Pohnpei's Protected Area Network: Gap Analysis & Spatial Prioritisation

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9 July 2015

EXECUTIVE SUMMARY

This report presents results from a gap analysis of Pohnpei's Protected Area Network and spatial prioritization analyses to identify priority areas to expand the existing network to fill representation gaps. These results are presented in support of efforts led by The Nature Conservancy (TNC) and the Conservation Society of Pohnpei (CSP) to improve the effectiveness of Pohnpei's protected areas.

At a broad resolution, Pohnpei's current protected area network achieves representation targets specified by the Convention on Biological Diversity and the Micronesia Challenge. However, coral reef habitats on Pohnpei's outer atolls are afforded much greater protection than those surrounding the man island, and some habitat types are underrepresented within the protected area network.

Of greater importance than achievement of international representation targets, is whether Pohnpei's protected area network achieves local objectives for "Healthy and abundant natural resources which sustain Pohnpei". Importantly, many marine protected areas are too small to effectively protect key fishery species of interest. Some of these species are afforded additional protection through size limits or seasonal sales bans, however these must be effectively enforced to have effect. Encouragingly, marine protected areas currently being designated, at Ant Atoll and Palaikir Pass, are better designed. Changing the boundaries of existing protected areas presents a greater challenge.

The effectiveness of protected areas in sustaining species and habitats within their boundaries requires that they be well managed. Monitoring data and stakeholders' perceptions indicates that management effectiveness is variable. Priority sites for improving management effectiveness are identified.

Spatial conservation prioritisation analyses were undertaken using the conservation planning software *Marxan with Zones*. Technical details of these analyses are included in an appendix. These results indicate priority areas for protected area network expansion, if representation of coral reef habitats surrounding the main island is to be improved. However, results should be interpreted with knowledge that they are dependent upon assumptions made about social and economic costs of protected area designation. Improving the data available on socioeconomic considerations, or at least refining the assumptions of the models used here, should be a priority for furthering conservation planning at the state level in Pohnpei. It should also be noted that habitat maps are available at a greater thematic resolution for marine habitats than terrestrial. Future efforts to improve the protected area network design would benefit from more detailed information on terrestrial conservation features, particularly mangroves.

Finally, the report includes as an appendix marine protected area "scorecards", which include site-specific information on the habitats included within each area, and species likely afforded protection. These can be used in discussions with communities as to how the design of individual marine protected areas might be improved.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

CONSERVATION PLANNING

Conservation planning is the process by which decisions are made regarding the location, design and management of areas to promote the conservation of biodiversity and sustain livelihoods that derive from its use. **Table 1** highlights key stages in a systematic conservation planning framework, emphasizing that the analytical processes of gap analysis and spatial prioritization (which are the focus of this report) should be bookended by stakeholder engagement, consultation and feedback.

Table 1. Key stages in the conservation planning process

1. Scoping & costing the planning process
2. Identifying & involving stakeholders
3. Describing the context for conservation areas
4. Identifying conservation goals
5. Collecting or collating data on biodiversity & other natural features
6. Collecting or collating data on socioeconomic variables & threats
7. Setting conservation objectives
8. Reviewing current achievement of objectives
9. Prioritizing additional conservation areas
10. Applying conservation actions to selected areas
11. Maintaining & monitoring conservation areas

Adapted from Pressey & Bottril 2009. Note that though the planning process is depicted as a linear sequence, in practice, some stages will be undertaken simultaneously and there will be many feedbacks from later to earlier stages.

A systematic conservation planning process can provide transparency in decision-making, efficiency in the use of limited resources, the ability to minimize conflict between diverse objectives, and to guide strategic expansion of local actions to maximize their cumulative impact. Nevertheless, any conservation planning process is limited by the quality of available information, and key datasets, particularly those representing social and economic considerations. Conservation planning should be an iterative process that uses the best available knowledge to make decisions. As such, plans may be revisited and revised as further information becomes available, for example on the spatial distribution and extent of biodiversity features, or the effectiveness of management actions. Map-based analyses should always be interpreted by experts and managers working in the area and supplemented with local knowledge before final decisions are made or actions taken.

Planning across regional scales allows for consideration of “the bigger picture”, of how a system of protected areas can work together to form a network that achieves more than the sum of its parts. Ideally protected area networks can be *complementary* in the features that they protect, and *connected* allowing individuals to move or disperse between protected areas. However, priorities identified through regional-scale analyses such as this one will need to be examined and refined at the local scale prior to implementation.

GAP ANALYSIS

At its simplest, a gap analysis is an assessment of the extent to which a protected area system meets conservation goals. The “gaps” are the difference between where the protected area system is now, and where we would like it to be. Gap analysis can be undertaken by overlaying a map of current protected and managed areas on to a map of biodiversity or other features of interest to conservation; this is usually done using a Geographic Information System (GIS).

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.

POHNPEI PROTECTED AREA NETWORK REVIEW: PROGRESS TO DATE

In June 2014 The Nature Conservancy (TNC), the Conservation Society of Pohnpei (CSP), and Pohnpei State Governor's Office convened a workshop to discuss the need to refine the design of Pohnpei's Protected Area Network (PAN). During this workshop (a report of the proceedings of which is available from TNC) stakeholders reviewed the context for conservation areas in Pohnpei (stage 3 in the conservation planning framework), identified conservation goals (stage 4), collated existing data on biodiversity features (there are few data available on socioeconomic variables & threats state-wide) (stages 5 & 6), and set conservation objectives for the PAN (stage 7).

In this section of the report, the outputs from the 2014 workshop are briefly summarized, to provide sufficient context for the following sections in which gap analysis (stage 8) and spatial conservation prioritization (stage 9) analyses are presented.

CONSERVATION FEATURES & REPRESENTATION TARGETS

High level conservation 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% 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 representative and well connected systems of protected areas and other effective area-based conservation measures.

Representation targets for conservation features of particular importance in Pohnpei were reviewed and agreed upon at the 2014 Protected Area Network workshop. An important output from this workshop was the Pohnpei PAN design principles presented in **Table 2**. These design principles make operational the conservation goals decided upon, by translating them (where possible) into quantitative representation targets which related to available datasets.

In addition to marine and terrestrial habitat representation targets, species-level targets were identified for reef fish spawning aggregations, turtle and seabird nesting sites, coconut crabs and the Pohnpei mountain starling (*Aplonis pelzelni*). Other features of interest could not be included in state-wide analyses, due to lack of spatial data. However, there may be opportunities to incorporate local knowledge of these features and their distributions in planning for individual protected areas.

The vision for Pohnpei's protected area network was described as: "Healthy and abundant natural resources which sustain Pohnpei".

Table 2. Design principles for Pohnpei's protected area network

Ecological Design Principles	Rationale	Proposed Application
1. Representation:		
Including 30% of each nearshore marine habitat [Figure 1] and 20% of each terrestrial habitat type [Figure 2] in protected areas	Since different species use different habitats, protection of all plants and animals and the maintenance of ecosystem health, integrity and resilience can only be achieved if adequate examples of each habitat are protected. Ensuring that all habitat types are represented in the PAN will also provide protection for species for which spatial data are not available	30% representation target for all marine habitat features [Figure 1] Minimum 20% representation target for terrestrial habitat features [Figure 2]
2. Risk Spreading:		
Include examples of each habitat type within each municipality	This minimizes the risk that all examples of a habitat will be adversely impacted by the same disturbance. Including examples from each municipality will also capture any differences in habitat or species composition in different parts of the main island, and on atolls.	Stratify habitat features by municipal boundaries
3. Protecting Critical, Special and Unique Areas:		
Fish spawning aggregation sites: Kehpara Palikir Pass Mwand Pass Nanwap Nanwap nearshore	When animals aggregate they are particularly vulnerable and often, the reasons they aggregate are crucial to the maintenance of their populations. Therefore the main sites where they aggregate must be protected to help maintain and restore populations	Include in PAN as: Year-round no take Seasonal protection Year-round no take 100% keep protected Seasonal protection
Nursery areas for key fisheries species	It is important to protect the range of habitats that species use throughout their lives, particularly areas that they use during critical life history phases (nursery areas, fish spawning aggregations and migration corridors among them)	30% representation target for mangroves (critical nursery habitat for fish species)
Important fishery species	Key objective of PAN is to ensure sustainability of key fishery species, and livelihoods dependent upon those species. Therefore the PAN must be designed to incorporate critical habitats for these species.	Representation targets for key habitats; where MPAs are not large enough, supplement with other fisheries management approaches
Wetlands Mangroves Palm forest Upland forest	Identified as critical habitats that play an important role in ecosystem functioning or are unique to Pohnpei.	At least 20% representation of palm forest habitat; 30% representation target for mangroves
Special, unique, endemic and locally important species	Key objective of PAN to protect special and unique species of local and cultural value	Feature specific targets

Ecological Design Principles	Rationale	Proposed Application
4. Adapting to Changes in Climate:		
Prioritizing for protection mangrove areas that have room for landward expansion / range shift	This will minimize the risk of mangrove loss due to sea level rise, associated with climate change and already observed in Pohnpei.	Use Digital Elevation Model to identify mangroves with room to move, and preferentially include these when meeting representation targets
5. Incorporating Connectivity:		
Using best available information on movement patterns of important fishery species· to determine the size, spacing and location of no-take marine protected areas	To be effective, marine reserves must be large enough to sustain target species within their boundaries. Spacing reserves to allow for connectivity among populations helps maintain fish stocks, diversity and builds ecosystem resilience by ensuring that marine reserves are mutually replenishing to facilitate recovery after disturbance.	Use information on movement patterns of important fishery species· to set design criteria for minimum MPA sizes
Protect key habitats used by focal species throughout their lives (e.g. mangroves, coral reefs and seagrass) and ensure PAs are spaced to allow for movements among them	Some species use different habitats for foraging and resting, or during different life history stages. To protect these species effectively, all habitats that they use must be included in the PAN.	Included in habitat representation targets above.
Prioritize for protection wetlands, mangroves (Figure 3) and marine habitats that are downstream of rivers with good water quality	Poor water quality may have adverse impacts on the ecological quality of ecosystems downstream. Ideally, high quality habitats should be protected, as these are more likely to support healthy and diverse ecological communities	Identify habitats that are downstream of watershed with water quality rated as "safe for recreation", and preferentially include these when meeting representation targets
6. Allowing Time for Recovery:		
Implement year-round MPAs, except where identified as seasonal closures to protect vulnerable life history stages (e.g. spawning) of key fishery species.	Benefits of improved ecosystem function and fisheries productivity can be quickly lost when marine reserves revert back to open access	Include in management plans for MPAs

·Important fishery species: Rabbitfishes, e.g. Pwoarin Mwomw (*Siganus doliatus*); Arong - Jacks and Trevallies; Mwomw Mei (*Hipposcarus longiceps*); Kemeik (*Bolbometopon muricatum*); Ah -Mullet; Merer (*Cheilinus undulatus*); Sopwou (*Ophiocara porocephala*); Kihs - Octopus ; Lipwei - bivalve sp.; Kopil - bivalve sp.; Pahsu - giant clam; Masaht - land crab; Loangon - elephant trunk fish; Penpen - st. species (sea cucumber); Werer - Pohnpei Speg (sea cucumber); Sumwumw – trochus.

Marine conservation features

Coral reef habitat information was based on a reclassification of the IMARS Millennium Coral Reefs Data[1]. Seagrass data were derived from a Rapid Ecological Assessment conducted by Seagrass Watch & CSP in 2005. Further details are provided in the technical appendices.

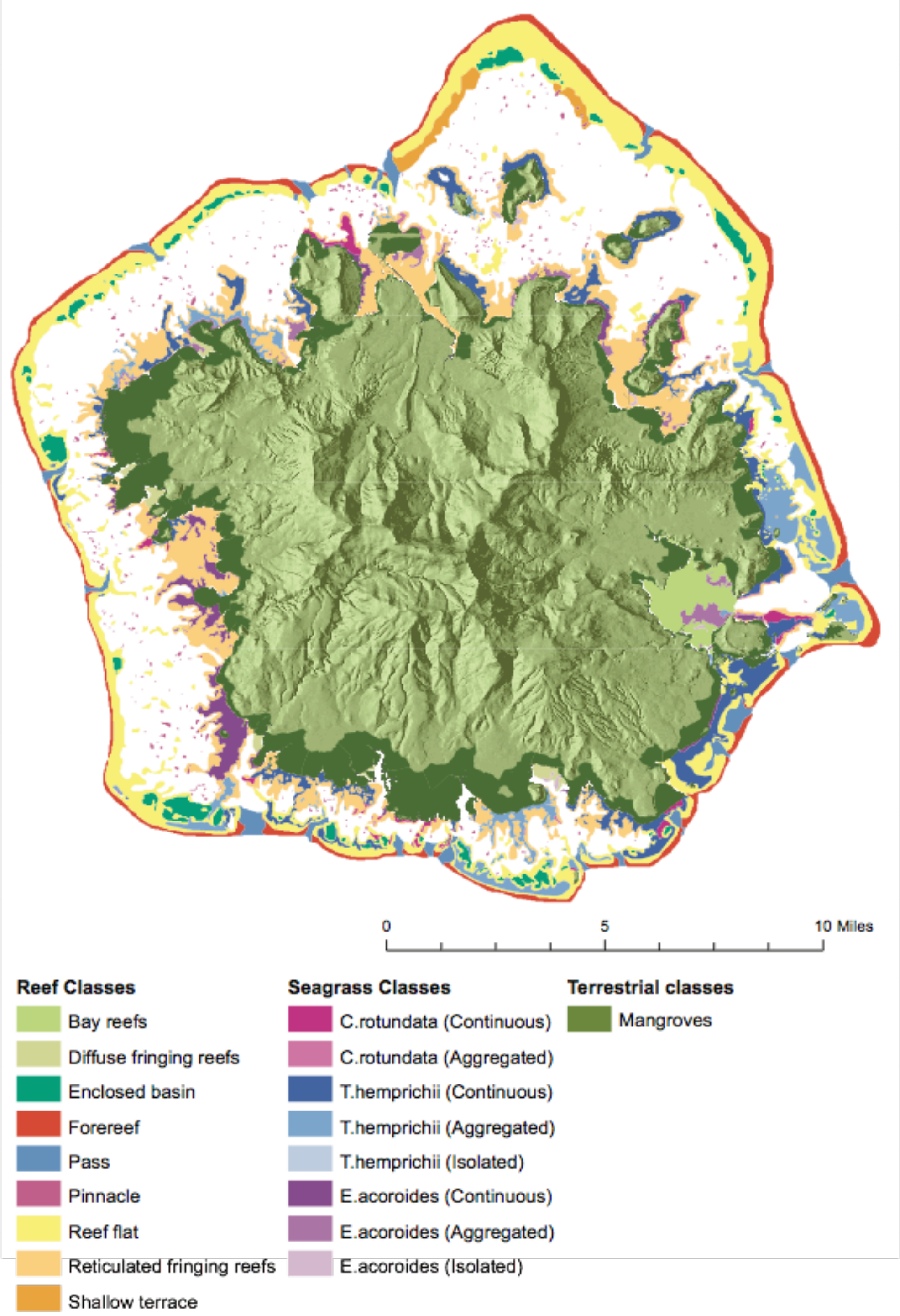


Figure 1a. Marine conservation features around Pohnpei main island

[1] Millennium Coral Reef Mapping Project validated maps provided by the Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF) and Institut de Recherche pour le Développement (IRD, Centre de Nouméa), with support from NASA.

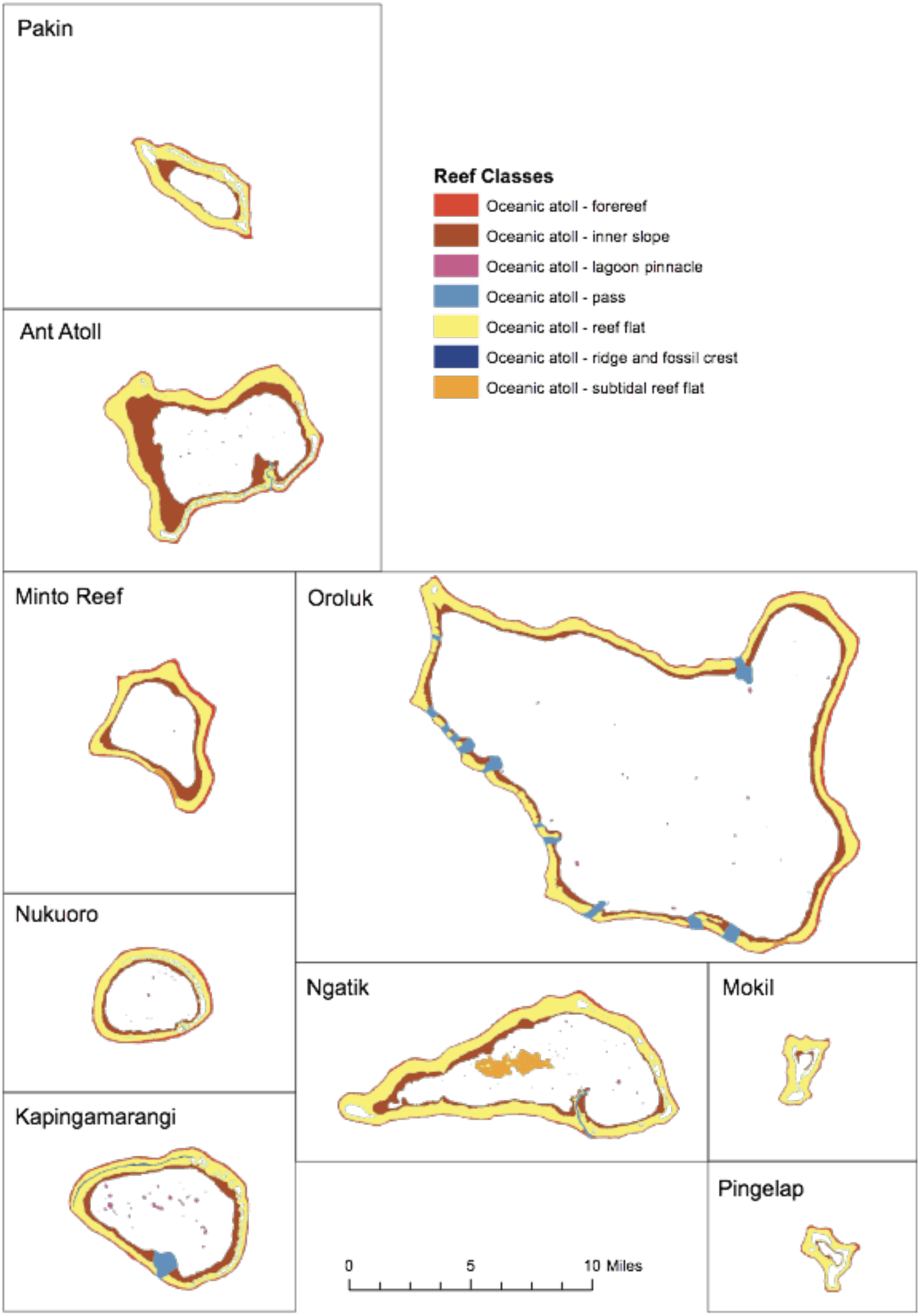


Figure 1b. Marine conservation features, Pohnpei outer islands & atolls

Terrestrial conservation features

Terrestrial conservation features were derived from US Department of Agriculture Landcover data. Mangrove areas predicted to have good water quality (**Figure 3**, next page) were identified from water quality surveys conducted by CSP: mangroves downstream from rivers found to have water quality levels rated as unsafe for recreation were marked as poor quality.

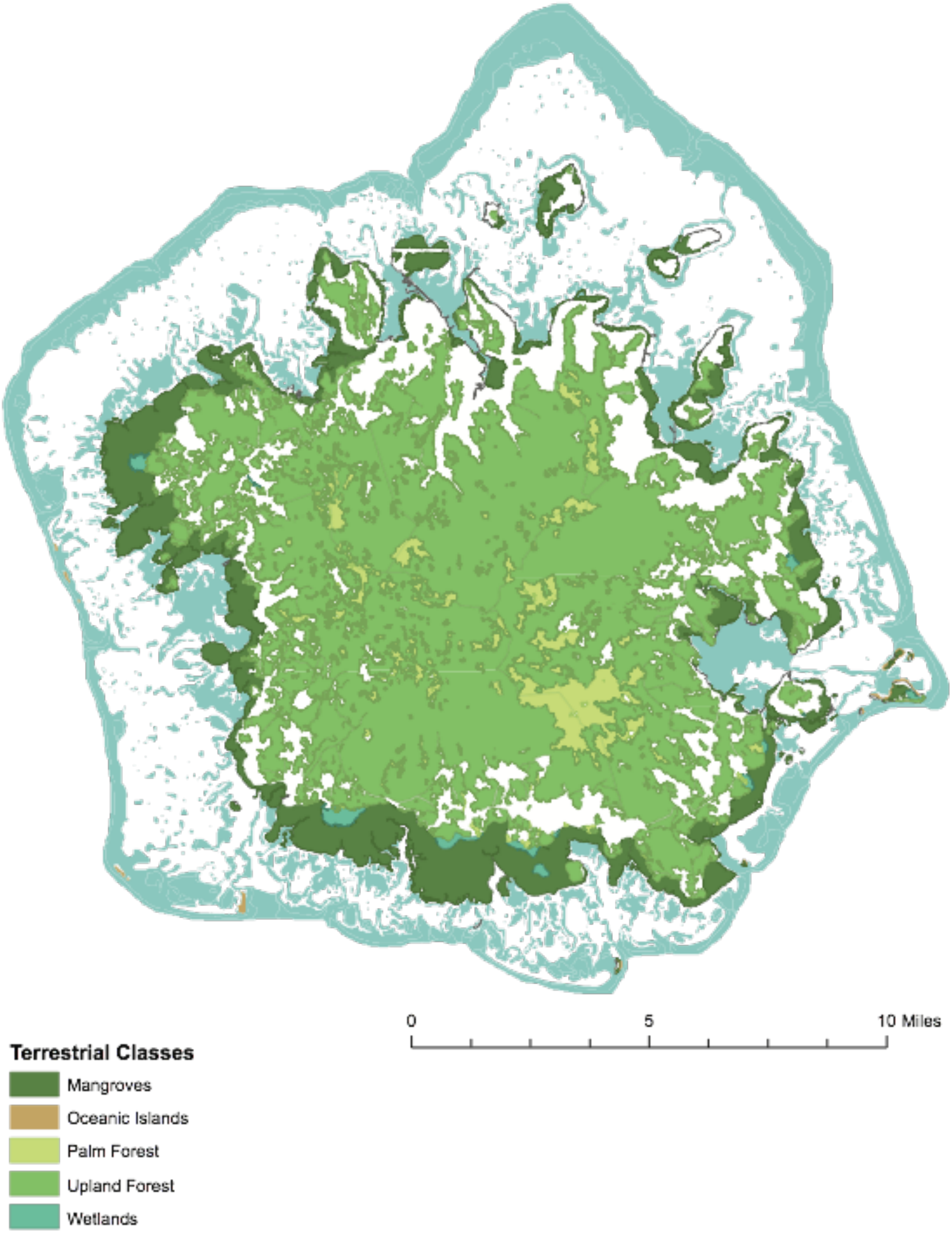


Figure 2. Terrestrial conservation features around Pohnpei main island

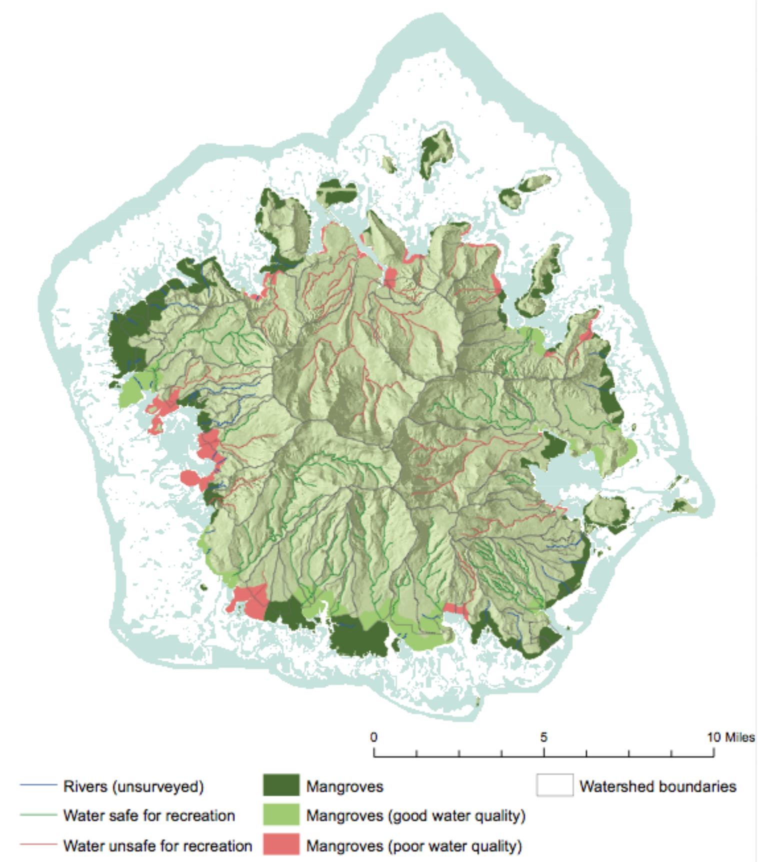


Figure 3. Mangrove habitat quality, derived from water quality surveys around Pohnpei and watershed modeling.

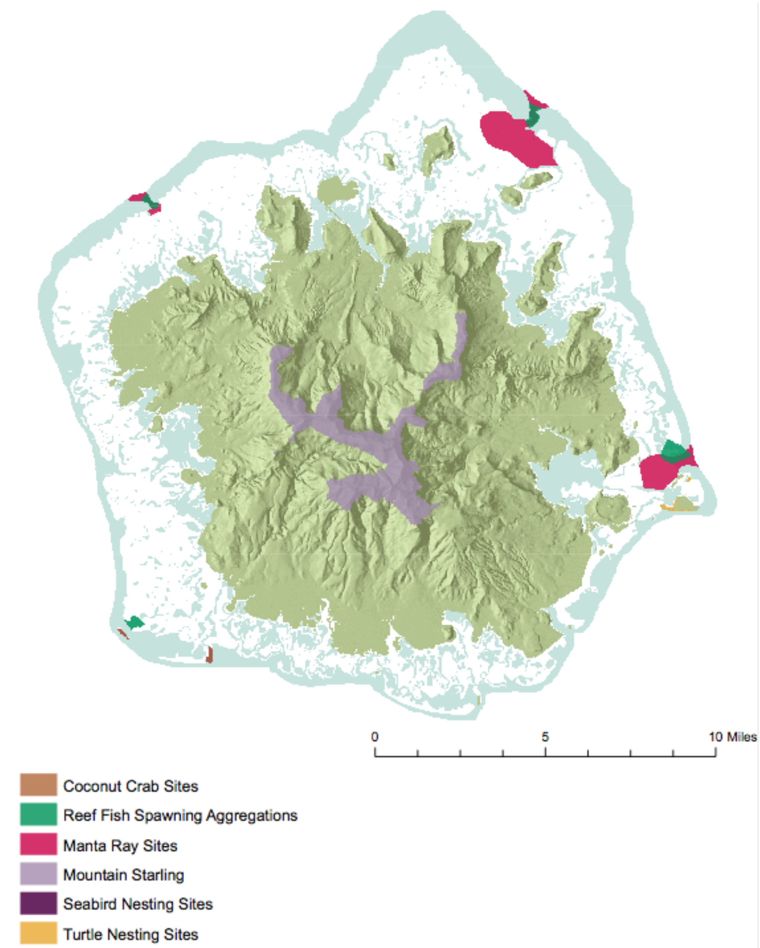


Figure 4. Species-level conservation targets identified at the 2014 workshop. Data layers are from previous iterations of conservation planning in Pohnpei.

