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TNC Pacific Island Countries
Report No 2/07

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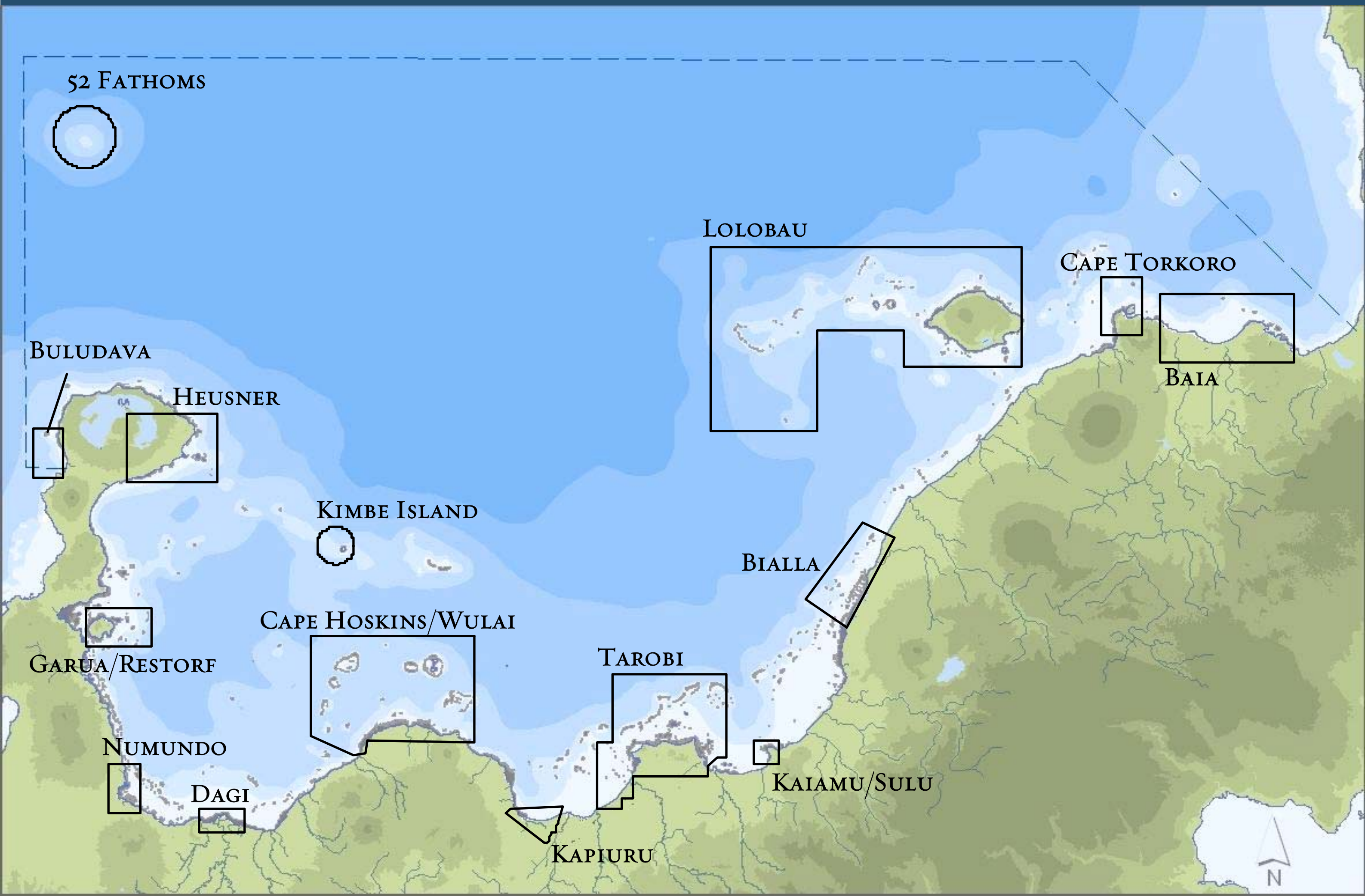

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Report by:
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This publication was made possible through support provided by The Nature Conservancy, The David and Lucile Packard Foundation and the Office of Procurement, U.S. Agency for International Development, under the terms of Award No. LAG-A-00-99-00045-00. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Agency for International Development, The David and Lucile Packard Foundation, and The Nature Conservancy.

