Spatial analysis in support of the development of a network of fisheries management areas in Chuuk, FSM

Dr. Rebecca Weeks
Senior Research Fellow
ARC Centre of Excellence for Coral Reef Studies, James Cook University

Elizabeth Terk
Protected Area Advisor
The Nature Conservancy, Pohnpei

Edmund Sacre
ARC Centre of Excellence for Coral Reef Studies, James Cook University

Javier Cuetos-Bueno
Fisheries Scientist
The Nature Conservancy, Palau

Mike Aulerio
Geographic Information Systems Specialist
The Nature Conservancy, Palau

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Lead author contact: Rebecca.Weeks@jcu.edu.au
TNC contact: eterk@tnc.org

Contents

1 EXECUTIVE SUMMARY

1.1 PURPOSE

In November 2017, The Nature Conservancy, Chuuk Conservation Society, and scientists from James Cook University convened a spatial planning workshop in Weno with the aim of integrating protected area network planning and state-wide fisheries management efforts. Our aim is to work with local stakeholders to develop a network of marine managed areas that is informed by best available science, and will achieve both biodiversity conservation objectives and those articulated by resource owners and community members. The analyses presented in this report are in support of that objective.

Local communities in Chuuk rely upon natural resources for their livelihoods and food security, and the long-term sustainability of marine resources is of particular concern. Fishing has been identified as the most urgent and critical threat to Chuuk's marine ecosystems, with the decline of marine biodiversity clearly linked to commercial exploitation of marine resources.

We thus orient our analyses towards designing marine managed areas that will be adequate to protect reef fish species of local importance, and towards identifying locations for managed areas that will maximize positive benefits to fisheries and biodiversity, whilst minimizing negative impacts on local communities.

1.2 GAP ANALYSIS

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 a protected area network is now, and where we would like it to be.

Permanent no-take marine protected areas are rarely implemented in Chuuk. Thus, we include in our analyses all forms of spatial fisheries management, including traditional temporary fisheries closures (*mechen* and *pau*). We collectively refer to these as managed areas, with the assumption that these are managed by resource owners, communities, or Chuuk State to achieve objectives that are compatible with sustainable fisheries management and the conservation of biodiversity. Nevertheless, it is important to acknowledge that managed areas in which fishing is permitted (either to some extent or at some times) will not provide equal benefits to permanent no-take areas. Best practices for managing temporary fisheries closures sustainably are included in *4.1 Spatial fisheries management*.

At present, less than 1% of Chuuk's reef habitats are within managed areas. This falls well short of the representation targets laid out in the Micronesia Challenge, and is also below that achieved by other FSM States. The small area currently under management highlights the need for conservation and fisheries management planning in Chuuk. It also indicates an opportunity to develop a protected area network that is informed by best available science and unconstrained by past decisions.

If all of the managed areas proposed by participants during the 2017 spatial planning workshop were to be implemented, this would increase the total percentage of reef area under management from 0.6% to 6.5%. This indicates the level of investment and engagement required for Chuuk to achieve the Micronesia Challenge targets. Nevertheless, managed area extent should not be considered as a sole (or ultimately a reliable) indicator of conservation effectiveness, and efforts should be directed towards ensuring that any new managed areas are well designed and effectively implemented (e.g. through meaningful engagement with resource owners and users) rather than on rapidly increasing the extent of managed areas.

Local patterns of resource ownership constrain the size at which managed areas can be implemented, particularly in Chuuk Lagoon, where ownership of fringing reefs is finely subdivided. Comparing the size of existing and proposed managed areas to the ecological requirements of key fish species (to be effective, managed areas should be at least twice the size of the species home range) indicates that many will only be able to provide protection for species with smaller home ranges (importantly, this does include some species which are favored food fish in Micronesia).

This emphasizes the importance of creating a network of managed areas. The managed areas currently being established by the community in Onei (Figure 4) are an excellent example. It will likely be more feasible to implement larger managed areas on the barrier reef and outer islands. Promisingly, when considered as a portfolio, the managed areas proposed at the spatial planning workshop provide good protection for all reef fish species except those with the largest home ranges (for whom size limits, species or seasonal bans would be more appropriate).

1.3 SPATIAL PRIORITIZATION

Spatial conservation prioritization aims to identify systems of notional conservation areas that collectively achieve specified objectives. Importantly, outputs are intended to *inform* decision-making, not to provide protected area network designs that are ready to implement.

Two spatial prioritization scenarios are explored here. In the ‘habitat representation’ scenario the conservation objective is to achieve representation targets for 30% of marine (and mangrove) habitats, as specified under the Micronesia Challenge. In the ‘opportunity costs’ scenario, the same level of habitat representation is achieved, whilst minimizing negative impacts on subsistence fishers.

Two proposed protected areas, near Piis and Falos islands, coincide with reefs that are prioritized under the ‘habitat representation’ scenario. These reefs have high conservation importance, are predicted to have lesser opportunity costs to subsistence fishers, and resource owners have expressed an interest in undertaking management;

they thus comprise a good starting point from which to add sites to Chuuk's protected area network.

1.4 NEXT STEPS

Additional prioritization scenarios to be developed are included in *5.3 Future prioritization scenarios and approaches*. These will be developed in early 2018. Concurrently, key messages for local stakeholders, and the marine managed area scorecards included here as an *Appendix* will be provided to Chuuk Conservation Society, so that they may be used in follow-up discussions with local stakeholders.

Additional prioritization scenarios will incorporate models from TNC's Mapping Ocean Wealth (MOW) project, and spatial patterns of reef ownership.

Outputs from the Micronesia MOW project include maps of past fishing impacts, predicted current biomass, and potential biomass, if fisheries management were improved. These models, which are currently being refined for Chuuk Lagoon, facilitate more explicit consideration of fisheries management objectives in spatial prioritization. For example, in addition to achieving habitat representation targets, we can prioritize reefs that will produce the greatest benefits in terms of increasing reef fish biomass. Other possible scenarios are those that prioritize recovery of populations on depleted reefs, that protect 'pristine' reefs before they are exploited, or that identify reefs with healthy fish populations that are imminently threatened by depletion.

Spatial patterns in reef ownership might indicate areas where conservation and management might be achieved more easily. Identifying where spatial priorities for biodiversity conservation or fisheries replenishment intersect with implementation contexts that are simpler from a customary ownership perspective might be a promising approach to conservation planning in Chuuk.

2 THE CONTEXT FOR CONSERVATION PLANNING IN CHUUK

2.1 GEOGRAPHY

The Federated States of Micronesia (FSM) is a federation of four semi-autonomous island states, from west to east - Yap, Chuuk, Pohnpei and Kosrae – together comprising 607 islands with land elevation ranging from sea level to the highest elevation of about 760 m. FSM's total landmass is 271 sq mi, with a declared Exclusive Economic Zone covering over 617,000 sq mi. Chuuk is the most populous state of the FSM with 48,654 inhabitants (2010 census), most of whom live within Chuuk Lagoon.

Chuuk Lagoon is one of the largest lagoon systems in the world. With nearly 800 sq mi of lagoon waters, 140 mi of barrier reefs, and dozens of reef passages and islands, Chuuk Lagoon presents a great variety of marine habitats, hosting a high biological diversity and complexity.

Marine and terrestrial resources are the foundation of the country's long term economic self-sufficiency. Maintaining the habitats and ecosystems that nurture this diversity is crucial to sustaining the country's rich ethno-biological traditions while improving Micronesians' quality of life: 60% of the population is dependent on subsistence livelihoods.

2.2 GOVERNANCE

Responsibility for environmental issues is shared between FSM National Government and the individual FSM State governments (Pohnpei, Chuuk, Kosrae and Yap). Each State, as owner of its surrounding natural resources out to 12 nautical miles, manages these resources through policies and plans (e.g., land use plans, coastal zone plans, legislation and regulations). The National Government provides, on request, guidance and technical assistance to the States, and manages the resources from 12 to 200 nautical miles.

Ownership of land and aquatic areas varies between States. In Chuuk, most land and aquatic areas are privately owned and are acquired through inheritance, gift or, more recently, by purchase. In all States, land cannot be sold to non-citizens of the FSM, although there are long term leasing options available for non-citizens. The Chuuk Constitution recognizes the primacy of customary law in resource protection. These resource ownership patterns greatly influence the strategies and actions required to sustainably manage biodiversity and fisheries resources.

2.3 HISTORY OF CONSERVATION PLANNING IN CHUUK

In 2002, a “blueprint" of the FSM's biological resources was created to provide a clear picture of areas of biodiversity significance (ABS) that can be found within the FSM and a prioritization of conservation needs. The “blueprint” contributes to the National Biodiversity Strategic Action Plan (NBSAP), the major goal of which is to protect and sustainably manage a full representation of the FSM's marine, freshwater, and terrestrial ecosystems.

In 2006, five governments (the Federated States of Micronesia, the Republic of the Marshall Islands, the Republic of Palau, the U.S. Territory of Guam, and the Commonwealth of the Northern Marianas Islands: see below) launched the Micronesia Challenge, which is a shared commitment to preserve the natural resources that are crucial to the survival of their traditions, cultures and livelihoods. The overall goal of the Challenge is to “*Effectively conserve at least 30% of near-shore marine resources & 20% of terrestrial resources across Micronesia by 2020”* (Houk et al. 2015). Each jurisdiction is now working towards achieving their commitments under the Micronesia Challenge using a variety of management approaches, including designing and establishing Protected Areas Networks (PANs) and applying other fisheries management tools. The same year, the Chuuk Conservation Society (CCS) led a Rapid Ecological Assessment to assess the existing marine protected areas (MPAs) and identify potential new sites, based on habitat types and threat status.

In 2009, a ‘Gap Analysis’ was completed for each state in FSM. Outputs from this project included a report on the status of all conservation features in relation to existing protected areas, illustrating how the ABS areas would complement the current protected areas, and maps of spatial priorities to achieve conservation goals within each State. Unfortunately, many of those currently working in resource management at the state level are unaware that the 2009 Gap Analysis took place, and have never seen the results. This has been attributed to not clearly identifying a staff member at the state level to take over the project, as well as staff turnover. Additionally, the 2009 Gap Analysis focused on biodiversity as the number one objective of designated protected areas, and did not consider other objectives, especially those of local communities.

Chuuk Lagoon is one of the largest lagoon systems in the world.

In 2017, TNC, CCS and scientists from James Cook University (Australia) convened a spatial planning workshop in Weno with the aim of integrating protected area network planning and state-wide fisheries management efforts (TNC 2017). The three-day workshop was attended by 65 participants, representing the Northern Namoneas (Northern Chuuk Lagoon), Southern Namoneas (South-East Chuuk Lagoon), Faichuuk (Western Chuuk Lagoon), Mortlocks (Outer islands) and the North-West region (Outer islands). This workshop was conceived as a first step towards prioritizing reefs in Chuuk to implement marine management plans that will achieve both biodiversity conservation objectives and those articulated by resource owners and community members. The spatial analyses presented in this report are in support of that objective.

2.4 KEY CHALLENGES AND OPPORTUNITIES

Local communities in Micronesia rely on natural resources for their livelihoods and food security. The benefits from coral reefs alone have been estimated to be $800 million annually. This dependence on natural resources makes islanders especially vulnerable to environmental threats, such as rising sea temperatures, coastal development, watershed based pollution, mass tourism and unsustainable fishing.

Of particular concern is overfishing and the long-term sustainability of marine resources (Houk et al. 2015). During the last few decades, driven by lack of income alternatives, a growing population, and by easy access to local and international markets, many people in Chuuk Lagoon have turned to fishing as their main source of income. This has dramatically increased the level of fishing pressure, including heavy exploitation of fish spawning aggregations. Fishing has been identified as the most urgent and critical threat to Chuuk's marine ecosystems, with the decline of marine biodiversity clearly linked to commercial exploitation of marine resources. In 2014, it was estimated that 265 mt (nearly 600,000 lb per year) of reef fish were commercially caught in Chuuk lagoon.

Chuuk’s fisheries are considered to be between fully exploited and overfished (Rhodes et al. 2011), as evidenced by decreasing trophic levels and size at capture with several preferred species being harvested below their mean reproductive sizes. Further indicators of overfishing are present: catch success is negatively correlated with proximity to human populations, and fishing success depends upon favorable fishing conditions / locations / seasons (J. Cuetos-Bueno).

The decline of coral reef fisheries is a serious problem throughout Micronesia, raising concerns regarding sustainable livelihoods and food security. Compared to other FSM states, Chuuk has relatively few existing marine protected areas with only < 1% of marine habitats protected by no-take areas. Recently, Chuuk State has made efforts to improve management of their marine resources through several state-wide fisheries regulations including a seasonal grouper ban and limitations on the export of marine products. However, due to the geographical expanse of Chuuk’s lagoon, and the fact that coral reefs are privately owned, these regulations are difficult to enforce and monitor. That there are few existing marine protected areas presents an opportunity to develop a protected area network that is informed by the best available science. In contrast, other States have been constrained by past implementation of MPAs, some of which are inadequate to protect key fishery species and poorly supported by resource users.

For centuries, Chuuk's marine resources were managed under customary management, which allowed for sustainable subsistence exploitation for generations. It is apparent that traditional management strategies are no longer adequate in the face of increasing pressures on marine resources. Nevertheless, traditional management practices, which include *mechen* (temporary fishery closures), provide a foundation for contemporary fisheries management informed by science.

Reef fish on sale at the market in Weno.

3 GAP ANALYSIS

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 should consider three different types of "gaps" in the protected area network:

> ***Representation gaps:*** there are either no representations of a particular species or habitat type in any protected area, or not enough examples of the species or habitat represented to ensure long-term persistence of that feature.
>
> ***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.

Given the importance of marine resources to Chuukese economies, food security and way of life, current discussions (e.g. at the 2017 spatial planning workshop in Weno) and analyses focus on the marine realm.

Results presented here related to *representation gaps* for marine habitats (including mangroves) and *ecological gaps*, in terms of the adequacy of existing and proposed marine managed areas to adequately protect key reef fish species.

No data are currently available to assess the *management gaps*. An MPA effectiveness assessment tool has been developed for Micronesia, modelled after the MPAME tool developed in Indonesia. This will allow for enhanced understanding of management effectiveness of marine protected area sites to be taken into consideration, regarding whether sites are appropriate of state goals and objectives based on management level and conservation effectiveness level. However, at presented there are few formally implemented protected or managed areas in Chuuk, and these have not been in place for long.

3.1 REPRESENTATION GAPS

3.1.1 HABITAT REPRESENTATION TARGETS

High level 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 (Houk et al. 2015). 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% of terrestrial and inland water, and 10% of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, be conserved through effectively and equitably managed, ecologically

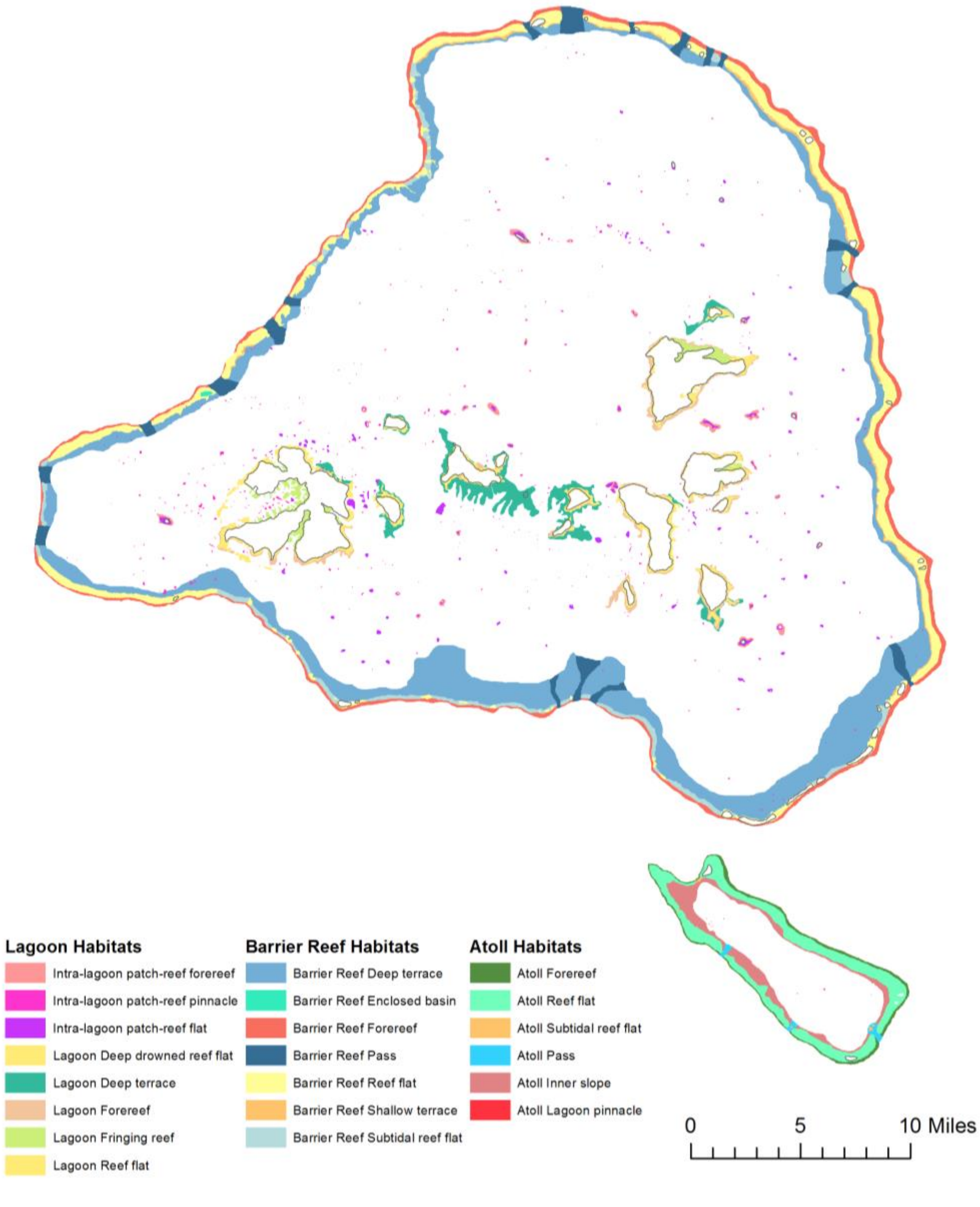


Figure 1. Marine habitats within Chuuk Lagoon

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, the representation targets specified under the Micronesia Challenge should be applied to the different habitat types present (e.g. Figure 1 - Figure 3), rather than to marine and terrestrial areas overall. Data on marine habitats In Chuuk (Figure 1 - Figure 3) was sourced from the Millennium Coral Reef Mapping Project data (IMaRS-USF & IRD, 2005).

3.1.2 EXISTING AND PROPOSED PROTECTED AREAS

Strict (i.e. permanent, no-take) marine protected areas are rarely implemented in Chuuk. Thus, we include in our analyses all forms of spatial fisheries management, including but not limited to traditional *mechen* and *pau* (temporary fisheries closures). We collectively refer to these as **managed areas**, with the assumption that these are areas managed by resource owners, communities, or Chuuk State to achieve objectives that are compatible with sustainable fisheries management and the conservation of biodiversity. Traditionally practiced forms of spatial fisheries management may classify as *'other effective area-based conservation measures'* under Aichi Biodiversity Target 11 (Laffoley et al. 2017); however, they need to be well designed and effectively managed (see *4.1 Spatial fisheries management*).

Existing managed areas are shown in Figure 4. Managed areas proposed by participants at the 2017 spatial planning workshop are shown in Figure 5 and Figure 6.

