February, October and December. Local knowledge of spawning behavior, timing, and locations is required to implement seasonal closures.

The most effective actions a community can take to improve the status of unicornfish populations are to:

- **Ban the unsustainable practices of night-time spearfishing and spearfishing on scuba (and enforce these bans where they are already in place)**
- **Protect lagoons and seaward reefs in well-managed no-take areas of sufficient size to encompass species' home ranges**

References: Meyer & Holland, 2005; Houk et al., 2012a; Ford et al., 2016.

Spatial conservation prioritization

Spatial conservation prioritization can help to identify priority areas where new conservation areas might be established to fill gaps in the existing PAN.

Methods

Marxan

Marxan (http://www.uq.edu.au/marxan/) is a decision-support tool that assists users to identify protected area networks that achieve specified conservation objectives, while minimizing socioeconomic impacts. When provided with information on the amount of each biodiversity feature (e.g. habitat types, species' occurrences) in each planning unit, Marxan identifies sets of planning units that achieve biodiversity representation targets in an efficient manner. Each Marxan "solution" comprises a set of planning units that achieves specified representation targets. When run multiple times, Marxan also produces a "selection frequency" output which indicates the number of times that each planning unit was selected for inclusion in a protected area network that achieved the representation targets. Sites that have a high selection frequency are more likely to be important to achieve the conservation objective.

Because Marxan finds efficient solutions (i.e. seeking to minimize cost), it is common for solutions to propose lots of small, scattered, protected areas. Unless planning units are very large (which creates other problems), such solutions are unlikely to be feasible to implement, or effective for conserving biodiversity (due to small size and edge effects). For this reason, Marxan allows users to adjust a boundary length modifier (BLM) parameter, which places increased importance on minimizing the total boundary length of protected areas, in addition to minimizing cost. Using the BLM has the effect of creating fewer, larger protected areas.

Spatial prioritization scenarios

Prioritization was conducted separately for Yap proper and for the outer islands. No trade-offs are incurred by taking this approach, as the habitat types present differ between the two planning sub-regions.

To facilitate the prioritization analysis, the planning regions were first divided into "planning units" which form the building blocks of protected area network designs. Each planning unit can be selected for inclusion in a network, or left open to alternative uses. Different management zones were not considered. Two sizes of planning units were used to design protected area networks: 25 ha for Yap proper, and 100 ha for the outer islands. These sizes were selected to reflect the greater feasibility of implementing larger protected areas in the outer islands.

Habitat representation targets were set following the Micronesia Challenge (Houk et al., 2015): 20% for all terrestrial habitats (excluding barren, cultivated and built up areas) and 30% for all marine habitats. A 30% representation target was set for mangroves.

For the outer islands prioritization, existing MPAs on Ngulu atoll and Falalop were "locked in" to solutions. Given that no information on opportunity costs or community preferences for management was available, the "cost" of selecting a planning unit was assumed to be equal to the area of habitat within it. It was assumed that it would be prohibitively difficult to enforce conservation areas further than 9.3 miles (15km) from an inhabited island, so planning units beyond this distance were excluded from selection. Given this condition, it was possible to achieve representation targets for all features except "drowned atoll rim", which only occurs on remote drowned atoll reefs. For the outer islands prioritization Marxan's BLM was used to create protected area sizes that appeared reasonable, compared to existing closures on Ngulu and Ulithi atolls.

The 25 ha planning units for Yap Proper were intersected (Union function in ArcGIS) with the boundaries of existing marine managed areas to allow these areas to be “locked in” to prioritization scenarios. Given that the traditional management zone in Tamil allows fishing activities, this area was not locked in.

In different scenarios, the “cost” of including a planning unit in Marxan solutions was determined by the total area of conservation features within the planning unit, or the seascape connectivity score (see below).

To focus the prioritization on areas within which communities had expressed willingness to establish or change the boundaries of existing managed areas (at the November 2016 PAN workshop, shown in Figure 14), the cost of these planning units was reduced relative to others. This means that Marxan is more likely to select planning units in areas where communities are willing to undertake management, however other areas will still be selected if required to achieve representation objectives.

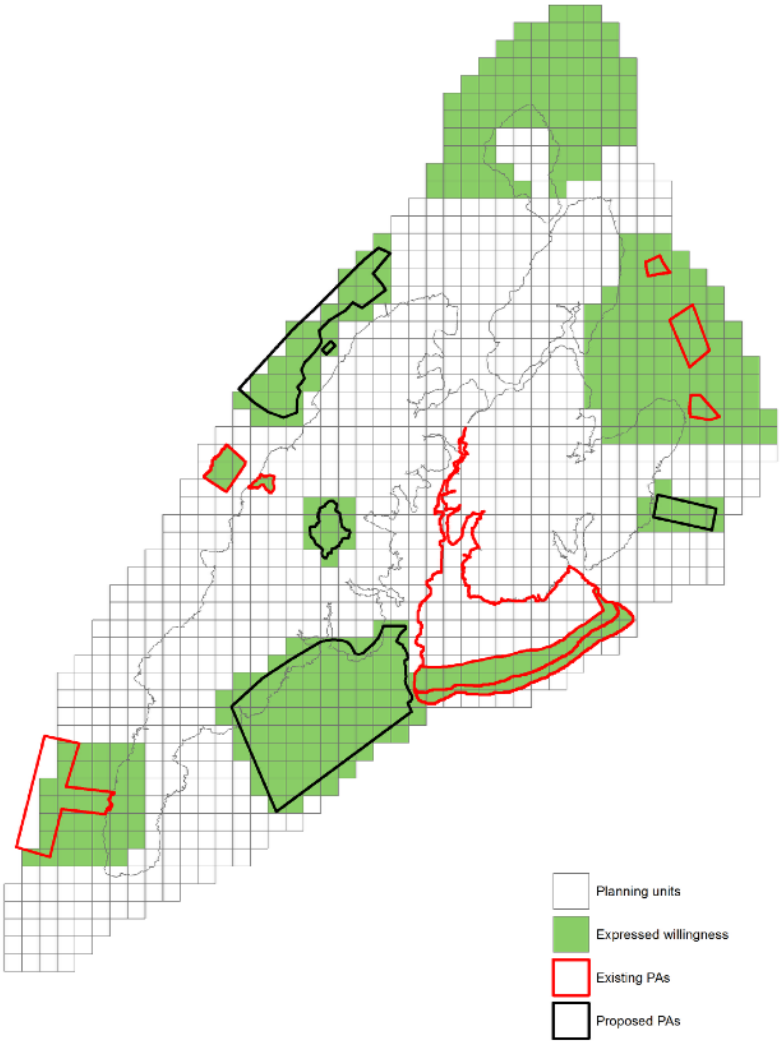


Figure 14. Areas in which communities expressed willingness to establish or change managed areas

For all prioritization scenarios, the feature spf values were parameterized so that all Marxan solutions would achieve all representation objectives to within 1% (i.e. if 99% of the required area was included, the solution was considered acceptable).

Seascape connectivity analysis

There has recently been a perceptual shift away from habitat representation as the sole focus of conservation prioritization towards consideration of ecological processes. A seascape connectivity approach considers the functionality provided by mosaics of different habitat types, which might be used by a species at different stages during their life history.

Back-reef systems (e.g. mangroves, seagrass beds, lagoonal reefs) often provide habitat for juveniles that subsequently make ontogenetic shifts to adult populations on coral reefs (Boström et al., 2011). These habitats are often overlooked for management in favor of reefs which have greater biomass of adult fish populations, yet are equally if not more at risk from habitat degradation and loss.

Research in the Caribbean demonstrated that the biomass of several commercially important fish species more than doubled when adult habitat was connected to mangroves (Mumby et al., 2004), reinforcing the need for conservation efforts to protect corridors of mangroves, seagrass beds and coral reefs. More recent studies in Australia and Solomon Islands also demonstrate that connectivity between reefs and mangroves within reserves promotes the abundance of harvested fish species (Olds et al., 2012, 2013). Within the Micronesian context of finely subdivided natural resource ownership, few opportunities exist to establish protected areas that include contiguous habitat from fringing mangroves to the outer reef slope. However, smaller reserves might be more effective if they are placed in areas that are well connected to other habitats in the seascape.

In Yap, bumphead parrotfish (***Bolbometopon muricatum***) are absent from outer islands and atoll reefs, pointing to the critical importance of mangroves as their juvenile habitat. Houk et al. (2012) found greater densities of juvenile humphead wrasse (***Cheilinus undulatus***) on lagoon reefs, pointing to their potential importance as juvenile habitat for that species. Areas of the outer reef that are close to mangroves and lagoons may therefore be more likely to support larger populations of adult ***Bolbometopon muricatum*** and ***Cheilinus undulatus***, and thus would be good candidate sites for community-based MPAs. Similarly, mangrove areas that are well connected to outer reefs would be good options for protection, as the juveniles which inhabit them might supplement adult populations on those reefs.

Operationalization

To incorporate seascape connectivity in the spatial prioritization for Yap proper, a seascape connectivity value was calculated for planning units containing outer reef or mangrove habitat, and was included as a cost layer in Marxan (see technical appendix). This has the effect of preferentially selecting planning units with high seascape connectivity value, whilst achieving representation objectives. In other words, Marxan will still select planning units to include 30% of the total extent of Yap's mangroves, but when deciding ***which*** planning units to select, it will choose those that are better connected to outer reefs.

A separate analysis was run to identify mangrove areas that are likely to act as nursery habitats for adult fish populations in the existing MPAs of Nimpal Channel, Reey and Tamil.