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Published by: The Nature Conservancy, Indo-Pacific Resource Centre

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Suggested Citation:
Green, A., Lokani, P., Sheppard, S., Almany, J., Keu, S., Aitsi, J., Warku Karvon, J., Hamilton, R and G. Lipsett-Moore 2007. Scientific Design of a Resilient Network of Marine Protected Areas. Kimbe Bay, West New Britain, Papua New Guinea. TNC Pacific Island Countries Report No. 2/07.

Maps: Stuart Sheppard and Jeanine Almany

ISBN 9980-9964-7-1

Available from:

Indo-Pacific Resource Centre
The Nature Conservancy
51 Edmondstone Street
South Brisbane, QLD 4101
Australia

Or via the worldwide web at:
conserveonline.org/workspaces/pacific.island.countries.publications

FOREWORD

Situated on the volcanic island of New Britain, West New Britain province is rich in biodiversity both on the land and under the sea. Our people pride themselves in a land tenure system which has been passed down from generation to generation, a clan ownership of land resources, which are shared out equally between clan communities. Originating from a subsistence economy where harvests from the land and catches from the sea were shared to ensure everyone had enough to live on and no one had less than another, we are now challenged by the cash economy in which we live today.

The need for better education, health and other services continue to increase and our people have to adapt to meet these situations with the various measures that they take. Earning an income has become a necessary means to meet their children's school fees and to get better medical services. Better health services have seen a rapid population growth which results in pressures on the environment as people lean towards cash cropping or marine resources for an income. Better education means knowledge and power that challenges the traditional leadership, which leads to a lack of respect and breakdown in traditional values and authority.

However, these challenges make us more persistent to make the best out of our situation and with organisations such as The Nature Conservancy, which ensures partnership is a major component of their work, we are truly privileged to witness the work they have done in the last 15 years.

The vision for the Kimbe Bay MPA network, which I fully endorse is "*Harnessing traditional and community values to protect and use land and sea resources in ways that maintain the exceptional natural and cultural heritage of Kimbe Bay."* This vision recognises and connects the people of my province with the natural resources and biodiversity of the province that has helped sustain our culture and livelihood for thousands of years.

Since 1992, The Nature Conservancy has been working in Kimbe Bay conducting various surveys and studies to find out the condition of the marine environment, and whether or not the area is ideal for a Marine Protected Area (MPA), and to date have identified 15 Areas of interest that make up an MPA design.

This publication, which outlines the design and implementation of the Kimbe Bay Marine Protected Area Network, aims to provide stakeholders with an in-depth report of the work carried out by The Nature Conservancy to date.

As the Governor of the West New Britain province I pledge my support to work with all stakeholders for the good of the province. I would like to encourage all stakeholders and partners to support the work of Non Government Organizations and especially The Nature Conservancy. At the end of the day conservation has been part and parcel of our life and it is fitting that we should continue to support it.

We congratulate The Nature Conservancy for their outstanding work and pledge our continued support.

Honorable Clement Nakmai
Governor – West New Britain Province

Acknowledgements

The Conservancy wishes to thank local communities for sharing their knowledge of Kimbe Bay, and the communities, Local Level, Provincial and National Governments for supporting the MPA network and the scientific design.

Many people have contributed to this project. The MPA network design was completed by The Nature Conservancy's core design team for Kimbe Bay (listed in Contributors). This team was responsible for assembling the scientific data, conducting the data analysis, and generating the design.

The Conservancy is grateful for scientific advice provided by technical experts regarding MPA network design (Rod Salm and Peter Mous, The Nature Conservancy), conservation planning and coral reef fish communities (Maria Beger, University of Queensland), ocean currents (Craig Steinberg, Australian Institute of Marine Science), biological patterns of connectivity (Glenn Almany, James Cook University), reef geomorphology (Serge Andrefouet, Institute for Marine Remote Sensing, IMaRS), dive tourism (Max Benjamin), and socioeconomic characteristics of the bay (Gina Koczberski and George Curry). We are also grateful to the technical experts who helped refine the guiding principles for the MPA network design in the First Scientific Workshop (see Green and Lokani 2004).