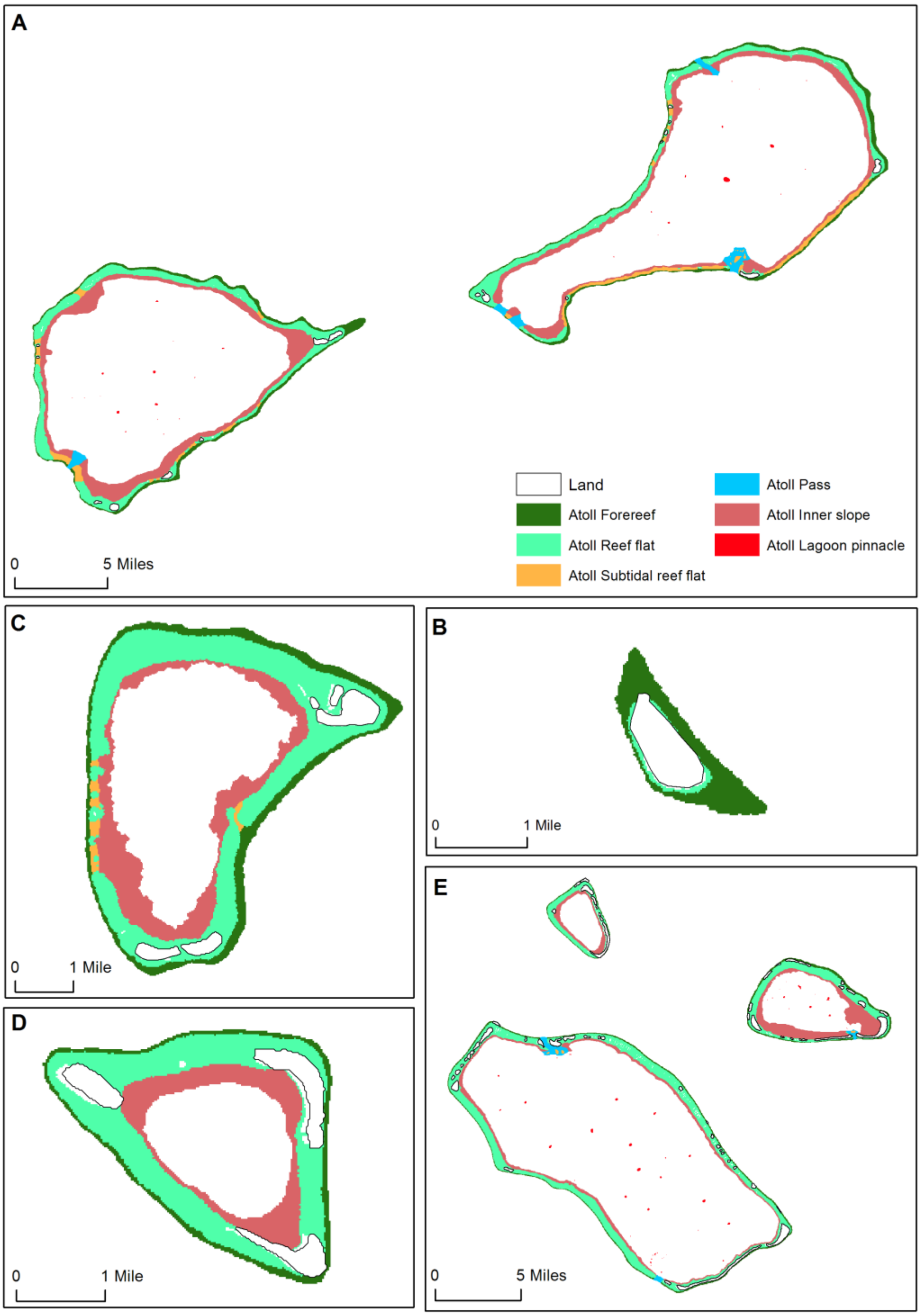


Figure 2. Marine habitats on Chuuk's outer atolls (part I)

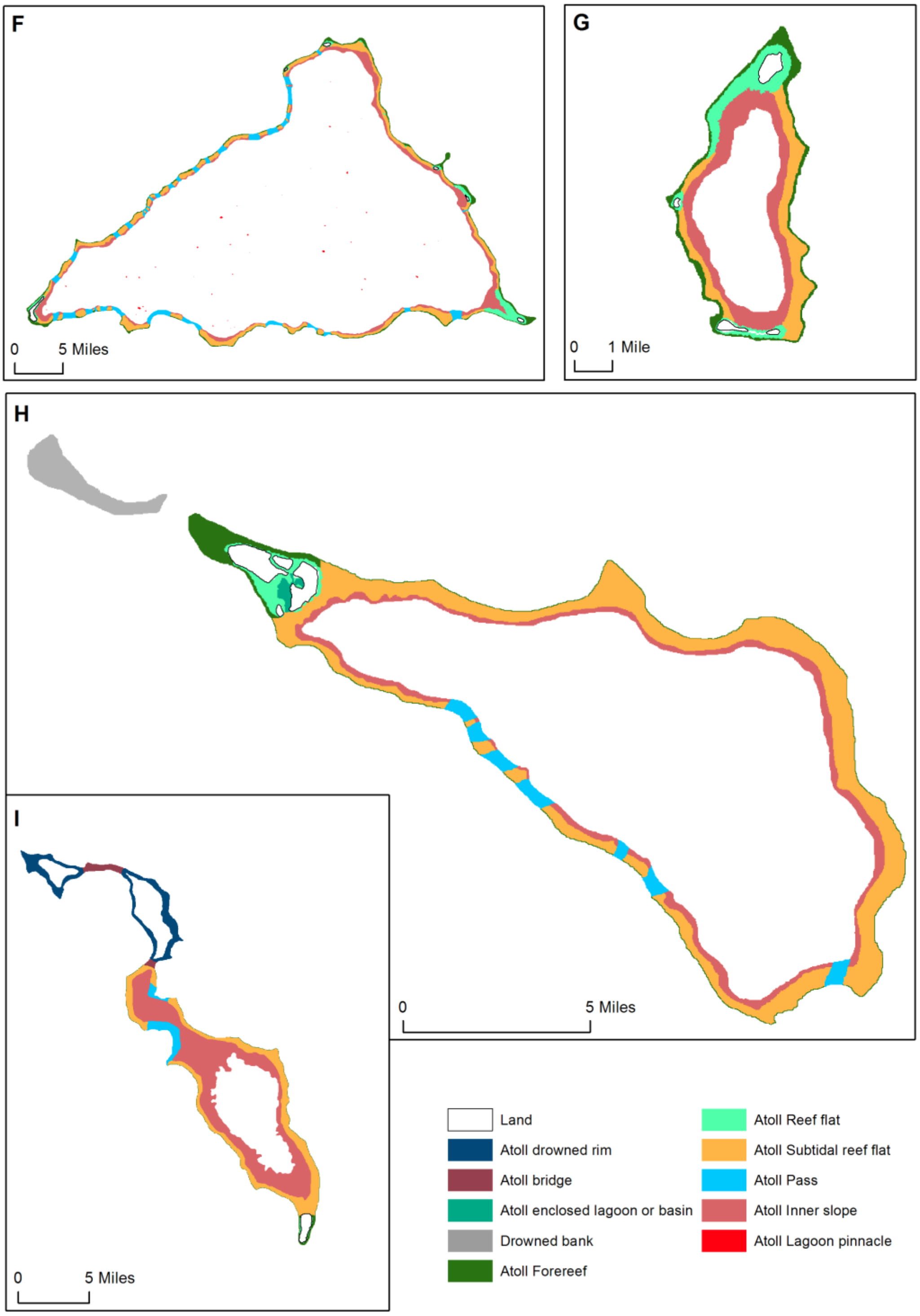


Figure 3. Marine habitats on Chuuk's outer atolls (part II)

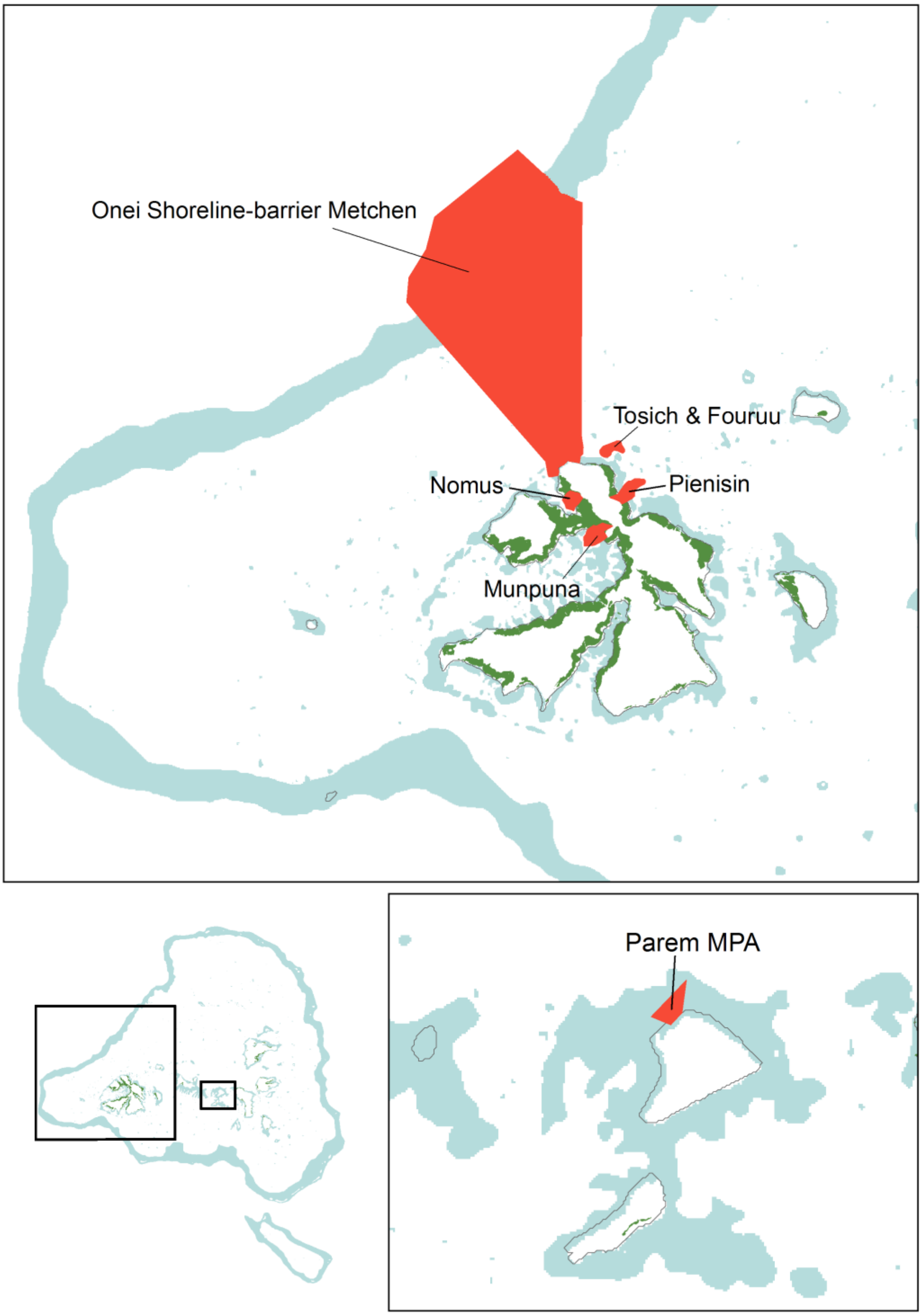


Figure 4. Existing marine managed areas in Chuuk Lagoon

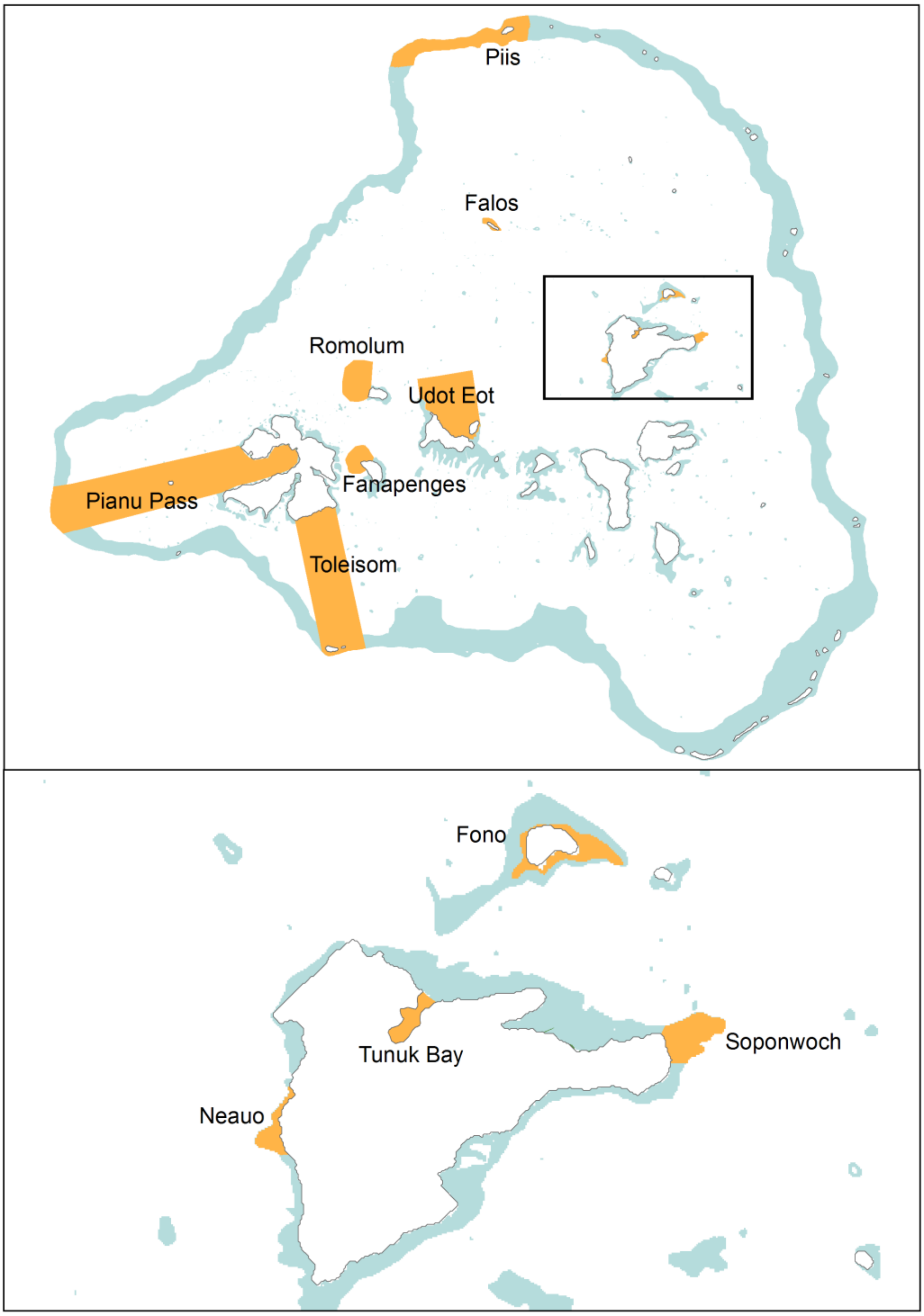


Figure 5. Proposed marine managed areas in Chuuk Lagoon

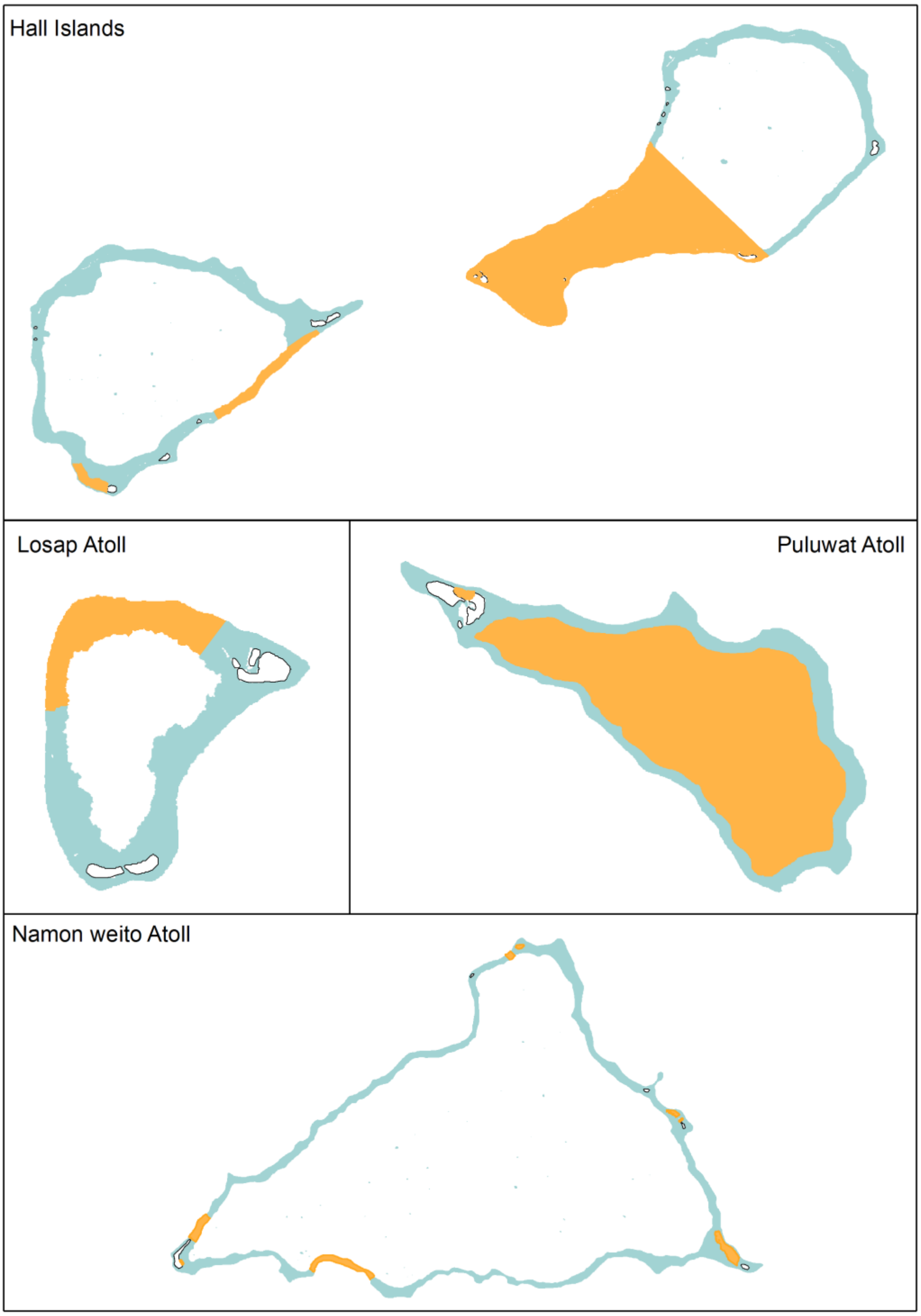


Figure 6. Proposed marine managed areas in Chuuk's Outer Islands

3.1.3 RESULTS

At present, less than 1% of Chuuk's reef habitats are protected within managed areas (Figure 7). This falls well short of the representation targets laid out in the Micronesia Challenge.

Compared to other States in FSM, there are few existing marine managed areas in Chuuk State. The small area under management highlights the need for conservation and fisheries management planning in Chuuk. It also provides a unique opportunity to develop a protected area network that is informed by best available science. In contrast, other States have been constrained by past implementation of MPAs, some of which are inadequate to protect key fishery species and poorly supported by resource users. For example, most of Pohnpei's existing MPAs are too small to achieve local fisheries management objectives, and the difficulty in altering the boundaries of areas that have already been legislated was identified as a major obstacle to adaptive management to improve their adequacy (Weeks et al. 2016).

Figure 7 also shows the improvement in habitat representation that would be achieved if all of the managed areas proposed during the 2017 spatial planning workshop were to be implemented. Including proposed areas increases the total percentage of reef area protected from 0.6% to 6.5%. Although this figure still appears low, it is important to remember that a substantial area of Chuuk's reefs is on remote and/or uninhabited atolls.

These results are indicative of the level of investment and engagement required for Chuuk to achieve the Micronesia Challenge targets. Nevertheless, managed area extent should not be considered as a sole (or ultimately a reliable) indicator of conservation effectiveness. It will be more important to ensure that managed areas are well designed and effectively implemented (e.g. through meaningful engagement with resource owners and users) than to rapidly increase the extent of managed areas. Similarly, adopting a range of spatial and non-spatial fisheries management tools might better achieve fisheries management objectives, rather than a sole focus on no-take MPAs (see *4 Management options for key fish species*).

3.2 ECOLOGICAL GAPS: ADEQUACY OF FISHERIES CLOSURES FOR KEY FISH SPECIES

Ecological gaps assess the adequacy of protected/managed areas to ensure the persistence of the features they are designed to protect; for example: do managed areas contain the habitat types that focal species require, and are they large enough to encompass their daily movements? This analysis focuses on the adequacy of Chuuk's existing and proposed marine managed areas in terms of protecting key fishery species.