EXISTING AND PROPOSED PROTECTED AREAS

The locations and boundaries of existing and proposed protected areas in Pohnpei state are shown in Figures 5a and 5b on the following pages.

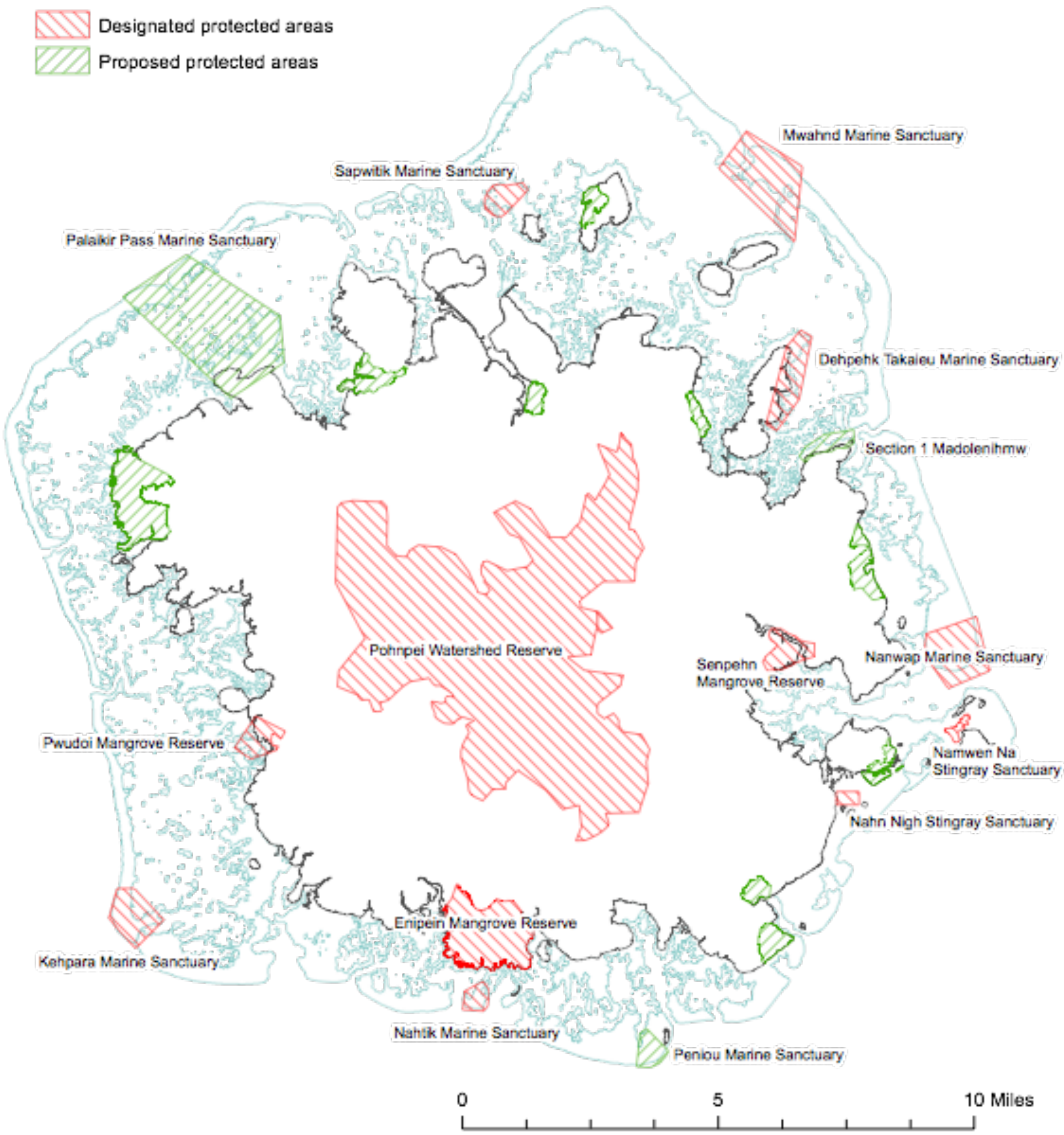


Figure 5a. Existing and proposed protected areas, Pohnpei Main Island

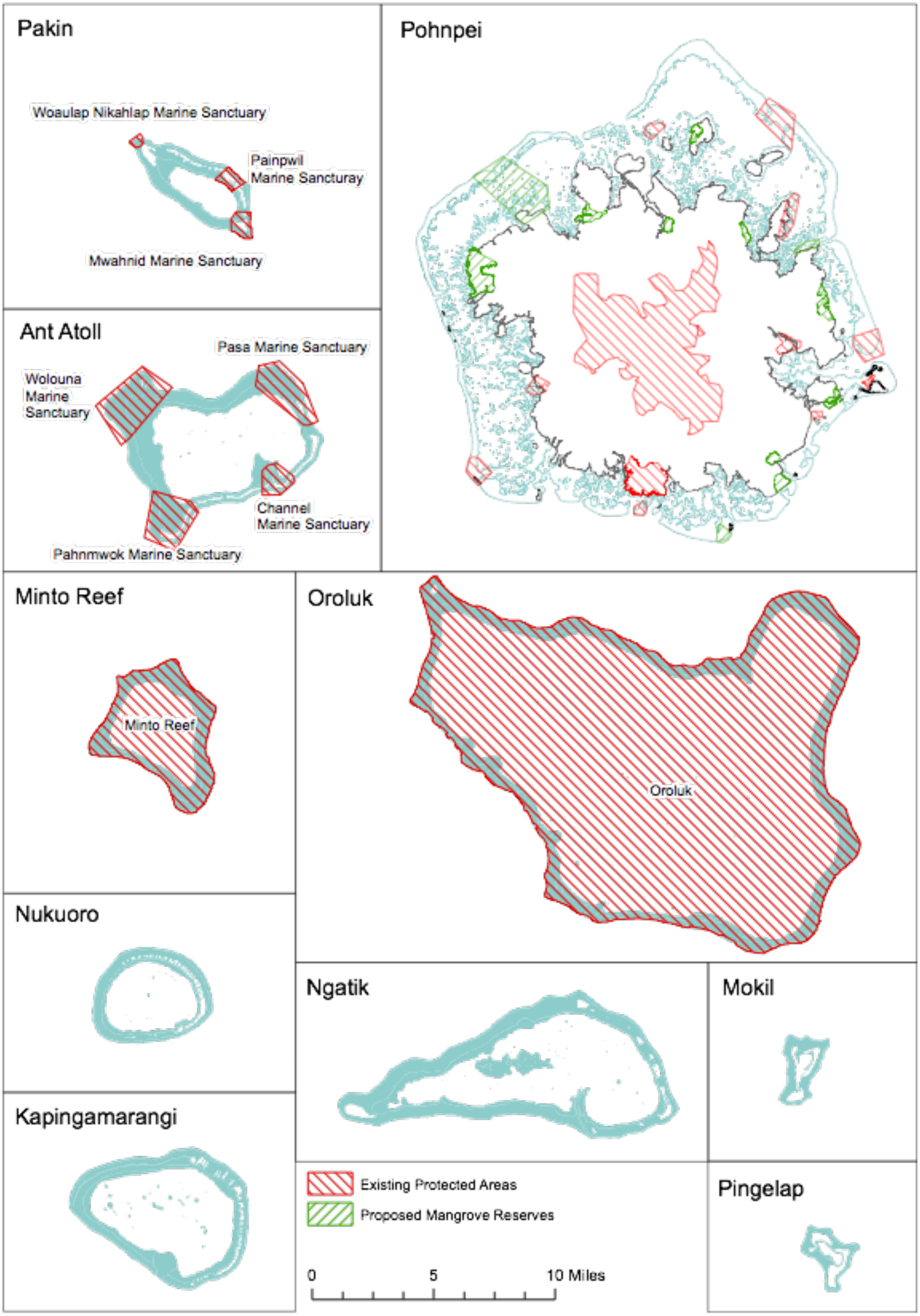


Figure 5b. Existing and proposed protected areas, Pohnpei

REPRESENTATION GAPS

Pohnpei currently achieves (and exceeds) the targets specified in the Micronesia Challenge, with 30% of near-shore marine habitats and 25% of terrestrial habitats within the protected area network (**Table 3** and **Figure 6**). However, if we look more closely at individual habitat types, the extent to which they are represented within the protected area network is highly variable (**Table 3** and **Figure 6**).

- Atoll reefs are afforded far greater protection (46%) than those around the main island of Pohnpei (6%).
- Due to the large Watershed Forest Reserve, palm forest and upland forest habitats are well represented, however mangroves and wetlands do not achieve their representation targets.
- The proposed mangrove reserves would greatly increase the proportion of mangroves protected, from 13% to 31%.
- All coral reef classes on main island reefs fall below their representation targets, and some classes are absent from the current protected area system. These representation gaps suggest that either existing MPAs around Pohnpei main island need to be made larger, or additional areas need to be designated.
- Seagrass habitats also require increased protection. Only 5% of seagrass meadows are within protected areas, and most of these of a single community type dominated by *C.rotundata*. Seagrass meadows act as nursery grounds for fish and invertebrates of commercial and artisanal fisheries importance, and benefit nearby corals by reducing sediment loads in the water (McKenzie & Rasheed, 2006).
- It should be noted that, though mangroves are considered as a terrestrial habitat for the purposes of the gap analysis, they also form a critical habitat for many important marine species, either as adults (e.g. crabs) or juveniles (many fishes). Thus, representing mangroves within the PAN contributes towards both marine and terrestrial conservation objectives.

Table 3. Conservation targets and their representation within Pohnpei's existing protected area network

Habitat type	*Total area (ha)*	*Representation target*	*Percentage protected in existing PAs*	*Percentage protected in existing + proposed PAs*
Marine	**47429**	**30%**	**30%**	**32%**
Main Island Reefs	14241	30%	6%	9%
Bay exposed fringing reef	593	30%	3%	3%
Diffuse fringing reef	153	30%	0%	0%
Enclosed basin	810	30%	3%	6%
Forereef	1634	30%	5%	7%
Reef pass	685	30%	12%	16%
Reef pinnacle	187	30%	0%	7%
Reef flat	5505	30%	9%	12%
Reticulated fringing reef	4419	30%	3%	7%
Shallow terrace	255	30%	0%	0%
Atoll Reefs	28864	30%	46%	46%
Atoll forereef	3732	30%	49%	49%
Atoll inner slope	8066	30%	50%	50%
Atoll lagoon pinnacle	133	30%	25%	25%
Atoll pass	1037	30%	66%	66%
Atoll reef flat	15284	30%	44%	44%
Atoll ridge and fossil crest	46	30%	0%	0%
Atoll subtidal reef flat	566	30%	17%	17%
Seagrass	4324	30%	5%	9%
C.rotundata	283	30%	12%	12%
E.acoroides	990	30%	2%	4%
T.hemprichii	3051	30%	5%	11%
Terrestrial	**27000**	**20%**	**25%**	**29%**
Mangroves	5622	30%	13%	31%
Palm forest	1830	20%	65%	65%
Upland Forest	19316	20%	25%	25%
Wetlands	232	20%	0%	0%
Oceanic Atoll	1576	20%	16%	16%
Oceanic Island	51	20%	9%	9%

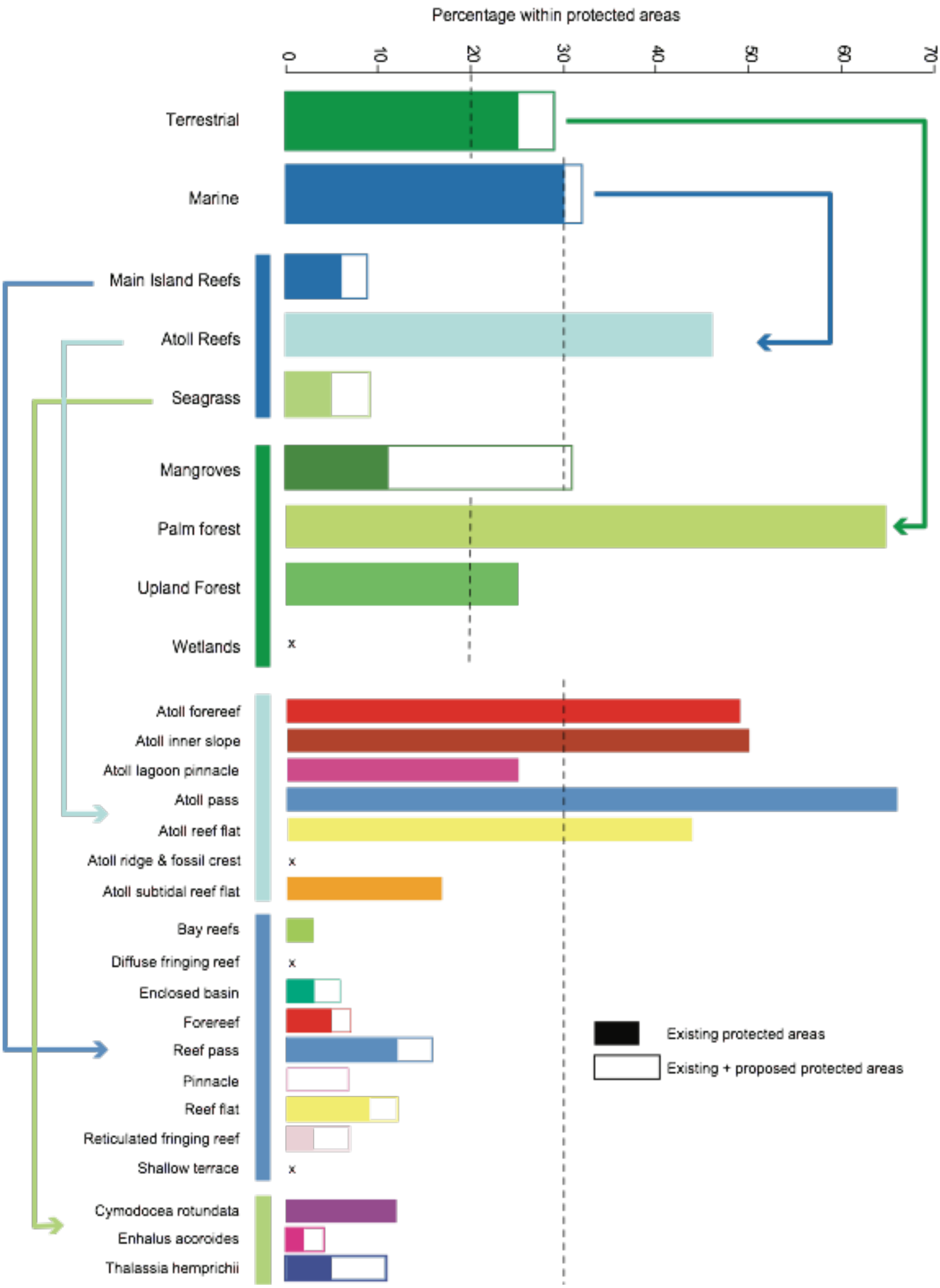


Figure 6. Representation gap analysis of marine and terrestrial habitat types in Pohnpei's protected area network

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? Few data are available on the spatial distribution or conservation requirements of terrestrial species of interest, so this analysis focuses on the adequacy of Pohnpei's marine protected areas.

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.*, 2014[2]). This will ensure that the reserve includes the entire home range of at least one individual, and will likely include many more where individuals have overlapping ranges.

Key fishery species of interest were identified by stakeholders at the 2014 Protected Area Network Design workshop. From this list, those for which movement data are available, or could be substituted from species of similar size and behavior also found in Micronesia, are listed in **Table 4**, along with the recommended minimum MPA size to protect that species.

Comparison with the size of MPAs in Pohnpei (**Figure 7**) highlights that many MPAs are too small to protect many species of interest.

- **Only species with very small home ranges, such as *Siganus doliatus* and *Cephalopholis argus* are likely to be well protected in the existing network**.
- 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[3]) 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,

[2] Green, A. L., Maypa, A. P., Almany, G. R., Rhodes, K. L., Weeks, R., Abesamis, R. A., et al. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. Biological Reviews. doi:10.1111/brv.12155

[3] Olds, A. D., Albert, S., Maxwell, P. S., Pitt, K. A., & Connolly, R. M. (2013). Mangrove-reef connectivity promotes the effectiveness of marine reserves across the western Pacific. Global Ecology and Biogeography, 22(9), 1040–1049. doi:10.1111/geb.12072

seagrass and coral reef habitats within their boundaries, or are within close proximity to these) are likely to provide better protection for these species.

- Many key fishery species of importance to Pohnpei aggregate to spawn. As indicated in **Table 2**, a representation target to include known fish spawning aggregation sites in Pohnpei's protected area network has not been specified, as other management tools, for example seasonal closures, are also used to manage these sites. **How these other management strategies interact with the spatial design of the PAN should be carefully considered.**

Table 4. Key fisheries species of interest, and recommended minimum MPA sizes

Species	English name	Pohnpei name	Recommended minimum MPA size (linear distance in miles)[a]
Naso unicornis	Bluespine unicornfish	pwilak / pwulak	0.6
Naso lituratus	Orangespine unicornfish	pwulangkin	2.5
Caranx melampygus	Bluefin trevally	oarongen / arong	7
Cephalopholis argus	Peacock hind	mwoalusulus / mwoalus	0.06
Epinephelus fuscoguttatus	Brown-marbled grouper		2.5 [b]
Plectropomus areolatus	Squaretail coralgrouper	ewen sawi / oawen sawi	1
Cheilinus undulatus	Humphead wrasse	merer	10
Bolbometopon muricatum	Bumphead parrotfish	kemeik	3
Chlorurus microrhinos	Steephead parrotfish		2.5
Hipposcarus longiceps	Pacific longnose parrotfish	mwomw mei	2.5 [b]
Lutjanus gibbus	Humpback red snapper	pwahlahl	2.5 [b]
Siganus doliatus	Barred spinefoot	pwoarin mwomw	0.25
Siganus punctatus	Gold-spotted rabbitfish	palapal	2 [b]

[a] Based on 2 x home range movement of species
[b] No data available, so substituted from species of similar size and behavior

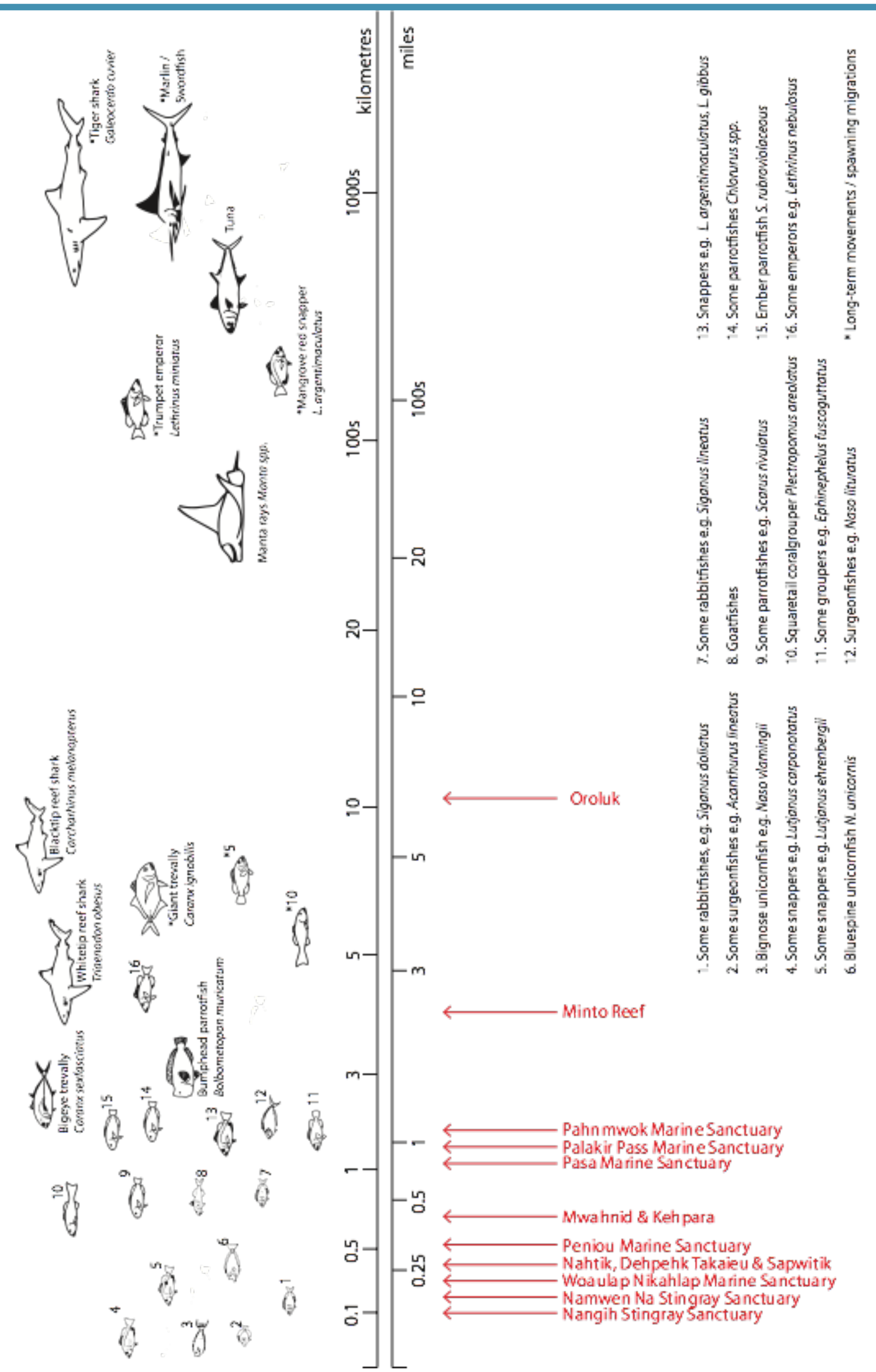


Figure 7. Home range movements of coral reef and coastal pelagic fish species and effective sizes of marine protected areas in Pohnpei.

(Fish movement data from Green, A. L., et al. (2014). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. Biological Reviews. doi:10.1111/brv.12155)

SPATIAL CONSERVATION PRIORITIZATION

PLANNING UNITS

To facilitate the prioritization analysis, 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 network, or left open to alternative uses. Planning units were created as a 5 hectare (12.4 acres) hexagonal grid covering the extent of all marine and terrestrial habitat features within Pohnpei's state boundary (planning units for the main island are shown in **Figure 8**).

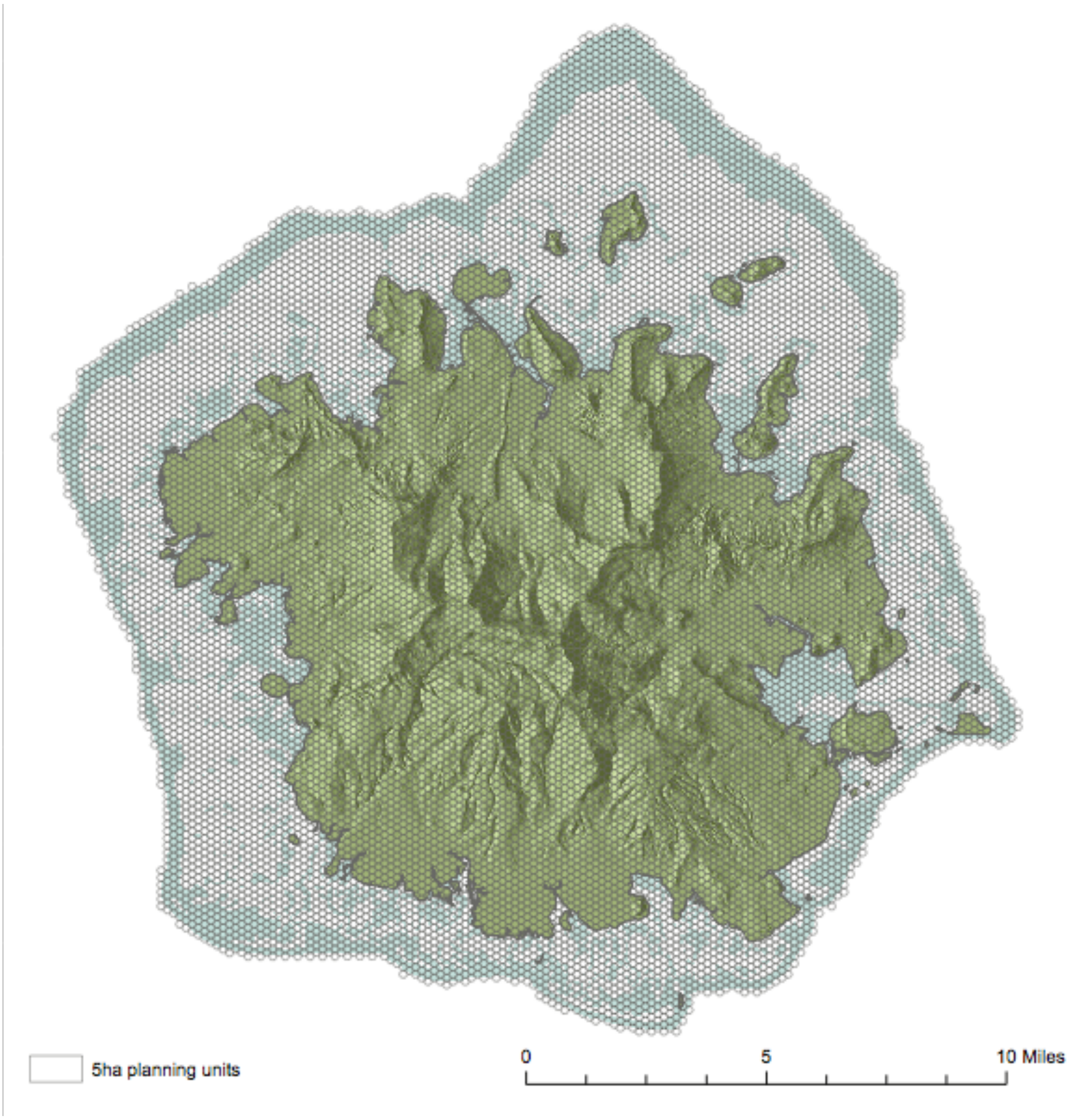


Figure 8. Planning units for the main island of Pohnpei

RESERVE DESIGN 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. 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 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. 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. For all scenarios presented, the BLM was used after calibration following best practice guidelines (more details in technical appendices).

FEATURE REPRESENTATION TARGETS

Targets for feature representation were the same as used in the gap analysis, presented in **Table 3**. For some feature-specific scenarios (see **Table 5**) a subset of these features only were targeted for representation.

OPPORTUNITY COSTS

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). It is assumed that minimizing stakeholders' opportunity costs will increase the likelihood that they will support and subsequently comply with conservation actions. In addition to improving the likelihood that conservation plans can be successfully implemented, incorporating social and/or 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).

For Pohnpei, two opportunity cost layers, one each for marine and terrestrial habitats, were created:

Terrestrial opportunity costs

The cost layer used for terrestrial areas reflects opportunities for protected area implementation. It was assumed that locations proximate to existing urban areas and infrastructure would have less likelihood of successful protected area implementation. This both anticipates potential future development of land adjacent to existing infrastructure, and accounts for the likely lower ecological value of those habitats.