This work would not have been possible without the generous support of USAID, the David and Lucile Packard Foundation, Charles Brown, AP Anon, Wyanne and Colleen Miniami, RARE, the LMMA network, The Nature Conservancy's Global Marine Initiative and our ongoing partnership with Mahonia Na Dari and Walindi Plantation Resort.

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Contents

List of Figures

Executive Summary

The Nature Conservancy's vision for Kimbe Bay is to *"Harness traditional and community values to protect and use land and sea resources in ways that maintain the exceptional natural and cultural heritage of the bay".* This will be achieved by working with local communities, governments and other stakeholders to establish a resilient network of Marine Protected Areas (MPAs), and develop strategies for improved management of marine resources and land use practices. This report focuses on a critical step in this process – designing a resilient network of MPAs for Kimbe Bay.

SCIENTIFIC DESIGN OF A RESILIENT MPA NETWORK

The objectives of the Kimbe Bay MPA network are twofold: to conserve marine biodiversity and natural resources of the bay in perpetuity, and to address local marine resource management needs. The scientific design of the Kimbe Bay MPA network is based largely on a scientific assessment of biodiversity values, and identifies 15 Areas of Interest that meet specific conservation goals. The design process involved expert scientific advice, targeted research and monitoring, and an analytical design process (using marine reserve software MARXAN).

Climate change represents a major threat to the long term future of coral reefs and associated ecosystems around the world, including Papua New Guinea. The scientific design of the Kimbe Bay MPA network represents one of the world's first MPA networks specifically designed to address this threat. In recent years, principles for designing MPA networks that are resilient to the threat of climate change have been developed. While most of these principles were applied successfully in Kimbe Bay, some aspects will require refinement over time as new scientific methods are developed and more information becomes available. The design will also be refined as implementation proceeds, with substantial input still required from local communities and other stakeholders.

Finalising the scientific design of the MPA network represents a major milestone for the Kimbe Bay Project, since it provides an excellent blueprint for biodiversity conservation in the bay. This design will form the basis for working with local communities and other stakeholders to refine and implement the design over time. Since communities are the marine resource owners and decision makers in Kimbe Bay, final decisions regarding the MPA network design will be at their discretion.

COMMUNITY ENGAGEMENT

The Nature Conservancy has a long history of community engagement in Kimbe Bay. Several options were considered for engaging communities in the scientific design process, and it was decided that the most effective strategy would be to engage communities after the design had been completed. There were several reasons for this. Firstly, there was concern that engaging all communities in the scientific design process would generate almost unanimous support across the bay, and raise communities' expectations well beyond our capacity to deliver. Indeed we were concerned that we would be faced with the scenario of being asked to support conservation activities in many locations outside key biodiversity areas of interest. Secondly, there are over 100 culturally diverse communities in Kimbe Bay, all of which hold complex and often overlapping traditional rights to sea resources, and it was considered logistically unrealistic to capture all of these communities' views and opinions in a scientific process. The scientific design process was also highly technical, and it was not considered practical for community members to participate in this process. Therefore, it was decided that the most effective strategy was to go through a scientific design process, and identify priority areas for conservation. Once these areas had been identified, the Conservancy would seek to work with communities that own and manage marine resources within these areas through a detailed community-based planning process.

While a full community engagement process was not undertaken during the scientific design process, several steps were taken to understand and incorporate the needs and interests of communities as far as practicable. Considerable informal community engagement was undertaken by field staff while collecting biological data for the design process. Valuable background information was also provided by a detailed socioeconomic study of six communities, which provided an understanding of the variety of socioeconomic situations in the bay. Socioeconomic design principles were also developed and implemented for the MPA network, which were specifically designed to address the needs and interests of local communities and other stakeholders.