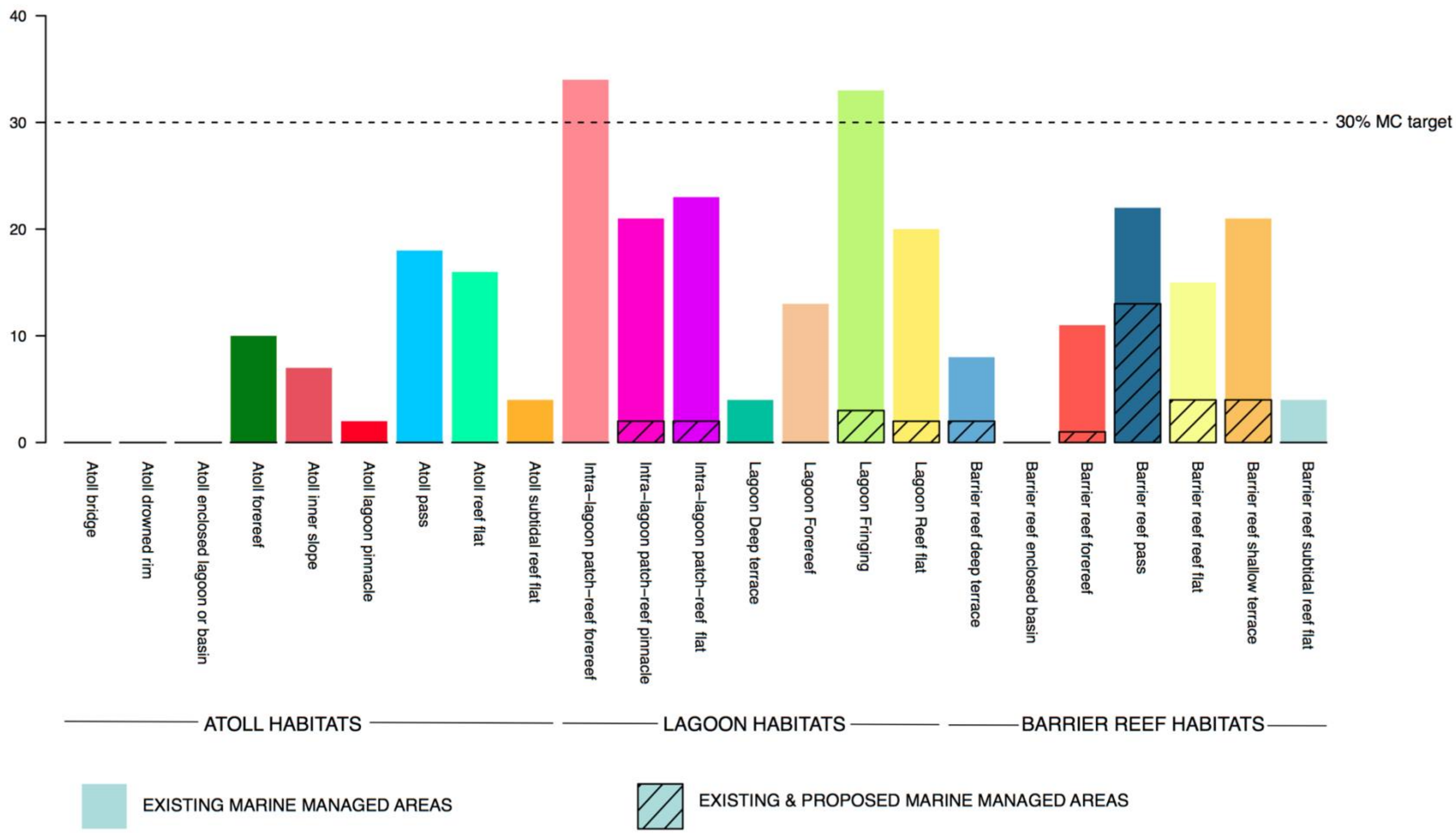


Figure 7. Representation gap analysis of Chuuk's existing and proposed marine protected area network

To sustain target species within their boundaries, managed 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).

To calculate the effective size of existing managed areas in Chuuk, the ArcGIS Minimum Bounding Geometry tool was used to calculate the shortest distance between any two vertices of the convex hull of the spatial fishery closure polygon. Key fishery species of interest, and the recommended minimum MPA size to protect those species are listed in Table 1.

Comparison with the size of existing managed areas in Chuuk (Figure 8) indicates that, while the Onei shoreline-barrier *mechen* affords protection to many key fishery species, many other managed areas are adequate for only a few species. Where resource owners have a relatively small reef area, it will be difficult for them to establish managed areas large enough to protect many species. This emphasizes the importance of creating a network of smaller managed areas, especially in Chuuk Lagoon where spatial patterns of reef ownership indicate that few large manage areas will be able to be established. Considered as a portfolio, the managed areas proposed at the spatial planning workshop (see Appendix) provide good protection for all reef fish species except those with the largest home ranges (for whom species or seasonal bans would be more appropriate).

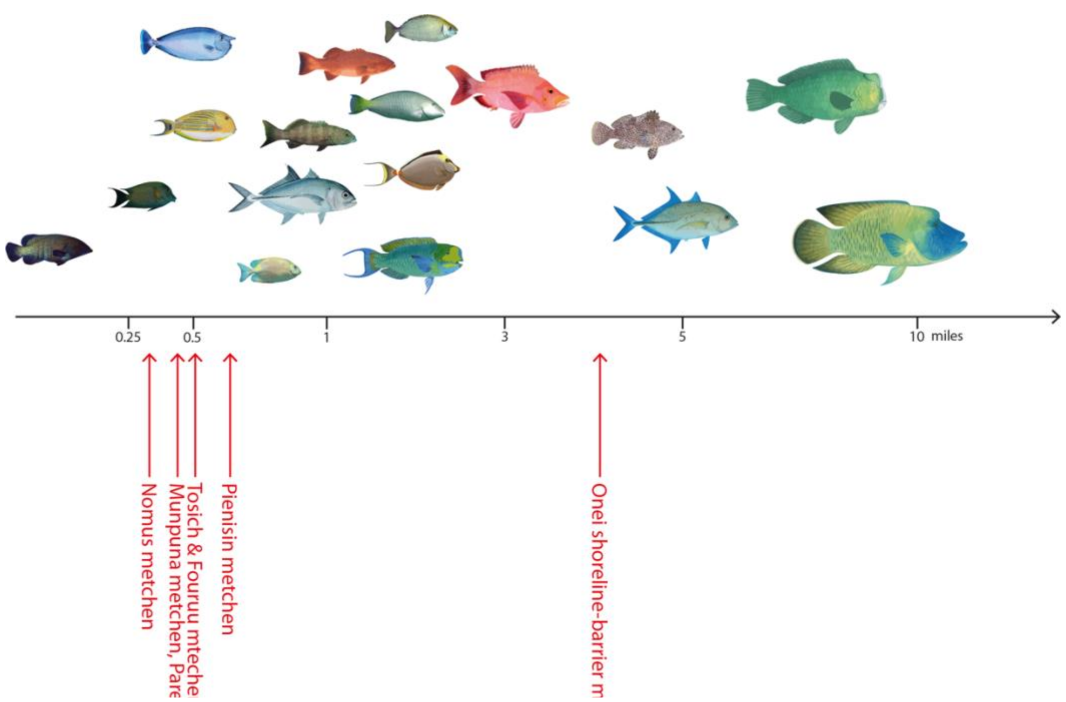


Figure 8. Home range movements of key fish species and effective sizes of existing marine managed areas in Chuuk

Table 1. Key fisheries species of interest, and recommended minimum MPA sizes

English / *Scientific name*	**Chuukese name**	**Fish Movement Information[a]**	**Minimum recommended MPA size[b]**
Lined surgeonfish / *Acanthurus lineatus*	Finang	Home range <0.3 miles.	0.6 miles
Bumphead parrotfish / *Bolbometopon muricatum*	Ukucho	Mean home range <1.5 miles (range up to 4.7 miles)	9.4 miles
Bluefin trevally / *Caranx melampygus*	Pueas	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*	Mesenap	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*	Ngor	Home ranges <0.03 miles. Larger maximum home ranges recorded in this family	0.12 miles
Plectropomus leopardus		Home ranges < 0.9 miles. Individuals make spawning migrations up to 11 miles	1.8 miles *NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs*
Plectropomus areolatus		Home ranges < 0.6 miles. Individuals make spawning migrations up to 9 miles or further	1.2 miles *NOTE - MPAs will need to be combined with other fisheries management measures to protect this species when they move outside MPAs*
Humphead wrasse / *Cheilinus undulatus*	Maam	Adult home ranges in Micronesia range between 1.2 and 6.2 miles	12 miles
Steephead parrotfish / *Chlorurus microrhinos*	Chamwechuk	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*	Arong	Home ranges <0.2 miles.	0.4 miles.
Highfin grouper / *Epinephelus maculatus*	Kunufou	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.*
Camouflage grouper / *Epinephelus polyphekadion*		Individuals make spawning migrations up to 23 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*	Aar	Home ranges <1.2 miles.	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*	Mesecha	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*	Puna	Home ranges <1.3 miles	2.6 miles
Bluespine unicornfish / *Naso unicornis*	Pweutut	Home ranges <0.3 miles	0.6 miles
Mottled spinefoot / *Siganus fuscescens*	Penua	Home ranges <1.3 miles.	2.6 miles
Golden-lined spinefoot / *Siganus lineatus*	Kuo	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.

3.2.1 MARINE MANAGED AREA SCORECARDS

Figure 9 shows an example of a marine managed area 'Scorecard', which indicates the key fishery species that are (and are not) adequately protected within an individual managed area. In Pohnpei and Yap, local communities have used this information to consider whether their MPAs are likely to achieve their objectives (Weeks et al. 2016). 'Scorecards' for all existing and proposed managed areas are included in the *Appendix*.

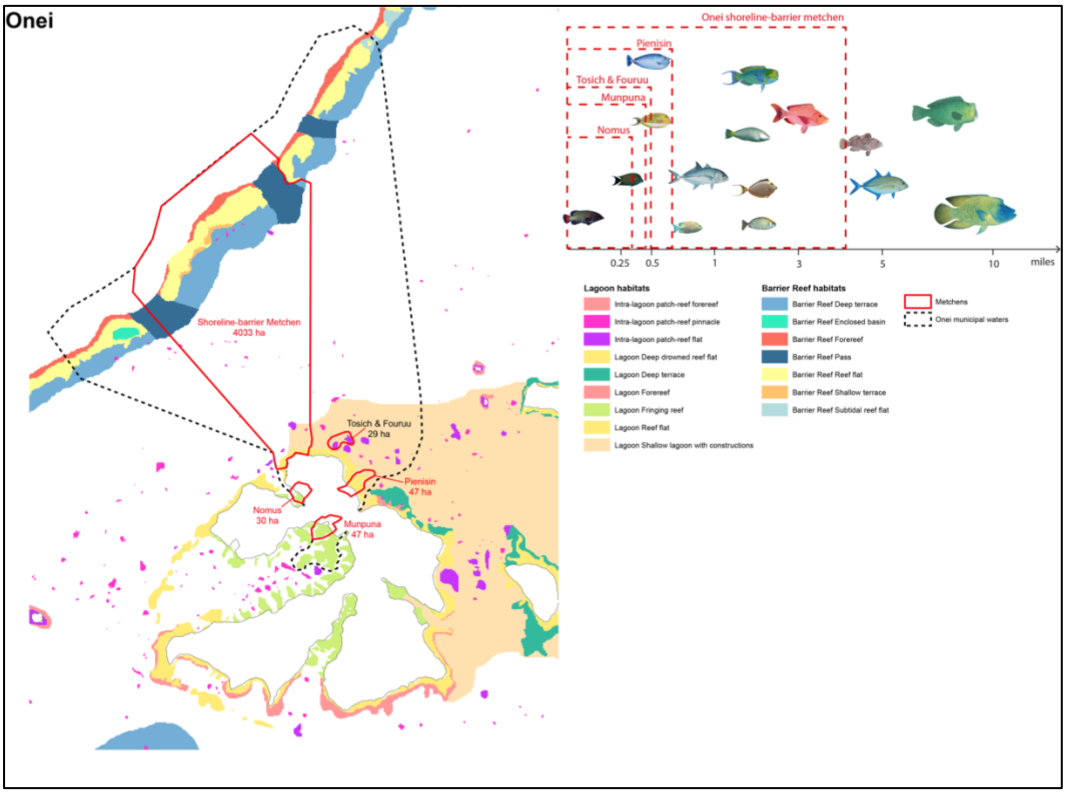
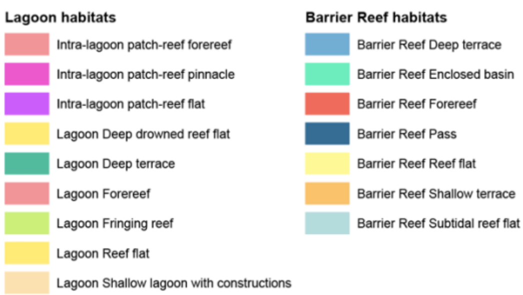


Figure 9. Example of an MPA scorecard

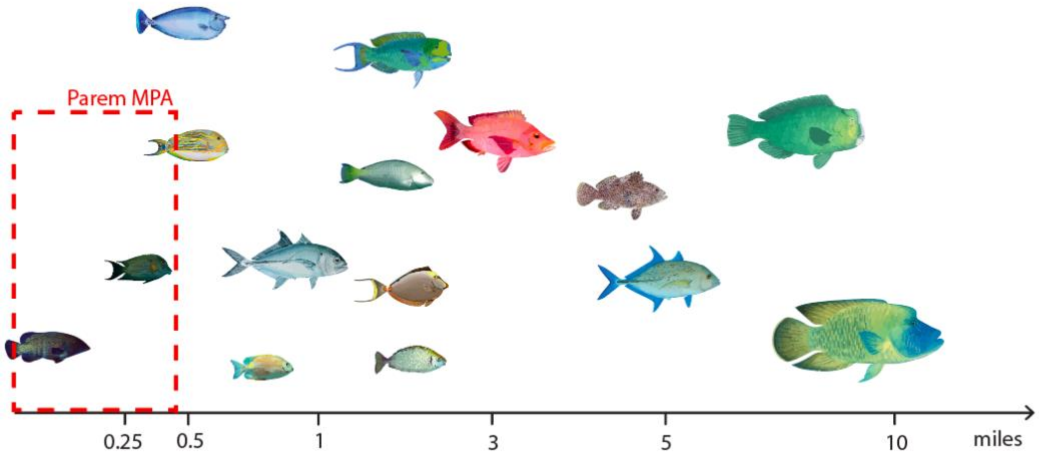
Habitat types

The first piece of information contained on the scorecard is the legend of habitat types which might be included within the managed area boundary (right). It is important that the managed area 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 managed area, 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 managed area to indicate which species will be adequately protected. The red dashed box indicates the effective size of the managed area. Species within the box are adequately protected. Species that are not within the box are not adequately protected. If the boundaries of the managed area cannot be extended, alternative fisheries management will be required to protect these species.



Box 1. Case Study of marine protected area scorecard use in Pohnpei

At 1,200 ha, Palikir Pass is the largest MPA on the reefs surrounding the main island of Pohnpei. The initial proposal for this MPA covered less than half of this area. Following discussions about MPA adequacy for focal fish species, using their MPA Scorecard, the community agreed to change the boundaries of the MPA to ensure that they encompass key habitat types utilized by many species, and a known grouper spawning aggregation.

4 MANAGEMENT OPTIONS FOR KEY FISH SPECIES

4.1 SPATIAL FISHERIES MANAGEMENT

Well-designed and effectively managed no-take marine protected areas (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 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 managed areas and spatial fishery closures, with specific guidance for implementation in Chuuk.

It is notable that Chuuk does not have a history of implementing permanent no-take MPAs, and there has been some confusion as to the definition of “no-take”. Two types of fishery closures have traditionally been implemented in Chuuk: *mechen* and *pau*. Both are temporary closures in which most or all fishing activity is prohibited.

Participants at the 2017 workshop agreed that Pau is a stricter "no-take" period of time that carries more expectation than a normal *mechen*. Violation of *pau* can be reprimanded very severely because it is a no-tolerance prohibition. *Mechen* can permit access into an area, but not allow harvest. *Pau* means totally no access, no take, no use of any resource for whatever purpose; it is usually imposed for high ranking chief or important family member. Representatives from the outer islands said their prohibited areas are taboos that no one should even come close to. Hereafter, the term ‘temporary fisheries closures’ is used to refer to all types of temporary fishery closures that might be implemented by reef owners or communities.

Managing temporary fisheries closures is a lot more complicated than permanent no-take MPAs, because in addition to making decisions about the size and location of the area, communities need to decide how long to leave the area closed, when to open it, how much fish biomass may be harvested when the area is opened, and which species may be taken. All of these extra variables can influence the effectiveness of this form of management for both fisheries sustainability and biodiversity conservation objectives.

Recommendations for using temporary closures as a management tool to achieve sustainable fisheries and biodiversity conservation objectives come from research undertaken in the Pacific Islands, where *tabu* areas have been used by communities for many generations (Jupiter et al. 2012; 2014; Goetze et al. 2016; 2017). *Tabu* areas share similar origins in traditional use as traditional temporary fisheries closures in Chuuk, with areas closed to fishing following the death of an important community member and reopened 100 days later to provide a large harvest for a celebratory feast. In contemporary use, *tabu* areas are expected to achieve a range of objectives, including fisheries management, conservation and maintaining cultural practices (Jupiter et al. 2014).

Just like in a permanent no-take MPA, when a temporary fisheries closure is closed to fishing, the number and size of fish inside the area increases through time. As fish start to feel safe inside the closed area, they forget to be afraid of fishers and become less cautious. When the area is opened for a harvest, there are lots of fish, and the fish are tame and easy to catch, particularly for spearfishes that can get much closer to their target before the fish swims away. Fishing communities benefit because they can catch a lot of fish, and large fish, within a short period of time. Thus, temporary fisheries closures are a particularly effective fisheries management strategy for increasing short-term fisheries yields from single harvest events. However, the increased catchability means that a lot of fish biomass can be removed quickly, with very little fishing effort. The risk of overharvesting compromises both future harvests and long-term management objectives.

Box 2. Best practices for managing temporary fisheries closures

Short-term benefits are greatest when temporary fisheries closures areas are:

1. Larger
   - like with permanent no-take MPAs, larger closures provide protection for more individuals of more species
2. Closed for longer
   - resource owners / communities need to allow enough time for fish populations to recover inside the closure before they harvest it. Some fish, like rabbitfish, grow and reproduce quickly; others like humphead wrasse need much longer
3. Well-enforced
   - everyone needs to know where the boundaries are, and steps should be taken to prevent poaching

To maintain benefits over time, temporary fisheries closures should be fished sustainably:

1. Strict controls are needed to prevent overfishing once closures are opened
   - Leave some fish behind to kick-start recovery for the next harvest
   - Focus harvest effort on fast growing and abundant species; avoid taking large predators (grouper, sweetlips, jacks, jobfish, sharks) and large parrotfish.
2. Strict deadlines are needed to stop fishing
   - Harvests should not generally last longer than 1-2 days.
3. Sufficient recovery time must be allowed for between harvests
   - At least 3 years of closure between harvests is recommended to restore fish abundance and biomass to pre-harvest levels.
   - Longer-lived, slower-growing species will need longer periods of closure for benefits to build up than those that are faster-growing.

To achieve long-term fisheries management and conservation objectives, it might be necessary to combine temporary fisheries closures with permanent no-take MPAs and other non-spatial fisheries management strategies.

4.2 COMPLEMENTARY NON-SPATIAL FISHERIES MANAGEMENT

While the focus of the analyses presented here is on identifying priorities for implementing spatial fisheries management, a range of other fisheries management strategies can also be implemented. These are especially relevant to species whose movement patterns means that they are unlikely to be protected within managed areas (see Table 1).

Complementary fisheries management strategies could include:

- **Minimum size limits for species with strong density-dependence responses to fishing**
  Minimum size limits ensure that fish are not caught before they have time to reproduce.

- **Limiting fishing during moon phases or seasons when species aggregate to** spawn
  Reef fish are especially vulnerable to overfishing during the periods when they aggregate to spawn. Chuuk State has implemented a state-wide a seasonal ban for grouper species.

- **Establishing a moratorium on fishing for slow growing species (e.g. humphead wrasse, bumphead parrotfish) until these populations have recovered**
  These species are locally depleted, and rarely appear in catch data.

Humphead wrasse *Cheilinus undulates* (Maam) have large home ranges and require additional non-spatial management. Photo: Robert Harding

- **Prohibiting the use of destructive and unsustainable fishing gears**
  Dynamite fishing is already banned within Chuuk State. Using nets with small mesh sizes should also be avoided, as these catch undersize fish and non-marketable species. Spearfishing can be sustainable, as fishers are able to be selective in the fish they catch, for example avoiding undersize species. However nighttime spearfishing is widely considered to be unsustainable for many species, incusing parrotfish.

- **Focus fishing effort on small, fast growing species rather than larger, slow growing species**
  Commercial fishers prefer to catch larger fish, as their income is determined by the weight of their catch, not the number of fish caught. Export demand is similarly for large-bodied species, which are preferred in Guam markets. However, Chuukese people prefer to eat small-bodied species, many of which are intrinsically more resilient to fishing pressure.

- **A shift to pelagic fisheries (*angarap*) might release some pressure from the coral reef fisheries (*ikenoch*) while they are recovering**

Commercial fishers prefer to catch larger fish, as their income is determined by the weight of their catch, not the number of fish caught.

5 SPATIAL CONSERVATION PRIORITIZATION

Spatial conservation prioritization aims to identify systems of notional conservation areas that collectively achieve specified objectives (Kukkala & Moilanen 2013). Importantly, outputs are intended to *inform* decision-making, not to provide protected area network designs that are ready to implement.

Regional-scale conservation prioritizations are able to incorporate relationships between individual protected areas, including complementarity (e.g. of habitat representation) and connectivity, so that protected area networks become more than the sums of their parts. Planners can explore different scenarios, for example varying biodiversity objectives, incorporating social or economic preferences, and perceived threats, costs or opportunities for conservation. Nevertheless, prior to implementation, the boundaries of potential conservation areas will always have to be adapted to the context within which they are to be applied (Pressey et al. 2013).