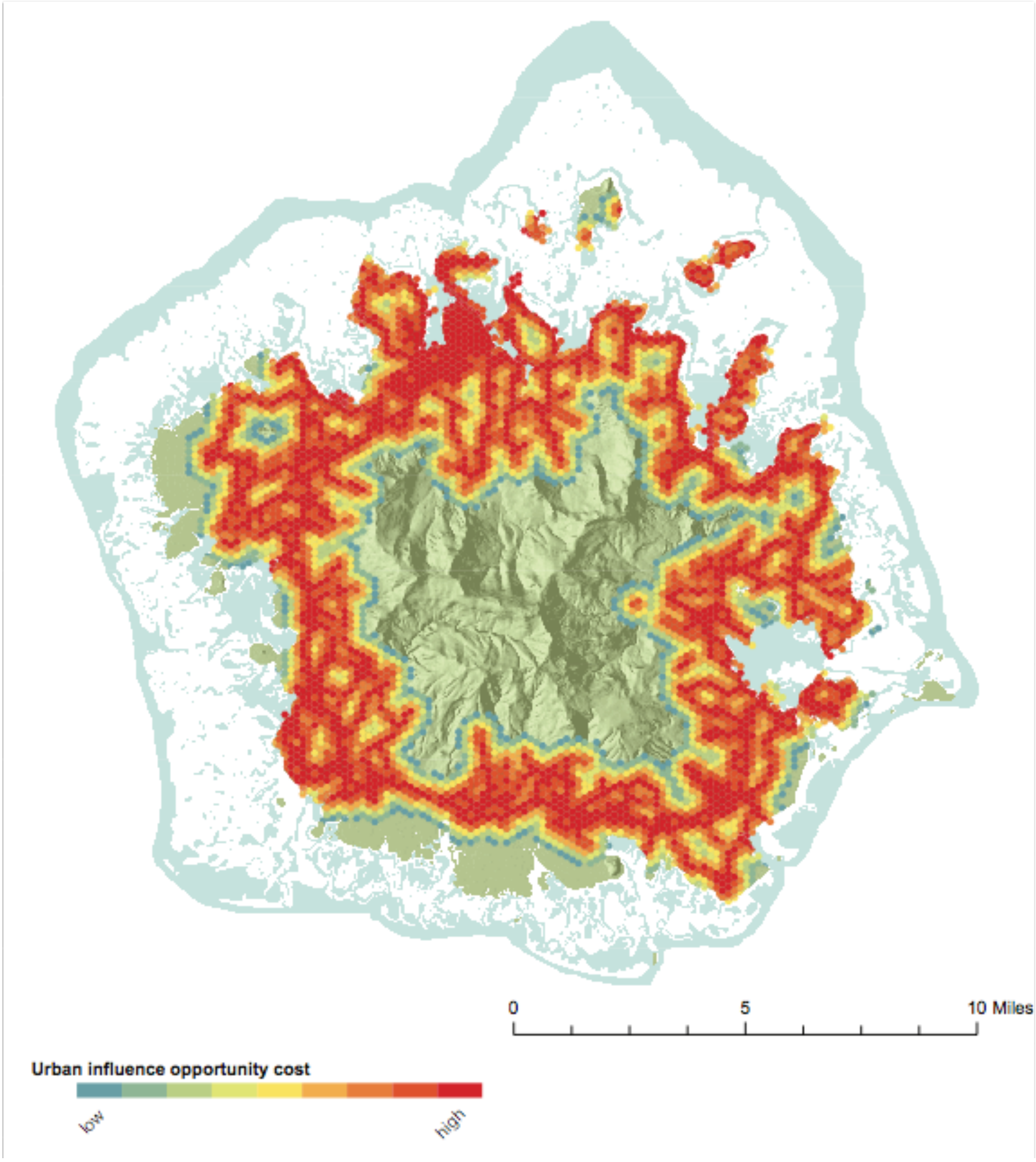


Figure 9. Terrestrial opportunity cost on Pohnpei main island, based on proximity to urban areas and infrastructure.

Marine opportunity costs

It was considered most important to minimize negative impacts on households that consume at least part of their catch, given that this might contribute towards food security. Areas closer to the coastline are assumed to have higher cost than those further offshore (out to 6 miles) and areas adjacent to populated places with greater relative proportion of households catching reef fish for consumption are assumed to have higher cost than areas adjacent to populated places with fewer households catching and consuming reef fish.

Previous work has demonstrated that surrogates based on the number of fishers in each community outperform those based on demographic data alone[4]. Nevertheless, this data does not account for heterogeneity in fishing practices between communities (e.g. boat ownership, fishing gear usage) or other factors that typically determine the spatial distribution of fishing effort (e.g. habitat productivity, traditionally important or favored fishing grounds, exposure to weather conditions etc.). It is hoped that ongoing small-scale fisheries surveys can provide improved data on the spatial distribution of fishing effort around Pohnpei, or at a minimum improve assumptions about travel distances and identify particularly important fishing grounds.

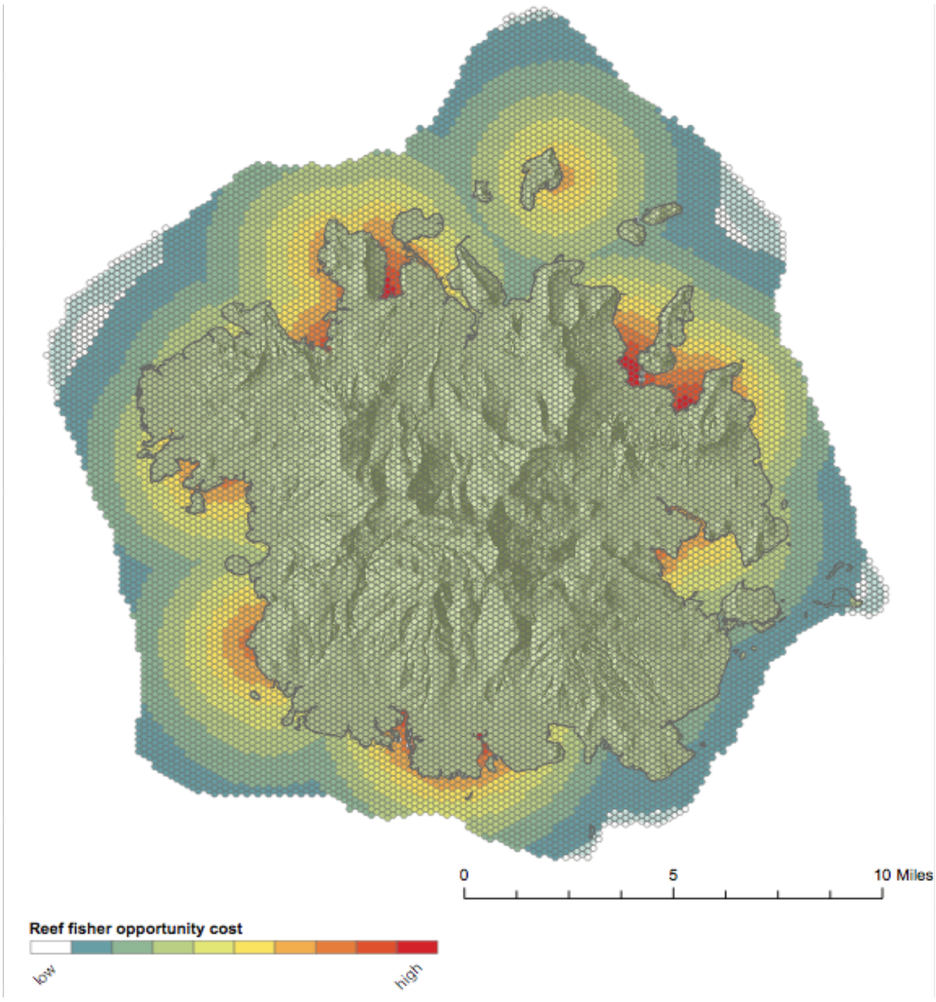


Figure 10. Marine opportunity costs around Pohnpei main island, based on the number of households catching reef fish for consumption

[4] Weeks, R., Russ, G. R., Bucol, A. A., & Alcala, A. C. (2010). Shortcuts for marine conservation planning: The effectiveness of socioeconomic data surrogates. *Biological Conservation*, *143*(5), 1236–1244. doi:10.1016/j.biocon.2010.02.031

PLANNING SCENARIOS

To explore different options for refining the design of Pohnpei's PAN, various different scenarios were run using Marxan (**Table 5**). These scenarios allow exploration of different representation targets, approaches to dealing with existing protected areas, and assumptions about cost, and thus provide more information to assist in decision-making. However, caution should be exercised when presenting outputs to stakeholders, so as not to overwhelm them with too much information. The most informative results should be selected, or key differences summarized, to facilitate comprehension by those unfamiliar with the technical aspects of the planning process.

Existing protected areas were either ignored (to provide a "clean slate" option), "locked in" to solutions (meaning that they must be included), or assigned a zero cost value (meaning that there is a strong preference to include existing reserves, but they do not have to be included.

Given that the opportunity cost data were derived from relatively coarse assumptions about spatial patterns of resource use, alternative scenarios use a basic assumption that planning unit cost is equal to planning unit area. This presents priorities from a conservation perspective without "second guessing" which areas might be important to resource users. Comparing outputs from scenarios using different cost layers illustrates the extent to which socioeconomic considerations influence spatial priorities.

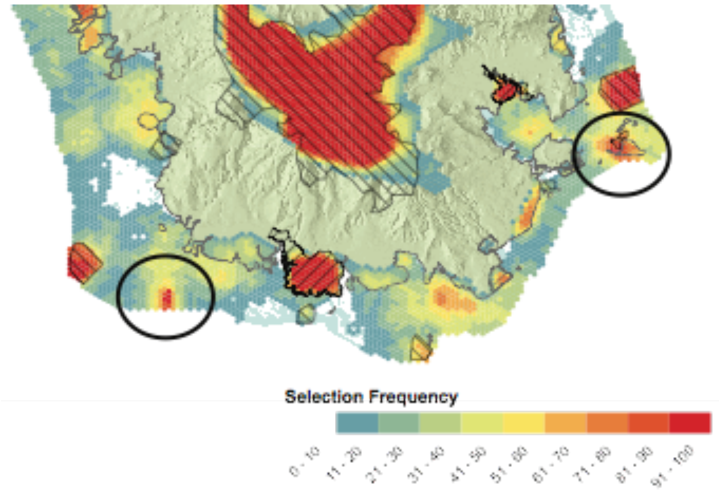
Table 5. Spatial prioritization scenarios

Scenario	Conservation Targets	Existing protected areas	Costs
1b (clean slate)	Pohnpei Workshop	Ignored (clean slate)	Area
2b (fill gaps - areacost)	Pohnpei Workshop	Locked in	Area
2c (fill gaps oppcost)	Pohnpei Workshop	Locked in	Opportunity cost
3a (clean slate oppcost)	Pohnpei Workshop	Ignored (clean slate)	Opportunity cost
3c	Pohnpei Workshop	Existing reserves have zero cost; Increase reserve size where beneficial	Area
3e	Pohnpei Workshop	Existing reserves have zero cost; Do not increase existing reserve size	Opportunity cost
3f	Pohnpei Workshop	Existing reserves have zero cost; Increase reserve size where beneficial	Opportunity cost
3g	Pohnpei Workshop	Existing reserves have zero cost; Increase the size of small reserves only	Opportunity cost
Scenario 8. Seagrass priorities	Seagrass targets only	Existing and proposed PAs locked in	Opportunity cost
Intermediate targets	Marine habitat targets at 20%	Existing and proposed PAs locked in	Area

RESULTS

To reduce processing time, the planning region was divided into two subregions: Pohnpei Main Island, and Outer Islands & Atolls. No conservation targets are common to both subregions (as the habitat types found in each differ), and so the analyses can be run as two parallel prioritisations without loss of efficiency. The initial results presented here focus on conservation prioritization for the main island sub-region only, as the gap analysis indicated greatest need to fill representation and ecological gaps in this area.

For each scenario, the summed selection frequency across 100 runs and three individual solutions are presented. The selection frequency results indicate areas that are likely to be important to achieve the conservation objective; warmer colors (e.g. red, yellow) indicate that a planning unit would be more likely to contribute to meeting the desired targets, whereas cooler colors (e.g. blue, dark blue) suggest that a planning unit would be less likely to be part of a potential planning solution. The individual solutions indicate the variety of different spatial solutions that can achieve the conservation planning problem posed in each scenario.



Note that some areas have high selection frequency under every scenario. In some cases (e.g. the two areas highlighted left) this is due to the presence of a feature with a 100% representation target (e.g. turtle and seabird nesting beaches), which means that these planning units must be selected to achieve conservation targets.

Existing and proposed protected areas are shown overlaid on all scenarios for quick reference.

It should be noted that **Marxan does not consider whether the size of individual protected areas is adequate for the species they are designed to protect.** Consequently the spatial priorities identified in these analyses should be combined by information from **Table 4** to ensure that protected areas are adequate.