Results

The spatial prioritization results presented below are all with respect to achieving Micronesia Challenge representation targets for 30% of marine (and mangrove) habitats and 20% of terrestrial habitats. Increasing or reducing these targets would result in more or less area being required, however it is unlikely that different areas would be prioritized.

Yap Proper

Figure 15 indicates priority areas for further developing the PAN on Yap proper, accounting for community willingness and seascape connectivity.

Comparing priorities identified with and without accounting for community willingness (Figure 16) indicates that including community willingness changes spatial priorities, increasing the focus on areas near Wacholab and Rumung. Similarities that remain, even when the analytical "cost" of including areas in which communities have expressed a willingness to implement management is reduced, indicates the need to increase protection for currently underrepresented habitat types - notably the enclosed lagoon and mangroves which are most extensive in Rull. More common habitat types, such as the fore reef and reef flat, can be protected in different locations around the island group, depending on where communities are willing to implement and able to enforce management.

Note that the map of community willingness (Figure 14) can be refined and used to update these results.

Seascape analysis

Figure 17 shows the seascape analysis for the three existing MPAs that contain outer reef habitat (Nimpal Channel, Reef and Tamil). For fish populations present on the reefs in the Tamil no-take area, their most likely nursery habitat (indicated in red) is the blue hole within, and mangroves adjacent to the Tamil traditional management zone. The Tamil community are thus well placed to manage the full range of habitat types used by species that migrate between habitats. For Reey and Nimpal, the lagoons and mangrove areas that may act as nursery habitat likely belong to other communities (lagoon and mangroves to the North of Reey, lagoons to the south of Nimpal), so this would require collaboration. The Kaday and Okaw mangrove reserve is however well p[laced to act as nursery habitat for the Nimpal Channel MCA.

Outer islands

Figure 18 shows an example Marxan solution for Yap's outer islands. This provides an indication of the total area required, and a potential configuration of MPAs that would achieve the Micronesia Challenge targets.

However, the location of protected areas and selection of complementary fisheries management strategies must be determined by the local communities themselves, informed by their knowledge of the condition of their natural resources and their resource use requirements.

One key result emerging from the outer islands prioritization is that it is possible to achieve the Micronesia Challenge targets for habitat representation without protecting areas further than 9.3 miles from an inhabited island. This is important if the ability to effectively enforce compliance with fisheries management rules, especially by outsiders, is a concern.

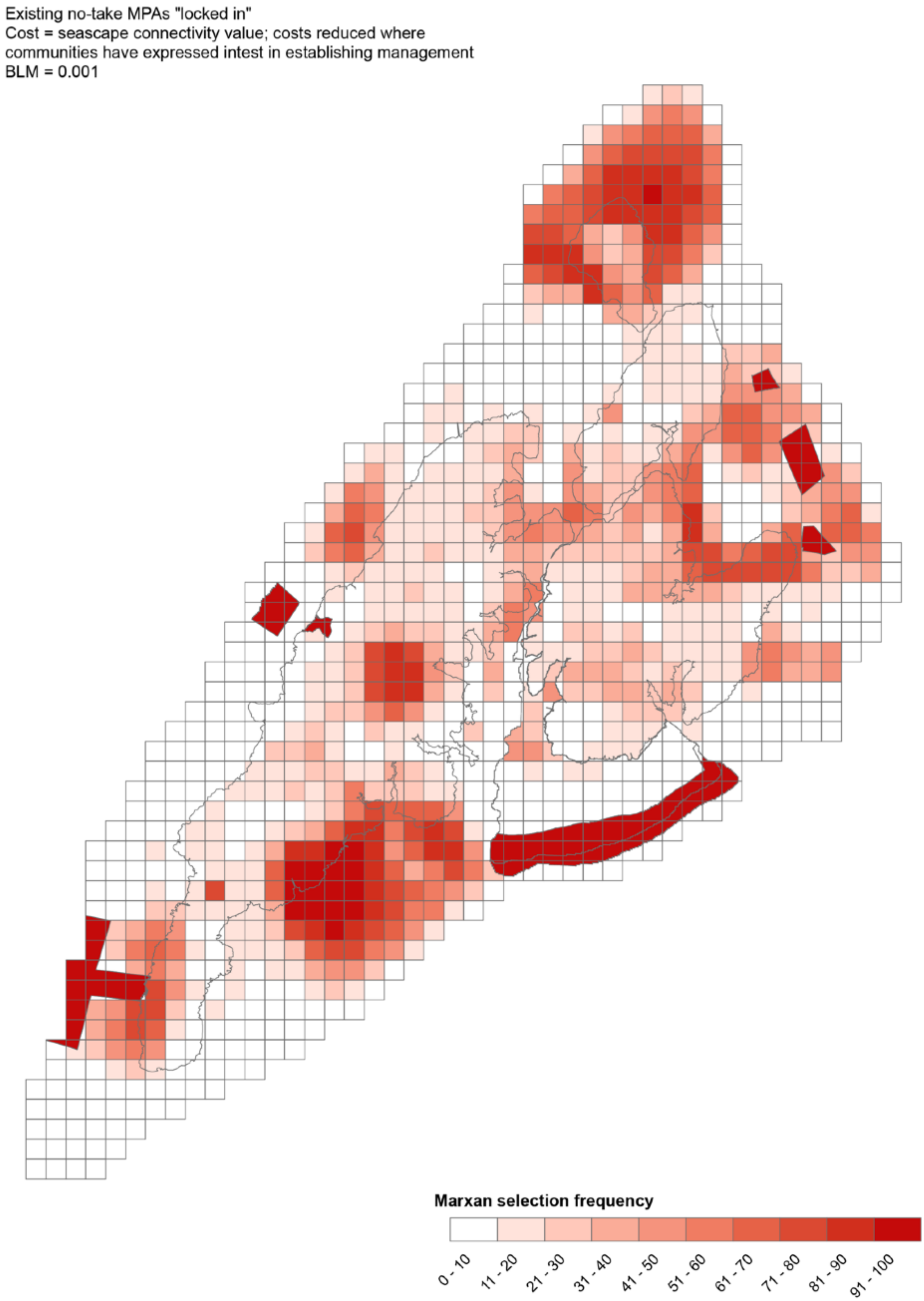


Figure 15. Conservation priorities, accounting for seascape connectivity and community willingness

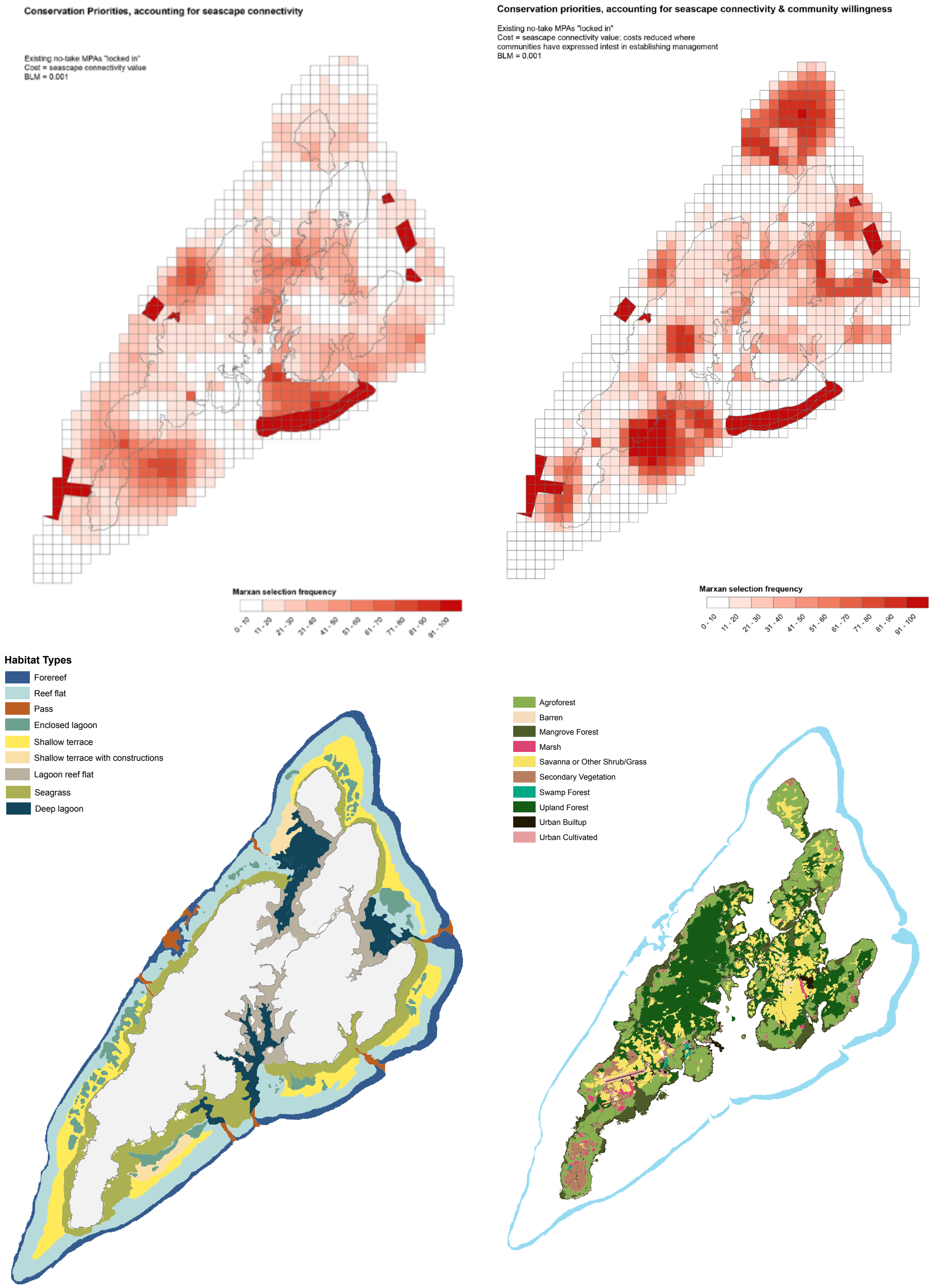


Figure 16. Comparison of priorities identified with and without accounting for community willingness Habitat maps are included here for ease of reference.