In a Micronesian context, spatial priorities might be used to guide engagement (for example by CCS or TNC) with resource owners, to begin a discussion about how they might manage their reefs both to achieve their own management objectives, and perhaps contribute towards a State-wide network. Where NGOs receive more requests for assistance than they are able to resource, prioritization outputs can provide a basis for choosing which to support. At a smaller scale, resource owners who are interested in implementing fisheries management can see the value of their reefs within the broader context of State-wide objectives; this might influence them towards selecting an area for management that will maximize conservation outcomes.

5.1 METHODS

5.1.1 PLANNING UNITS

The planning region was first divided into 'planning units' which form the building blocks of protected area network designs. Each planning unit can be selected for inclusion in the protected area network, or left open to alternative uses. In this analysis, different management zones were not considered. Planning units were created as 25-hectare grid covering the extent of all marine habitat features and land within Chuuk's state boundary (planning units for Chuuk Lagoon are shown in Figure 10).

5.1.2 RESERVE-SELECTION SOFTWARE

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 (Ball et al. 2009). When provided with information on the amount of each biodiversity feature (e.g. habitat types) within each planning unit, Marxan identifies sets of planning units that achieve biodiversity representation targets in an efficient manner (i.e. seeking to minimize the summed "cost" of selected planning units). 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 specified conservation objective.

Whilst costs in conservation planning can be monetary (e.g. costs associated with purchasing or managing protected areas), more frequently, conservation planners use estimates of opportunity costs, which represent alternative uses (e.g. fishing) that must be forgone in order to pursue a certain action (i.e. protected area implementation) (Naidoo et al. 2006). It is assumed that minimizing stakeholders' opportunity costs will increase the likelihood that they will support and subsequently comply with conservation actions (Weeks et al. 2010a). In addition to improving the likelihood that conservation plans can be successfully implemented, incorporating social and/or

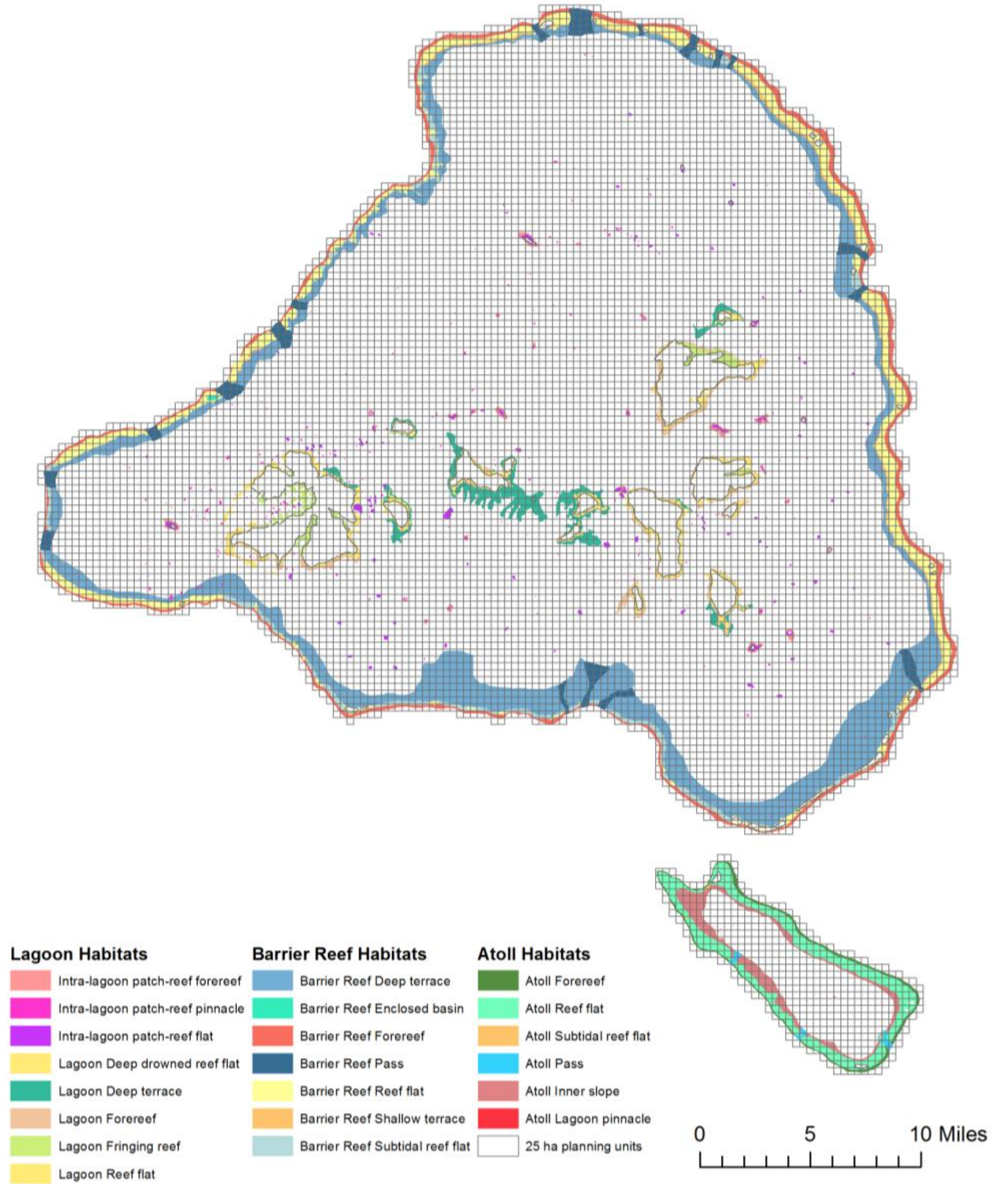


Figure 10. Planning units covering Chuuk Lagoon

economic cost information can help to identify spatial priorities, particularly where conservation objectives are relatively unconstrained (i.e. features to be represented occur in lots of places, so there are many potential reserve network designs that achieve objectives).

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.

5.1.3 PRIORITIZATION SCENARIOS

Results are presented here for two basic scenarios: 'habitat representation' and 'opportunity costs'. Additional analyses that can be performed are discussed in a later section (*5.3 - Future prioritization scenarios and approaches*).

In the 'habitat representation' scenario, the conservation objective was to achieve representation targets for 30% of marine (and mangrove) habitats, as laid out in the Micronesia Challenge (Houk et al., 2015). The "cost" of including a planning unit in Marxan solutions is determined as the total area of conservation features within the planning unit. No existing or proposed areas were considered. This scenario does not incorporate any socioeconomic considerations, and is intended to be indicative of the area of reef that would need to be protected to achieve the Micronesia Challenge targets only.

In the 'opportunity costs' scenario, the conservation objective remains the same (protect 30% of marine habitats), however the "cost" of including a planning unit in Marxan solutions is determined by the modelled opportunity cost to subsistence fishers (see *5.1.4 - Modelling opportunity costs*). No existing or proposed areas were considered. This scenario seeks to understand whether and how Micronesia Challenge targets could be achieved whilst minimizing negative impacts on subsistence fishers. Given that opportunity costs were modelled for reef habitats in Chuuk lagoon only, this scenario is only explored for that sub-region.

For all prioritization scenarios, the feature penalty factor values (applied when representation targets are not achieved) were parameterized such 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). Marxan's BLM was calibrated to create protected area sizes that appeared reasonable, compared to existing and proposed protected areas in Chuuk and elsewhere in FSM.

5.1.4 MODELLING OPPORTUNITY COSTS

In previous spatial planning processes undertaken in Micronesia, fishers have been reluctant to share the location of favored fishing ground with planners (Victor et al. 2015; Weeks, 2015). This reluctance is not uncommon amongst small-scale fishers globally, and may be attributed to the confidential nature of fishing activity (i.e. fishers do not want others to learn about locations they know to be productive or profitable), fear that favored fishing locations might be prioritized for management that would exclude fishers, or historical (dis)trust between fishers and scientists more broadly.

In contexts where direct participatory mapping methods are difficult to conduct, indirect approaches that quantify the relative importance (weight) of criteria involved in fishing ground selection (e.g., habitat type, exposure, distance from home) can facilitate the mapping of fishing suitability (Thiault et al. 2017). We applied one such approach, using a rapid participatory survey to elicit factors that influence subsistence fishers' spatial preferences, during the 2017 spatial planning workshop. Participants were asked to rank the importance of four factors in determining where subsistence fishers choose to fish: reef zone (flat, crest, slope), reef type (fringing, patch, barrier), distance to shore (very close, close, far), and wave energy (low, medium, high). Reef zone was subsequently removed from analysis, because high resolution maps of the flat, crest, and slope were not available; additionally, night-time spearfishing is the primary mode of fishing, which is likely to only occur on the reef flat and crest. Surveys were completed by 45 people.

Subsequently, elicited preferences were combined with available GIS data to create a fine-scale model of fishing effort distribution across Chuuk Lagoon (Figure 11). The reefs

Fishing on the fringing reefs in Ckuuk Lagoon

of Chuuk Lagoon were divided into 50 metre by 50 metre grid cells. The wave energy of each cell was calculated using the Wave Energy ArcGIS Extension developed by the University of Guam Marine Laboratory. The reef type of each cell was determined using the Millennium Reefs data. Distance to land was calculated using the Euclidian Distance tool in ArcGIS. Each of these variables was weighted according the mean ranking of these factors among the survey responses.

To incorporate opportunity costs to subsistence fishers in the spatial prioritization for Chuuk lagoon, the modelled fishing effort was included as a cost layer in Marxan. This has the effect of preferentially selecting planning units with lower costs, whilst achieving representation objectives. In other words, Marxan will still select planning units to include 30% of the total extent of Chuuk's reef habitats, but when deciding *which* planning units to select, it will choose those that have lower associated opportunity costs.

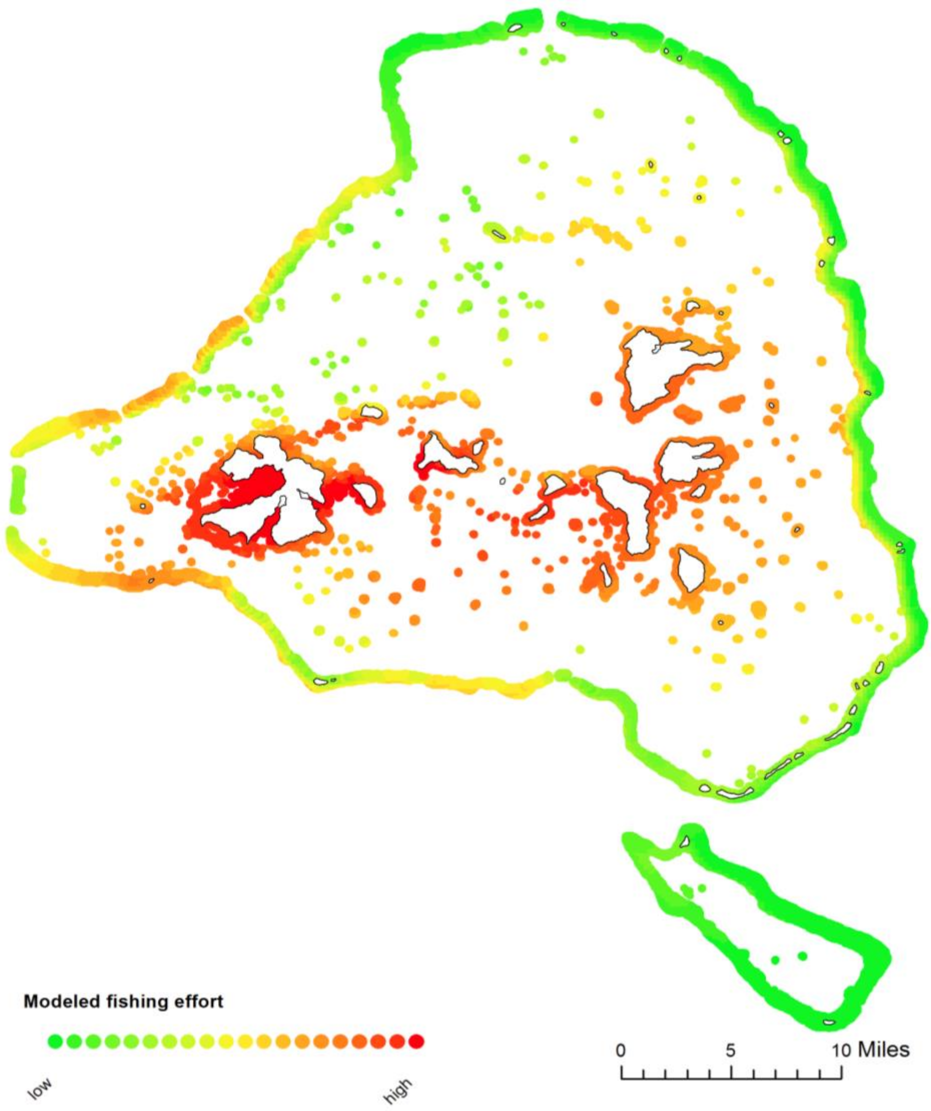


Figure 11. Modelled fishing effort for reefs in Chuuk Lagoon

5.2 RESULTS

5.2.1 HABITAT REPRESENTATION

To facilitate visualization and interpretation, results are presented separately for Chuuk lagoon and for inhabited outer atolls.

Figure 12 shows one possible configuration of protected areas that would achieve the specified representation targets. Note that this output is intended to be indicative of the area of reef that would need to be protected to achieve the Micronesia Challenge targets only; the location and boundaries of any areas prioritized for protection would need to be considered and approved by reef owners and local communities prior to implementation.

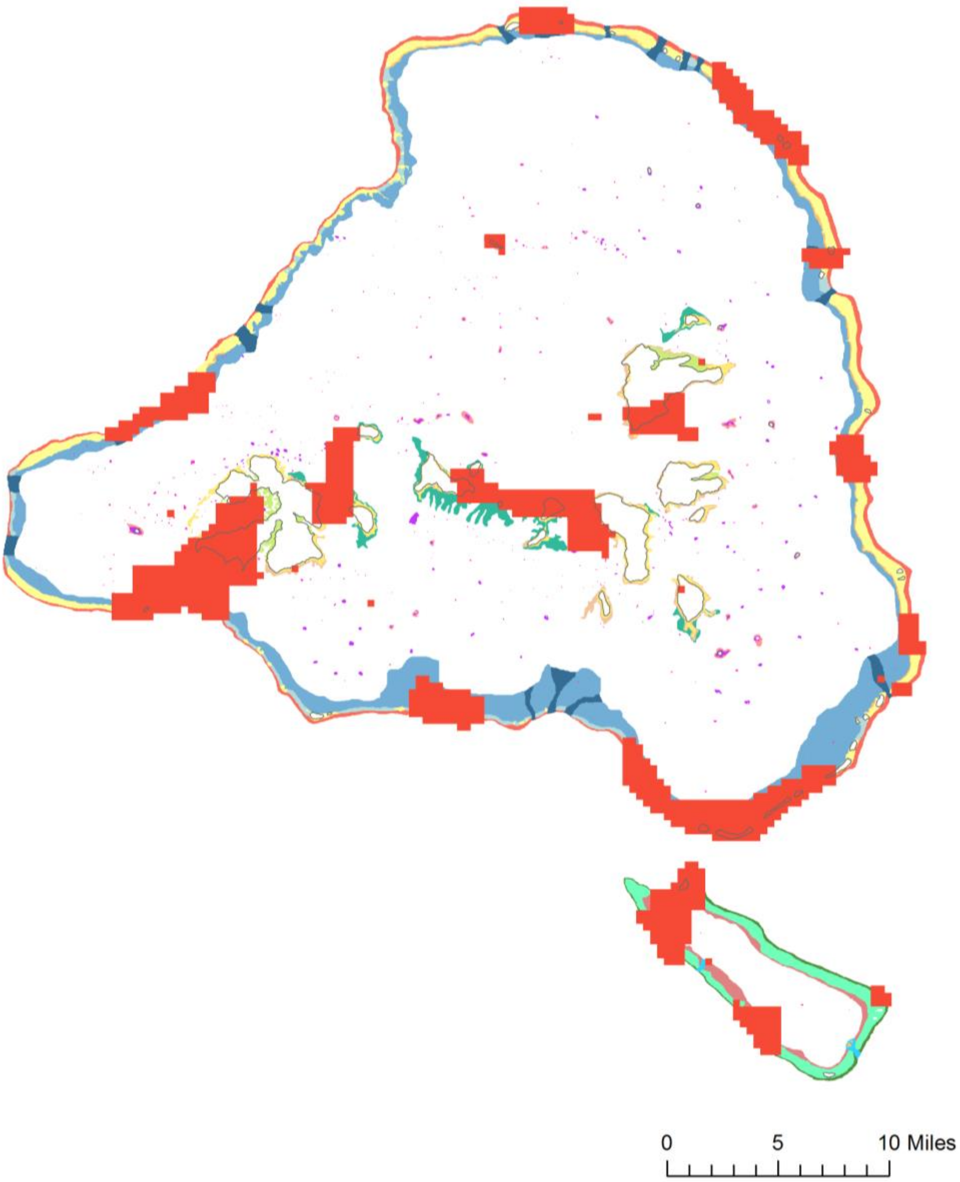


Figure 12. Example "best" Marxan output for Chuuk Lagoon under the 'habitat representation' scenario

Figure 13 shows the selection frequency of planning units under the *habitat representation* scenario for Chuuk lagoon. Planning units with higher selection frequencies (i.e. orange and red) can be considered to have greater conservation importance, as it is more likely that they would be required to achieve conservation targets. In this scenario, most planning units have relatively low selection frequencies. This indicates that there is a lot of flexibility in the solution space, i.e., without considering socioeconomic constraints, there are many different protected area network designs that can achieve the conservation objective. In this scenario, planning units with high selection frequencies are those that contain relatively rare habitat types.

Equivalent results for the *habitat representation* scenario on Chuuk's outer atolls are shown in Figure 14 - Figure 17.