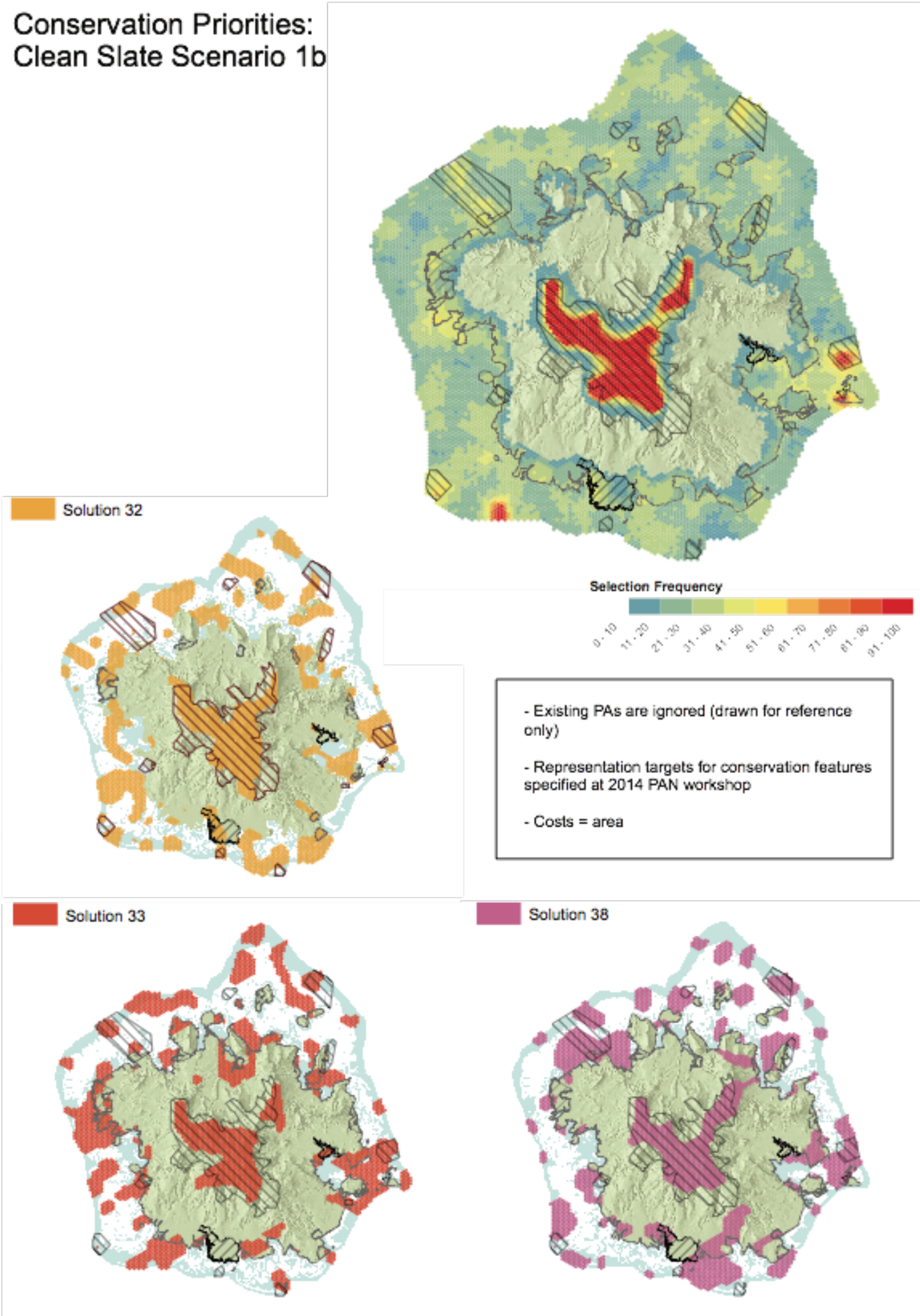


Figure 11. Results for Scenario 1b - clean slate

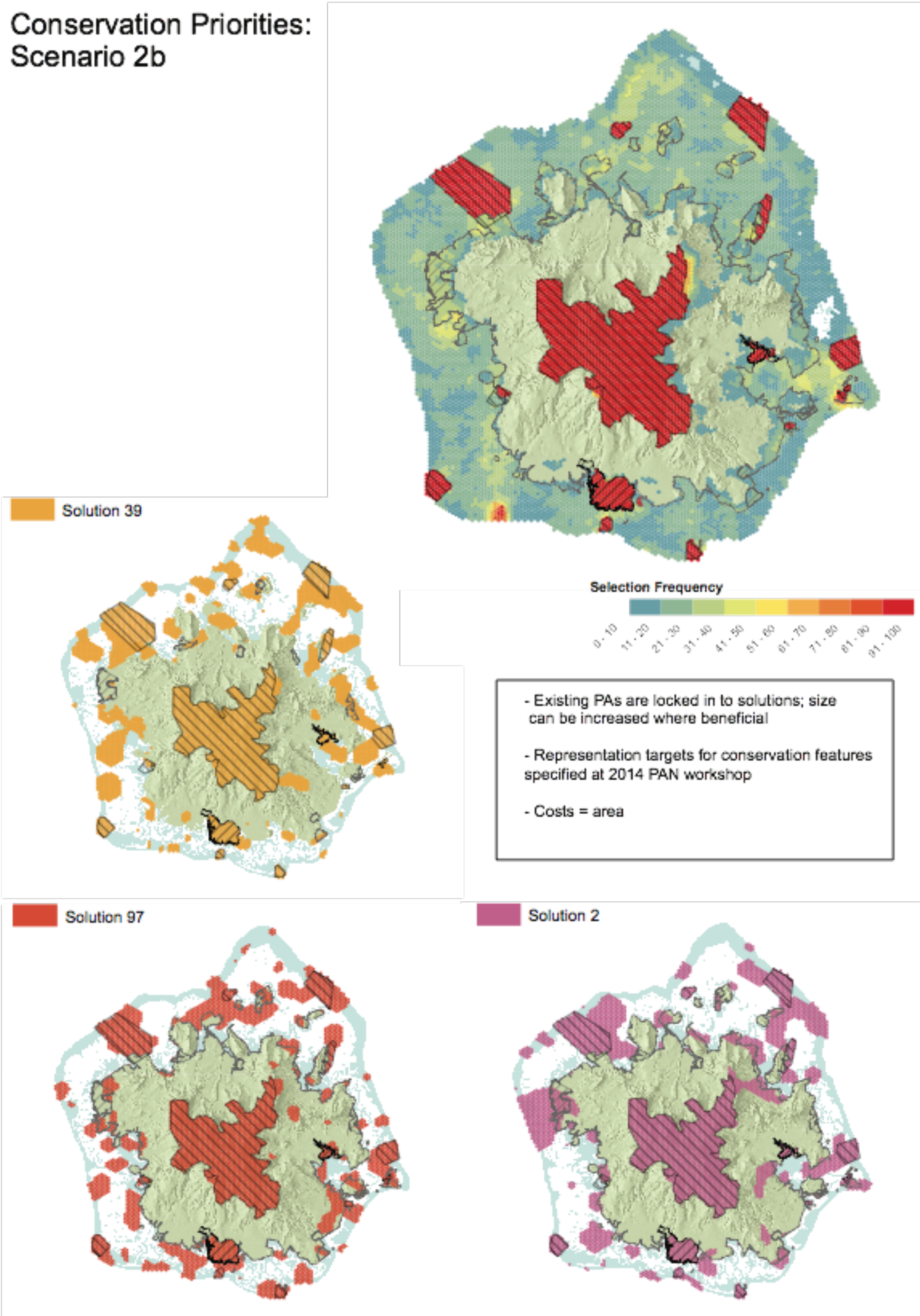


Figure 12. Results for Scenario 2b

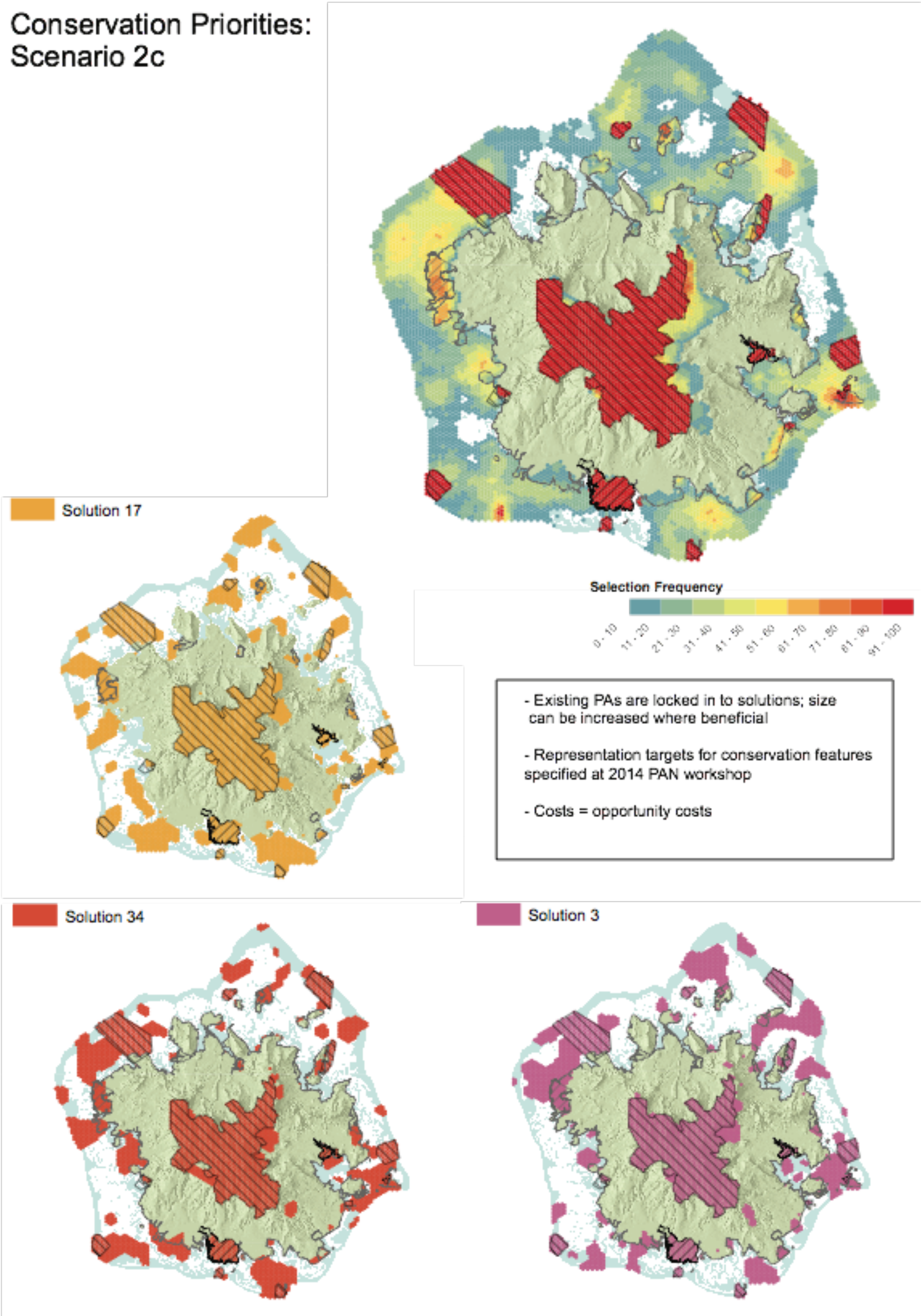


Figure 13. Results for Scenario 2c

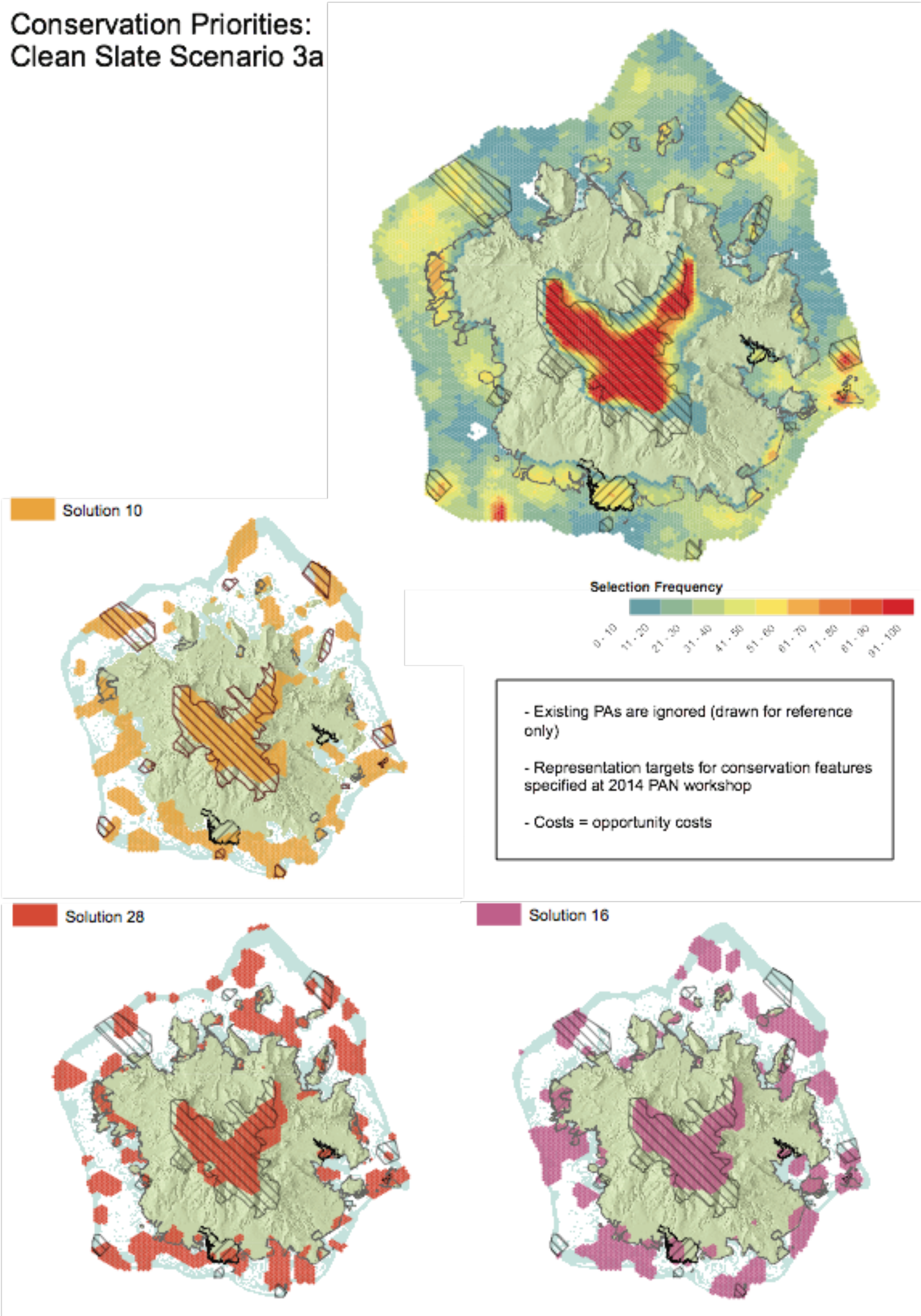


Figure 14. Results for Scenario 3a

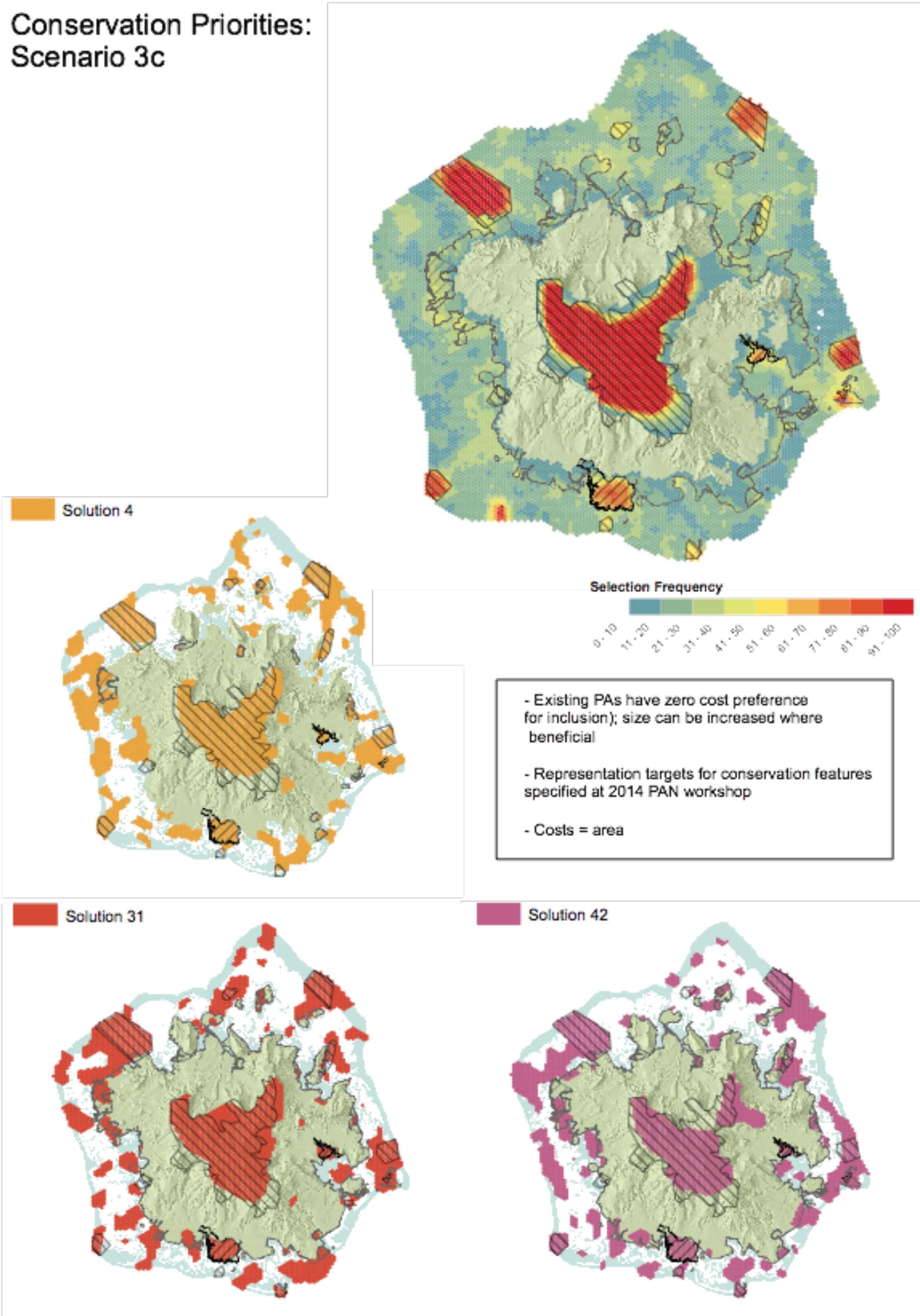


Figure 15. Results for Scenario 3c

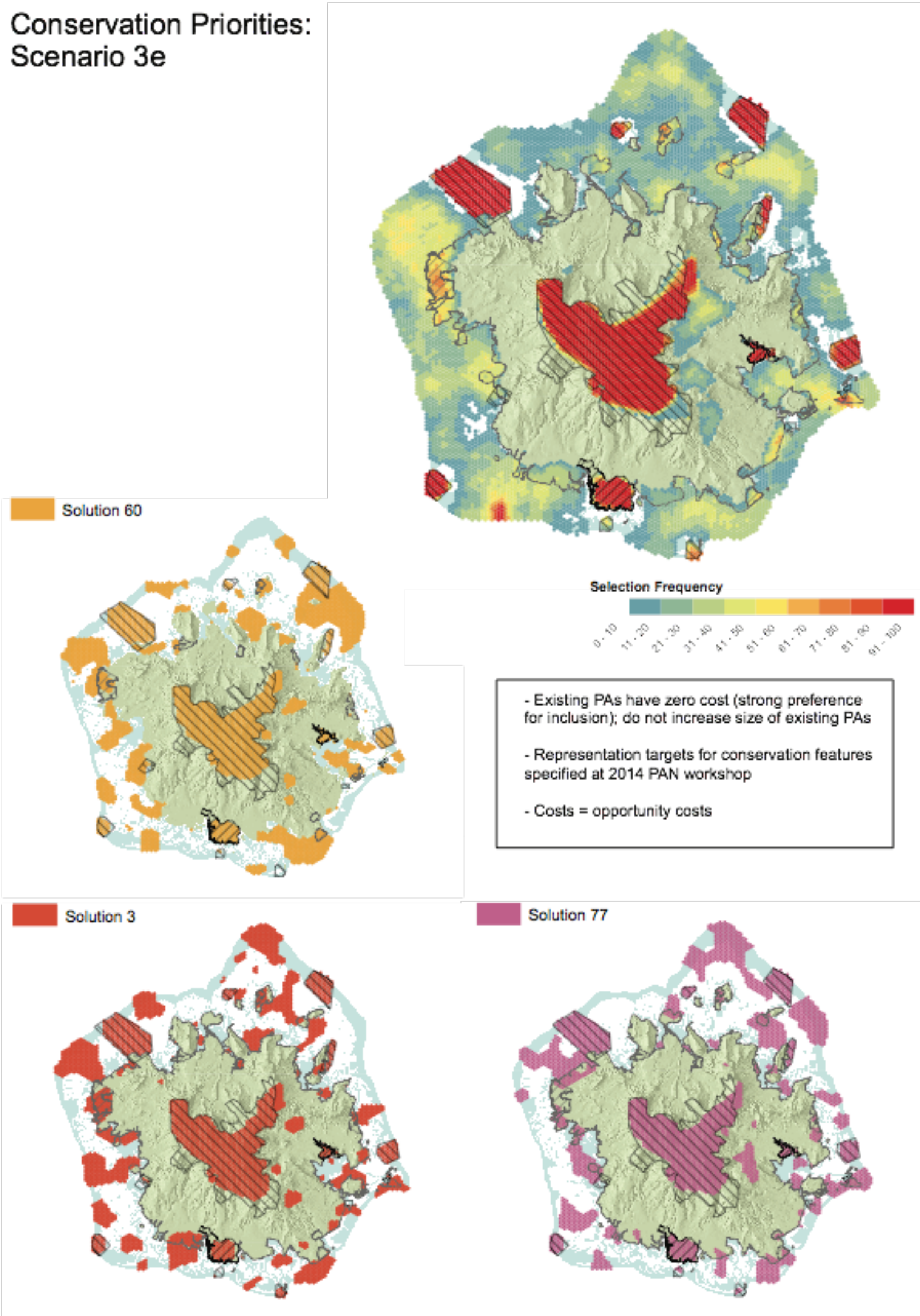


Figure 16. Results for Scenario 3e

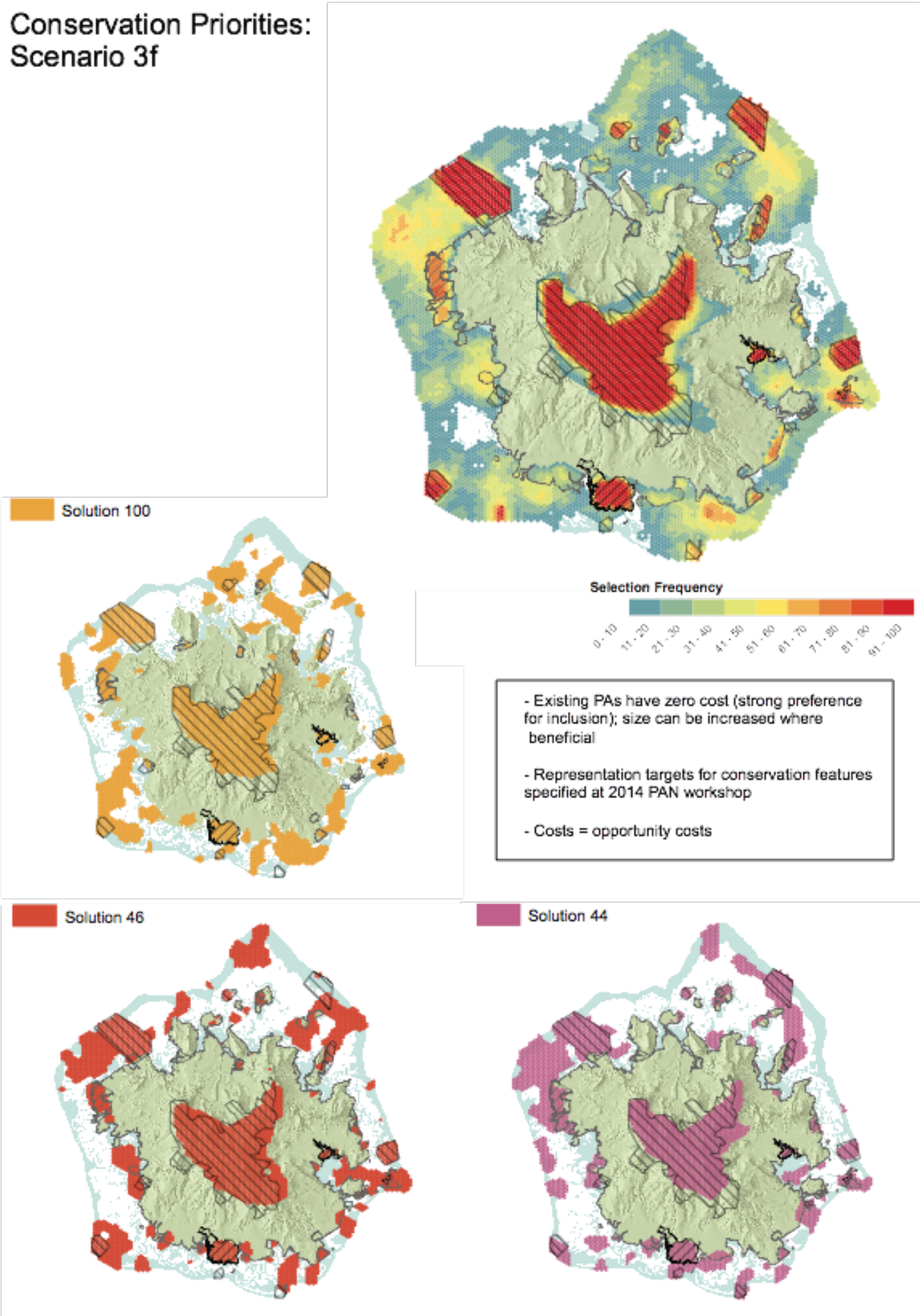


Figure 17. Results for Scenario 3f

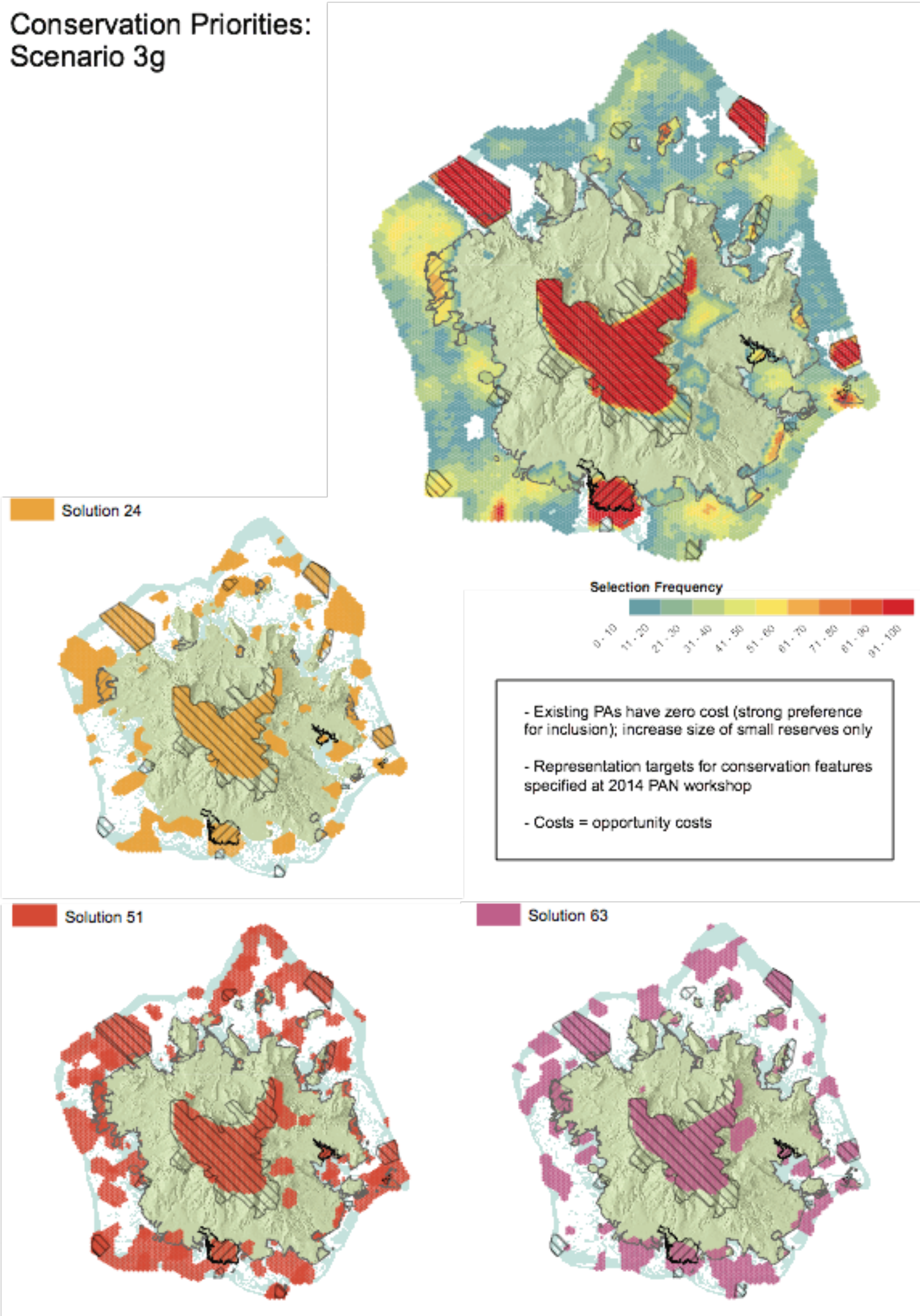


Figure 18. Results for Scenario 3g

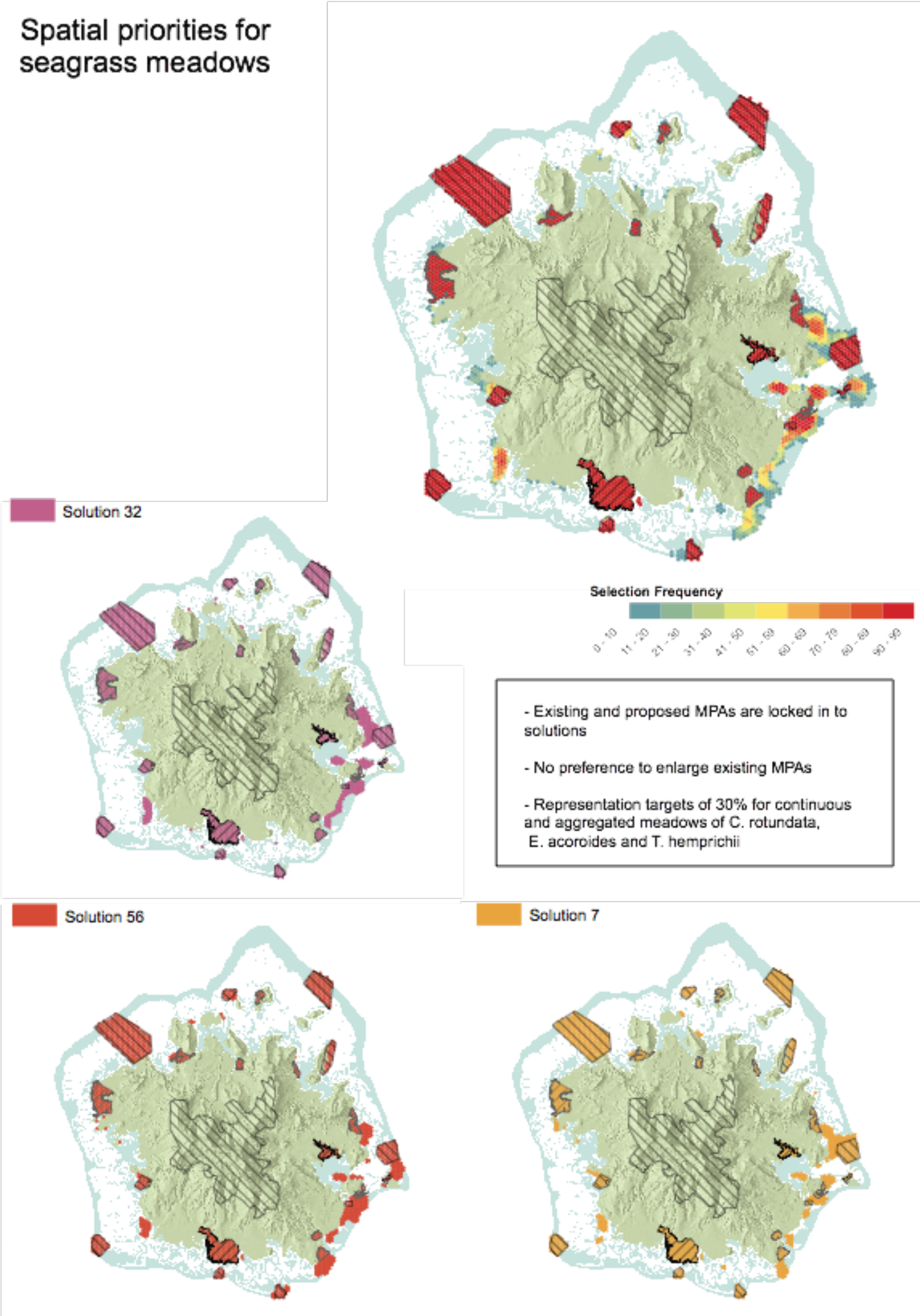


Figure 19. Spatial priorities for seagrass meadows

Scenario 7: Marine targets at 20%

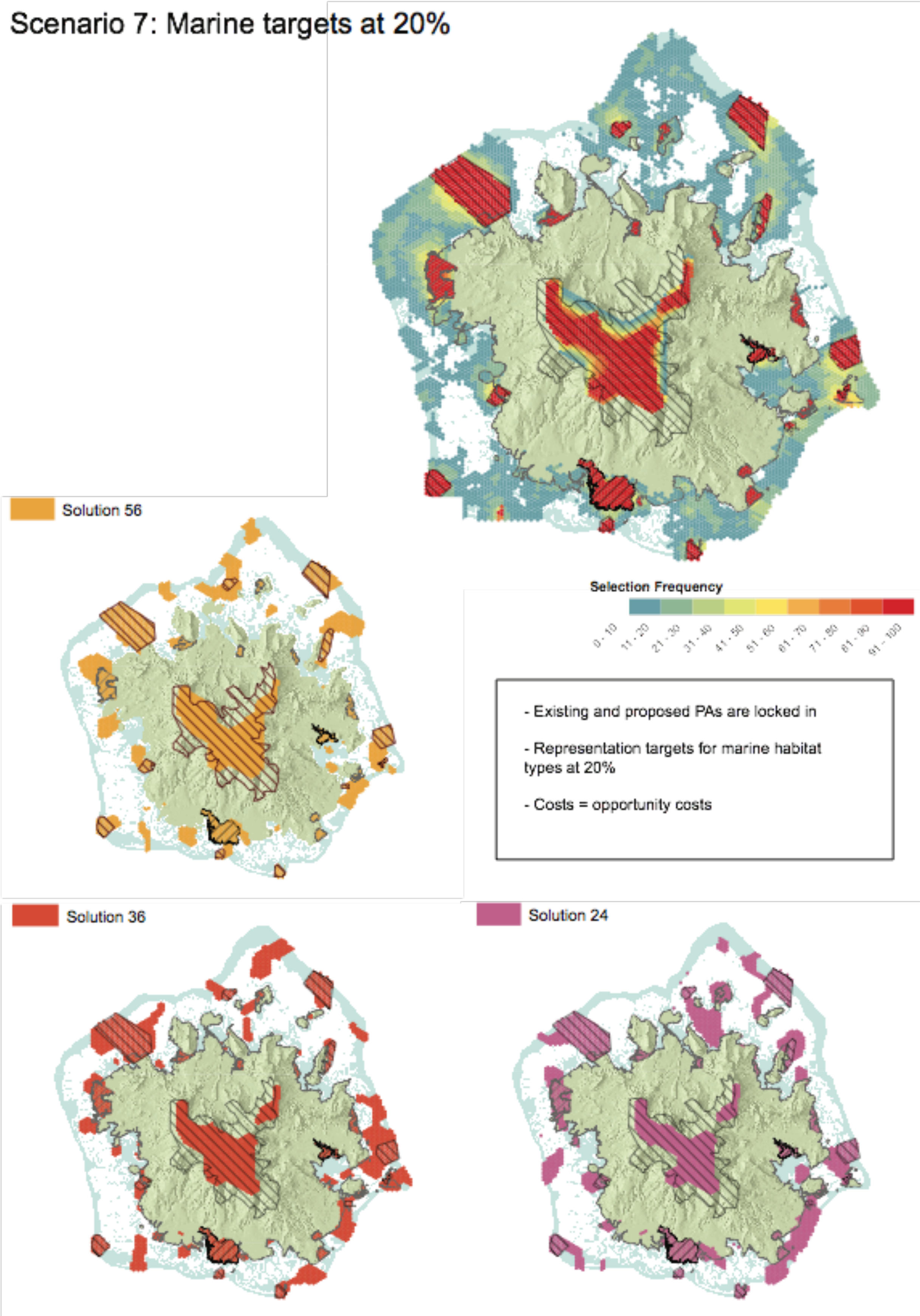


Figure 20. Results for intermediate marine targets

DISCUSSION

Scenario development & treatment of existing protected areas

A starting point for analysis was to run a "clean slate" scenario (Scenario 1b, **Figure 11**), which ignores all existing and proposed protected areas in Pohnpei, and seeks to identify potential protected area networks to achieve representation targets specified for conservation features. The high priority areas in Figure 11 are indicative of the locations of conservation features which were allocated a 100% representation target - the Pohnpei mountain starling, turtle and seabird nesting beaches. There are few other clear spatial priorities, because the conservation planning problem is very flexible - there are many different reserve configurations that can achieve the representation targets, and no easy way to choose between them.

By "locking in" existing protected areas (Scenario 2b, 2c, **Figure 12**), areas where representation targets can be best met in conjunction with existing protected areas are shown. However, there is still a lot of flexibility in how targets can be achieved.

Rather than ignoring existing protected areas or locking them into final solutions (and recognizing that the boundaries of some existing protected areas might be open to adjustments), in most scenarios, planning units within existing protected areas were assigned zero cost (Scenario 3c, 3e, 3f, 3g) (**e.g. Figure 15**). This has the effect of expressing a strong preference for these areas to be included in prospective protected area network designs, without requiring that they be included.

Further, it was then possible to either allow or prevent Marxan from selecting planning units immediately adjacent to existing protected areas, which has the effect of increasing their size. Given that many marine protected areas are too small to protect many key fisheries species of interest, in many cases it is informative to see where their boundaries could be extended. However, it will likely not be feasible to increase the size of the larger existing protected areas, so some scenarios (e.g. Scenario 3g, **Figure 18**) allow only small protected areas to be increased in size.

In summary, the following options are available for existing protected areas:

1. Ignore existing PAs
2. Lock existing PAs into the prospective network designs
3. Prefer that existing PAs be included in prospective network designs by reducing their cost to zero
4. Allow existing PAs to increase in size
5. Allow only small existing PAs to increase in size
6. Do not allow any existing PAs to increase in size

Effect of cost layers

The effect of using alternative cost layers can be seen in **Figure 21**, which compares the selection frequency results for pairs of scenarios with the same representation targets and treatment of existing protected areas, but different cost layers (Scenarios 2b and 3c use cost = area of the planning unit, 2c and 3f use the opportunity cost layers).

Spatial priorities are much clearer (i.e. there are more distinct areas which have high selection frequency) when a variable cost layer is used. This happens because many of the conservation feature targets are relatively flexible, i.e. there are lots of different combinations of protected areas that can achieve them. The additional information of which planning units are more or less costly to include in the PAN further constrains the options, leading to clearer priorities.

- When opportunity costs are used, mangroves in Pelieniak, Western Palaikir (location of proposed mangrove reserve), mangroves and fringing reefs in Western Kitti, the coral reef system on the border between Kitti and Madolenihmw and mangroves in Nankoaroak (south of Temwen) emerge as priority areas for conservation. These areas have lower opportunity cost than other areas with the same conservation features.
- It is notable that some (though not all) of the proposed mangrove reserves are located in areas with high priority when opportunity costs are considered.
- Given that the opportunity cost layers used in these analyses were based on proxy data and assumptions, these should be carefully examined before taking action.
- Ideally, both marine and terrestrial opportunity cost layers would be refined through discussion with stakeholders and further data collection.