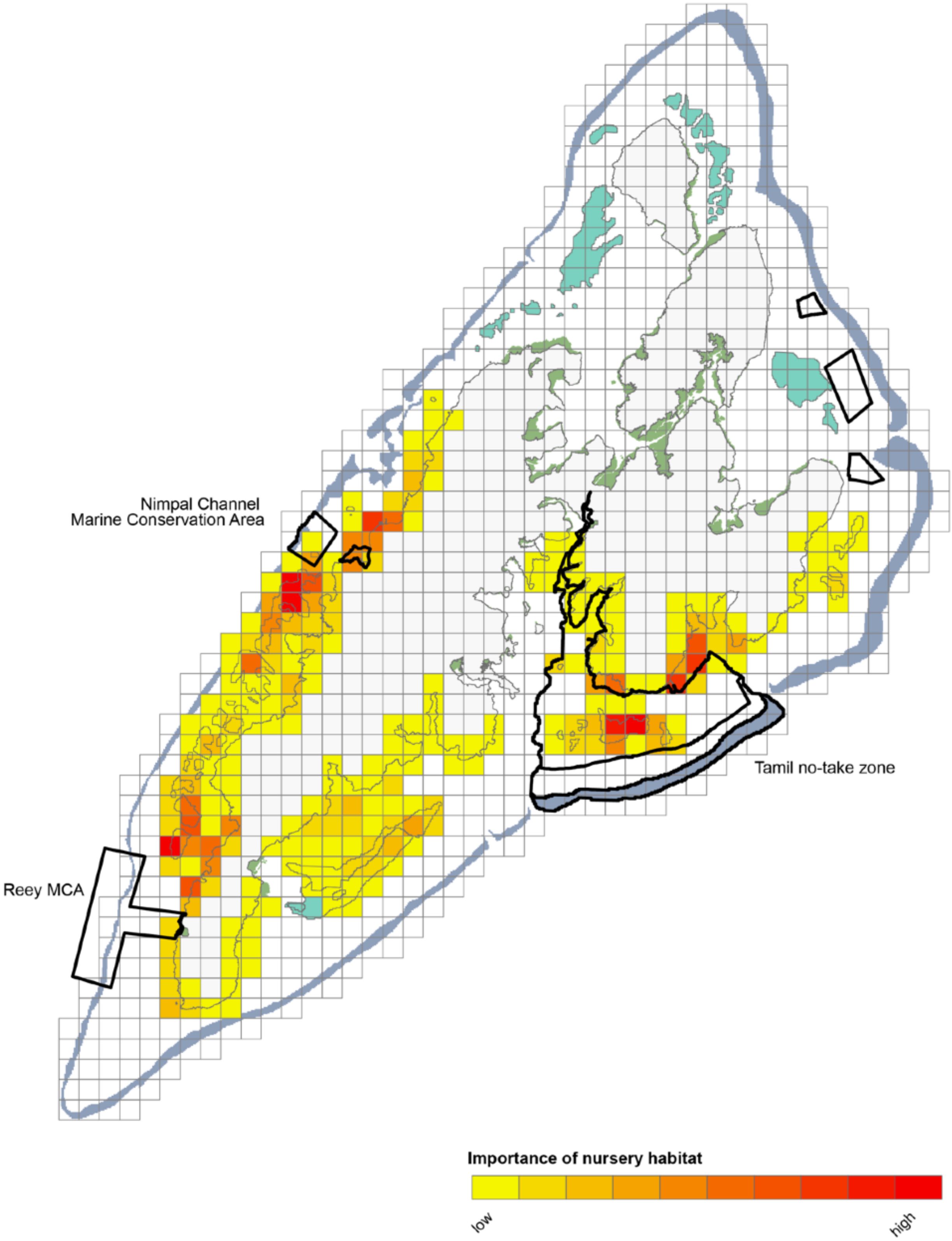


Figure 17. Seascape analysis to identify potentially important nursery habitat for fish populations within existing MPAs