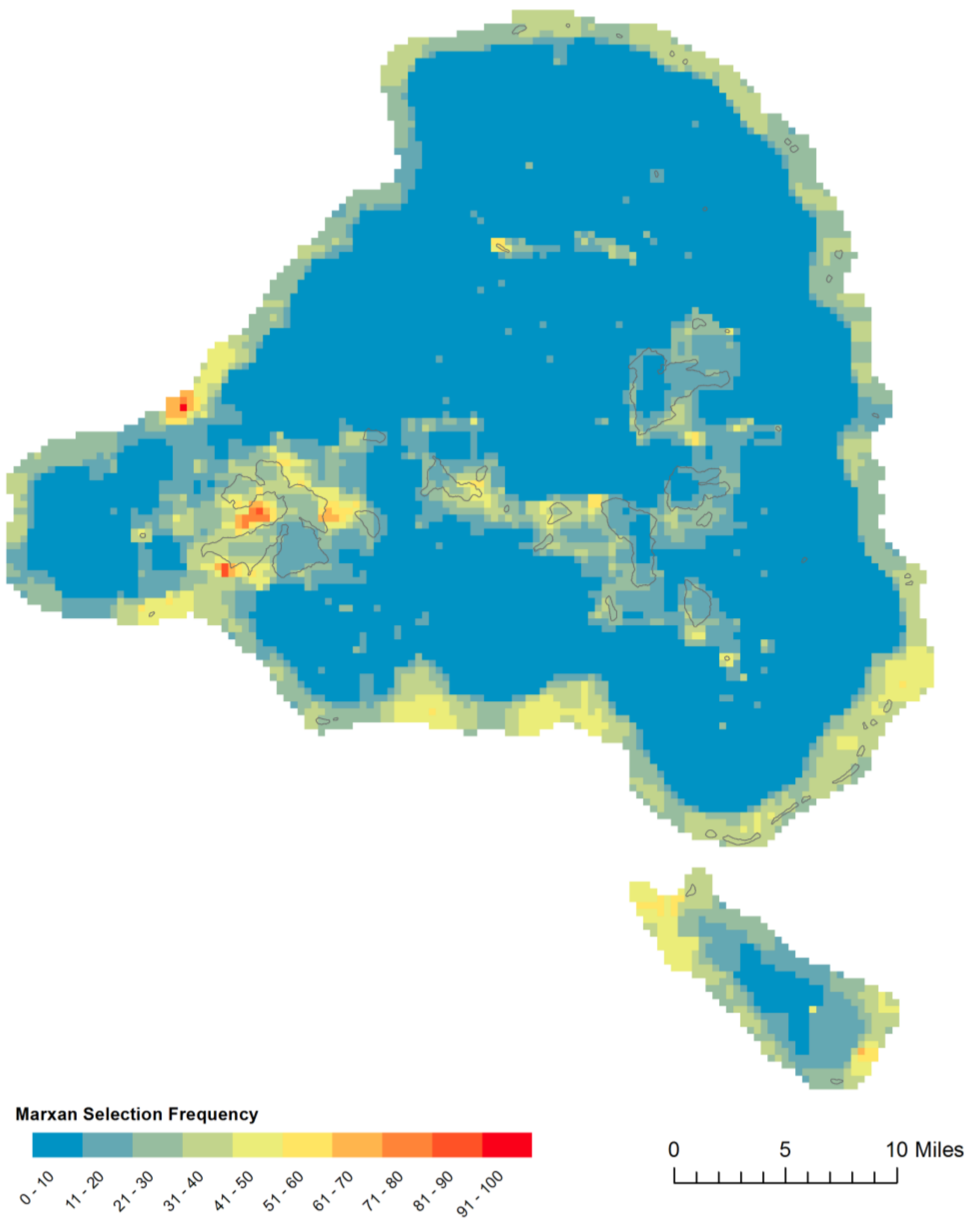


Figure 13. Selection frequency output map for Chuuk Lagoon, under the 'habitat representation' scenario

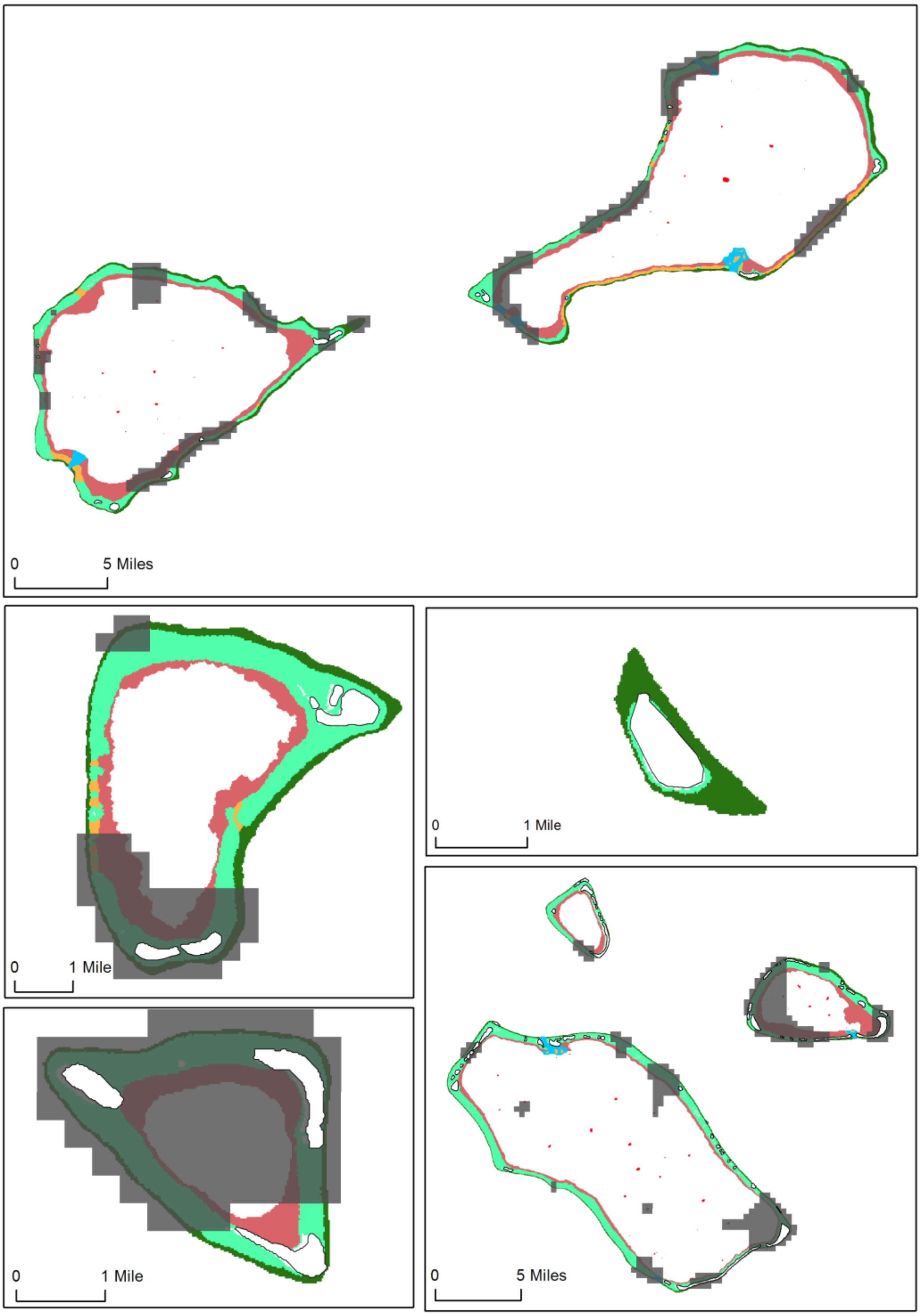


Figure 14. Example "best" Marxan output for Chuuk's outer atolls under the 'habitat representation' scenario (part I)

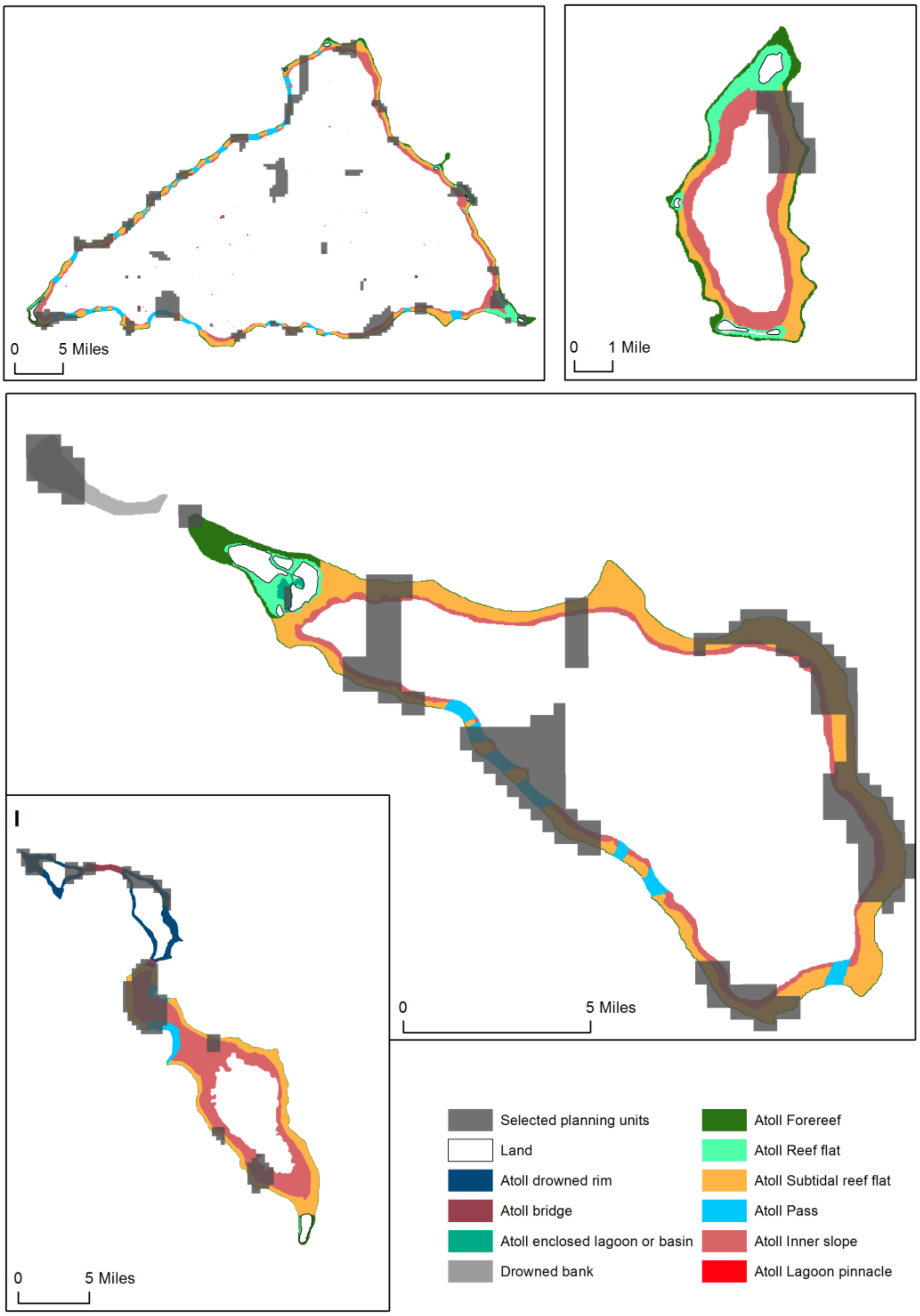


Figure 15. Example "best" Marxan output for Chuuk's outer atolls under the 'habitat representation' scenario (part II)

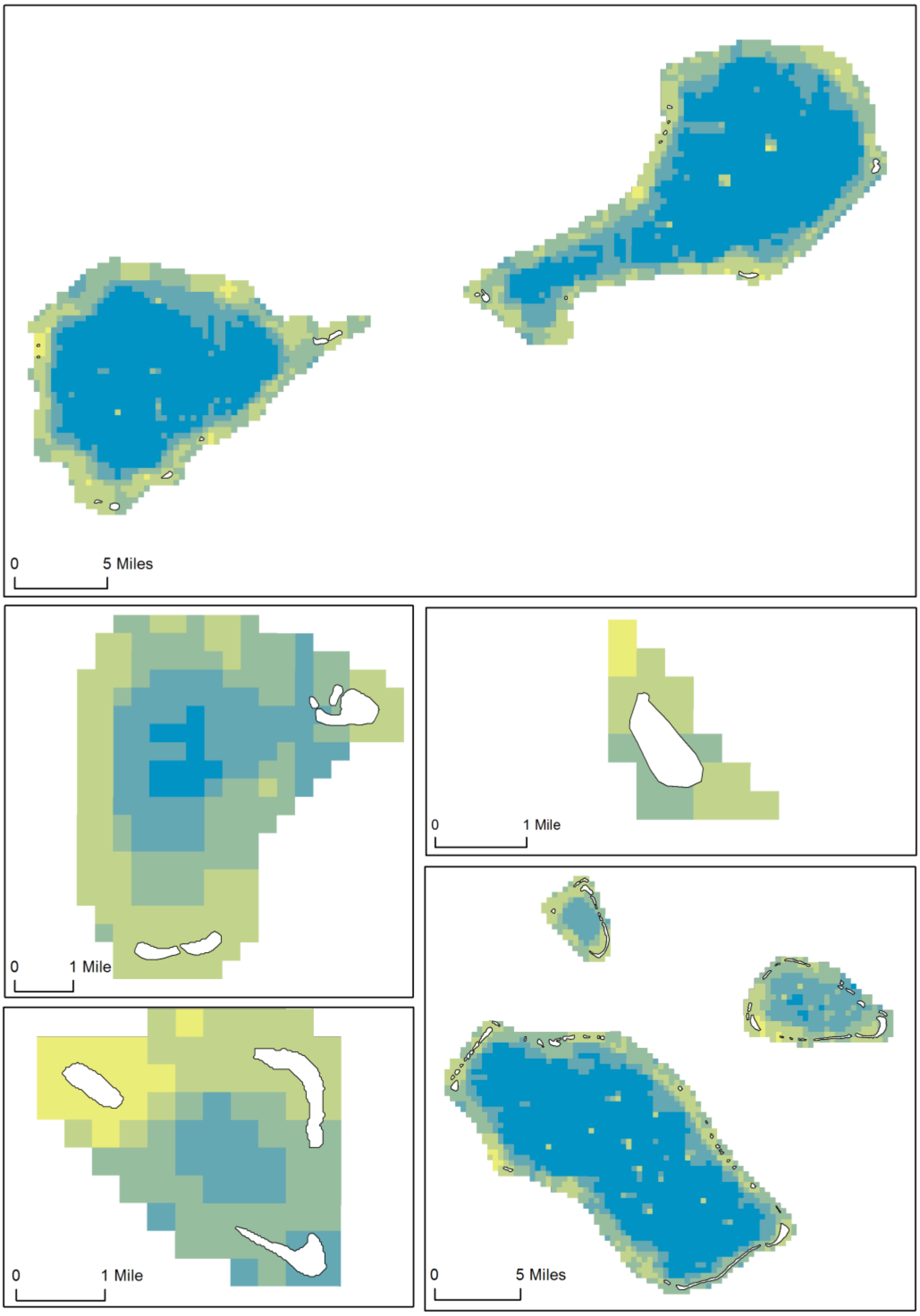


Figure 16. Selection frequency of planning units in Chuuk's outer atolls under the 'habitat representation' scenario (part I)

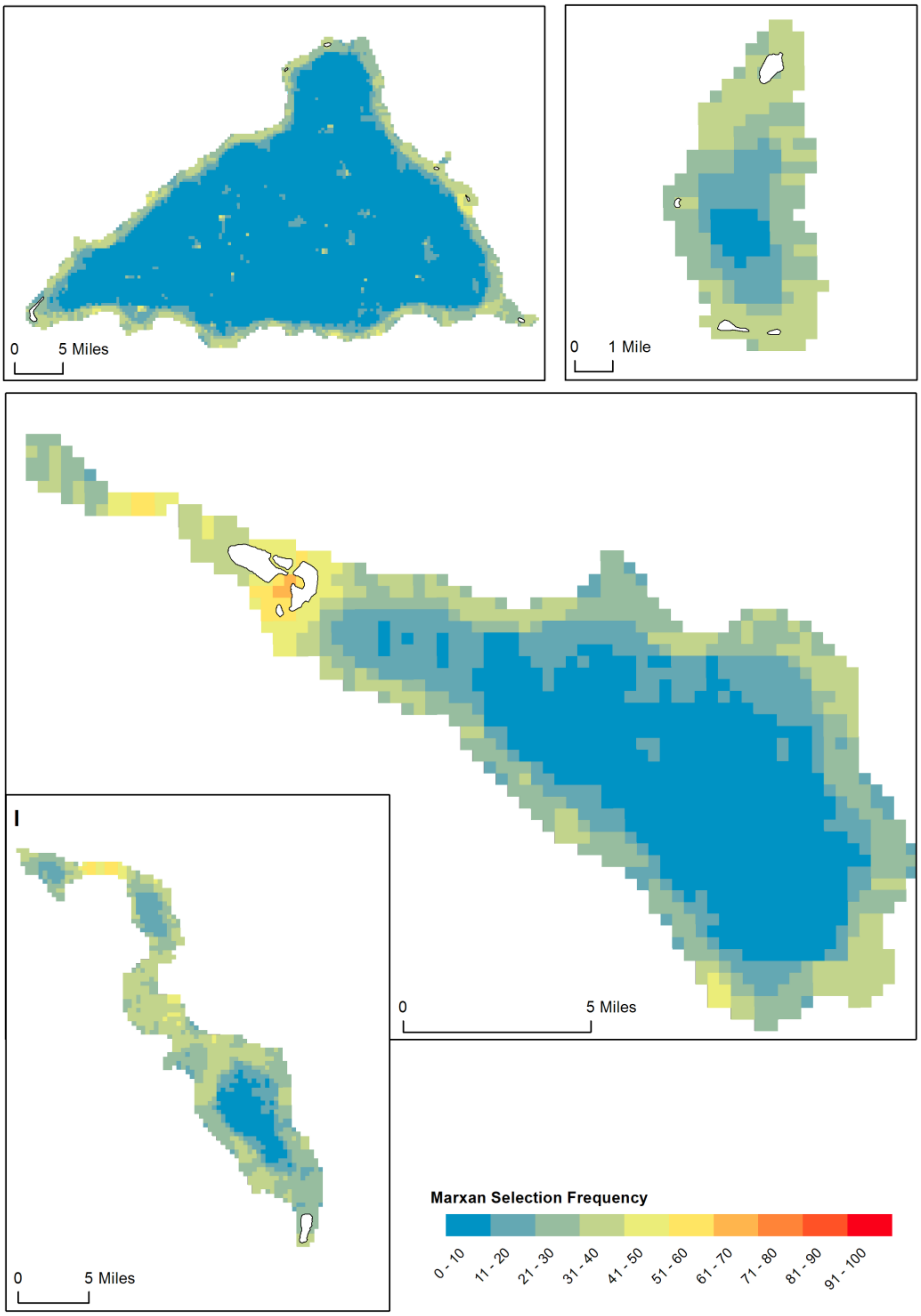


Figure 17. Selection frequency of planning units in Chuuk's outer under the 'habitat representation' scenario (part II)

5.2.2 OPPORTUNITY COSTS

Figure 18 shows the selection frequency of planning units under the *opportunity costs* scenario. Planning units with higher selection frequencies (i.e. orange and red) can be considered to have greater conservation importance, as it is more likely that they would be required to achieve habitat representation targets whilst minimizing impacts on subsistence fishers. In this scenario, planning units with high selection frequencies either contain relatively rare habitat types, or contain more common habitat types in areas predicted to be subject to less fishing pressure.

Notably, the proposed protected areas near Piis and Falos islands coincide with reefs that have high selection frequency in this scenario. These reefs have high conservation importance, are predicted to have lesser opportunity costs to subsistence fishers, and resource owners have expressed an interest in undertaking management. They thus comprise a good starting point from which to add sites to Chuuk's protected area network.

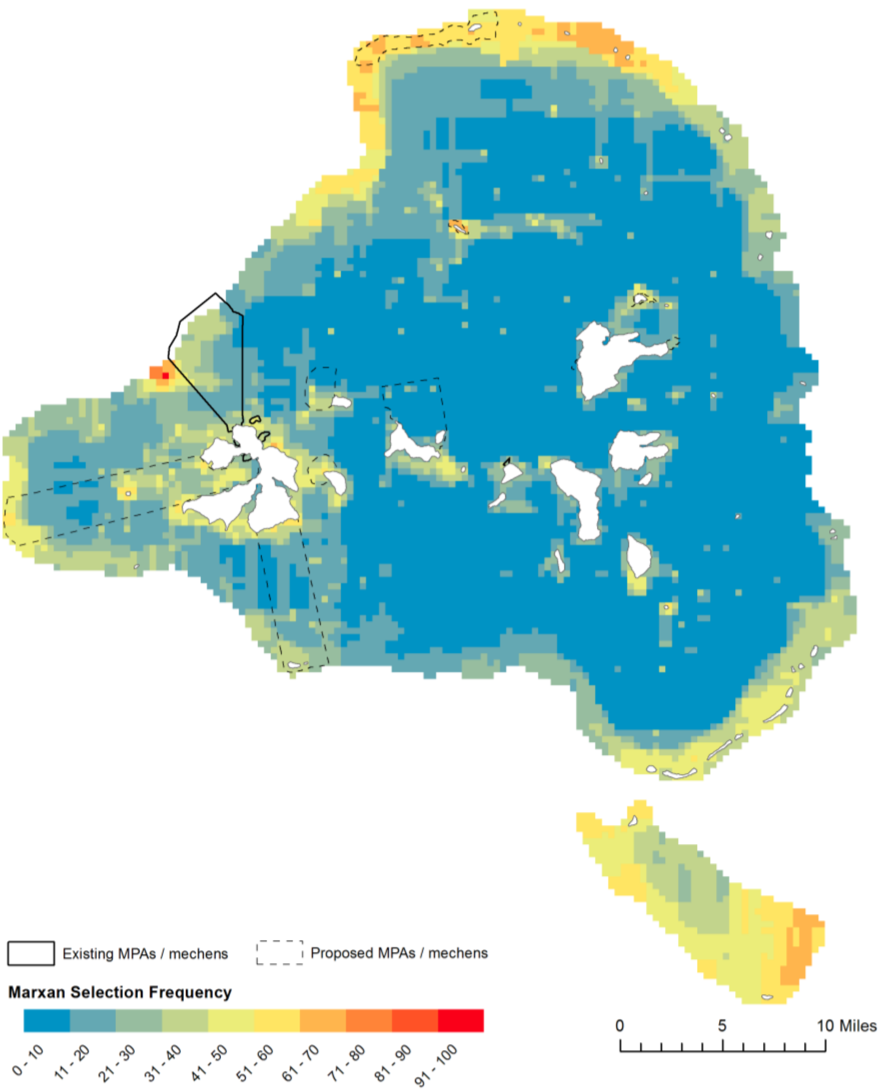


Figure 18. Selection frequency output map for Chuuk Lagoon, under the 'opportunity costs' scenario with locations of existing and proposed MPAs overlaid.

The planning units of high conservation importance (red) immediately to the West of the Onei shoreline-barrier mechen are prioritized because they contain a unique habitat type: an enclosed basin in the barrier reef system (see Figure 1). Although the Onei shoreline-barrier mechen is already large, and adequate to protect many species of fisheries importance (Figure 4), the boundaries could possibly be amended to include this area. In some Micronesian reef systems, enclosed basins can provide valuable nursery habitat for fishery species (Weeks 2017). However, the habitat data used here are derived from remote sensing information, so the value of this area as important habitat for fish and/or biodiversity should be ground-truthed before any action is recommended.

Figure 19 shows how the selection frequency of planning units changes, depending upon the planning scenario. Planning units in red are selected more frequently when opportunity costs to subsistence fishers are considered. Unsurprisingly, these are reefs further away from heavily populated islands.