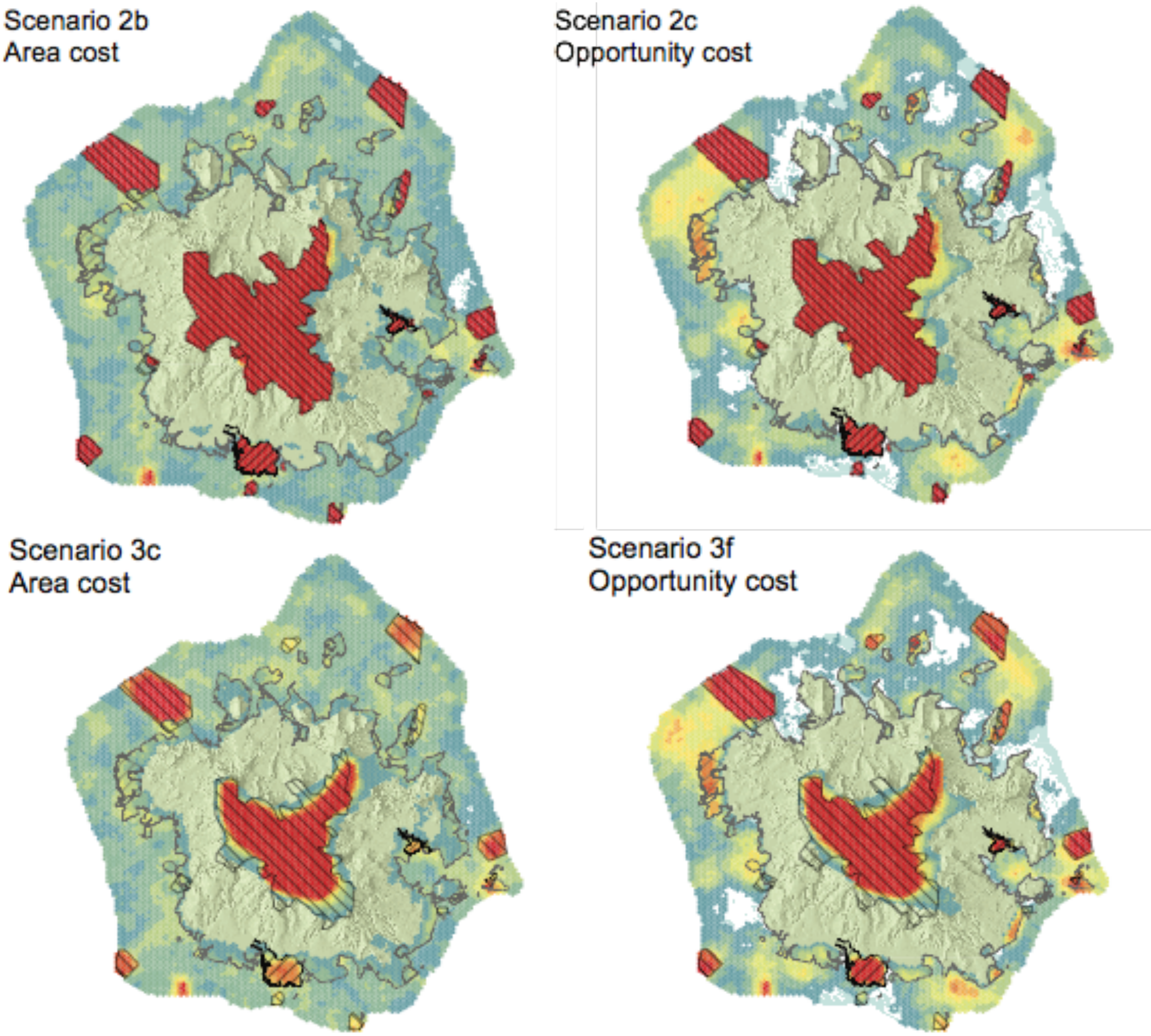


Figure 21. Comparison of selection frequency results for scenarios with different cost layers

Intermediate targets

Achieving the 30% representation target for all marine habitat types around the main island of Pohnpei requires a substantial increase in the extent of protected areas. This might either be achieved by increasing the size of existing MPAs (e.g. individual solutions, Scenario 3f), or by adding new MPAs (e.g. individual solutions, Scenario 3g) to protect complementary habitat types. Recommendations to greatly increase protected area extent can seem unachievable however, and risk overwhelming stakeholders and MPA managers, resulting in inaction.

It may therefore be useful to look at spatial priorities to achieve intermediate representation targets, which require a smaller increase in protected area extent. Provided that high priority areas to achieve lower representation targets are nested within those to achieve higher representation targets, this approach can provide guidance to incrementally develop the protected area network. Priority areas to achieve intermediate representation targets for marine habitats are shown in **Figure 20**.

Another approach is to look at priority areas for specific conservation features that are highly underrepresented within the current protected area network. For Pohnpei, seagrass meadows and mangroves are good examples.

Feature-specific priorities: Seagrass

Seagrass meadows are currently under-protected in the Pohnpei MPA network, with only 8% of their total extent within MPAs. Running a prioritization scenario for seagrass features only (**Figure 19**) illustrates clear spatial priorities to improve their conservation:

- The greatest area of seagrass meadows (approximately 42%) surrounding Pohnpei are within the boundaries of Madolenihmw municipality[5], so most high priority areas fall within the Madolenihmw lagoon.
- In particular, there might be an opportunities to extend the Nangih and Namwen Na stingray sanctuaries to include adjacent seagrass meadows in the vicinity of Nan Madol.
- The seagrass communities dominated by *E. acoroides,* which occur extensively across Nankoaros and around Dolehtik Island, are underrepresented elsewhere, making this another priority area for seagrass conservation.

Seagrass meadows around Nan Madol

[5] McKenzie, L.J. and Rasheed, M.J. (2006). Seagrasses: Pohnpei Island and Ahnd Atoll Marine Assessment: Technical report of survey conducted 26 October – 3 November 2005. (Seagrass-Watch HQ, DPI&F, Cairns). 60pp.

Feature-specific priorities: Mangroves

Though the current representation of mangroves within the Pohnpei PAN is just 12%, the proposed mangrove management areas would greatly improve mangrove conservation, easily exceeding the 30% representation target. **Figure 22** shows the location of proposed mangrove management areas in relation to water quality information. Mangroves downstream of rivers surveyed as having poor water quality are likely to have lower conservation value; in contrast, those known to have good water quality are good options for protection. However, at present only the spatial distribution of mangrove is known; ideally, management decisions would be based on information about the different biological communities resent on mangrove forests around the island.

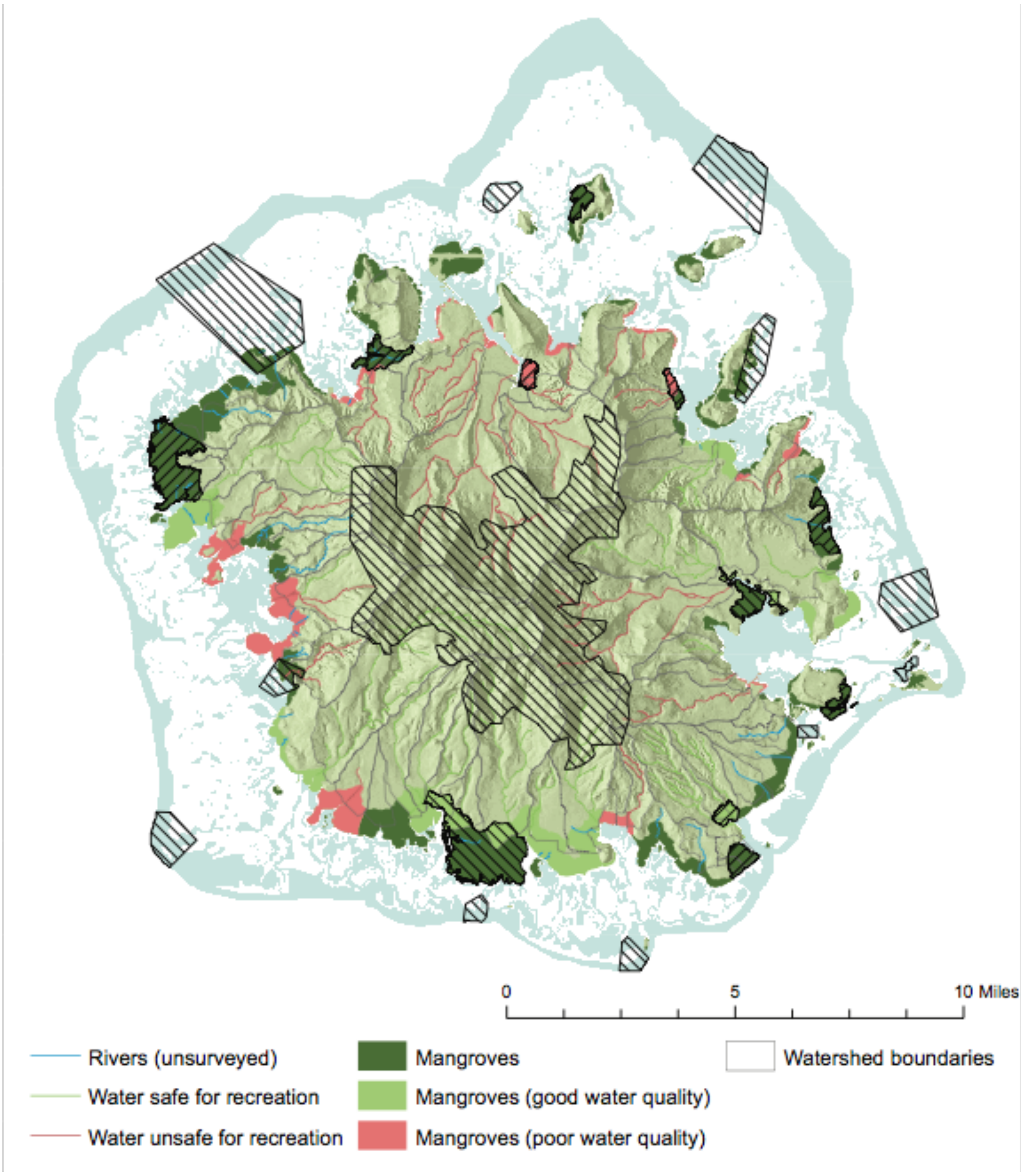


Figure 22. Proposed mangrove areas overlaid on mangrove catchment water quality information

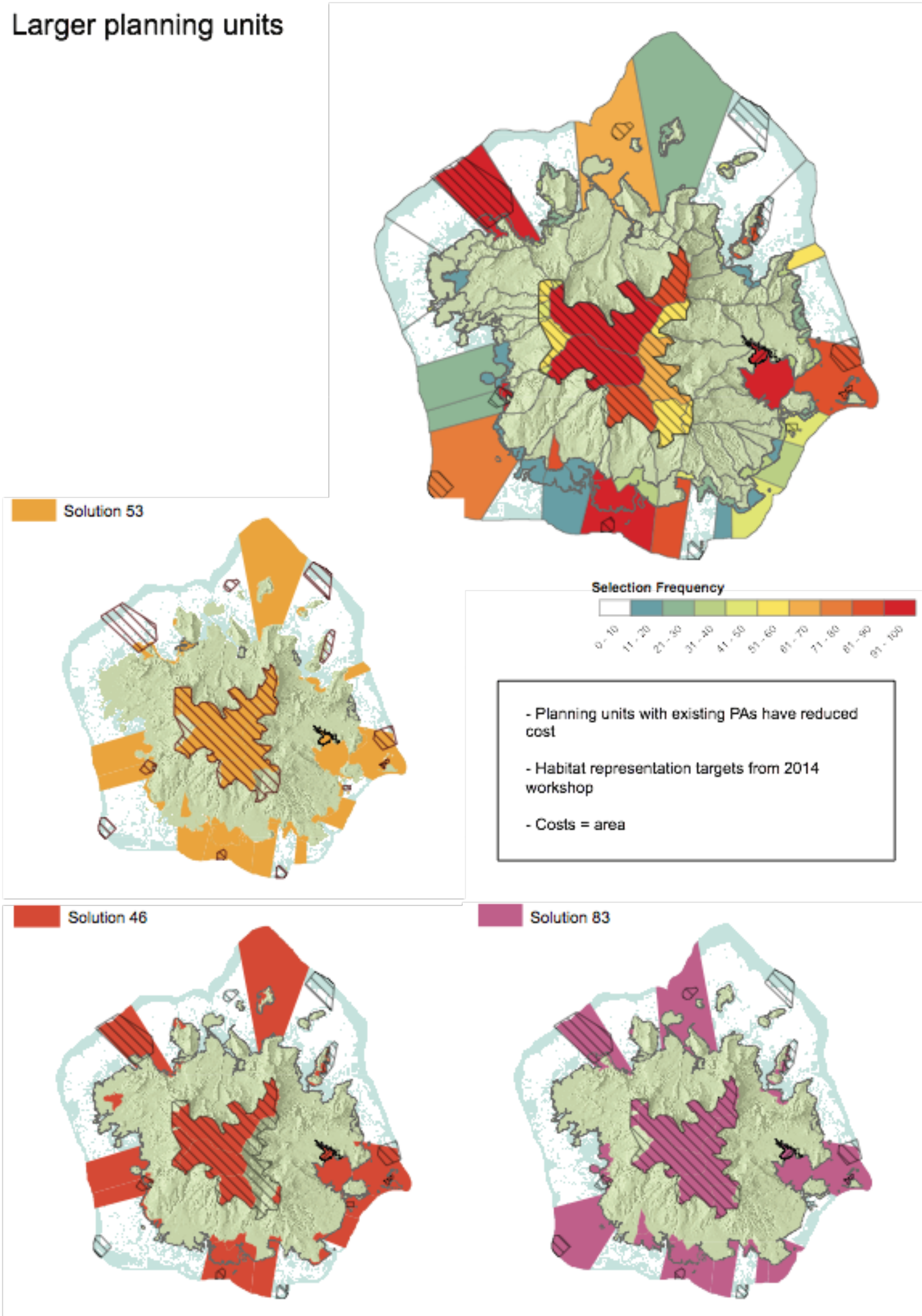


Figure 23. Marxan results with larger planning units

RECOMMENDATIONS

In June 2015, results from the gap analysis and spatial prioritization analyses were presented back to stakeholders in Pohnpei at the Pohnpei Protected Areas Network Analysis Workshop (hereafter, 2015 PAN workshop). The following recommendations reflect both the expert analysis of the results that was presented, and subsequent discussions.

SPECIFIC RECOMMENDATIONS

Following presentations on marine protected area adequacy and management effectiveness assessments, participants at the 2015 PAN workshop used individual MPA scorecards (see appendix 1) to discuss and rate the design and management of each MPA on a qualitative scale ranging from poor to excellent (**Figure 24**). Dividing this matrix into four quadrants indicates priority actions for different groups of MPAs:

- Nanwap, Ant Atoll and Dehpehk Takaieu fall into the upper right quadrant, indicating that they are both well designed and well managed.
- Kehpara, Mwahnd and Palaikir Pass marine sanctuaries fall in the lower right quadrant, indicating that they are well designed, but not presently well managed. Efforts should focus on understanding the causes for poor management effectiveness (e.g. for Palaikir Pass, the sanctuary is still to be finalized) and resolving these.
- Nahtik marine sanctuary falls in the upper left quadrant, indicating that it is well managed, but would benefit from improvements to the MPA design. Discussing ecological design principles for marine protected areas with Nahtik stakeholders, to look for opportunities to improve the MPA design should be a priority here.
- Peniou and Sapwitik marine sanctuaries, and Nahn Ngih and Namwen Na stingray sanctuaries were rated in the bottom left quadrant, indicating that they have both poor design and poor management effectiveness. Consequently, these MPAs need careful consideration to identify the best course of action to enable them to contribute more effectively towards the PAN objectives. In some instances, improving the MPA design might lead to improved management effectiveness, if the newly designed MPA better achieves local stakeholders' objectives. In other cases, it might be better to look for an alternative site altogether.

Finally, the priority actions identified for specific MPAs was incorporated in a state-wide Marxan prioritisation such that MPAs considered to be well designed (Nanwap, Dehpehk Takaieu, Kehpara, Mwahnd and Palaikir Pass) were locked in to the design (**Figure 25**).

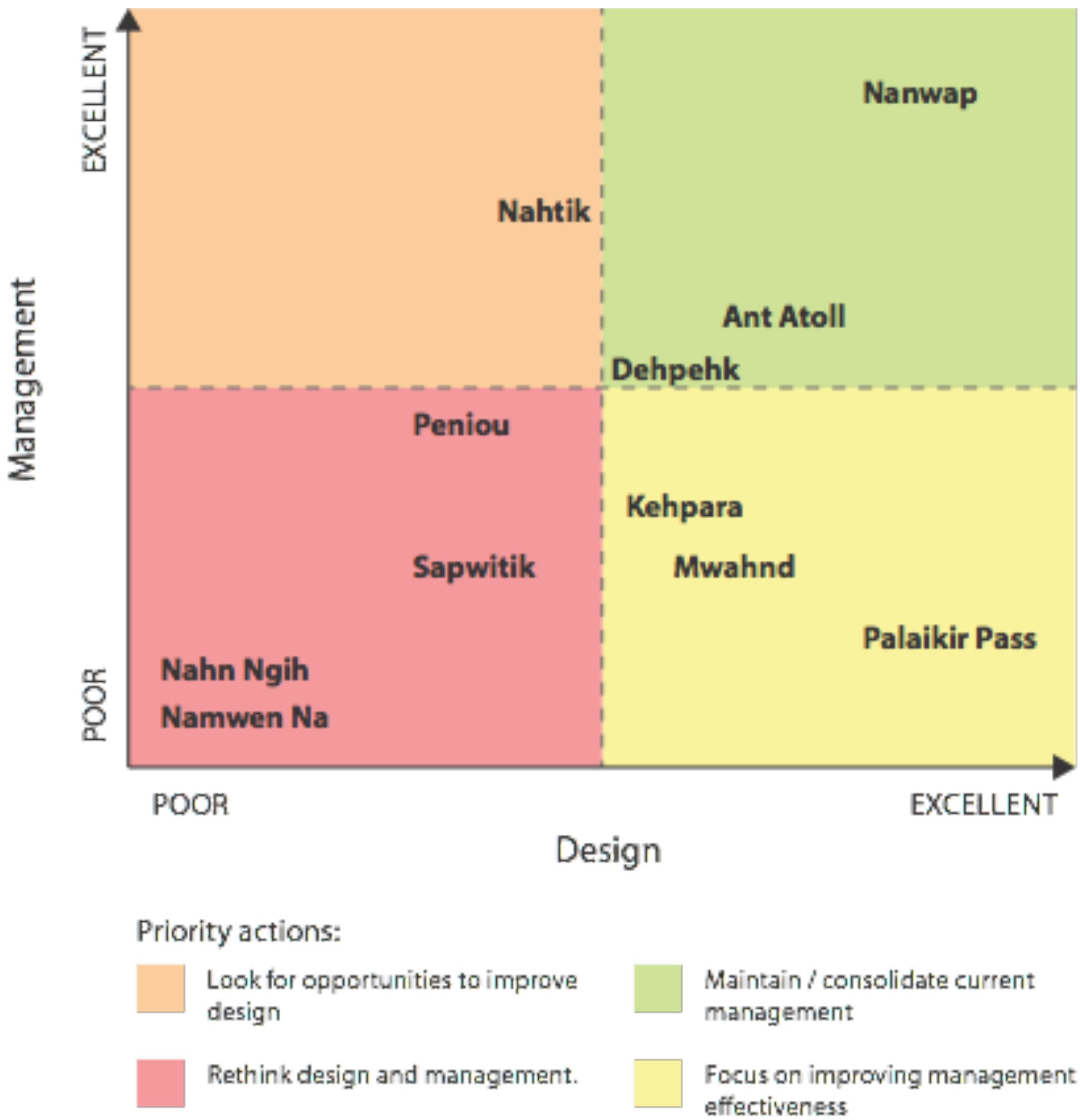


Figure 24. Design and management effectiveness of Pohnpei's marine protected areas[6]

GENERAL RECOMMENDATIONS

- At a broad resolution, Pohnpei's current protected area network achieves representation targets specified by the Convention on Biological Diversity and the Micronesia Challenge (not accounting for management effectiveness of existing protected areas). However, when examined more closely, some habitat types are underrepresented within the PAN, and many marine protected areas are not adequate to protect key reef-associated fishery species.
- The effectiveness of any protected area network depends upon good compliance with management restrictions in place. In regions like Micronesia, this requires that local communities and other stakeholders are supportive of the protected area network, both in terms of the broad vision and objectives, and specific protected area boundaries and management rules in place. A key piece of information missing

[6] Ratings determined by participants at the 2015 PAN workshop; locations represent averages from four breakout groups.

from this analysis is a good spatial description of the socioeconomic and cultural costs (and benefits) to establishing protected areas. The various different conservation planning scenarios explored demonstrate that spatial priorities are determined to a great extent by the cost information used. **Improving the data available on socioeocnomic considerations, or at least refining the assumptions of the models used here, should be a top priority for furthering conservation planning at the state level in Pohnpei.**

- Habitat maps are available at a greater thematic resolution (i.e. more different habitat types are mapped) for marine habitats than for terrestrial, and this higher resolution information exposed gaps in the marine protected area network. Pohnpei's terrestrial features are protected primarily within the large Watershed Forest Reserve (WFR); **if the boundaries of the WFR are to be refined, more detailed spatial information on terrestrial conservation features should be sought**. Similarly, **information on the different mangrove communities around Pohnpei main island would better inform mangrove conservation efforts**.
- Given the need for stakeholder support for conservation action, **refinements to the design of Pohnpei's PAN should focus on achieving local objectives**, rather than international commitments. The vision for Pohnpei's protected area network is "Healthy and abundant natural resources which sustain Pohnpei". To this end, **efforts should primarily be directed towards ensuring that protected areas are adequate to sustain the natural resources which Pohnpei values**, such as the key fishery species identified in Table 4.
- Declining water quality in Pohnpei's catchments was also a key concern raised at the PAN workshop in 2014. Given that most of Pohnpei's upper catchments are within the Watershed Forest Reserve, improving water quality will be achieved through refinements to policy and management rules in place, rather than spatial reconfiguration of the PAN. This example highlights that **protected areas cannot reduce all threats to biodiversity, and must be implemented within a broader ecosystem based management plan that is supported by policy and enforcement**.
- Though many marine protected areas are either poorly designed or too small to protect key fishery species, workshop participants noted that it is difficult to change boundaries once they have been legislated. **Immediate efforts should focus on improving management effectiveness** at these sites, and ensuring that MPAs yet to be officially delineated (e.g. Ant Atoll and Palaikir Pass) are well designed.
- Some species with larger home ranges are protected under alternative management (e.g. size restrictions, and species bans for kemeik and merer). However, these are not always adequately enforced. Given that Pohnpei's MPAs are too small to afford protection for these species, **improving compliance with other fisheries management should be a priority**.
- The proposed mangrove reserves would greatly improve conservation of these critical habitat types. Some of the proposed areas cover mangroves downstream of catchments known to have good water quality, and predicted to have low opportunity cost to protected area establishment, and these should be prioritized for implementation. Given that marine protected areas have been shown to be more effective in conserving some fish species when they are close to mangroves, efforts should be made to extend the protection provided by MPA designation to include mangrove habitats within their boundaries (e.g. for Dehpehk Takaieu MPA).
- Improving MPA signage would improve general awareness of MPA locations and regulations, which might help to improve management effectiveness.

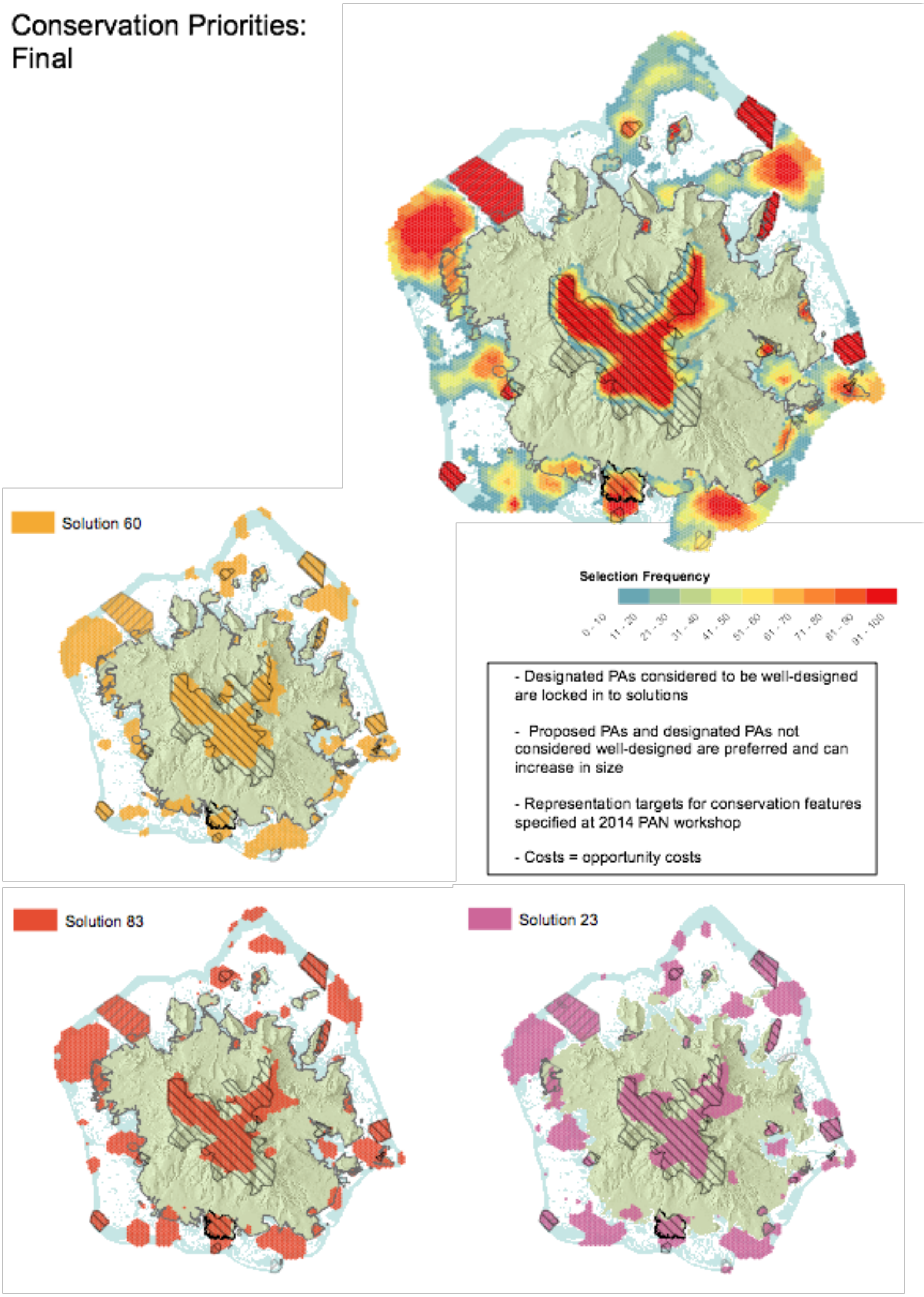


Figure 25. Final spatial priorties

Dehpehk Takaieu Marine Sanctuary

Reef Classes

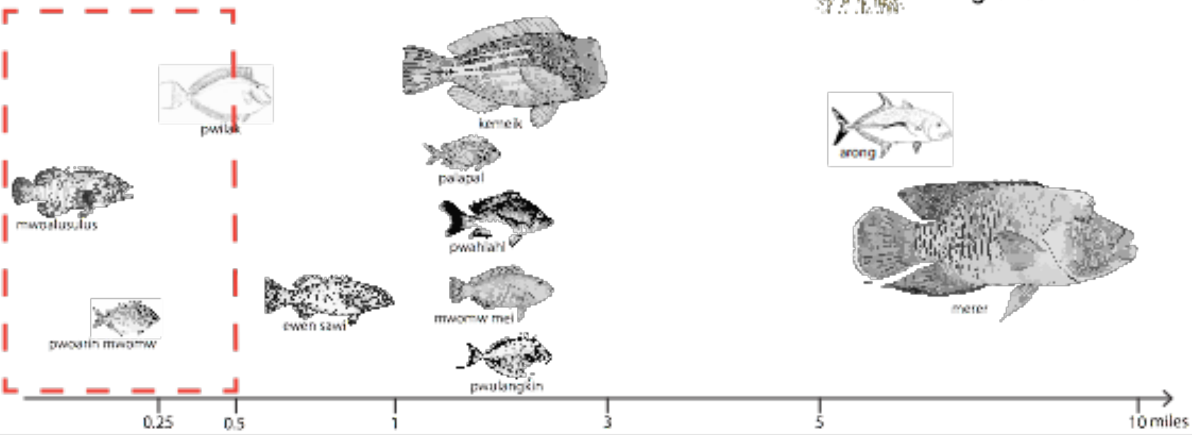
- Bay exposed fringing reef
- Diffuse fringing reef
- Enclosed basin
- Forereef
- Pass
- Pinnacle
- Reef flat
- Reticulated fringing reef
- Shallow terrace