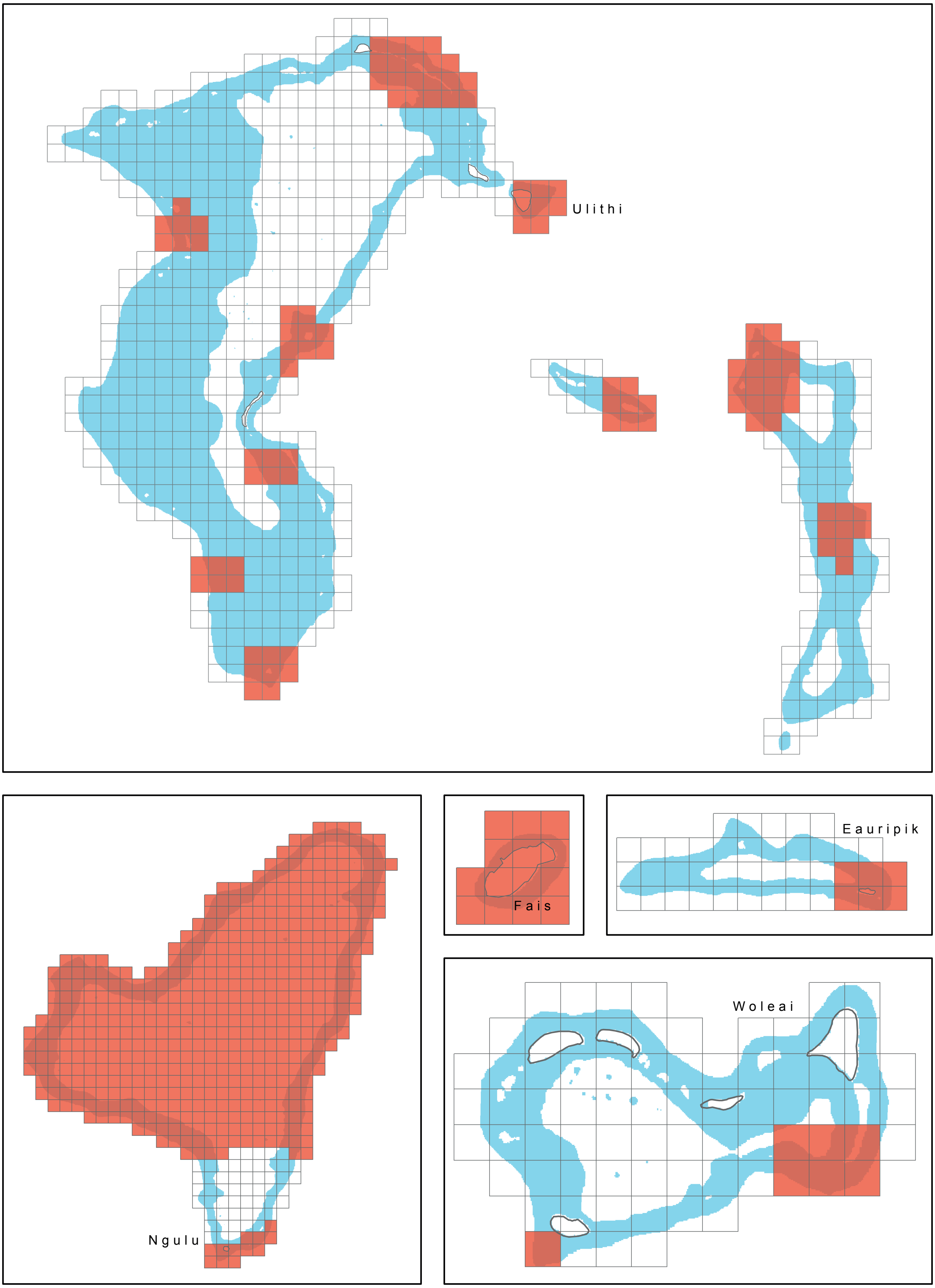


Figure 18. Example Marxan solution for Yap's outer islands

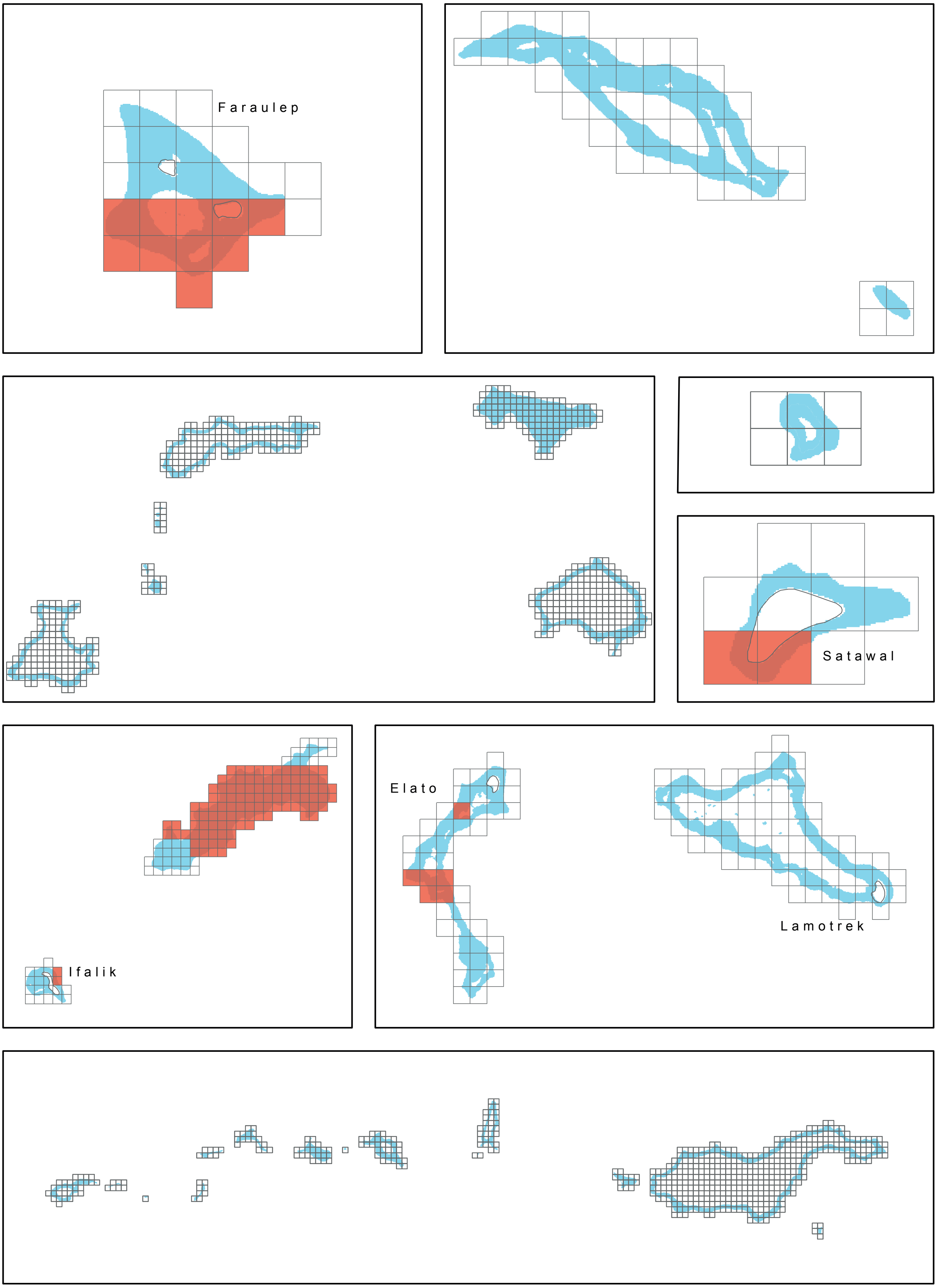


Figure 18 continued.

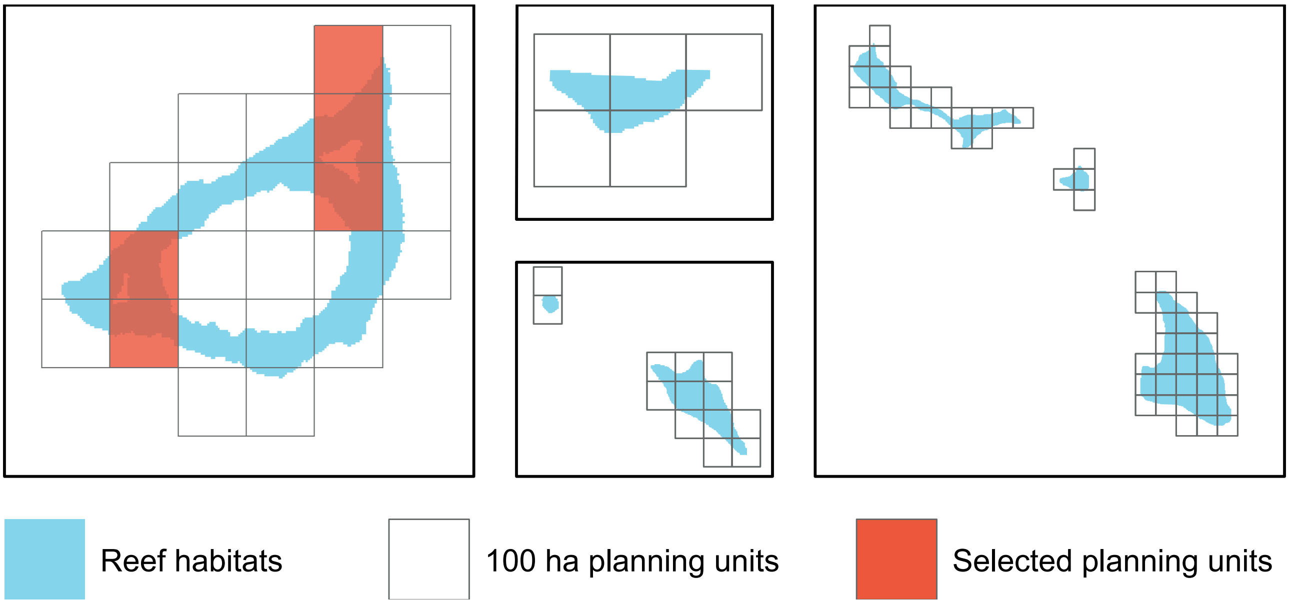


Figure 18 continued.

Recommendations for improving the design of Yap's PAN

For all existing MPAs, communities should consider whether their current design is likely to benefit the species that they care about most, using the information provided in Table 2 and Figure 12. This information can also be used to interpret monitoring efforts - species with home range sizes much greater than an MPA's effective size would not be expected to increase in abundance, for example. If monitoring indicates that the MPA is not working to increase the abundance of species that should be protected within it's boundaries, there might be problems with compliance or management effectiveness that need to be addressed.

Specific recommendations are not provided here for communities on the outer islands, as other groups have been providing advice on the development of resource management strategies that will achieve their objectives.

Wacholab

The two existing closures are small, and thus provide adequate protection only for species with very small home range sizes. If it is possible to make these areas larger, or combine the two areas to make one larger closure, this would provide better protection for more reef fish species.

If the mapped boundaries are correct, the existing closures protect areas of the reef flat and sandy shallow terrace. Whilst these habitats are important foraging areas for some species, many key fishery species spend most of their time on the outer reef slope, or in the enclosed lagoons / blue holes. Extending the existing closures to the edge of the outer reef, and/or including one of the two blue holes in this area inside a managed area would be a good idea.

If additional fisheries management is not yet in place, embedding the closures within a traditional management area (as in Tamil) in which fishing activities are well managed and monitored, is likely to improve their effectiveness.

Riken

Similar to Wacholab, this area is quite small, and would be more effective if the closure were to extend to include the fore reef habitat, and ideally also to the coastline, to include additional seagrass area.

Gagil

The Gachpar community has proposed to establish a marine conservation area covering the blue hole and adjacent habitats. This is an excellent area to protect, but the benefits would likely be greater in the boundaries can be extended to the edge of the reef slope, and if complementary management is established on the adjacent mangrove area.

Reey

The Reey Marine Conservation Area covers a 2 mile long section of the fore reef habitat, providing good protection for species that reside on the outer reef. The area also extends from the coastline to the outer reef, allowing for fishes that use different habitats to move between them. It is important to also make sure that the mangroves along the coastline in this area are well managed, as they might be nursery habitats for species which live within the MCA and on the adjacent reefs as adults. The MCA is narrower on the seagrass area close to the coast - this might still provide adequate protection for species which use seagrass habitats as juveniles, when their home range size is often smaller than as an adult. Some species of rabbitfishes that forage on seagrass also have relatively small home ranges. However, if managing species which inhabit seagrass and lagoonal areas is an objective for the MCA, the community should monitor their catch of these species and if it is declining, consider making the MCA wider there.

Tamil

The Tamil managed area protects c. 4 miles of the outer reef, and provides management from the coastline to the reef within a traditional management area. This is likely to provide good protection for many reef fish species. Fishing (and other) activities allowed within the traditional management zone should be consistent with the recommendations made for key fish species. It is especially important that any fishing activity within the blue hole in the traditional management zone is well managed; this is currently the only blue hole under management in Yap, and it has been identified as a potentially important nursery habitat for humphead wrasse and other species. Ensuring that the mangrove areas adjacent to the fishing ground are well managed is likely to improve the effectiveness of the no-take area - several studies have shown that MPAs on reefs close to mangroves have better results.

Nimpal, Kaday & Okaw

The Nimpal Channel MCA is well placed to include the outer reef and channel, and also a small enclosed lagoon area. The proximity of the Kadaw & Okaw mangrove reserve is likely to improve protection for species that use mangroves as nursery habitats, as well as benefitting the water quality within the MCA and on adjacent reefs. Little seagrass is included within the existing boundaries however, so the communities should consider whether species that inhabit seagrass meadows require protection. Species with more extensive home range movements cannot be protected within an area this size, so alternative fisheries management strategies, should be considered for those species.

Rumung

The Rumung community have expressed an interest in establishing a conservation area. When deciding on the location and boundaries for a new MCA, the community should consider which species are most important for management, and ensure that the managed area is large enough to encompass their home range requirements, and placed on the habitat types that those species use. In terms of contributing to the Yap State PAN, enclosed lagoon habitats are currently underrepresented. The blue holes around Rumung island are likely to provide habitat for many reef fish and invertebrate species, so would be excellent candidate areas for protection. If possible, a managed area should extend from the coastline to the outer reef to allow for species that utilize habitats across the reef shelf.

Ngulu

Management was reviewed in 2014, so does not need to be revisited. The size of the no-take zone on Ngulu provides excellent protection for a wide range of reef fish species.