Note that this is just one example of a scenario that attempts to take socioeconomic considerations into account. Here, opportunity costs to *subsistence* fishers are minimized, and spatial priorities for management are based towards the barrier reef. However, nearly all (96%) commercial reef fish landings are caught in the barrier reef, so minimizing opportunity costs to commercial fishers would likely result in different recommendations. Additional prioritization scenarios that might be explored are discussed in section 5.3.

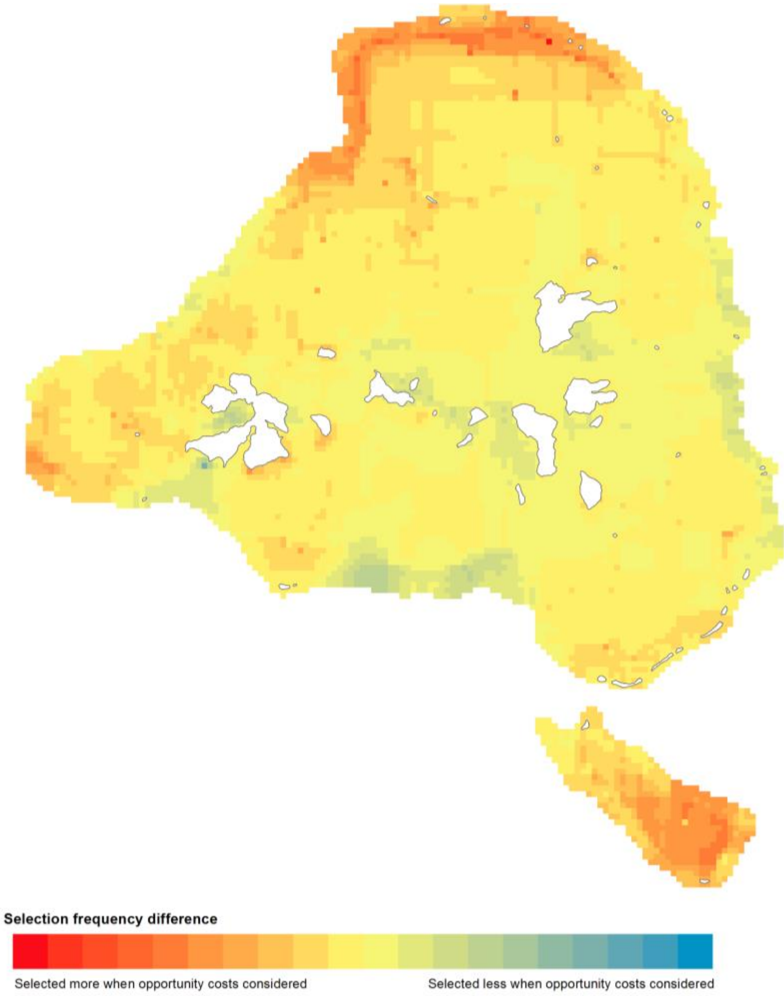


Figure 19. Difference map showing planning units that are selected more or less frequently when opportunity costs to subsistence fishers are considered.

5.3 FUTURE PRIORITIZATION SCENARIOS AND APPROACHES

5.3.1 INCORPORATING OCEAN WEALTH

In 2015, TNC initiated the Mapping Ocean Wealth (MOW) project, which aims to quantitatively describe ecosystem services provided by the oceans to facilitate better decision-making for conservation and management. In Micronesia, TNC worked with global leaders in coral reef fisheries modelling and leading scientists and practitioners from the region to model and map ocean wealth from coral reef fisheries across the five jurisdictions of the Micronesia Challenge (Harborne, 2016).

Outputs from the Micronesia MOW project include:

- spatially continuous maps of fishing impacts on key fisheries species (indicative of past fishing pressure),
- predicted current biomass or ocean wealth (in terms of standing stock), and
- potential standing stock, if fisheries management were improved

By comparing the differences between current and potential standing stock, it is possible to identify reefs where increases in fish biomass are expected to be greatest as a result of improved management (e.g. by establishing no-take MPAs or applying other fisheries management measures). This potential for improvement is a measure of 'impact' – the positive difference we can make through implementing conservation or management actions.

Outputs show that even in the absence of humans, standing stock varies considerably among reefs. Some areas (typically remote reefs and those surrounding outer islands) are already in good condition are thus likely to benefit little from improved management. In contrast, other areas (including some reefs in Chuuk lagoon) have the potential for large increases in standing stock of focal fisheries species if effective no-take MPAs or other fisheries policies are implemented.

This information facilitates the explicit inclusion of fisheries productivity in spatial prioritization. For example, depending on their management objectives, decision-makers might choose to prioritize for management reefs with high standing stock before they are exploited, or those that are likely to show the greatest benefits from management.

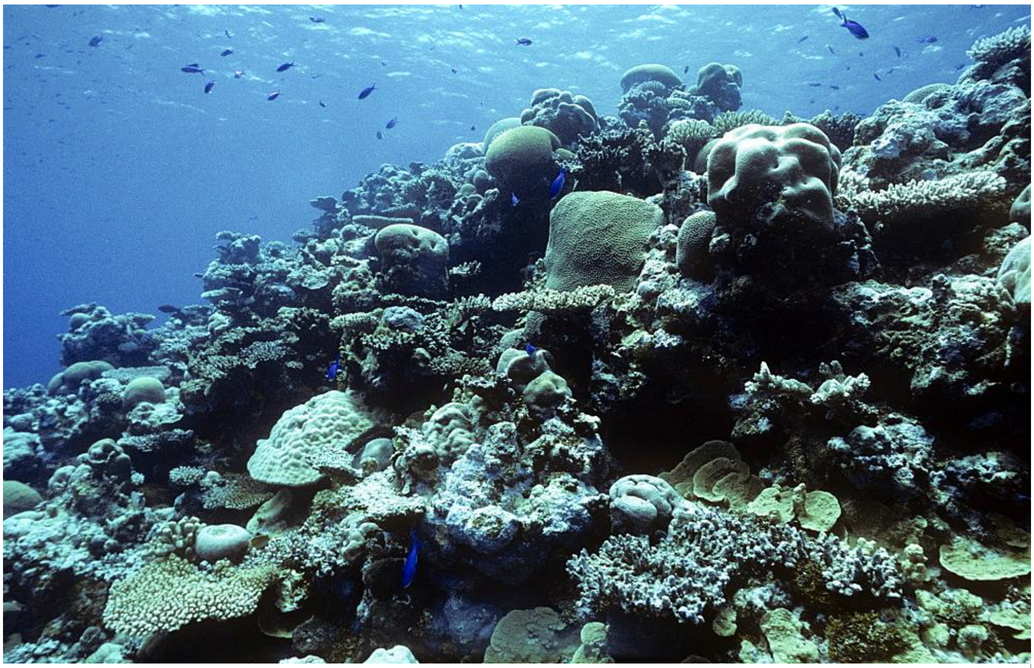
However, while the Micronesia-wide MOW outputs illustrate trends at a regional level, local-scale inaccuracies (caused by data limitations) reduce the usefulness of these products for spatial planning at finer scales. A further impediment to their use in Chuuk is that the models were parameterized using survey data collected on reef slopes and fringing reefs, and thus their ability to predict reef fish standing stock and recovery on lagoon reef habitats is uncertain.

To address these inadequacies, we are refining the MOW models for Chuuk lagoon, using reef fish survey data collected for Chuuk Lagoon and Kuop Atoll during the 2016 rapid ecological assessment (Houk *et al.* 2016) and fisheries-dependent data from commercial fisheries (J. Cuetos-Bueno, unpublished data). Including and weighting these local data in the models will increase the accuracy and relevance of the model outputs to inform spatial planning in Chuuk.

An additional limitation of the MOW outputs with respect to utilization in spatial planning, is that the model of fishing impact is a measure of the cumulative impact of past fishing pressure on fish assemblages, which may not reflect current (or future) patterns of fishing effort. Figure 11 shows an estimate of current spatial patterns of fishing effort, modelled from fishers' preferences elicited at the 2017 spatial planning workshop. We can also develop an independent model predicting the current distribution of commercial fishing effort for Chuuk Lagoon and Kuop Atoll, using fisheries data collected by J. Cuetos-Bueno. This model will relate and extrapolate information on the fishing pressure at different reefs, local population size, and travel time from population center to reefs. Travel time is a useful predictor of patterns of fishing effort as it also acts as a proxy for fuel expense, or reef accessibility to fishers without motorized boats.

Refined MOW outputs for Chuuk lagoon and an improved model of the current distribution of fishing effort will allow the exploration of additional spatial prioritization scenarios, as follows:

- Scenario '*MC + fish*' would seek to achieve Micronesia Challenge targets for habitat representation, whilst prioritizing reefs that will produce the greatest benefits in terms of increasing reef fish biomass. To operationalize this scenario in Marxan, the MOW predicted impact layer would be included as an inverse cost layer, so that planning units with high predicted impact (low cost) would be preferentially selected, subject to achieving representation targets (note that opportunity costs to fishers are not considered in this scenario).



Scenario 'MC + fish' would seek to achieve Micronesia Challenge targets for habitat representation, whilst prioritizing reefs that will produce the greatest benefits in terms of increasing reef fish biomass

- A *'proactive fisheries'* scenario would prioritize reefs with high current standing stock before they are exploited (i.e. where current fishing pressure is low, and reefs are at or close to their potential standing stock). Counter-intuitively, this would be operationalized in Marxan by seeking to minimize two cost layers – current fishing pressure and predicted impact (predicted impact is low where reefs are at or close to their potential standing stock). This is made possible through the use of Marxan with Zones (Ball et al. 2009), which allows users to specific more than one cost layer. It is possible to minimize both costs equally, or to assign different weightings to the cost layers.

  Note however that in pursuing a proactive management strategy, there is a risk that management actions can be "residual", i.e. have no positive impact for conservation or fisheries management objectives. Residual management would occur if, rather than protecting sites with high current standing stock from future threats, sites with high current standing stock but not subject to current *or* future fishing pressure (i.e. those remote from human populations) are prioritized. To ensure that the *'proactive fisheries'* strategy is proactive and not residual, it would be necessary to predict future patterns of fishing pressure. Alternatively, we could work on the assumption that all reefs in Chuuk lagoon are sufficiently close to human population centers as to be potentially subject to fishing pressure in future, and thus no prioritization strategy would be residual. The need to ensure that management actions are not residual remains pertinent to the outer islands, however.

- A '*reactive fisheries'* scenario would prioritize reefs with healthy fish populations that are imminently threatened by depletion, i.e. those with high current fishing pressure and low predicted impact. This strategy could be operationalized in Marxan by using current fishing pressure as an inverse cost layer, and predicted impact as a positive cost to be minimized. Note that this strategy might be difficult to implement, given that it is associated with high opportunity costs. Nevertheless, it might be more effective in ensuring the sustainability of Chuuk's fisheries in the short-term.

- A *'fisheries recovery'* scenario would prioritize reefs with high predicted impact (regardless of current fishing pressure), indicating that fish populations on these reefs have already been depleted substantially. Though these reefs might appear to have high opportunity costs, management might meet with less than expected opposition from fishers, who would be aware of fisheries declines. Note that fisheries benefit from this strategy are contingent upon recovery of depleted populations, so will be realized over a longer time-frame.

Note that the '*proactive'*, '*reactive'*, and '*recovery'* strategies would also seek to achieve habitat representation targets, thus contributing towards both biodiversity conservation and fisheries management goals. By parametrizing Marxan's penalty factor (applied when habitat representation targets are not achieved) it would be possible to change whether primacy is given to fisheries or conservation objectives.

Rather than choosing to pursue any one of these proposed strategies, understanding spatial differences in selection frequency patterns across them may provide decision-makers with options to pursue a portfolio approach to prioritization (Hobbs et al. 2017): selecting for management some sites with high recovery potential and others that currently have close to their potential standing stock. Recognizing the connectivity between reefs, the latter sites might provide sources of larvae to promote recovery in the former.

The MOW models also offer an approach to compare the predicted performance of different protected area network designs (both outputs from spatial prioritization using Marxan, and locally-proposed designs) in terms of maintaining or improving fisheries stocks (by setting fishing pressure to zero in proposed protected areas to simulate no fishing, and recalculating overall standing stock in the system). During the 2017 workshop, several participants proposed no-take areas that they were considering implementing on their reefs.

Finally, by modelling rates of recovery for key species, we could estimate the time required for different reefs to recover to achieve their potential standing stock. This would provide additional information to decision-makers seeking to resolve trade-offs between immediate, short- and long-term benefits from management actions.

5.3.2 INCORPORATING REEF OWNERSHIP

Reefs in Chuuk may be owned by individuals, traditional leaders, families or municipalities. During the 2017 spatial planning workshop, participants mapped reef ownership for their islands and reefs. In general, most reefs within Chuuk lagoon are owned by individuals or families, whereas outer island and atoll reefs that are far from inhabited islands tend to be owned by traditional leaders or the municipality.

This data is uncommon: customary tenure boundaries are rarely delineated, and doing so can cause conflict where ownership is contested or unclear (Foale & Macintyre 2000). For this reason, spatial planners rarely attempt to map customary ownership, or to explicitly include this in prioritization. Nevertheless, it is implicit that protected area planning and implementation processes in regions with customary ownership of or rights access to natural resources must necessarily involve rights holders.

Where resource use rights can be mapped spatially, this can be considered in spatial prioritization. For example, in the Philippines, fishing grounds accessible to different communities were included as a feature in Marxan, to ensure that in proposed MPA network designs, all communities retained access to at least 85% of their fishing grounds (Weeks et al. 2010b). Such an approach might not be appropriate in Chuuk, where reef ownership is more complex, and the extent of reefs to which fishers have access is highly variable.

While the spatial data we have for reef ownership in Chuuk is far from complete or definitive, broad patterns in reef ownership might indicate areas where conservation and management might be achieved more easily. For example, it might be easier for an individual with ownership over a large reef area to set aside some of that area as a no-take closure. It might also be more straightforward to establish management on municipal or state-owned reefs than those owned by individuals or families.

An additional consideration is that customary ownership of resources often occurs at a spatial scale incompatible with effective resource management (Foale & Manele 2004). For example, resource owners with small reef areas might be restricted to establishing only very small no-take closures. The dynamics and scale of population replacement processes for most fished species indicates that small no-take closures will be less effective than larger closures, and may be inadequate for most species (see section 3.2).

Identifying where spatial priorities for biodiversity conservation or fisheries replenishment intersect with implementation contexts that are simpler from a customary ownership perspective might be a promising approach to conservation planning in Chuuk.

Participants at the 2017 spatial planning workshop mapping reef ownership. Photo: Rebecca Weeks