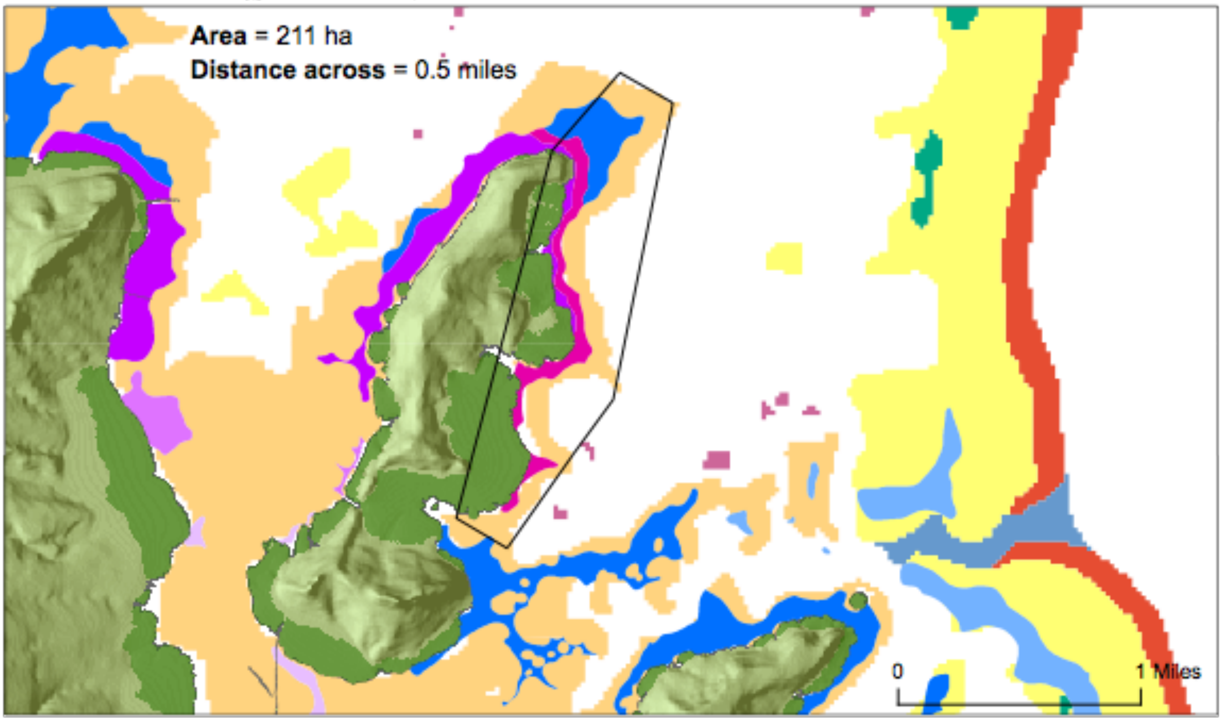
Seagrass Meadows

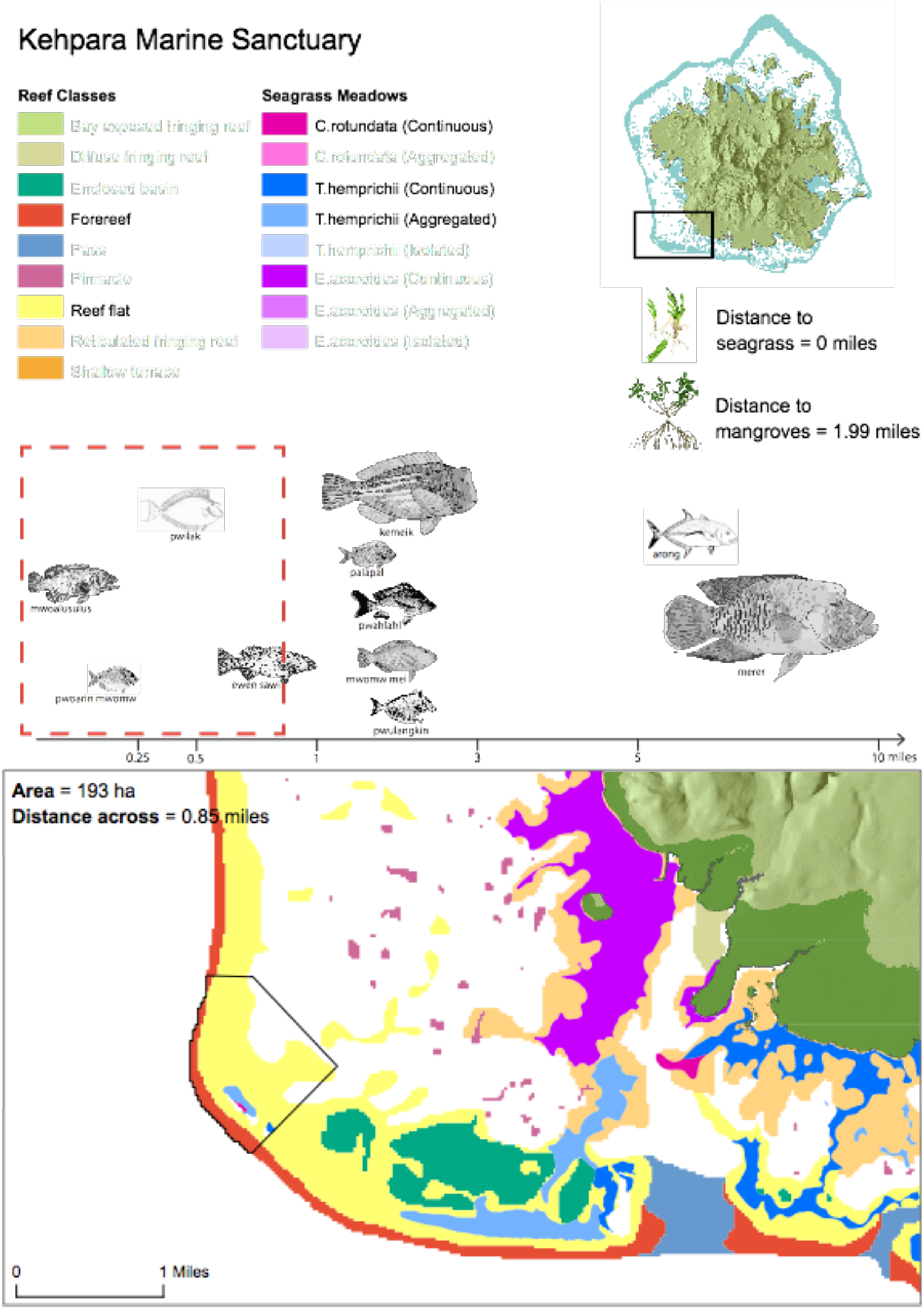
- C.rotundata (Continuous)
- C.rotundata (Aggregated)
- T.hemprichii (Continuous)
- T.hemprichii (Aggregated)
- T.hemprichii (Isolated)
- E.acoroides (Continuous)
- E.acoroides (Aggregated)
- E.acoroides (Isolated)

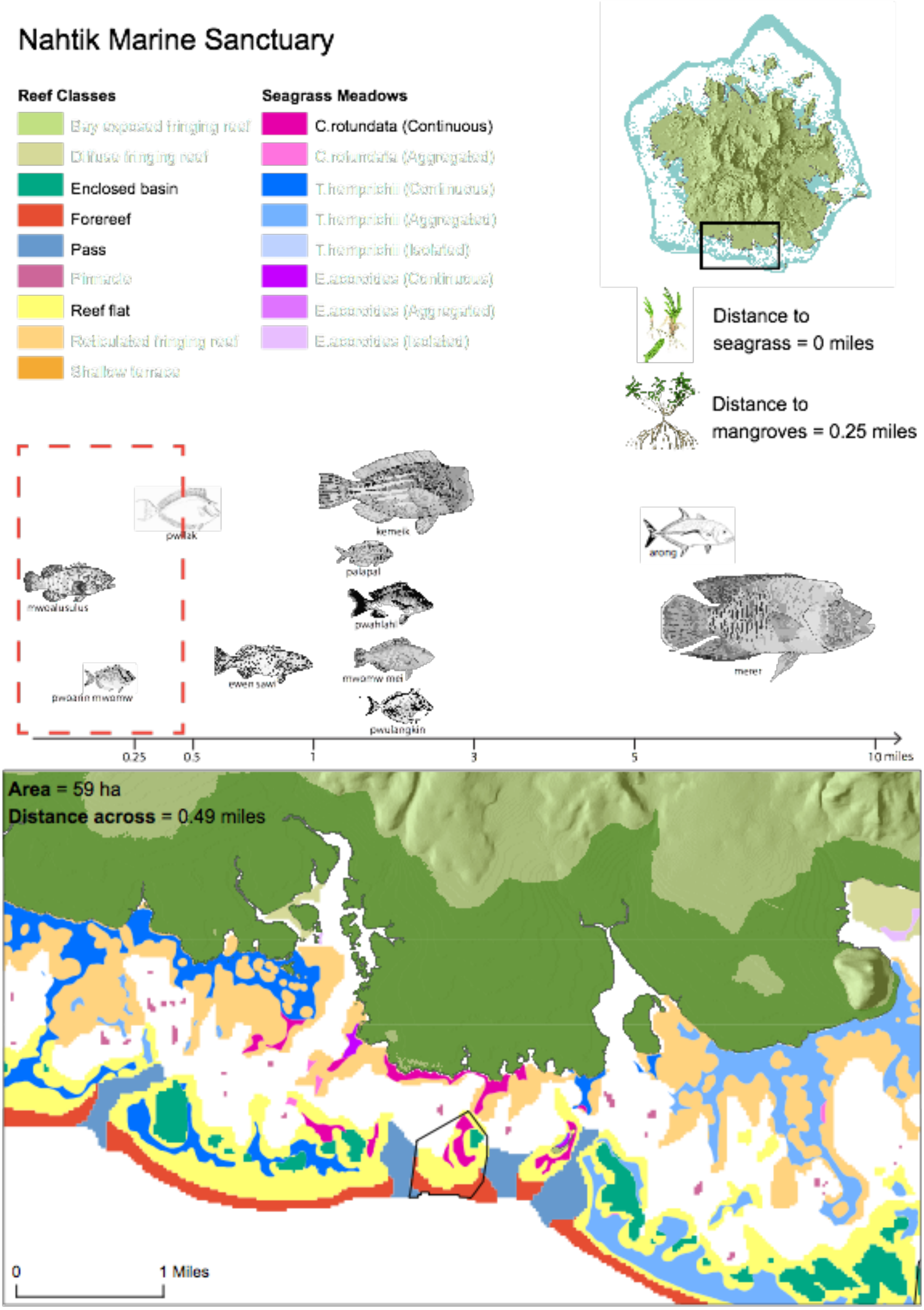
Distance to seagrass = 0 miles

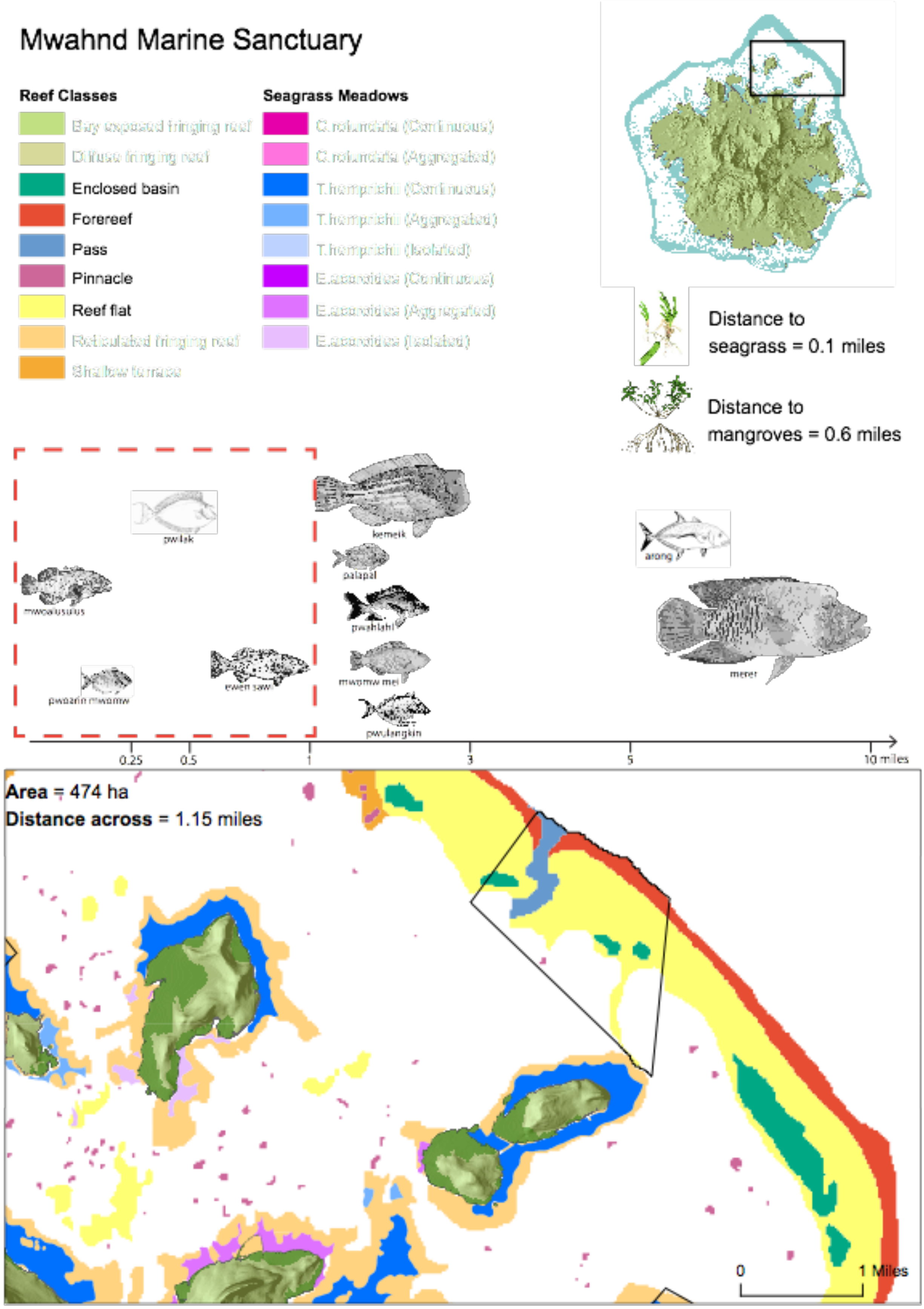
Distance to mangroves = 0 miles



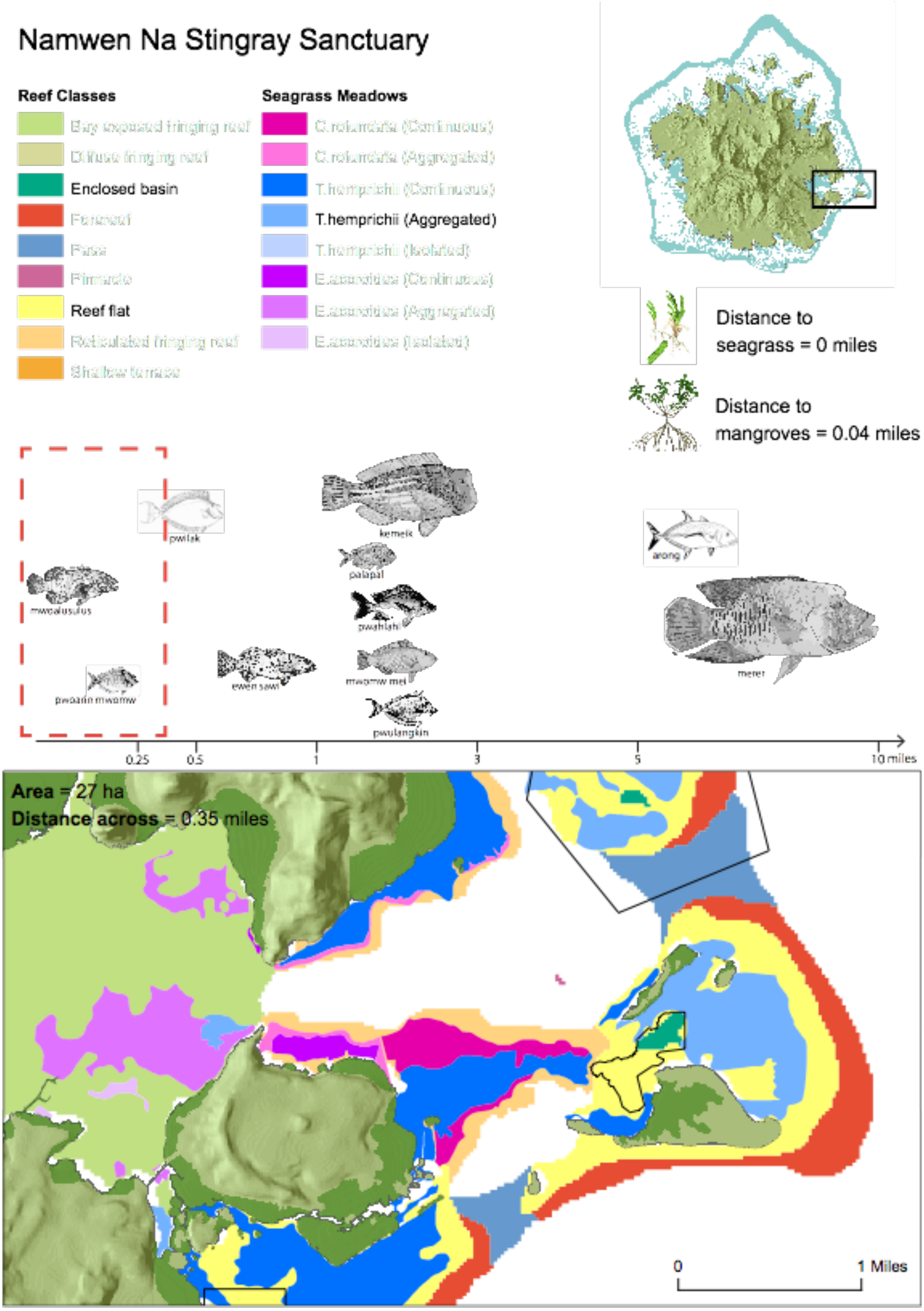



Kehpara Marine Sanctuary
Reef Classes
Bay exposed fringing reef
Diffuse fringing reef
Enclosed basin
Forereef
Pass
Pinnacle
Reef flat
Reticulated fringing reef
Shallow terrace
Seagrass Meadows
C.rotundata (Continuous)
C.rotundata (Aggregated)
T.hemprichii (Continuous)
T.hemprichii (Aggregated)
T.hemprichii (Isolated)
E.acoroides (Continuous)
E.acoroides (Aggregated)
E.acoroides (Isolated)
Distance to seagrass = 0 miles
Distance to mangroves = 1.99 miles
pwilak
mwoalusulus
pwoarin mwomw
ewen sawi
kemeik
palapal
pwahlahl
mwomw mei
pwulangkin
arong
merer
0.25
0.5
1
3
5
10 miles
Area = 193 ha
Distance across = 0.85 miles
0
1 Miles

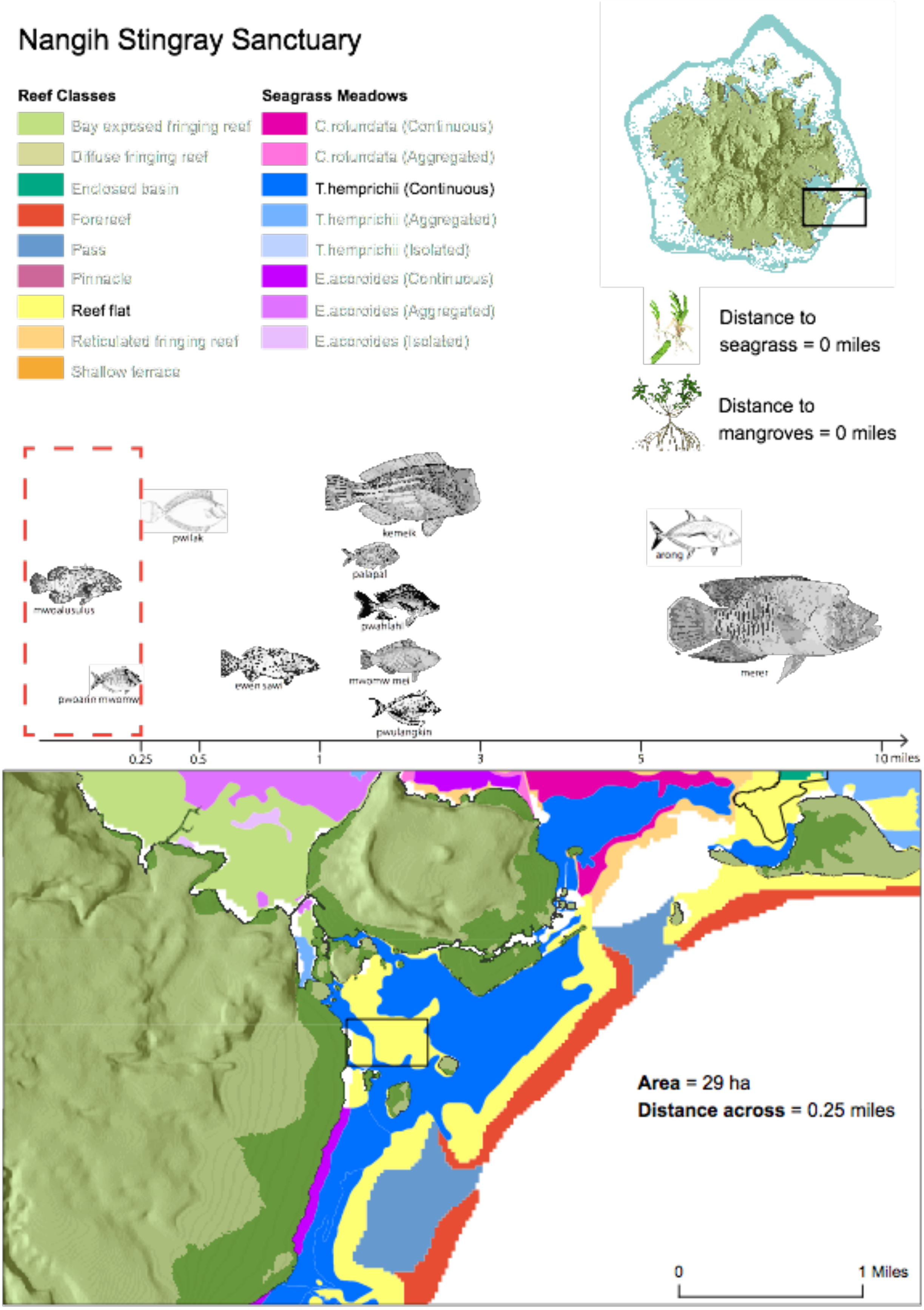

Nahtik Marine Sanctuary
Reef Classes
Bay exposed fringing reef
Diffuse fringing reef
Enclosed basin
Forereef
Pass
Pinnacle
Reef flat
Reticulated fringing reef
Shallow terrace
Seagrass Meadows
C.rotundata (Continuous)
C.rotundata (Aggregated)
T.hemprichii (Continuous)
T.hemprichii (Aggregated)
T.hemprichii (Isolated)
E.acoroides (Continuous)
E.acoroides (Aggregated)
E.acoroides (Isolated)
Distance to seagrass = 0 miles
Distance to mangroves = 0.25 miles
pwilak
mwoalusulus
pwoarin mwomw
ewen sawi
kemeik
palapal
pwahlahl
mwomw mei
pwulangkin
arong
merer
0.25
0.5
1
3
5
10 miles
Area = 59 ha
Distance across = 0.49 miles
0
1 Miles


Mwahnd Marine Sanctuary
Reef Classes
Bay exposed fringing reef
Diffuse fringing reef
Enclosed basin
Forereef
Pass
Pinnacle
Reef flat
Reticulated fringing reef
Shallow terrace
Seagrass Meadows
C.rotundata (Continuous)
C.rotundata (Aggregated)
T.hemprichii (Continuous)
T.hemprichii (Aggregated)
T.hemprichii (Isolated)
E.acoroides (Continuous)
E.acoroides (Aggregated)
E.acoroides (Isolated)
Distance to seagrass = 0.1 miles
Distance to mangroves = 0.6 miles
pwilak
mwoalusulus
pwoarin mwomw
ewen sawi
kemeik
palapal
pwahlahl
mwomw mei
pwulangkin
arong
merer
0.25
0.5
1
3
5
10 miles
Area = 474 ha
Distance across = 1.15 miles
0
1 Miles