Rull

There are no existing protected or managed areas in Rull, however communities have proposed to establish a Marine Conservation Area. The proposed Marine Conservation Area covers almost 3 miles of the fore reef habitat, which would provide good protection for species that reside on the outer reef. It should be noted that the mangrove areas around Luweech are some of the most extensive in Yap. These, combined with the large lagoon area adjacent, could potentially play an important role in providing nursery habitat for many reef fish species, and would be a good candidate site for management.

Fanif

Communities in Fanif have proposed to establish a marine conservation area. The spatial prioritization analyses suggest that the reef embayment, and adjacent seagrass and mangrove habitats, would be a good location. Protecting the mangroves in Fanif may also provide additional benefits to the Nimpal Channel MCA, if they act as nursery grounds for fish on the reefs there. The proposed MCA on the blue hole in Fanif is small, but would likely benefit fish species who use it as juvenile habitat or to shelter as adults.

Marine Protected Area Scorecards

How to use the MPA scorecards

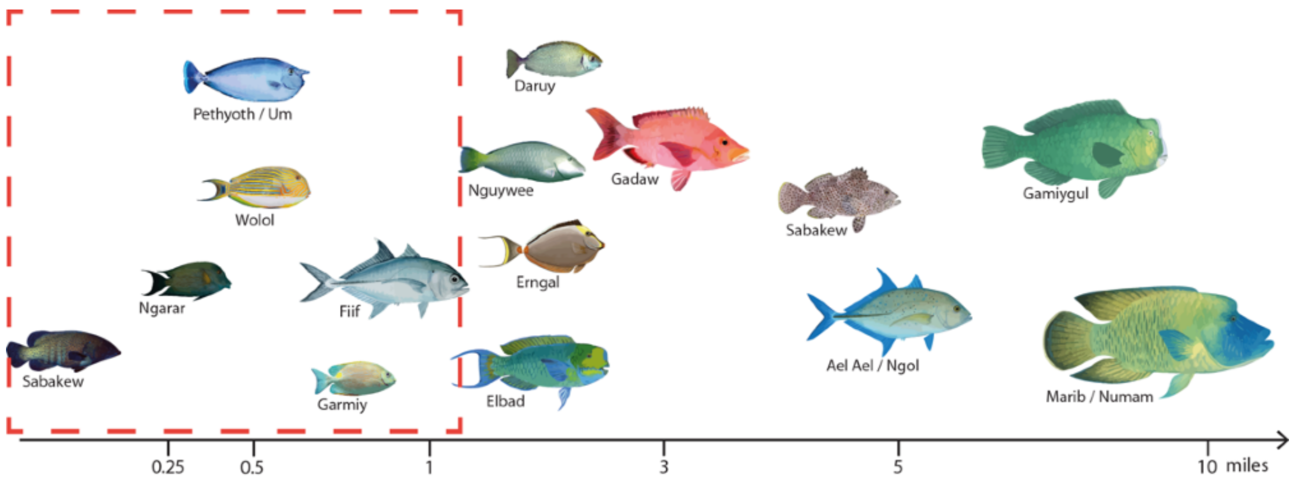
- Forereef
- Reef flat
- Pass
- Enclosed lagoon
- Shallow terrace
- Shallow terrace with constructions
- Lagoon Reef Flat
- Seagrass
- Deep lagoon
- Mangrove

Habitat types

The first piece of information contained on the scorecard is the legend of habitat types which might be included within the MPA boundary. (left). It is important that the MPA contains the primary habitat types utilized by key fish species. For example, rabbitfish typically inhabit shallow seagrass beds, lagoons and the reef flat. If protecting these species is an objective for the MPA, it should contain those habitat types. Other species, such as groupers and unicornfish prefer the forereef habitat.

Adequacy for key fish species

The schematic below uses information on reef fish home range size and the effective size of the MPA to indicate which species will be adequately protected within the MPA. The red dashed box indicates the effective size of the MPA. Species within the box are adequately protected. Species that are not within the box are not adequately protected - if the boundaries of the MPA cannot be extended, alternative fisheries management will be required to protect these species.

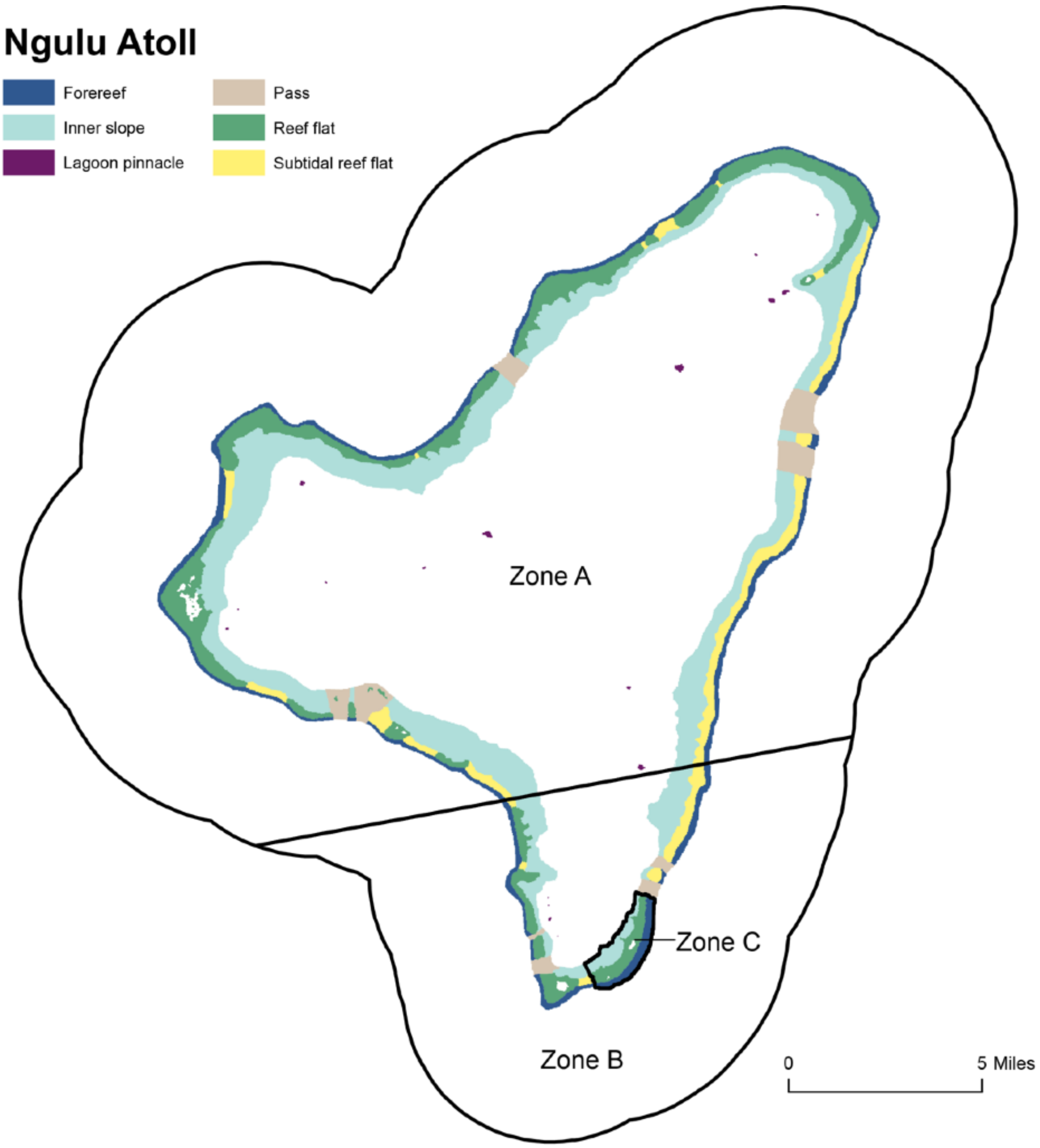


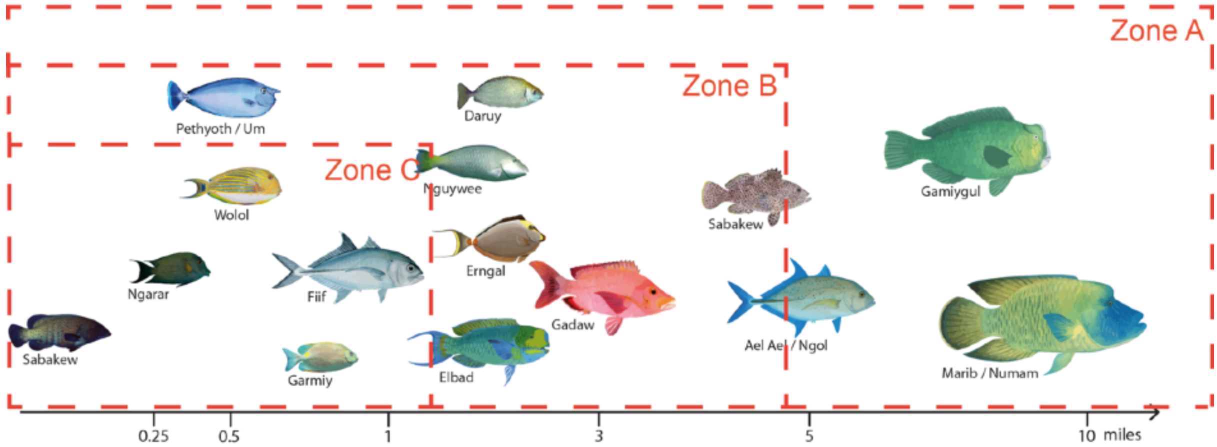
Seascape connectivity

Finally, the distance from the MPA boundary to the nearest patch of seagrass and mangrove habitat is indicated (right). This is a proxy for how well connected MPAs on reef habitats are to potential nursery habitats for many reef fish species. Ideally, seagrass, mangrove and reef habitats will be within the MPA boundary. Where this isn't possible, placing MPAs close to those habitat types (and lagoon reefs) is a good idea.