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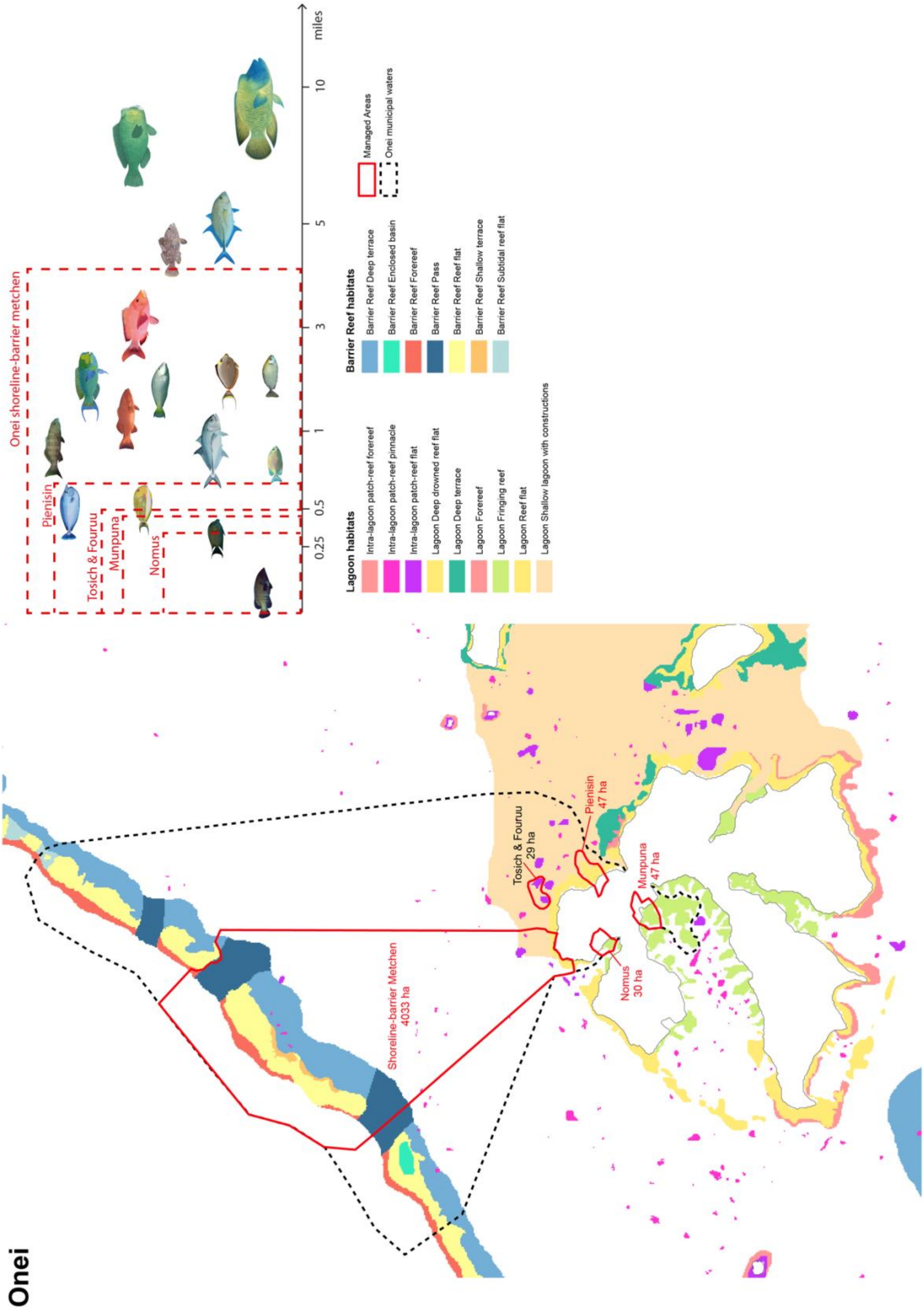
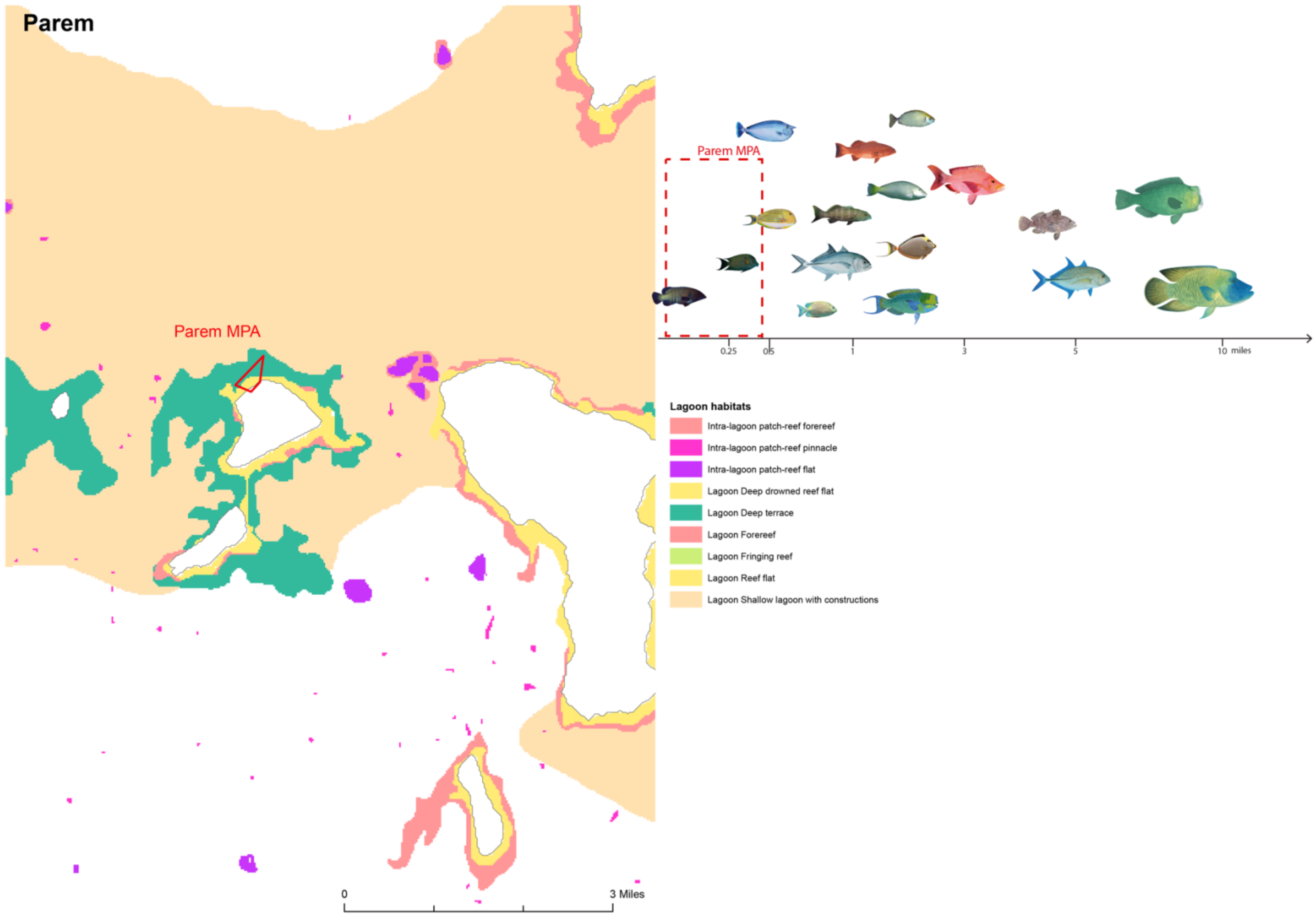
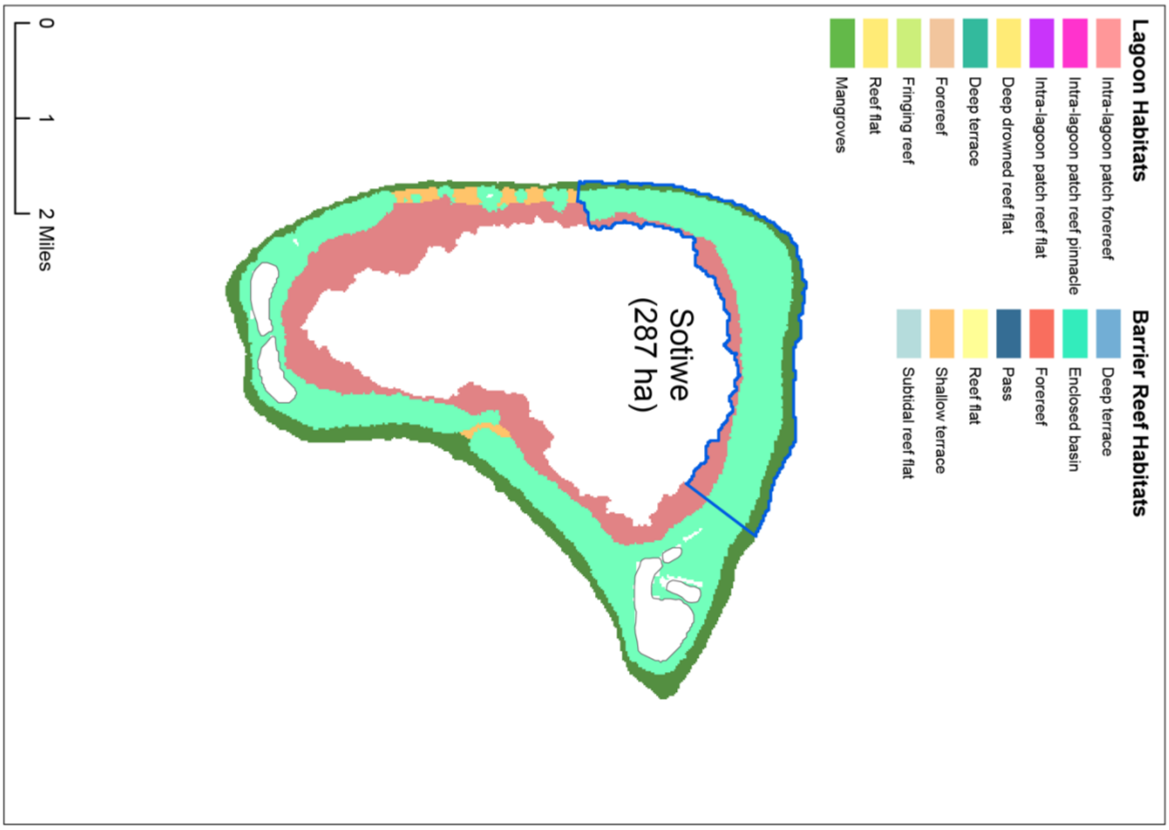
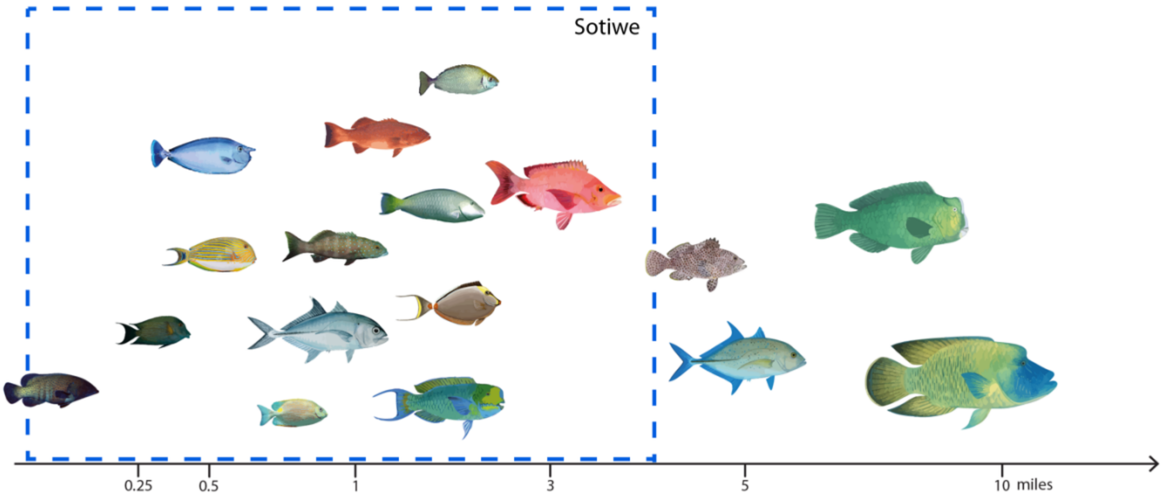
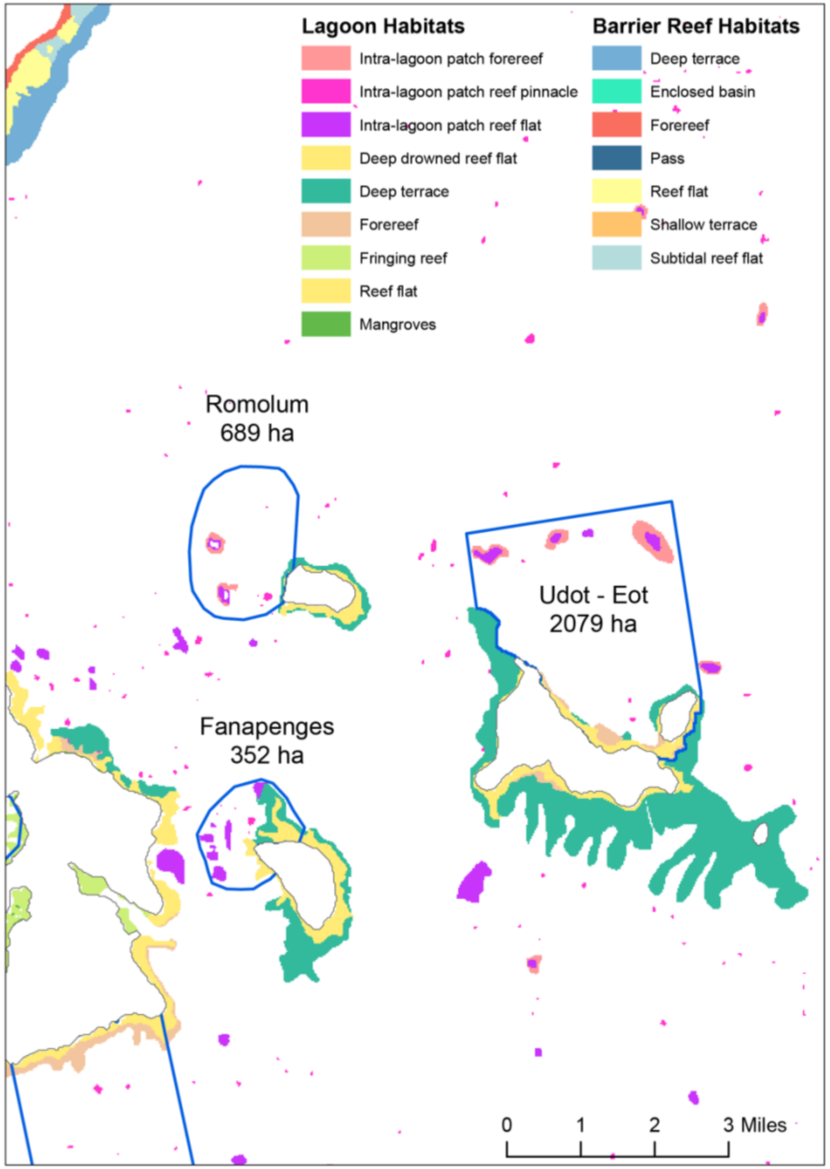

Onei
Onei shoreline-barrier metchen
Pienisin
Tosich & Fouruu
Munpuna
Nomus
0.25
0.5
1
3
5
10
miles
Lagoon habitats
Intra-lagoon patch-reef forereef
Intra-lagoon patch-reef pinnacle
Intra-lagoon patch-reef flat
Lagoon Deep drowned reef flat
Lagoon Deep terrace
Lagoon Forereef
Lagoon Fringing reef
Lagoon Reef flat
Lagoon Shallow lagoon with constructions
Barrier Reef habitats
Barrier Reef Deep terrace
Barrier Reef Enclosed basin
Barrier Reef Forereef
Barrier Reef Pass
Barrier Reef Reef flat
Barrier Reef Shallow terrace
Barrier Reef Subtidal reef flat
Managed Areas
Onei municipal waters
Shoreline-barrier Metchen
4033 ha
Tosich & Fouruu
29 ha
Pienisin
47 ha
Munpuna
47 ha
Nomus
30 ha

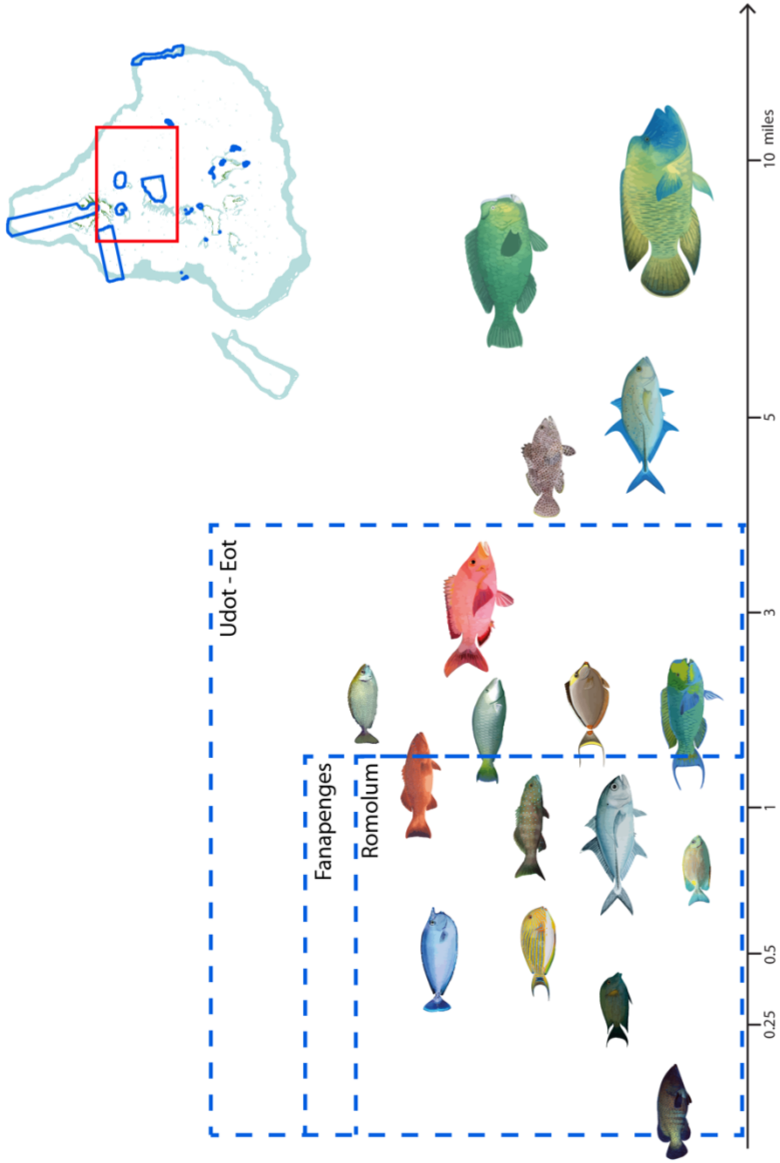


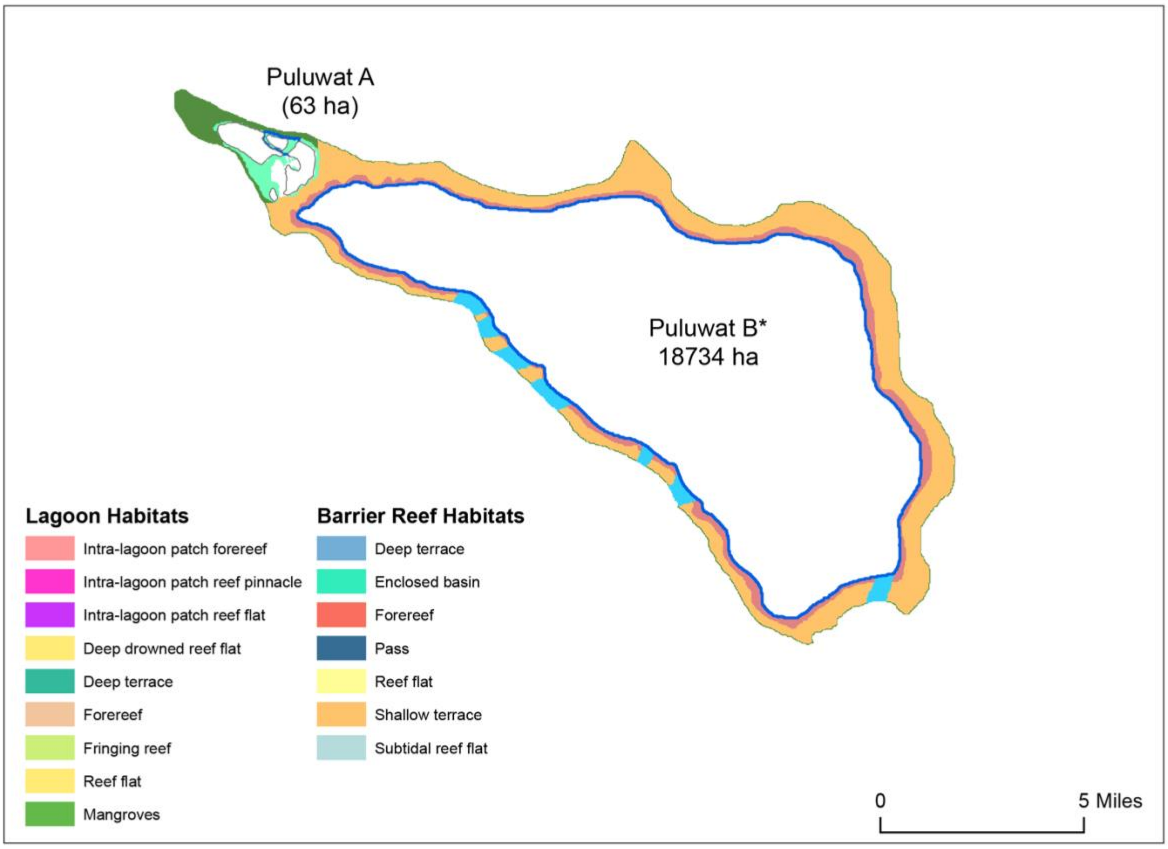
Parem
Parem MPA
Parem MPA
0.25
0.5
1
3
5
10 miles
Lagoon habitats
Intra-lagoon patch-reef forereef
Intra-lagoon patch-reef pinnacle
Intra-lagoon patch-reef flat
Lagoon Deep drowned reef flat
Lagoon Deep terrace
Lagoon Forereef
Lagoon Fringing reef
Lagoon Reef flat
Lagoon Shallow lagoon with constructions
0
3 Miles

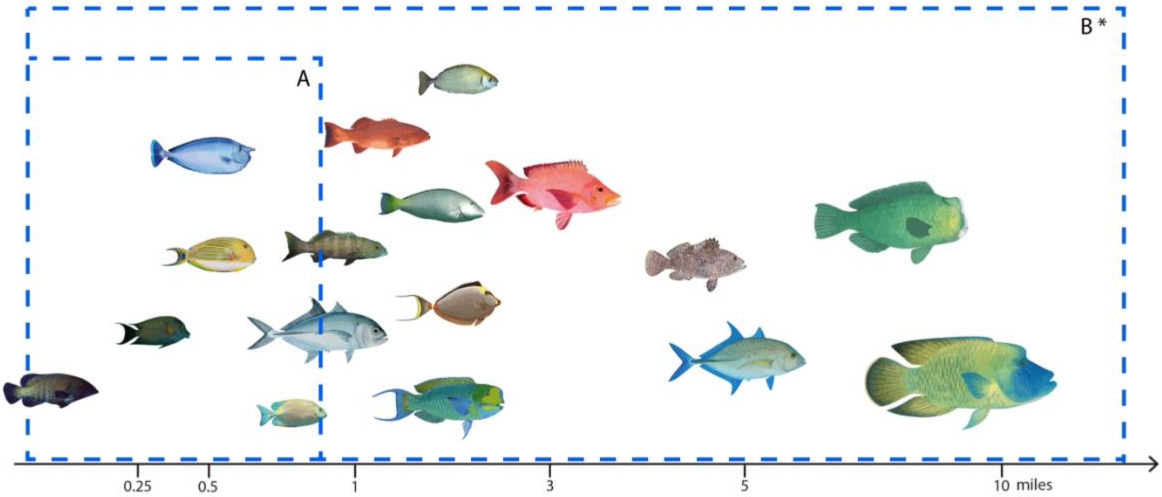

Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat
Sotiwe
(287 ha)
0
1
2 Miles


Sotiwe
0.25
0.5
1
3
5
10 miles

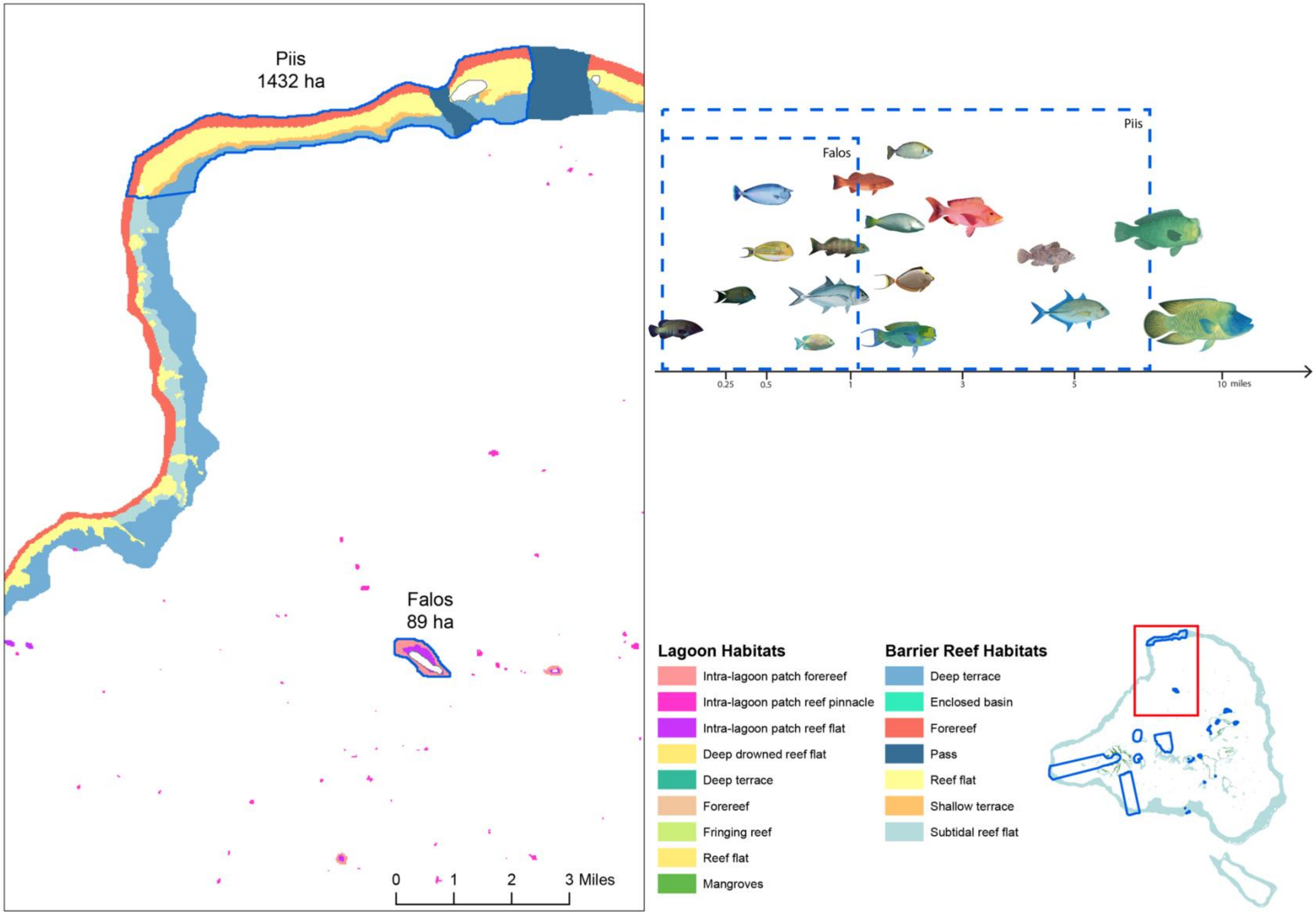

Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat
Romolum
689 ha
Udot - Eot
2079 ha
Fanapenges
352 ha
0
1
2
3 Miles