IMPLEMENTATION

Implementing the design will require multiple strategies for working with local communities and government at a range of scales. Locally Managed Marine Areas will be the primary strategy for nearshore areas, while other strategies will be required for offshore areas. These may include protecting areas through partnerships with the tourism industry and government. Broader scale strategies will also be required for the entire MPA network area, particularly regarding marine resource use and land use management. The implementation process is expected to take approximately five years to complete, and will rely heavily on partnerships with local communities, industry, other NGOs (particularly Mahonia Na Dari), and all levels of government. While not all potential partners were engaged in the scientific design process, those that were have demonstrated support for the MPA network and the scientific design.

In order for implementation to be successful, strong support will be required from local communities and all levels of government (Local, Provincial and National). Meetings with local communities have demonstrated that there is strong support for the MPA network in areas where we already work, although a community engagement process is still required in other areas. The MPA network and the scientific design have also been endorsed by all levels of government. An ongoing commitment to working with local communities, government and other stakeholders will be required for this network to be successful in the long term.

LESSONS LEARNED

This was one of the first attempts to design a resilient network of MPAs, and the first to design an MPA network for Melanesia. Many lessons were learned that may be useful to others undertaking a similar exercise. They include:

- It is important to have a clear plan for the design and a process for achieving it, and for this process to be properly integrated within a broader implementation plan.
- It is important to take implementation into account in the way in which the MPA network is designed, and to identify the most effective strategy for engaging stakeholders in the process.
- There are still some scientific challenges that need to be addressed for designing resilient MPA networks. In the interim, rules of thumb can be used to address these challenges.
- Marine reserve software (MARXAN) is an excellent tool for processing large amounts of information for MPA network design, but it is important to remember that it is a decision support tool and not the decision maker.
- The minimum amount of information required to complete a scientific design of an MPA network is the location of conservation targets, threats and opportunities.
- A multidisciplinary team is required including scientific experts, a GIS specialist, local managers and representatives who can contribute local knowledge and have a clear understanding of the culture, needs and interests of local communities and other stakeholders.
- It takes time, with a minimum of five to seven years required for design and implementation.
- Costs were relatively low compared to those expected for developed countries.

Lessons learned in the scientific design process, and lessons we are still learning in the implementation of the Kimbe Bay MPA network, will be used to inform other MPA design processes in the Bismarck Sea and elsewhere in the Coral Triangle.

1. INTRODUCTION

1.1 THE NATURE CONSERVANCY'S CORAL TRIANGLE PROGRAM

The Nature Conservancy's mission is *"To preserve the plants, animals and natural communities that represent the diversity of life on earth by protecting the lands and waters they need to survive."* Recently, the Conservancy announced an ambitious ten year goal, which states that *"By 2015, we will work with others to ensure the effective conservation of places that represent at least 10% of every Major Habitat Type on Earth."* Marine Protected Areas (MPAs[3]) will play an important role in achieving this goal for marine habitats around the world.

In the Asia Pacific Conservation Region, The Nature Conservancy's Tropical Marine Program is focused on the global centre of marine diversity, known as the Coral Triangle (Green and Mous 2006: Figure 1). While the Coral Triangle encompasses a large area (7,077,203 km^2), it comprises less than 2% of the world's oceans. And yet it encompasses 53% of the world's coral reefs, and a staggering proportion of the world's biodiversity: 76% of coral species (Veron 2000) and 50% of coral reef fish species (G.R. Allen unpubl. data). This area also includes all or part of six countries in Melanesia and Southeast Asia: Papua New Guinea, Solomon Islands, Philippines, Indonesia, Malaysia (Sabah) and East Timor. Since these are all developing countries where many people live subsistence lifestyles, these reefs support the livelihood of 126 million people and the protein needs of millions more. The Conservancy is committed to conserving this critically important area by establishing resilient[4] networks[5] of MPAs that are effectively managed, sustainably financed, and designed to survive the threat of climate change. Kimbe Bay is located in Papua New Guinea in the eastern side of the Coral Triangle (Figure 1).