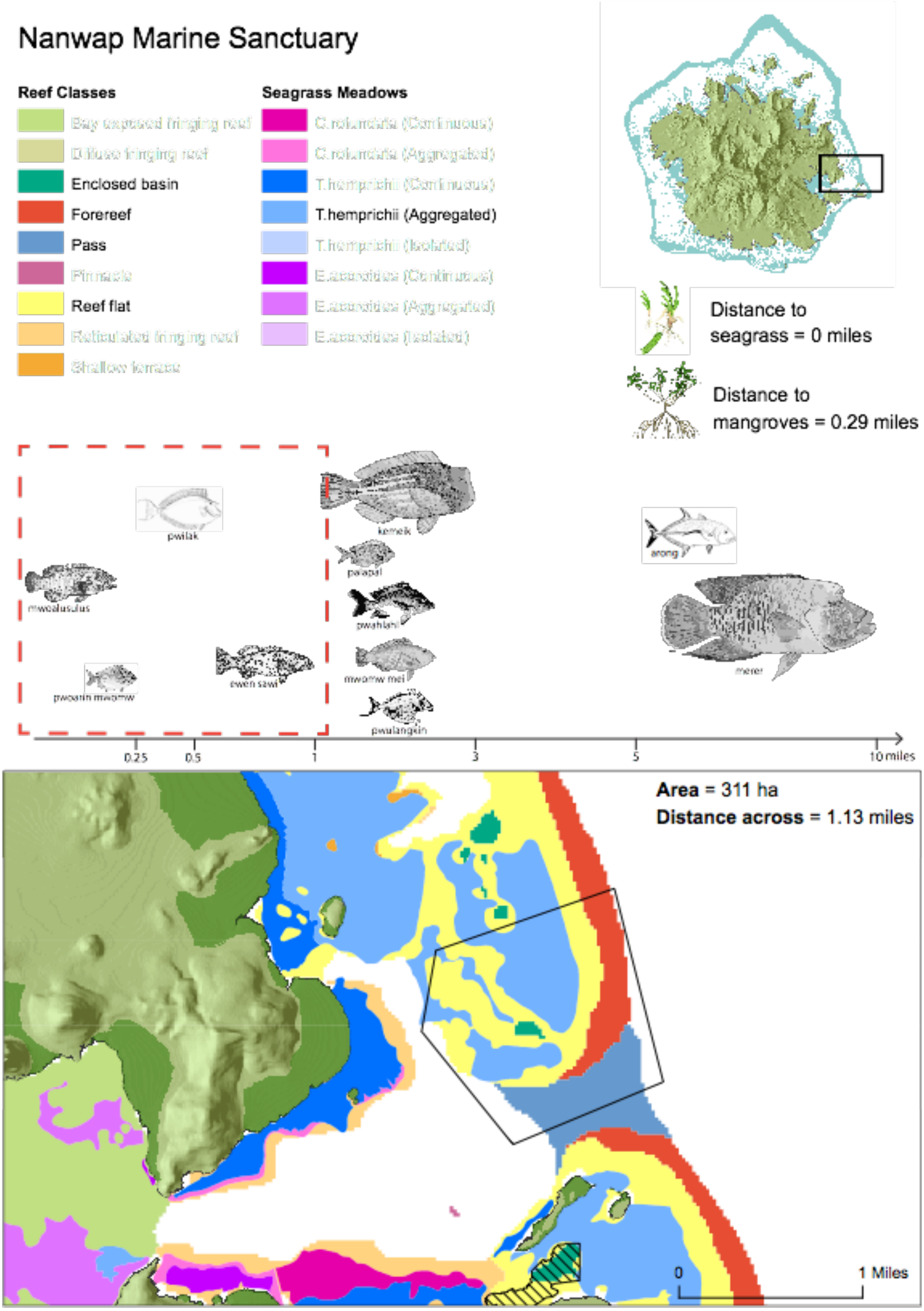
Namwen Na Stingray Sanctuary

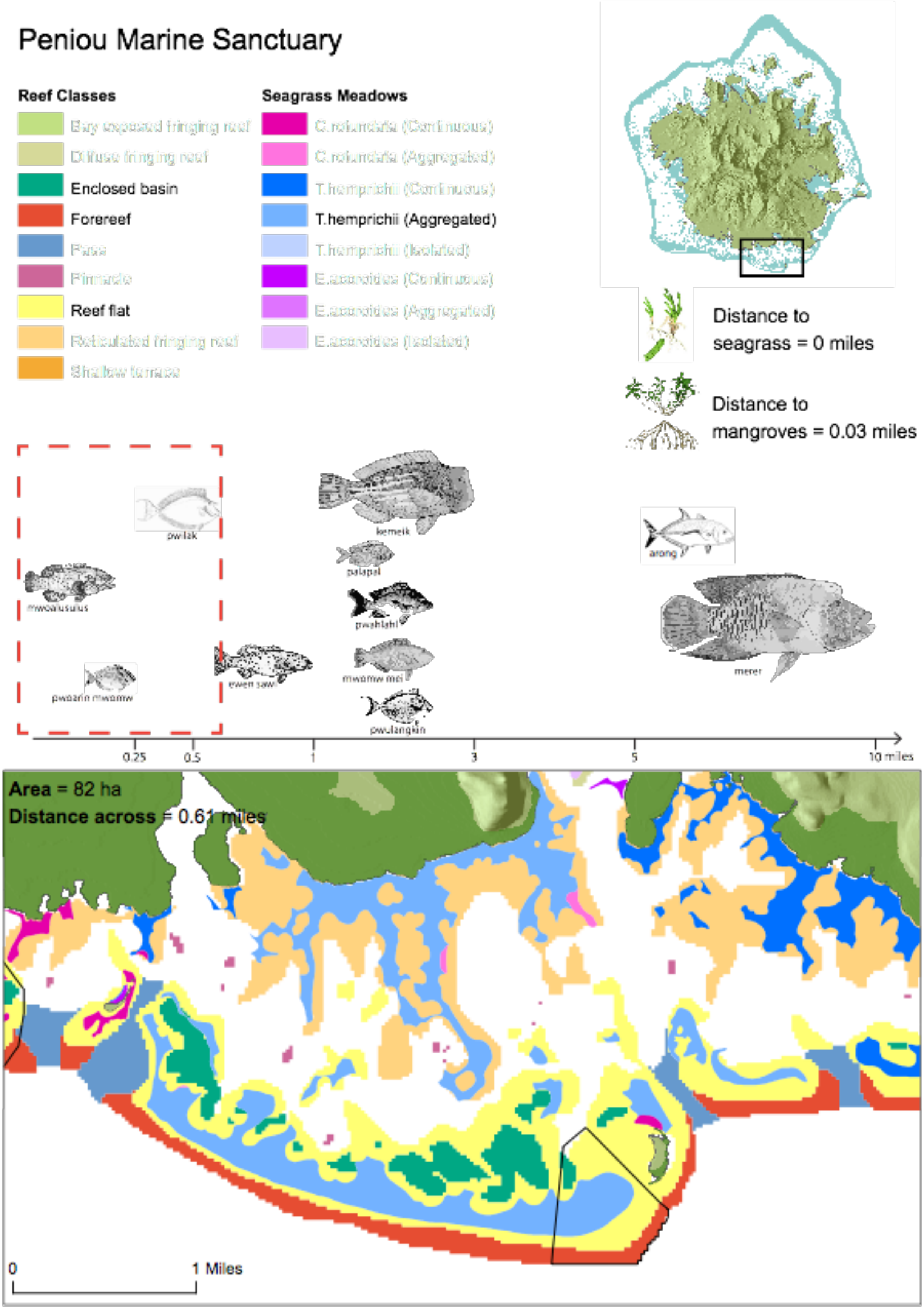


Nangih Stingray Sanctuary

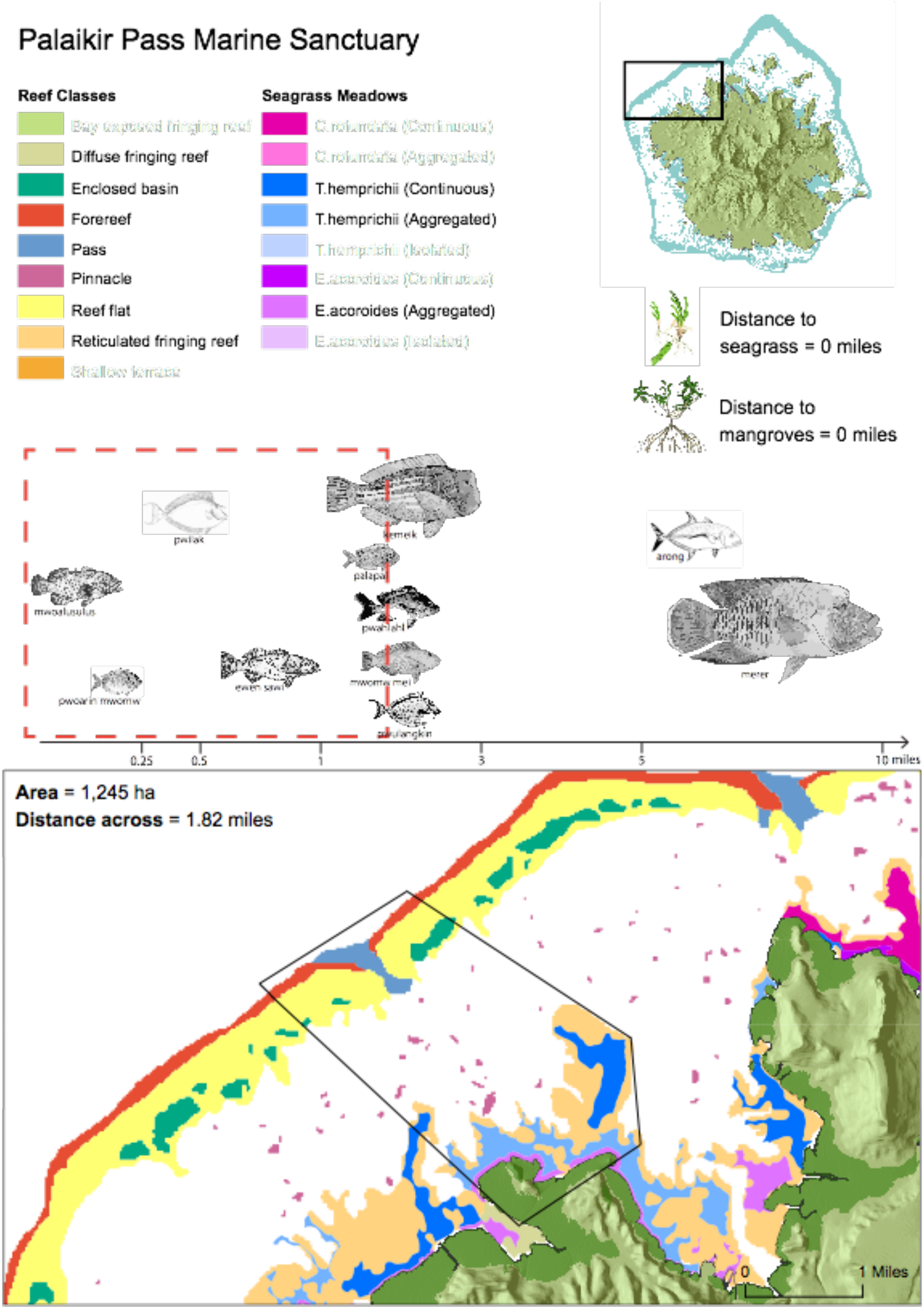


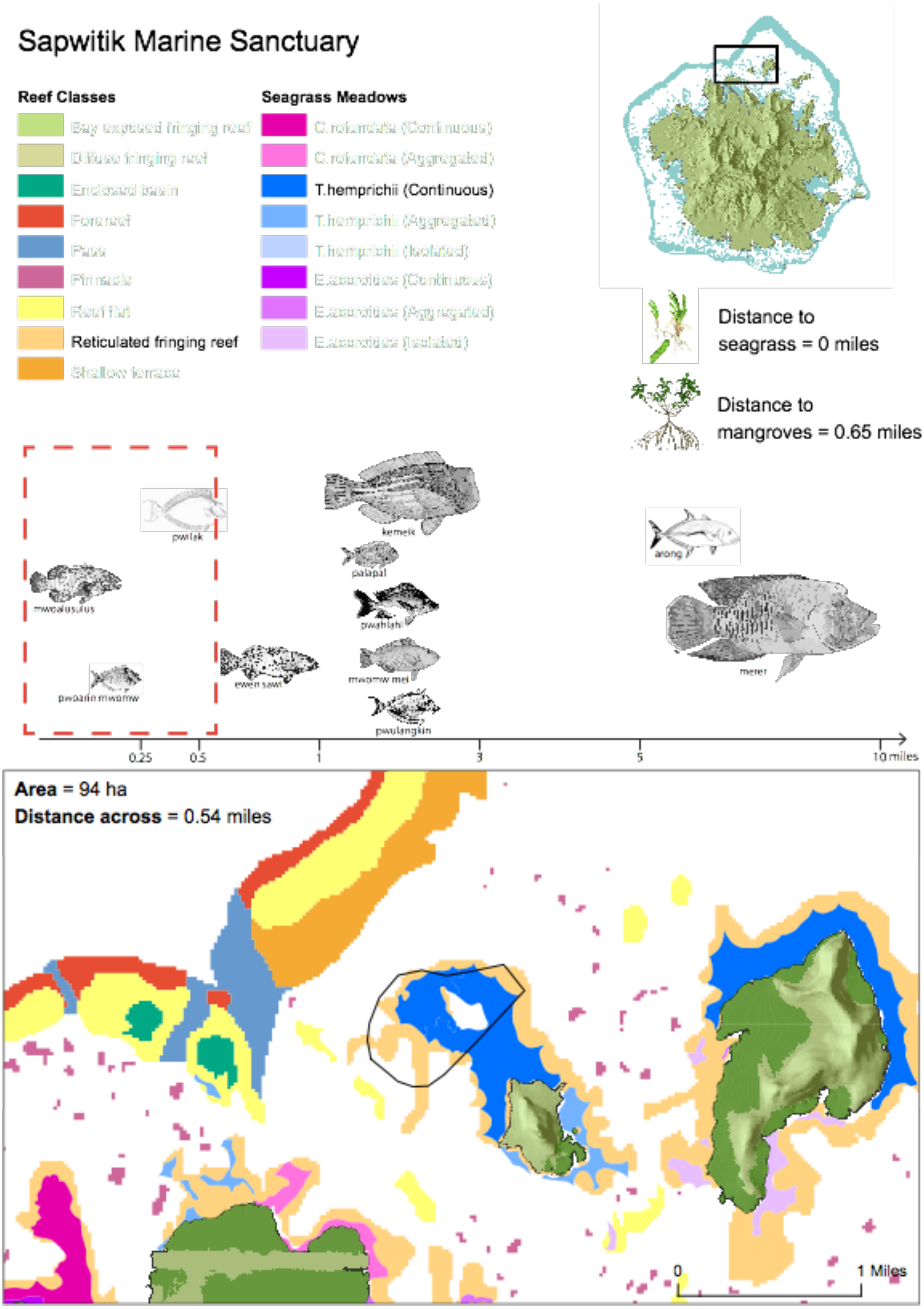
Nanwap Marine Sanctuary



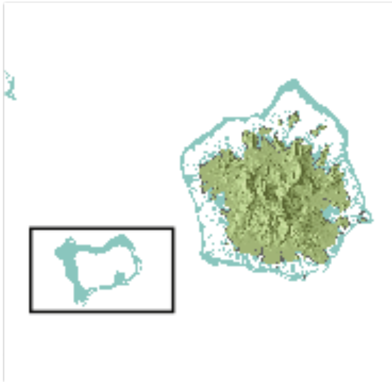

Peniou Marine Sanctuary
Reef Classes
Bay exposed fringing reef
Diffuse fringing reef
Enclosed basin
Forereef
Pass
Pinnacle
Reef flat
Reticulated fringing reef
Shallow terrace
Seagrass Meadows
C.rotundata (Continuous)
C.rotundata (Aggregated)
T.hemprichii (Continuous)
T.hemprichii (Aggregated)
T.hemprichii (Isolated)
E.acoroides (Continuous)
E.acoroides (Aggregated)
E.acoroides (Isolated)
Distance to seagrass = 0 miles
Distance to mangroves = 0.03 miles
pwilak
mwoalusulus
pwoarin mwomw
ewen sawi
kemeik
palapal
pwahlahl
mwomw mei
pwulangkin
arong
merer
0.25
0.5
1
3
5
10 miles
Area = 82 ha
Distance across = 0.61 miles
0
1 Miles

Palaikir Pass Marine Sanctuary

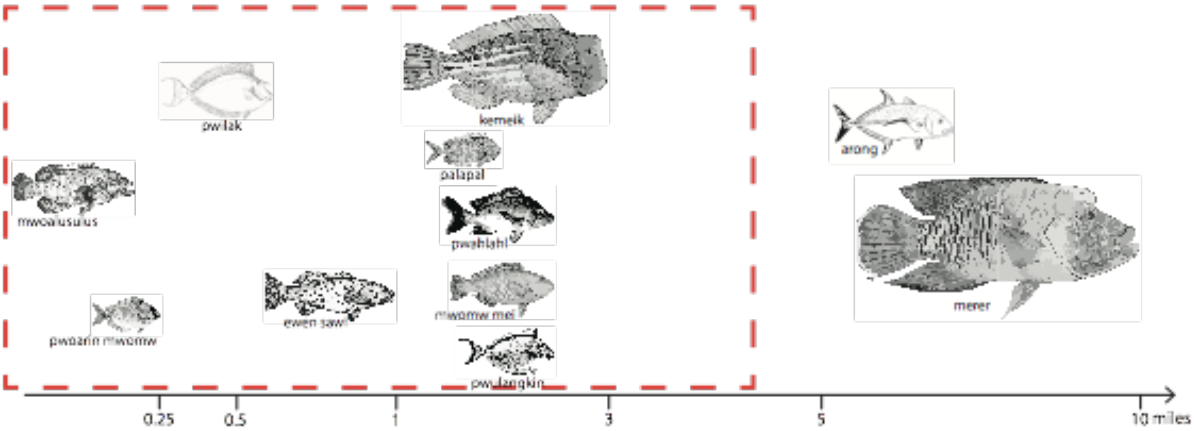


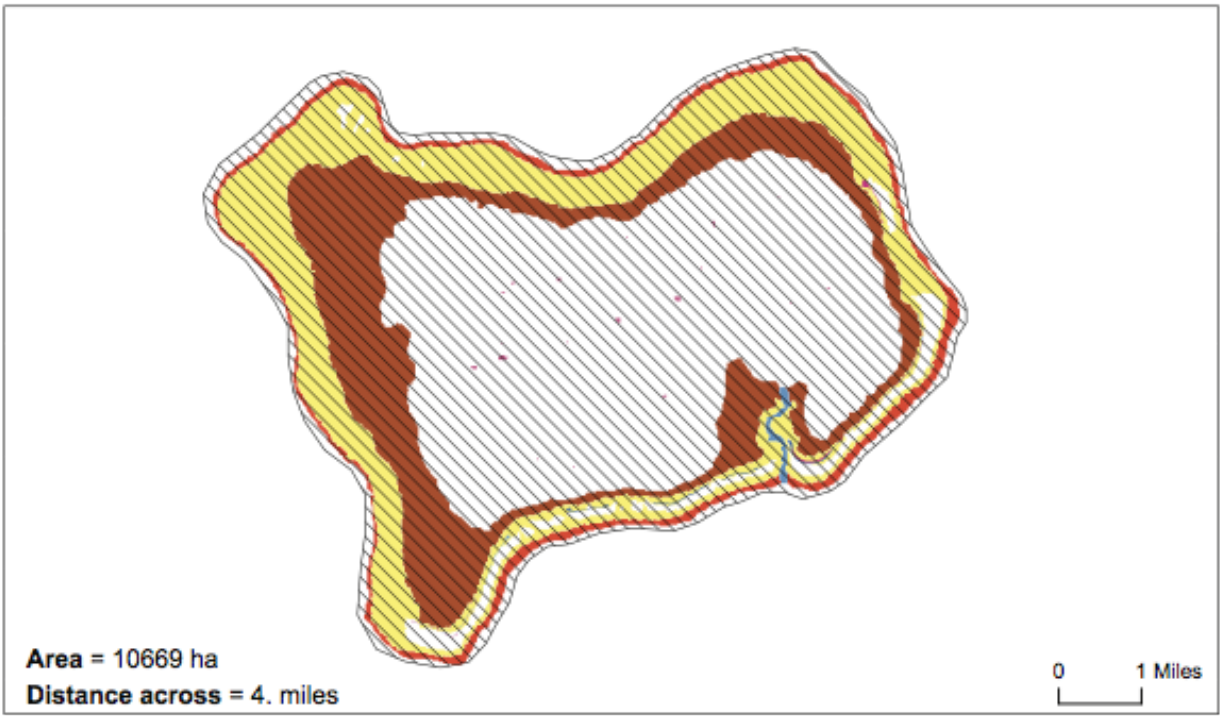

Sapwitik Marine Sanctuary
Reef Classes
Bay exposed fringing reef
Diffuse fringing reef
Enclosed basin
Forereef
Pass
Pinnacle
Reef flat
Reticulated fringing reef
Shallow terrace
Seagrass Meadows
C.rotundata (Continuous)
C.rotundata (Aggregated)
T.hemprichii (Continuous)
T.hemprichii (Aggregated)
T.hemprichii (Isolated)
E.acoroides (Continuous)
E.acoroides (Aggregated)
E.acoroides (Isolated)
Distance to seagrass = 0 miles
Distance to mangroves = 0.65 miles
pwilak
kemeik
palapal
arong
mwealusulus
pwahlahl
meret
ewen sawi
mwomw mei
pwoaiin mwomw
pwulangkin
0.25
0.5
1
3
5
10 miles
Area = 94 ha
Distance across = 0.54 miles
0
1 Miles

Ant Atoll

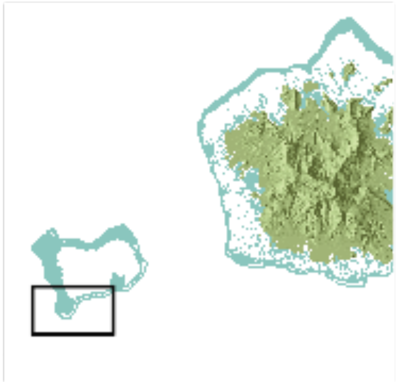


Reef Classes	Seagrass Meadows
Atoll Forereef	C.rotundata (Continuous)
Atoll inner slope	C.rotundata (Aggregated)
Lagoon pinnacle	T.hemprichii (Continuous)
Atoll pass	T.hemprichii (Aggregated)
Atoll reef flat	T.hemprichii (Isolated)
Atoll ridge and fossil coral	E.acoroides (Continuous)
Atoll subtidal reef flat	E.acoroides (Aggregated)
	E.acoroides (Isolated)





Pahnmwok Marine Sanctuary

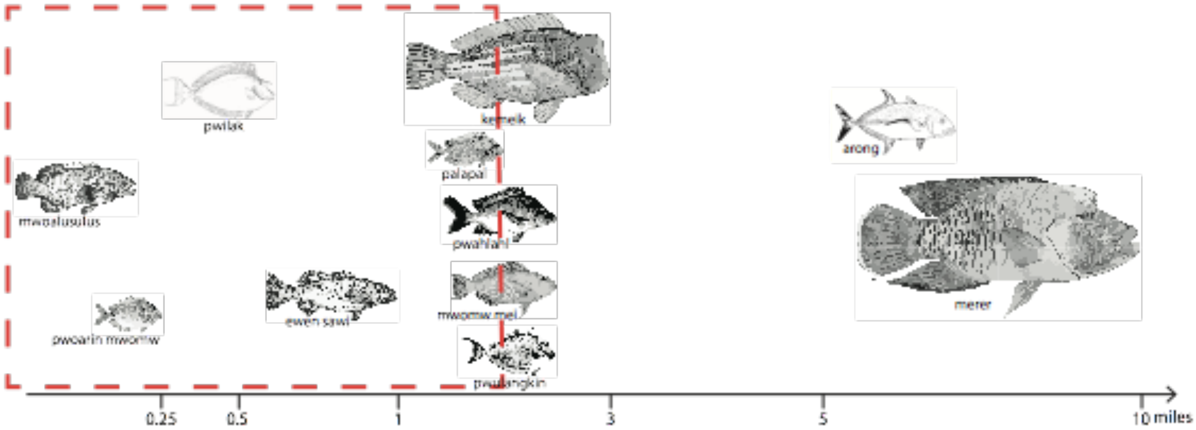


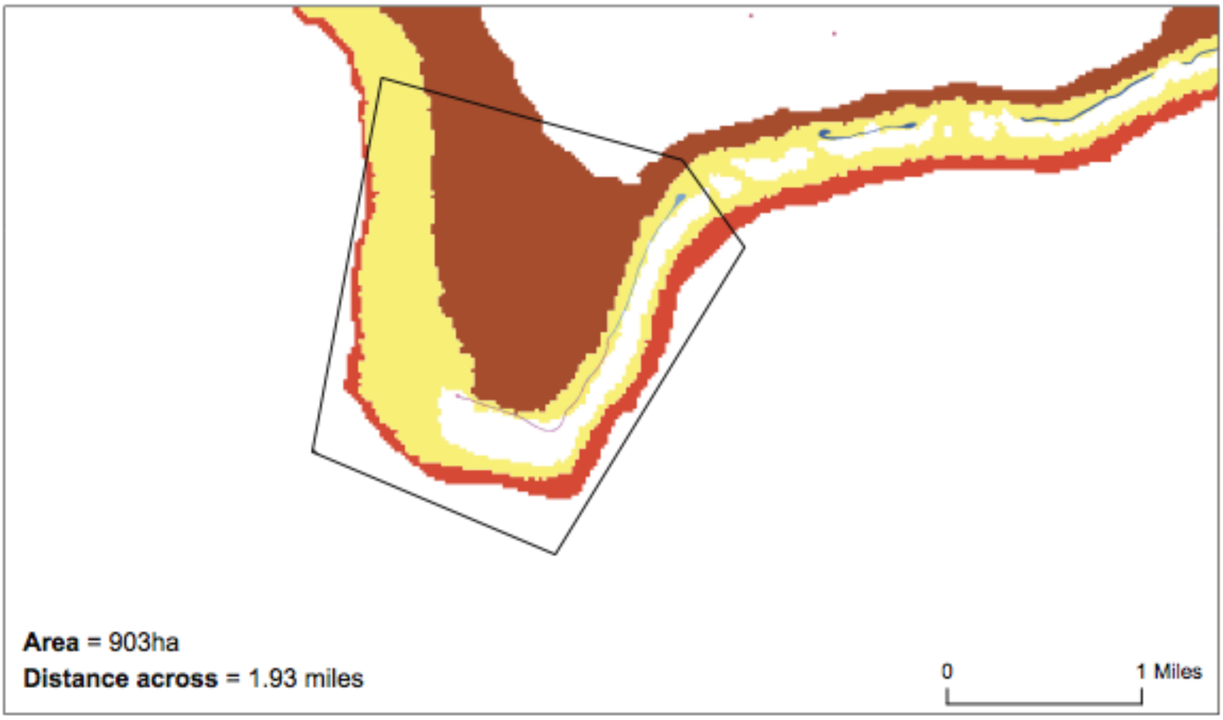
Reef Classes

- Atoll Forereef
- Atoll inner slope
- Lagoon pinnacle
- Atoll pass
- Atoll reef flat
- Atoll ridge and fossil crest
- Atoll subtidal reef flat

Seagrass Meadows

- C.rotundata (Continuous)
- C.rotundata (Aggregated)
- T.hemprichii (Continuous)
- T.hemprichii (Aggregated)
- T.hemprichii (Isolated)
- E.acoroides (Continuous)
- E.acoroides (Aggregated)
- E.acoroides (Isolated)

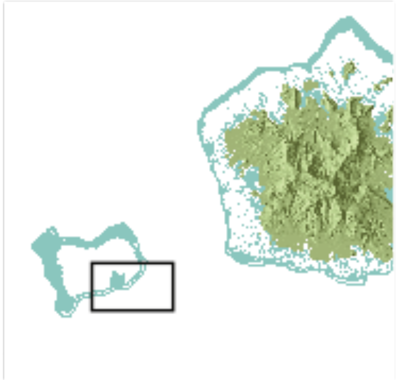




Area = 903ha

Distance across = 1.93 miles

Channel Marine Sanctuary

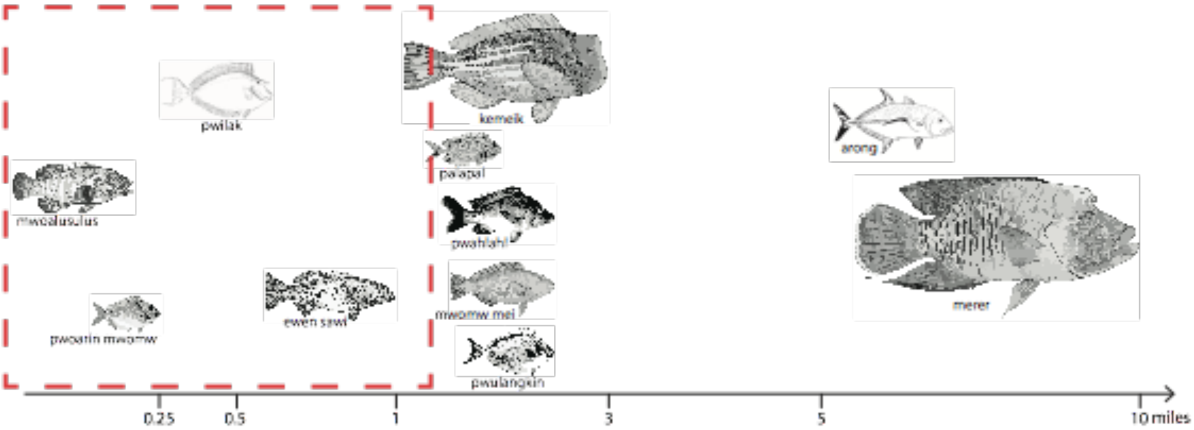


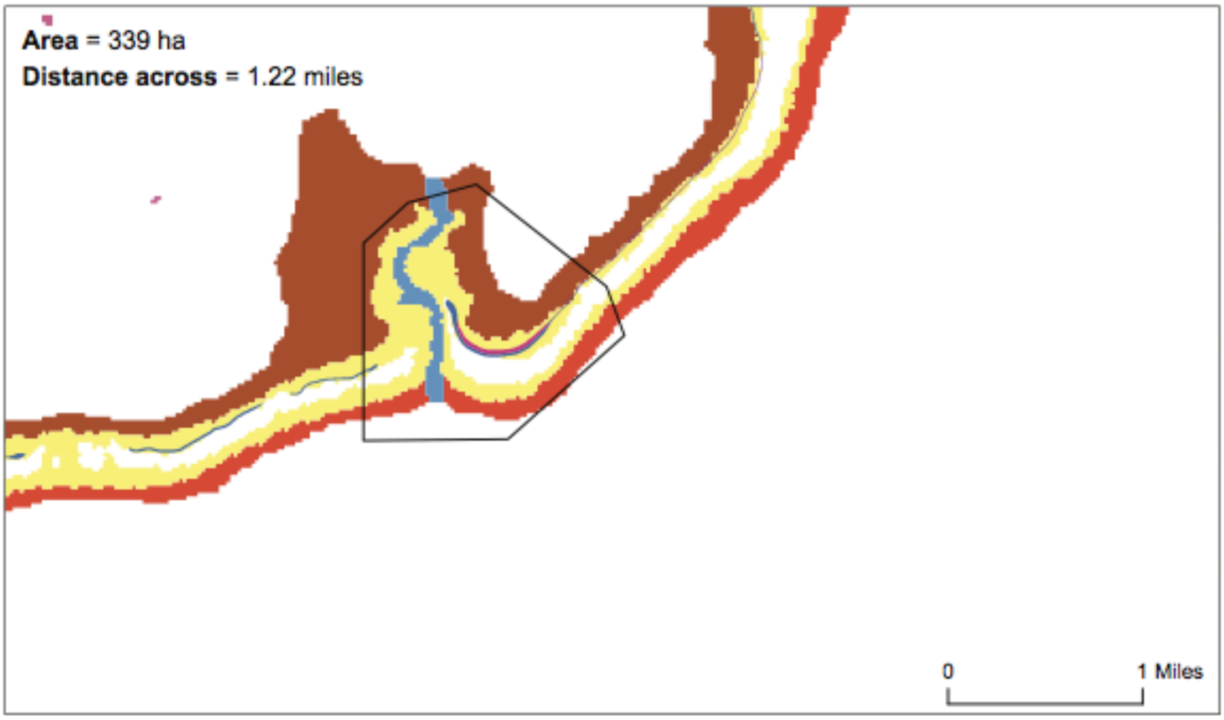
Reef Classes

- Atoll Forereef
- Atoll inner slope
- Lagoon pinnacle
- Atoll pass
- Atoll reef flat
- Atoll ridge and fossil crest
- Atoll subtidal reef flat