Udot - Eot
Fanapenges
Romolum
0.25
0.5
1
3
5
10 miles

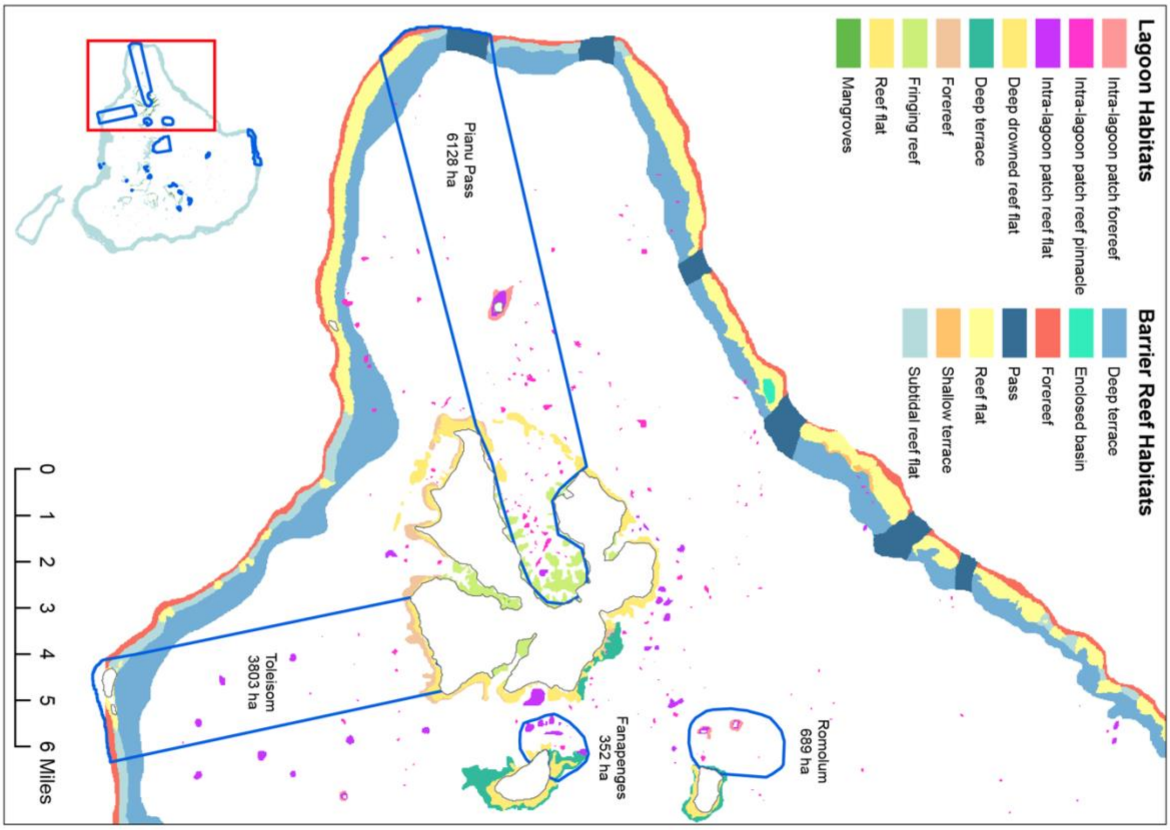




* Note that proposed boundaries do not include fish habitat.
Unless habitat for key species is included, they will not be protected



Piis
1432 ha
Falos
89 ha
0
1
2
3 Miles
Piis
Falos
0.25
0.5
1
3
5
10 miles
Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat


Lagoon Habitats
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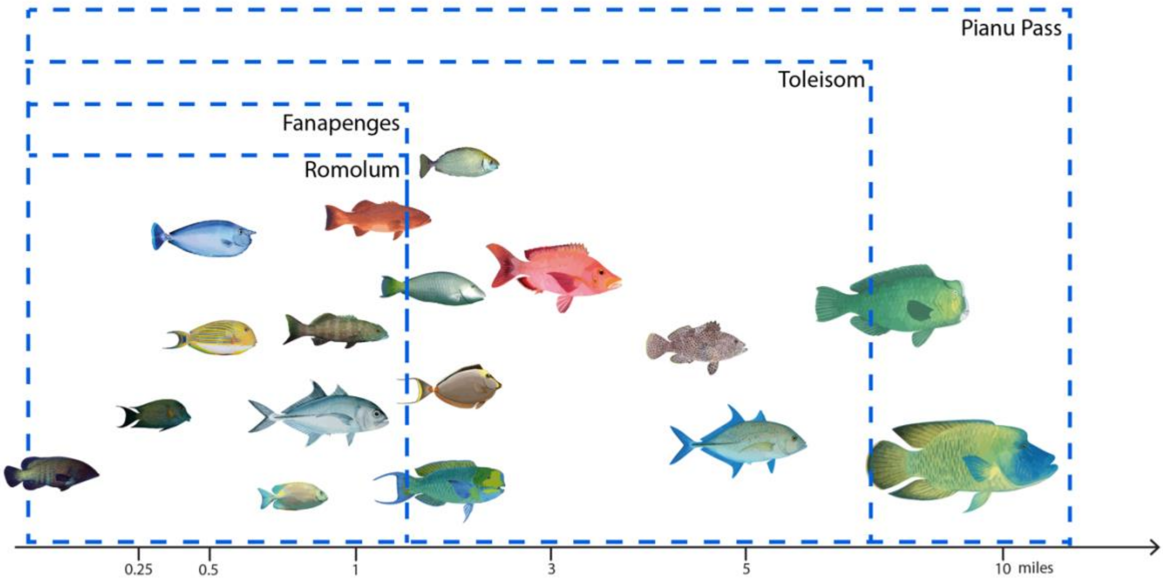
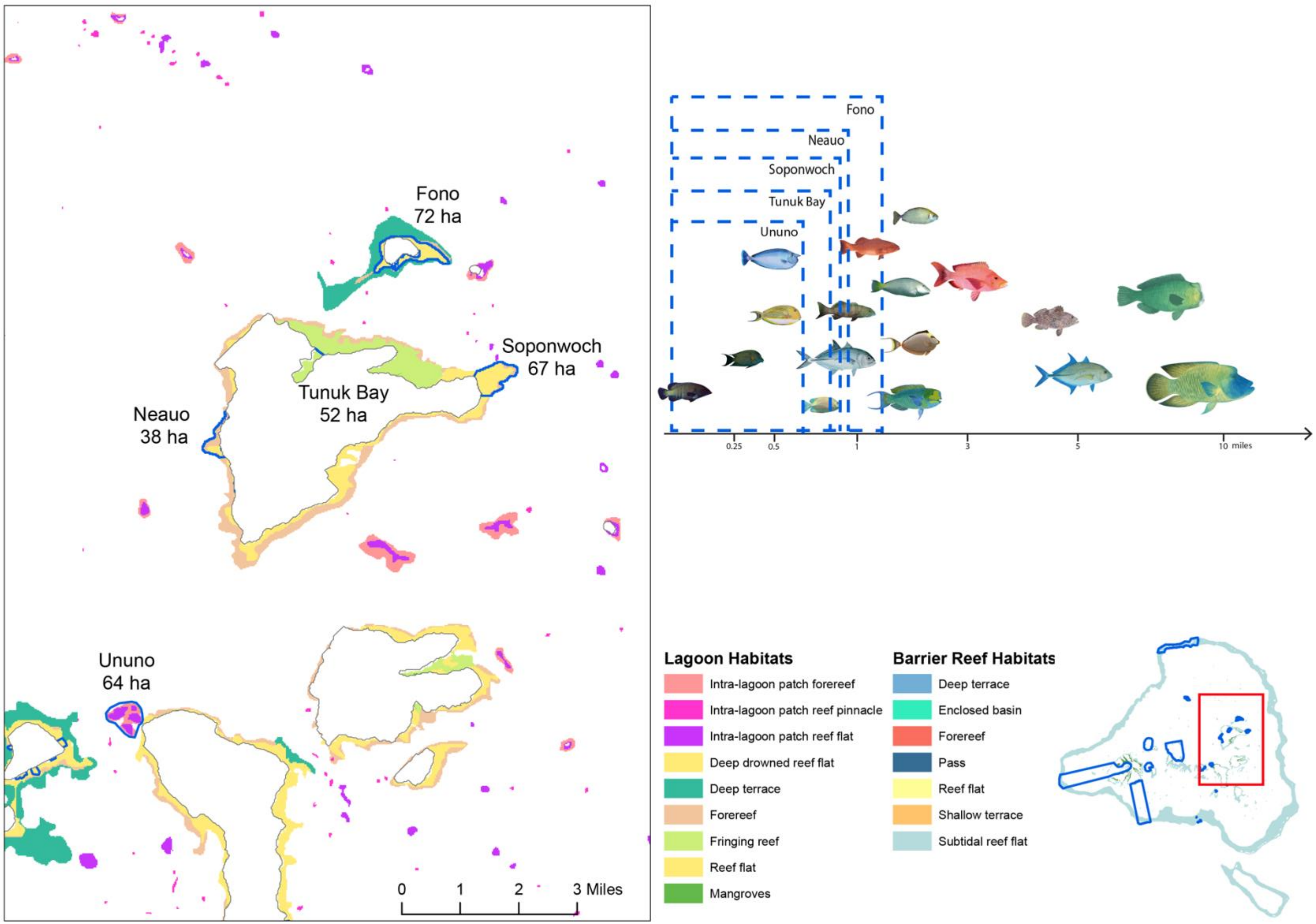
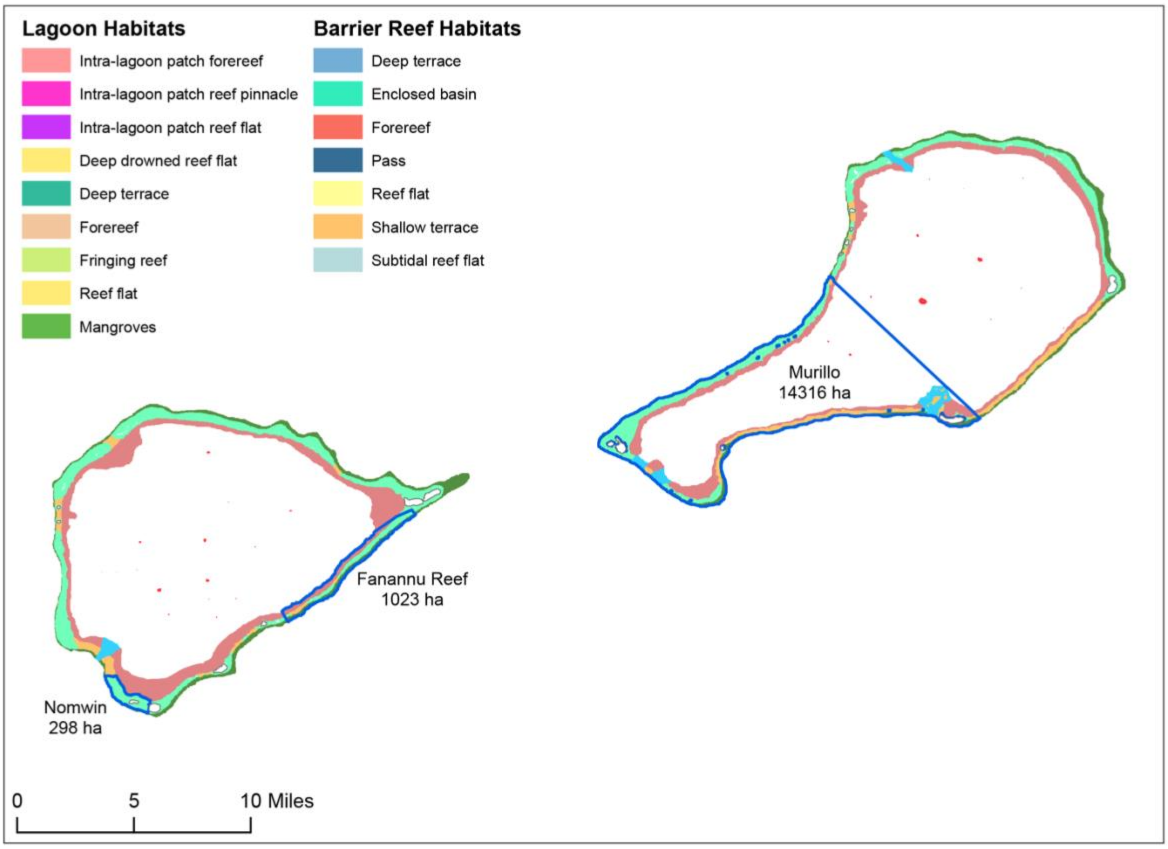
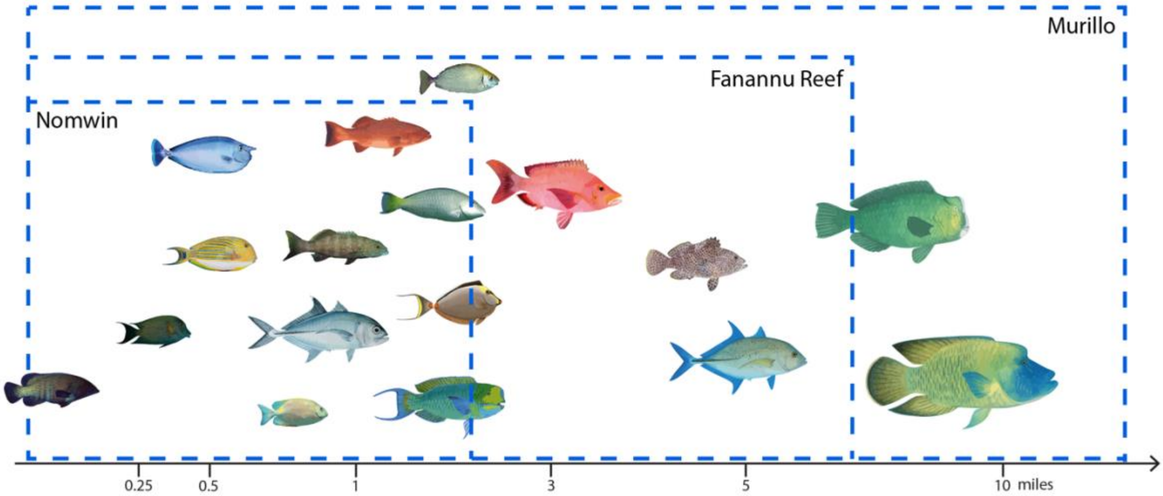
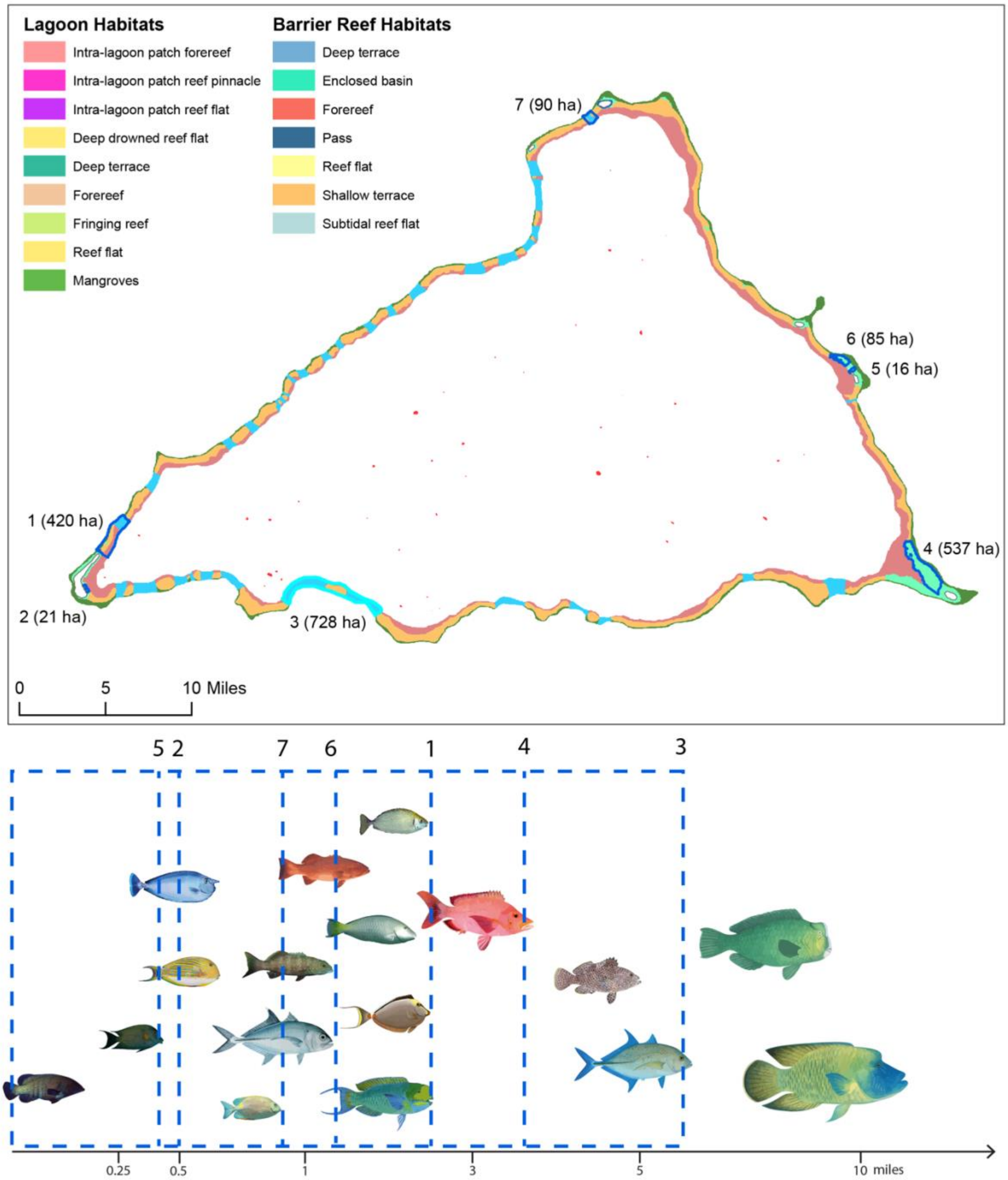
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat
Pianu Pass
6128 ha
Toleisom
3803 ha
Fanapenges
352 ha
Romolum
689 ha
0 1 2 3 4 5 6 Miles


Pianu Pass
Toleisom
Fanapenges
Romolum
0.25
0.5
1
3
5
10 miles


Fono
72 ha
Soponwoch
67 ha
Tunuk Bay
52 ha
Neauo
38 ha
Ununo
64 ha
0
1
2
3 Miles
Fono
Neauo
Soponwoch
Tunuk Bay
Ununo
0.25
0.5
1
3
5
10 miles
Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat


Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat
Murillo
14316 ha
Fanannu Reef
1023 ha
Nomwin
298 ha
0
5
10 Miles


Murillo
Fanannu Reef
Nomwin
0.25
0.5
1
3
5
10 miles


Lagoon Habitats
Intra-lagoon patch forereef
Intra-lagoon patch reef pinnacle
Intra-lagoon patch reef flat
Deep drowned reef flat
Deep terrace
Forereef
Fringing reef
Reef flat
Mangroves
Barrier Reef Habitats
Deep terrace
Enclosed basin
Forereef
Pass
Reef flat
Shallow terrace
Subtidal reef flat
7 (90 ha)
6 (85 ha)
5 (16 ha)
1 (420 ha)
4 (537 ha)
2 (21 ha)
3 (728 ha)
0
5
10 Miles
5 2
7
6
1
4
3
0.25
0.5
1
3
5
10 miles