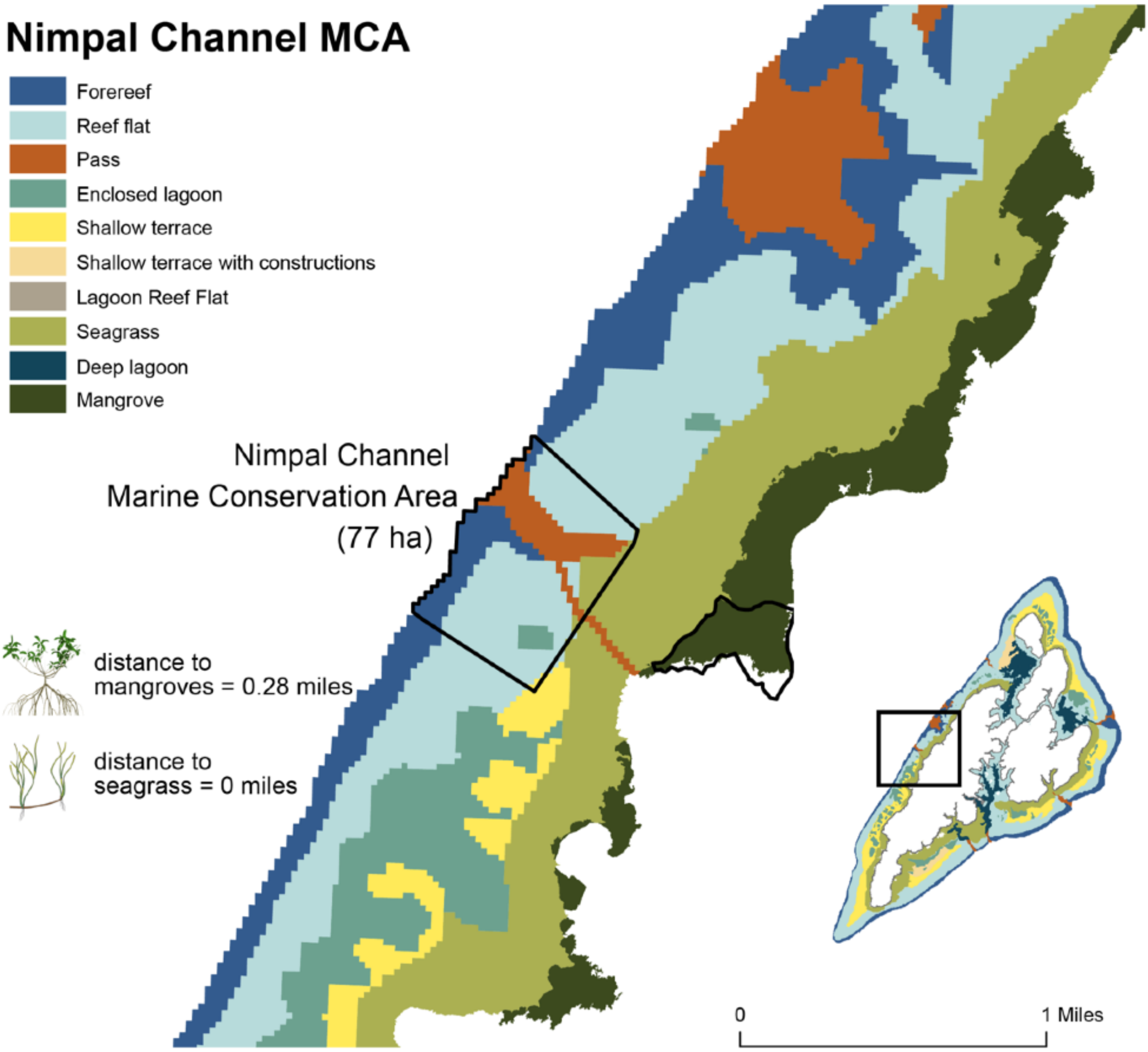
distance to seagrass = 0 miles

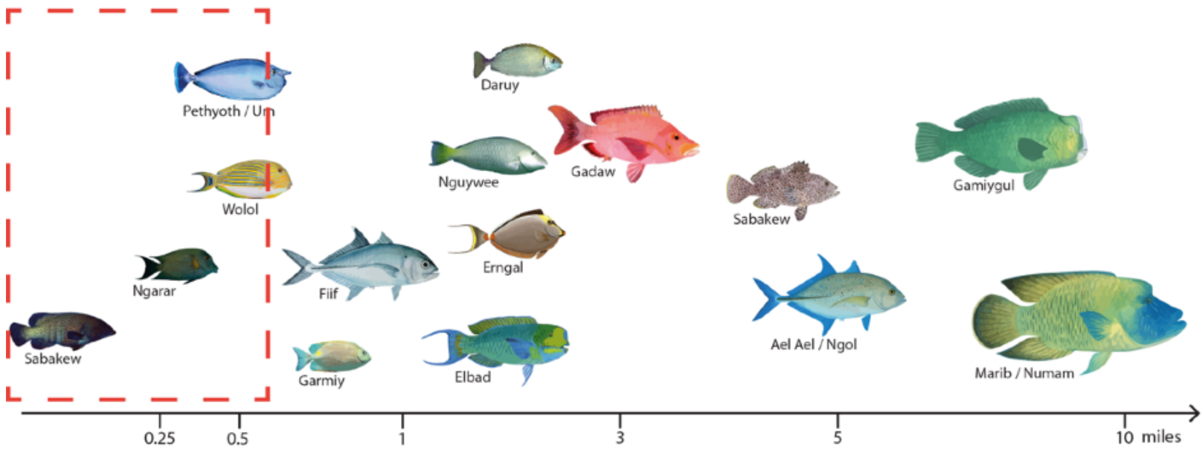
distance to mangroves = 0.3 miles



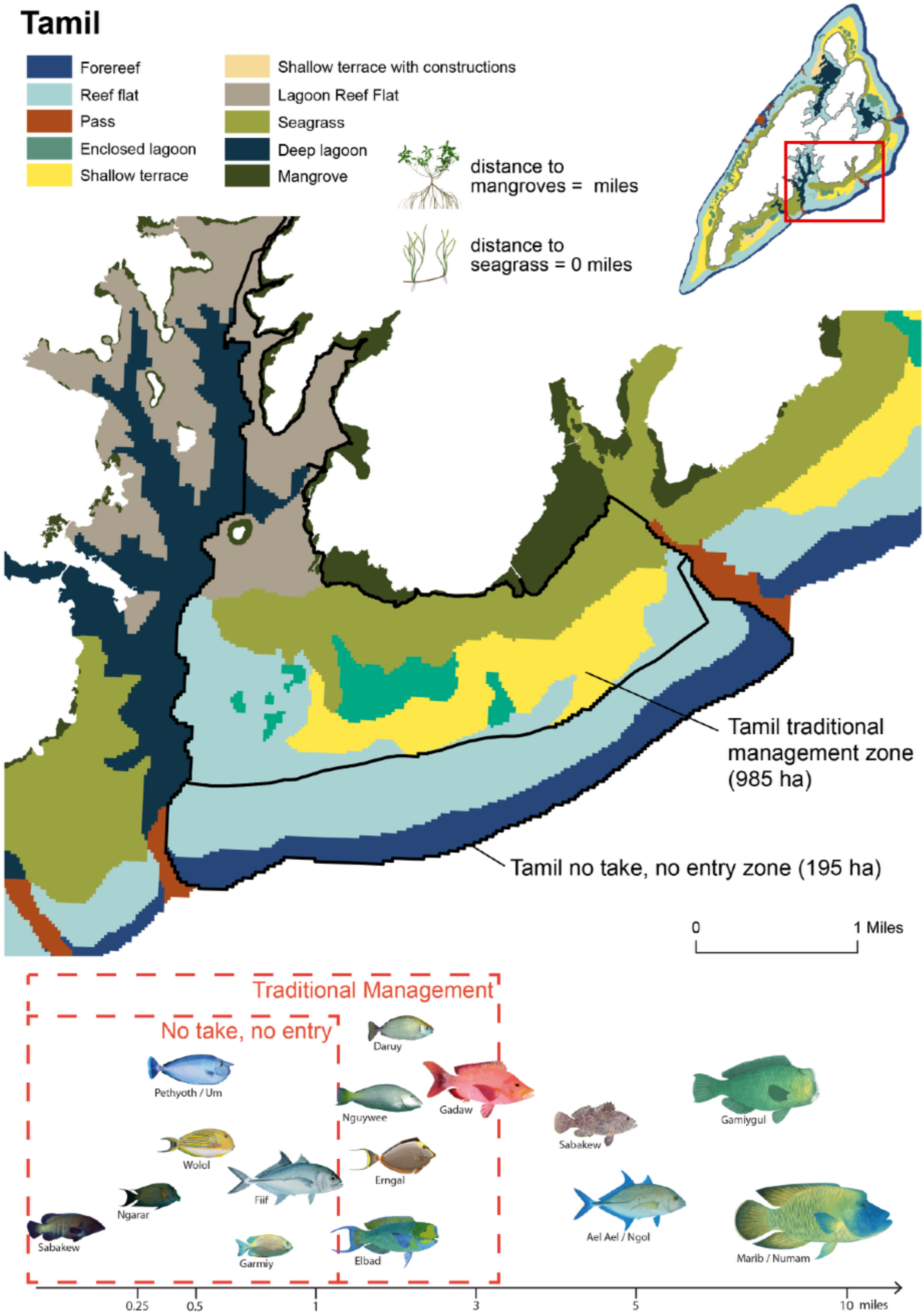


MPA Scorecard for Ngulu Atoll

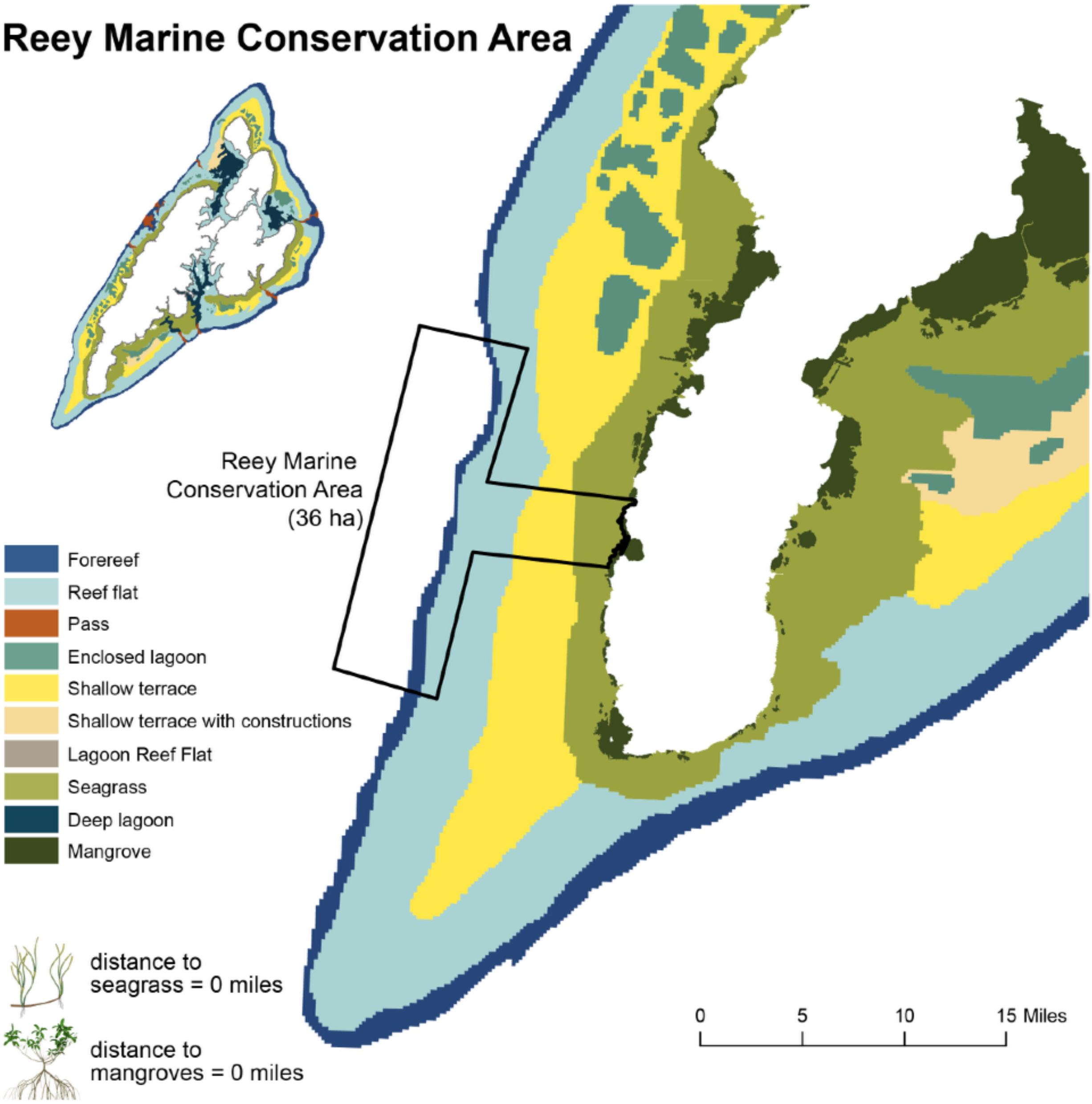


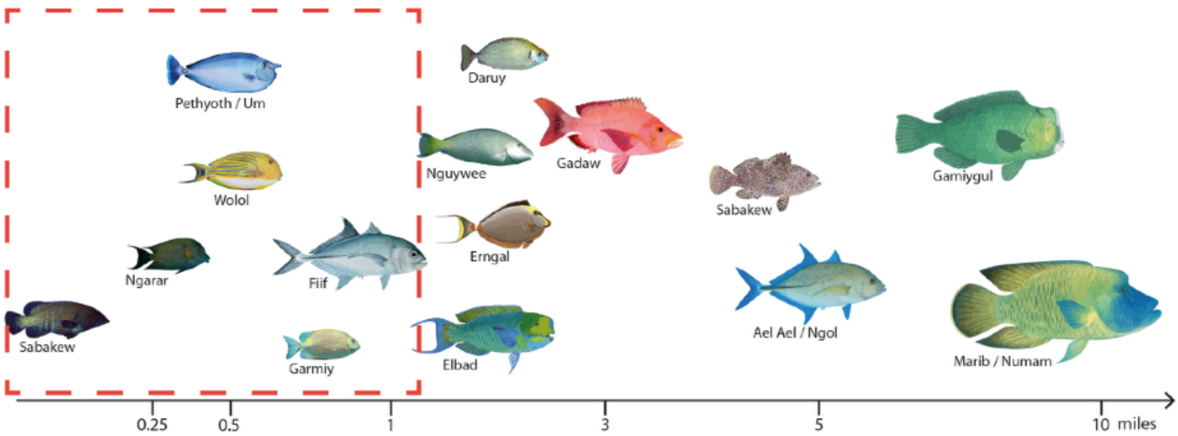


MPA Scorecard for Nimpal Channel Marine Conservation Area

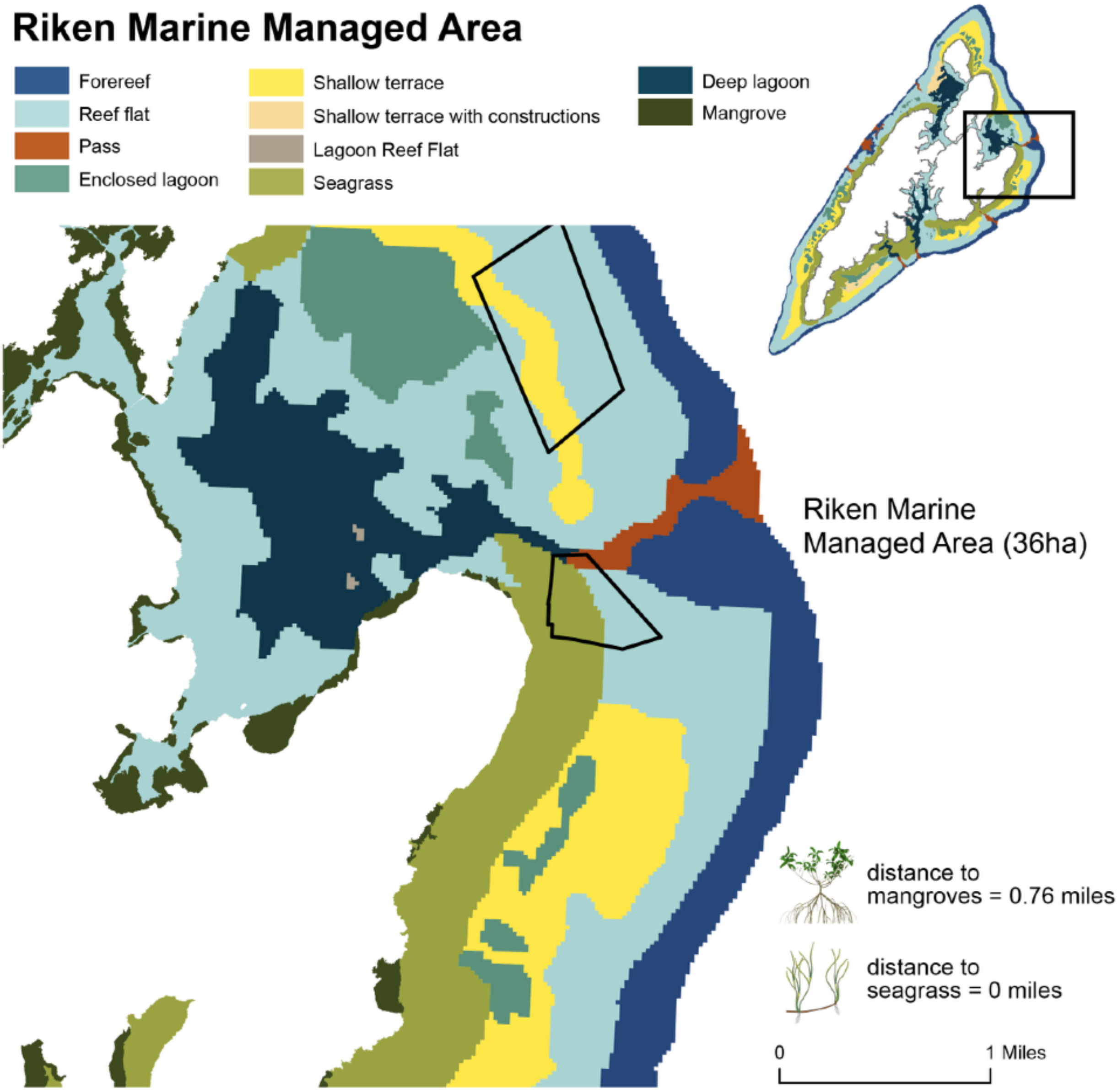


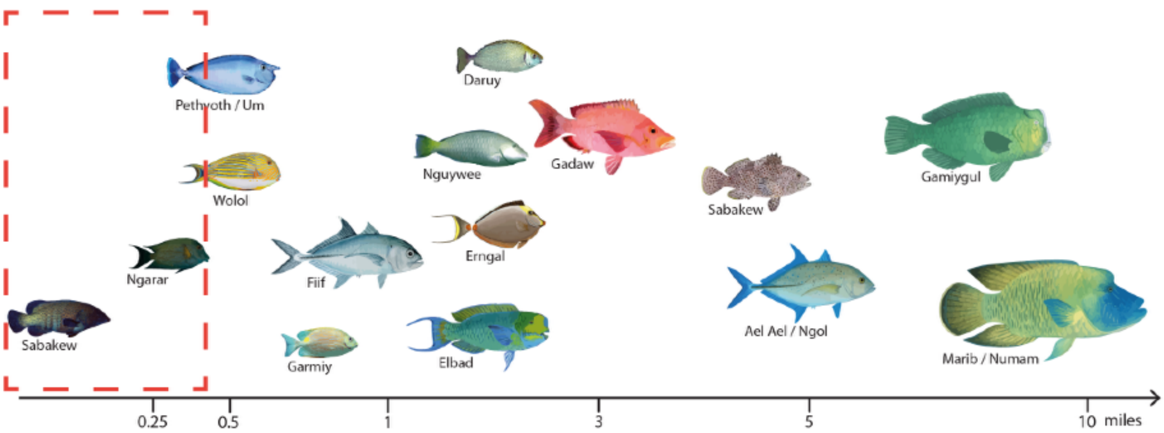
MPA Scorecard for Tamil Marine Managed Area



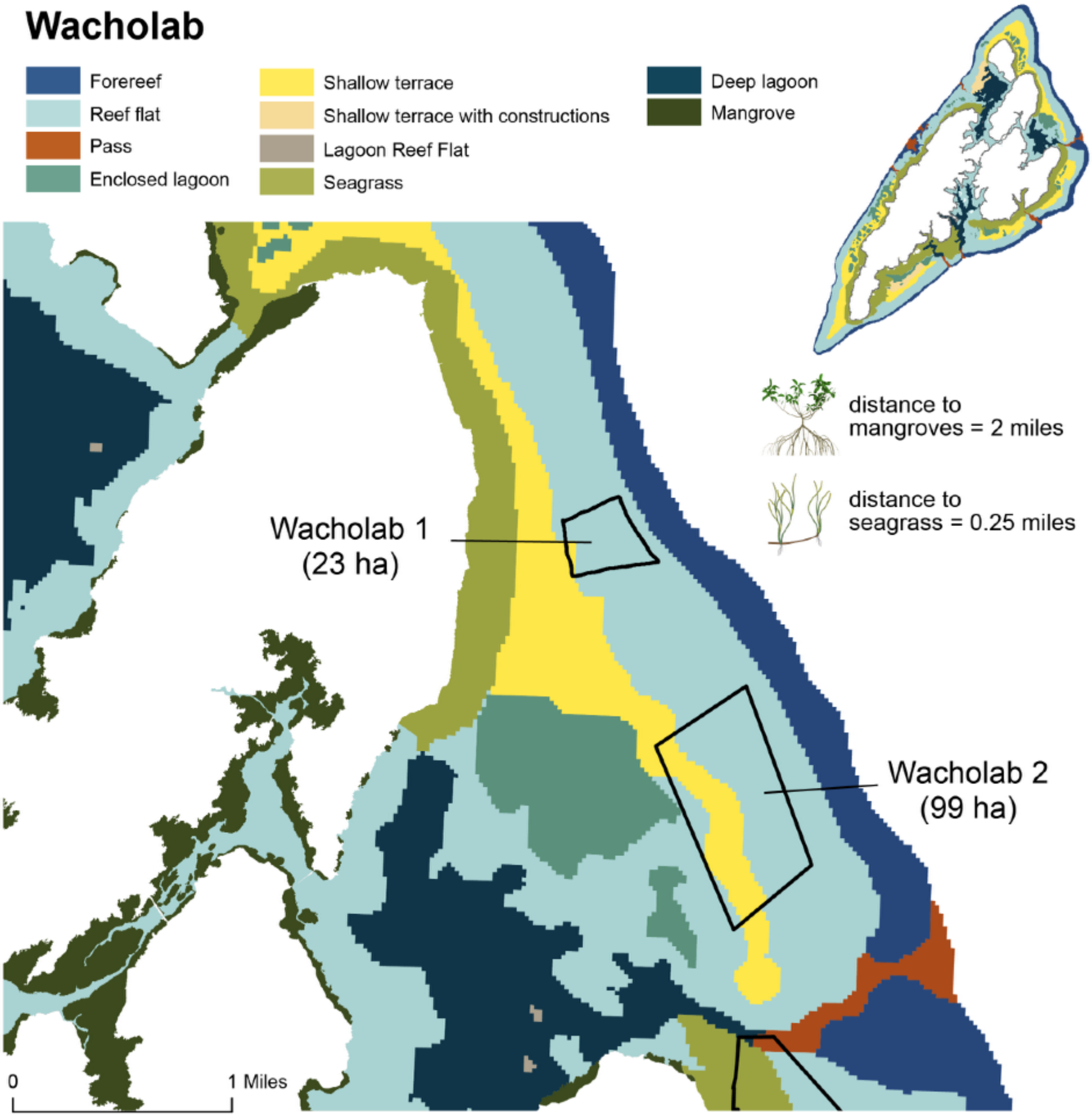


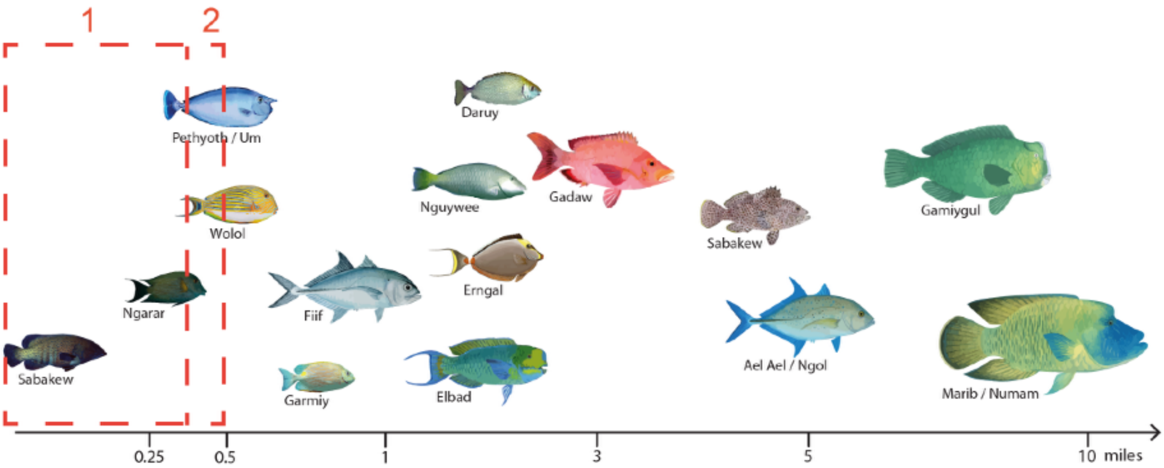
MPA Scorecard for Reey Marine Conservation Area





MPA Scorecard for Reey Marine Managed Area





MPA Scorecard for Wacholab Marine Managed Areas

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Technical Appendix