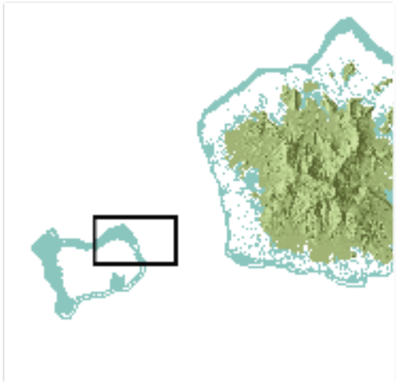
Seagrass Meadows

- C.rotundata (Continuous)
- C.rotundata (Aggregated)
- T.hemprichii (Continuous)
- T.hemprichii (Aggregated)
- T.hemprichii (Isolated)
- E.acoroides (Continuous)
- E.acoroides (Aggregated)
- E.acoroides (Isolated)





Pasa Marine Sanctuary

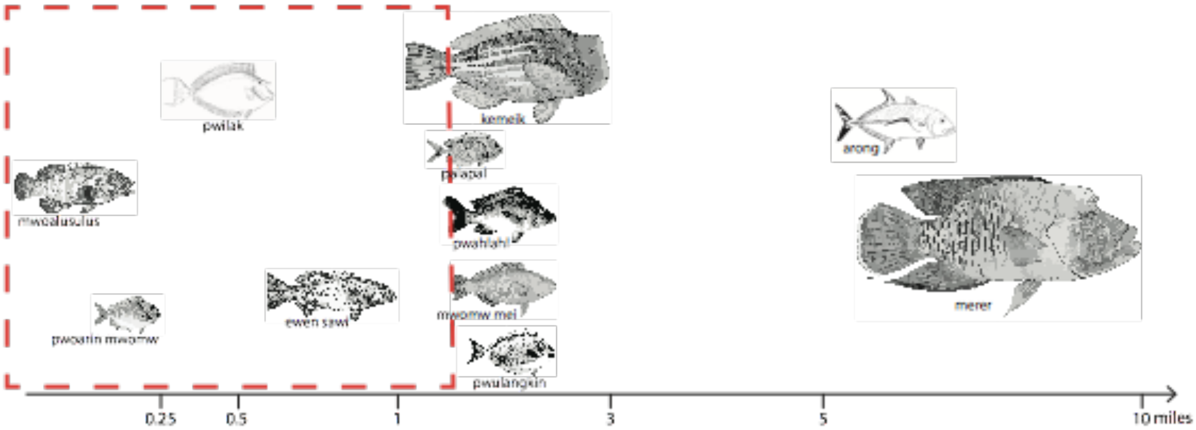


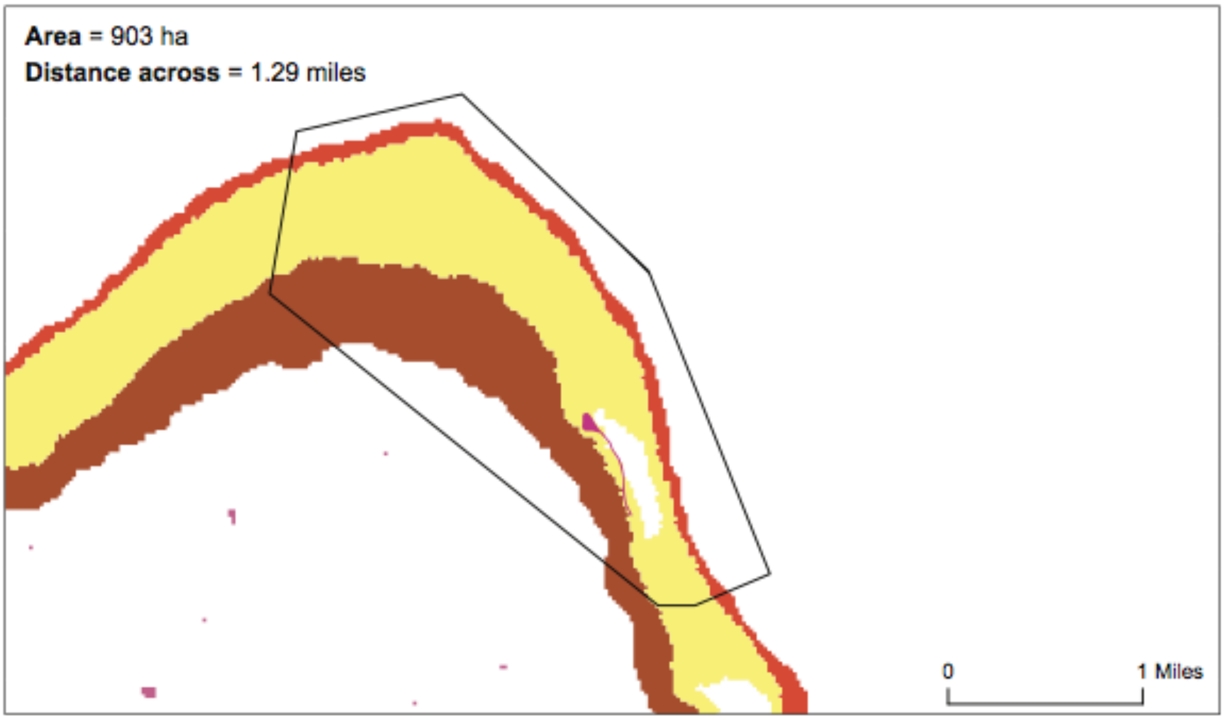
Reef Classes

- Atoll Forereef
- Atoll inner slope
- Lagoon pinnacle
- Atoll pass
- Atoll reef flat
- Atoll ridge and fossil crest
- Atoll subtidal reef flat

Seagrass Meadows

- C.rotundata (Continuous)
- C.rotundata (Aggregated)
- T.hemprichii (Continuous)
- T.hemprichii (Aggregated)
- T.hemprichii (Isolated)
- E.acoroides (Continuous)
- E.acoroides (Aggregated)
- E.acoroides (Isolated)

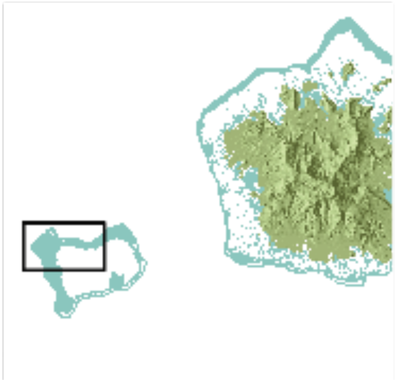


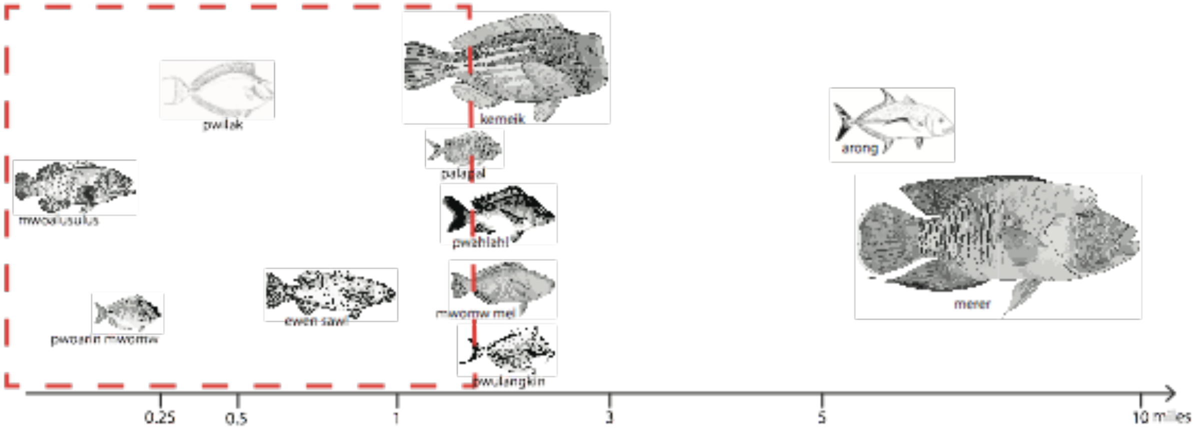


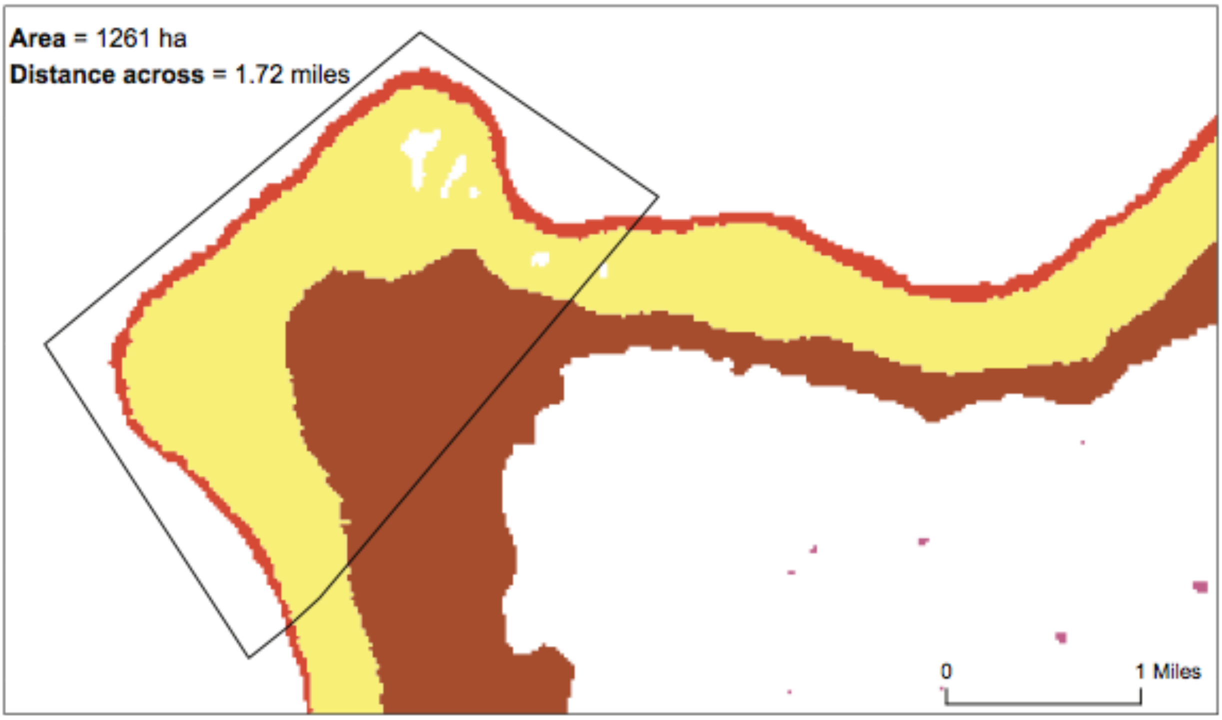
Wolouna Marine Sanctuary

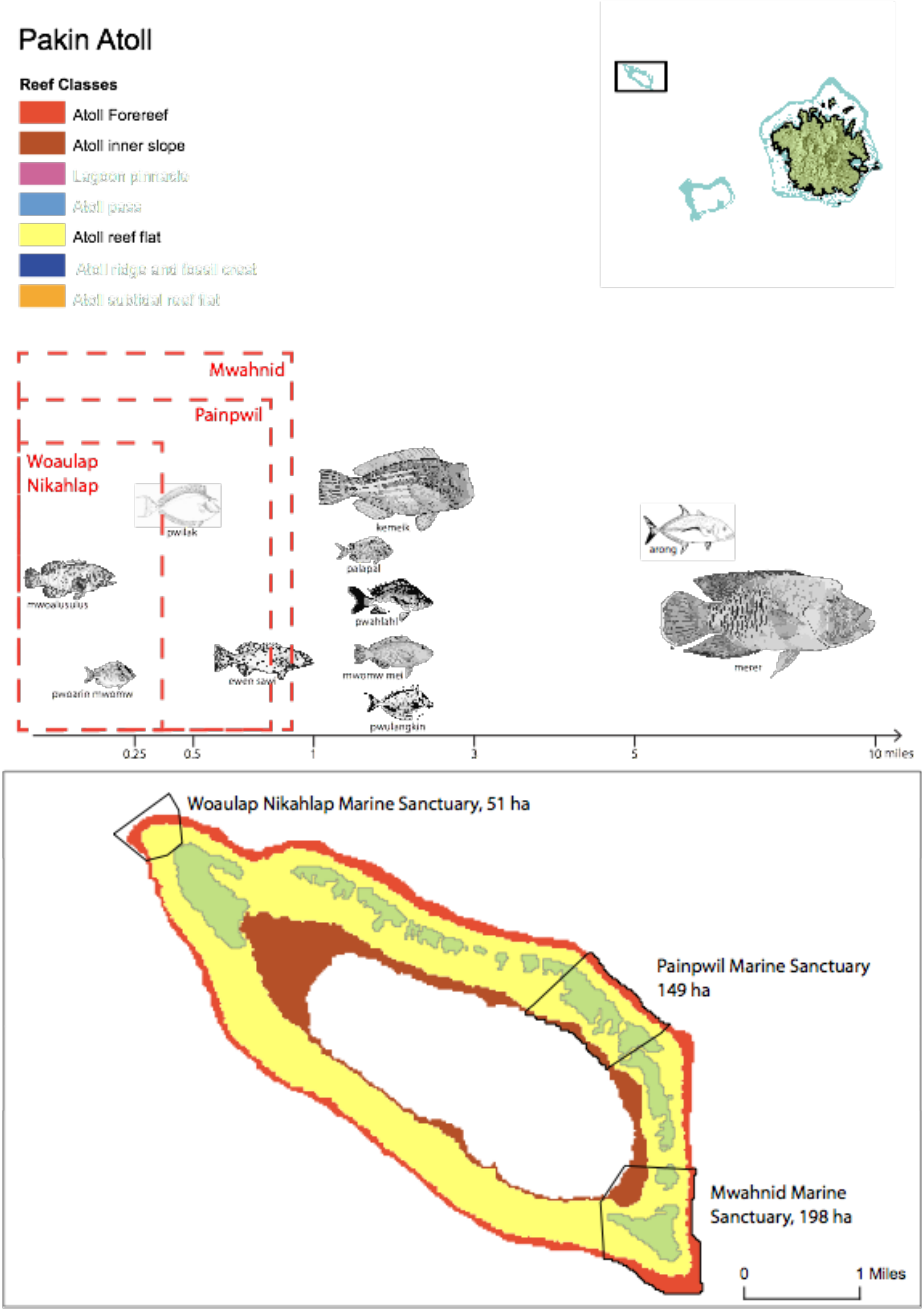
Reef Classes
- Atoll Forereef
- Atoll inner slope
- Lagoon pinnacle
- Atoll pass
- Atoll reef flat
- Atoll ridge and fossil crest
- Atoll subtidal reef flat

Seagrass Meadows
- C.rotundata (Continuous)
- C.rotundata (Aggregated)
- T.hemprichii (Continuous)
- T.hemprichii (Aggregated)
- T.hemprichii (Isolated)
- E.acoroides (Continuous)
- E.acoroides (Aggregated)
- E.acoroides (Isolated)








Pakin Atoll
Reef Classes
Atoll Forereef
Atoll inner slope
Lagoon pinnacle
Atoll pass
Atoll reef flat
Atoll ridge and fossil crest
Atoll subtidal reef flat
Mwahnid
Painpwil
Woaulap
Nikahlap
pwilak
mwoalusulus
pwoarin mwomw
ewen sawi
kemeik
palapal
pwahlahl
mwomw mei
pwulangkin
arong
merer
0.25
0.5
1
3
5
10 miles
Woaulap Nikahlap Marine Sanctuary, 51 ha
Painpwil Marine Sanctuary
149 ha
Mwahnid Marine
Sanctuary, 198 ha
0
1 Miles

APPENDIX 2: TECHNICAL INFORMATION

INPUT DATA

Seagrass

Data origin: Seagrass REA conducted by Seagrass Watch & CSP, 2005

Pre-processing: clipped to align with terrestrial boundary and reef features

Features: Dominant species x meadow type

- C. rotundata Aggregated
- C. rotundata Continuous
- E. acoroides Aggregated
- E. acoroides Continuous
- E. acoroides Isolated
- T. hemprichii Aggregated
- T. hemprichii Continuous
- T. hemprichii Isolated

Coral Reefs

Data origin: IMARS Millennium Coral Reef Mapping Project

Features: L2 L4

Terrestrial Habitats

Data origin: USDA Landcover

Features:

- Marsh
- Palm Forest
- Swamp Forest
- Upland Forest
- Mangrove*

Species Targets

Data Origin: Previous planning exercise / workshop / CSP

- Coconut Crab
- Manta Ray
- Mountain Starling
- FSAs
- Seabird nesting areas
- Turtle nesting areas
- ABS areas

Marine Opportunity Costs

Data on the number households per enumeration area catching reef fish for consumption as a percentage of all households catching reef fish for consumption were used to create a spatial model of MPA opportunity costs around the main island of Pohnpei. This data could be extracted from the FSM 2010 census, providing a measure that can be used state-wide. It was considered most important to minimize negative impacts on households that consume at least part of their catch, given that this might contribute towards food security (the corollary is that fishers selling all of their catch are assumed to have greater spatial, if not occupational mobility).

Cost values were assigned to planning units using a concave distance decay, such that areas closer to the coastline are assumed to have higher cost than those further offshore (out to 6 miles) and areas adjacent to populated places with greater relative proportion of households catching reef fish for consumption are assumed to have higher cost than areas adjacent to populated places with fewer households catching and consuming reef fish. Whilst many fishers likely travel further than 6 miles, minimizing costs within this distance will reduce opportunity costs to fishers without motorized boats, who have reduced spatial mobility in where they fish and would be most impacted by MPA implementation.

- Population census data extracted from http://www.spc.int/prism/data/popgis2
- Report number of households per enumeration area catching reef fish for consumption: H19. HH catches fish/shell fish and use – HH catches reef fish – 2010 census (HH uses reef fish to consume + HH uses reef fish to consume and sell)
- Calculated relative importance of fishing in each EA as number of households catching reef fish for consumption as percentage of all households in Pohnpei catching reef fish for consumption
- Identify populated places in each EA from PNI_PopulatedPlaces GIS layer (for EAs with no populated place, add one based on assumption of proximity to main road).
- Where >1 populated place per EA, distribute percentage of HH catching reef fish for consumption equally between places, otherwise assign EA value to single place.
- Use TNC PAT tools v3. ERS tool to create a distance decay of predicted fishing pressure:
    - intensity = proportion of HH catching reef fish for consumption, as integer
    - influence distance = 10000m
    - overlay = maximum
    - decay type = concave 2
    - scale 0 - 100
- Use ArcGIS Zonal statistics as table to assign raster values to 5 ha planning units (marine only)

Terrestrial Opportunity Costs

Terrestrial opportunity costs were modeled as a linear distance decay of one mile from existing roads (i.e., areas immediately adjacent to roads are considered highly unsuitable for conservation, areas further than one mile away are unaffected by the cost layer). This both anticipates potential future development of land adjacent to existing infrastructure, and accounts for the likely lower ecological value of those habitats.

Note that modified habitats (e.g. secondary vegetation, cropland) are not targeted for inclusion in the PAN. The urban influence cost layer acts to express a preference for protecting targeted habitat features further away from urban areas where possible.

A more sophisticated model of terrestrial opportunity costs might account for the potential for land conversion to agriculture or other uses, based on, for example existing vegetation, soil and slope attributes. It might also reduce opportunity costs for protecting habitats with recreational and/or cultural value, e.g. historical sites and waterfalls.

- Input data layers = PNI_Roads, PNI_PopulatedPlaces
- Use TNC PAT tools v3. ERS tool to create a distance decay of urban influence:
    - intensity = 100
    - influence distance = 806m (0.5 mile)
    - overlay = maximum
    - decay type = linear
    - scale 0 – 100
- Clip raster to main island boundary (derived from USDA Landcover)
- Use ArcGIS Zonal statistics as table to assign raster values to 5 ha planning units

MARINE PROTECTED AREA ADEQUACY ANALYSIS

To calculate the linear length of each MPA, 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.

MARXAN WITH ZONES

Zones

Three zones were specified: available, existing, and proposed. The existing, and proposed zones both contribute equally towards representation targets. By using PUZONE to limit planning units to particular zones, it was possible to preferentially include existing protected areas in some scenarios, and control, to a certain extent, whether the size of existing protected areas would be increased.

Costs

Three cost layers (planning unit area, urban influence and reef fishers) were generated. Marxan with Zones assigns a multiplication factor between each cost layer and each zone. For example, in the table below, existing reserves are assigned zero cost (expressing a strong preference for them to be included in scenarios) and planning units assigned to the proposed zone are subject to opportunity costs both on land and in the sea. The available zone always has zero cost. The proposed zone always has a nominal area cost, to prevent the (relatively few) planning units with zero opportunity cost from always being selected.

	Available	Existing	Proposed
Area	0	0	1
Urban Influence	0	0	5
Reef Fishers	0	0	5

Calibration

For all scenarios:

NUMITNS = 1000000

NUMREPS = 100

FPF values were calibrated for each scenario individually, as follows:

7. Start with an FPF value of 1 (FPF values were homogeneous for all features targeted for representation in each scenario)
8. Run Marxan and view the minimum proportion of targets met (MPM) for 10 solutions. Solutions with MPM > 0.99 were considered to achieve objectives.
9. Increase or decrease the FPF by an order of magnitude, depending on whether targets were over- or underachieved in step 2.
10. Set the FPF at the midpoint between previous runs that over and underachieved targets. Run Marxan again and check MPM values.
11. Repeat step 4, ending calibration when the smallest FPF score (to one decimal place) that achieves MPM > 0.99 for all 10 solutions has been identified.

ZONEBOUNDCOST was used to express a preference for clumping within and between the three zones specified (open, existing and proposed). Calibrating ZONEBOUNDCOST is more complicated than calculating the BLM between two zones, because relationships are represented in a zone x zone matrix, where each element in the matrix represents the boundary relationship between the pair of zones referencing that element. Some hints:

- The relationship between any zone and itself is always 0.
- Increasing the multiplication factor between the open zone and the proposed zone expresses a preference spatial clumping of planning units assigned to the proposed zone.

- Increasing the multiplication factor between the open zone and the existing zone expresses a preference spatial clumping of planning units assigned to the existing zone.
- If the multiplication factor between the proposed and existing zones is 0, and both of these zones have a >0 factor relationship to the available zone, the proposed and existing zones will be clumped together, with the effect that existing reserves can increase in size. The relative values of the multiplication factors throughout the matrix determine the strength of this preference.
- A very high factor between available and existing zones will have the effect that existing protected areas are "buffered" by proposed planning units, increasing PA size.

ZONEBOUNDCOST was calibrated as follows:

- Calibrate zone relationships one at a time, starting with available-proposed, then available-existing, then existing-proposed.
- Start off by increasing the multiplication factor by an order of magnitude at a time. To fine tune the values, we reduce the magnitude of increases (and decreases) to midpoints, until the degree of spatial clumping required for each zone is achieved.
- Calibrate each zone until it achieves a "moderate" level of spatial clumping. This was assessed visually, as a trade-off between the number of individual planning units selected for inclusion in that zone (ideally none, more indicates value set too low) and over-clumping, identified as spatial artifacts in individual solutions, such as very long thin (usually diagonal) selected sets of planning units (ideally none, presence indicated value set too high).

After calibrating ZONEBOUNDCOST, adjustments to the FPF were often required. Thus, for each scenario, calibration was performed iteratively: FPF v1; ZONEBOUNDCOST v1; FPF final; ZONEBOUNDCOST final.

Scenario	FPF	ZONEBOUNDCOST
1b (clean slate)	0.03	003 000 300
2b (fill gaps - areacost)	0.2	002 000 200
2c (fill gaps oppcost)	0.2	004 000 400
3a (clean slate oppcost)	0.05	007 000 700
3c	9	023 200 300
3e	6	016 106 660
3f	6	046 400 600
3g	9	019 1010 9100
Seagrass priorities	0.9	002 000 200
Intermediate targets	3	026 200 600

MARXAN RESULTS

For each scenario, the summed selection frequency across 100 runs and three individual solutions are presented. Given that scenarios were parameterized so that the minimum proportion of each target met exceeds 99% (MPM > 0.99), identifying the "best" solution as per Marxan outputs is not especially informative. Instead, individual solutions were selected using a cluster analysis (Bray-Curtis dissimilarity) of zone 3 (proposed protected areas) across all solutions: the tree was cut into three groups, and one solution from each group presented. This indicates the variety of different spatial solutions to the conservation planning problem posed in each scenario.

Selection frequency maps offer a clear way to communicate priorities to stakeholders, and do not have the appearance of a "decision already made". Selection frequency maps are most informative in relatively constrained scenarios, where clear patterns emerge (i.e. some planning units are selected much more frequently than others). When there is a lot of flexibility in the reserve selection problem (i.e. there are many different combinations of planning units that achieve the conservation objective with equally low cost) planning units are selected with equal frequency and clear priorities do not emerge. This situation is typically indicative of the need to incorporate more information in the Marxan scenario, for example fine-scale biodiversity data or socioeconomic data that is likely to constrain where protected areas can be established most easily or effectively.