Seascape connectivity metric derivation

The seascape connectivity value for planning units containing reef habitat (***SCR***) was calculated as:

$$SCR_i = \sum_{j=1}^{n} \left(\frac{M_j}{d_{ij}^{\ 2}} \right) + \left(\frac{L_j}{d_{ij}^{\ 2}} \right)$$

where M_j is the area of mangrove habitat in planning unit ***j***, L_j is the area of lagoon reef habitat in planning unit ***j***, and d_{ij} is the distance between planning unit ***i*** and planning unit ***j*** (measured as Euclidean distance avoiding land and deep water barriers, and up to a maximum threshold distance of 7.6 km, the longest recorded movement distance for ***Bolbometopon muricatum***).

The seascape connectivity value for planning units containing mangrove habitat (***SCM***) is calculated as:

$$SCM_i = \sum_{j=1}^{n} \left(\frac{R_j}{d_{ij}^{\ 2}} \right)$$

where R_j is the area of seaward reef habitat in planning unit ***j***.

Seascape connectivity values were subsequently rescaled from 0-1, and inverted, so that a low value of SC_{new} indicates well-connected habitat:

$$SC_{new} = 1 - \left(\frac{SC_{old} - Min(SC_{old})}{Max(SC_{old}) - Min(SC_{old})} \right)$$

Finally, to calculate the seascape connectivity cost (SCC) for each planning unit, seascape connectivity values were weighted by the area of relevant habitat within each planning unit:

$$SCC_i = SCR_i \left(\frac{R_i}{A_i} \right) + SCM_i \left(\frac{M_i}{A_i} \right) + \left(1 - \frac{R_i + M_i}{A_i} \right)$$

where Aj is the area of planning unit ***i***.