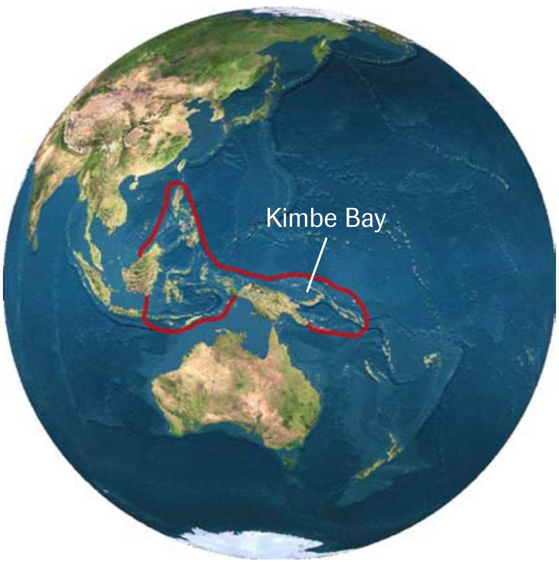


Figure 1. The Coral Triangle (red line), showing the location of Kimbe Bay in Papua New Guinea.

[3] Consistent with international usage (Kelleher 1999), MPAs are defined as "any area of the intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment." This includes Locally Managed Marine Areas.
[4] Resilience is the ability of a system to undergo, absorb, and respond to change and disturbance, while maintaining its functions (Carpenter et al. 2001).
[5] An MPA network is a portfolio of biologically connected MPAs that is fully representative of the range of target ecosystems, species, and processes

1.2 KIMBE BAY: MARINE CONSERVATION PLATFORM SITE IN PAPUA NEW GUINEA

Kimbe Bay is located on the north coast of the island of New Britain in the Bismarck Sea, West New Britain Province, Papua New Guinea (Figure 2: 5° 15'S; 150°15'E). Kimbe is one of The Nature Conservancy's platform sites, where the aim is to establish a resilient network of MPAs. Lessons learned will be used as the basis for establishing a larger scale network of MPAs throughout the Bismarck Sea, beginning with Manus Island in Manus Province. The Conservancy will also work with conservation partners to expand the network to other areas in the Bismarck Sea, and to link with other MPA networks throughout the Coral Triangle.

The Nature Conservancy's vision for Kimbe Bay is to *"Harness traditional and community values to protect and use land and sea resources in ways that maintain the exceptional natural and cultural heritage of Kimbe Bay"*. Our goal is that *"By 2008, a large-scale, resilient MPA network will be designed for Kimbe Bay, and at least 20% of high priority areas will be effectively protected, with an additional 30% in the process of being protected."*

Figure 2. Bismarck Sea in Papua New Guinea, showing the location of Kimbe Bay.

1.3 WHY KIMBE BAY?

Kimbe Bay is an excellent choice for establishing a resilient network of MPAs due to its outstanding biophysical characteristics, and its socioeconomic characteristics which provide a good opportunity for marine conservation. Conservation activities over the last decade have also provided a strong basis for marine conservation in the bay.

1.3.1 Biophysical Characteristics

Kimbe Bay is a spectacular land and seascape, with outstanding natural features. The landscape is dominated by numerous volcanic cones, which reach heights of over 2000m close to shore (Figure 3), four of which are active volcanoes.

The seascape is also quite dramatic (Figure 3). Most of the bay is deep (more than 500m), with a narrow shelf (less than 200m deep) along the coast. On the eastern and outer portions of the bay, the shelf drops off steeply into very deep water (more than 2000m) very close to shore. The western portion of the bay is shallower than the eastern side, but still reaches depths in excess of 600m.

Kimbe is a large, well-defined bay (140km x 70km in area) with distinct boundaries: Willaumez Peninsula to the west and Cape Torkoro to the east (Figure 5). Because of the size and shape of the bay, it comprises a distinct functional seascape[6] (Green and Mous 2006), which provides a natural unit for designing a resilient network of MPAs.

Kimbe Bay is one of the world's most diverse and significant tropical marine environments. The bay comprises a wide variety of shallow (coral reefs, mangroves, and seagrasses) and deepwater marine habitats (oceanic waters, seamounts, and possibly deep-sea canyons and hydrothermal vents) in close proximity. Many of these habitats are of high conservation value.

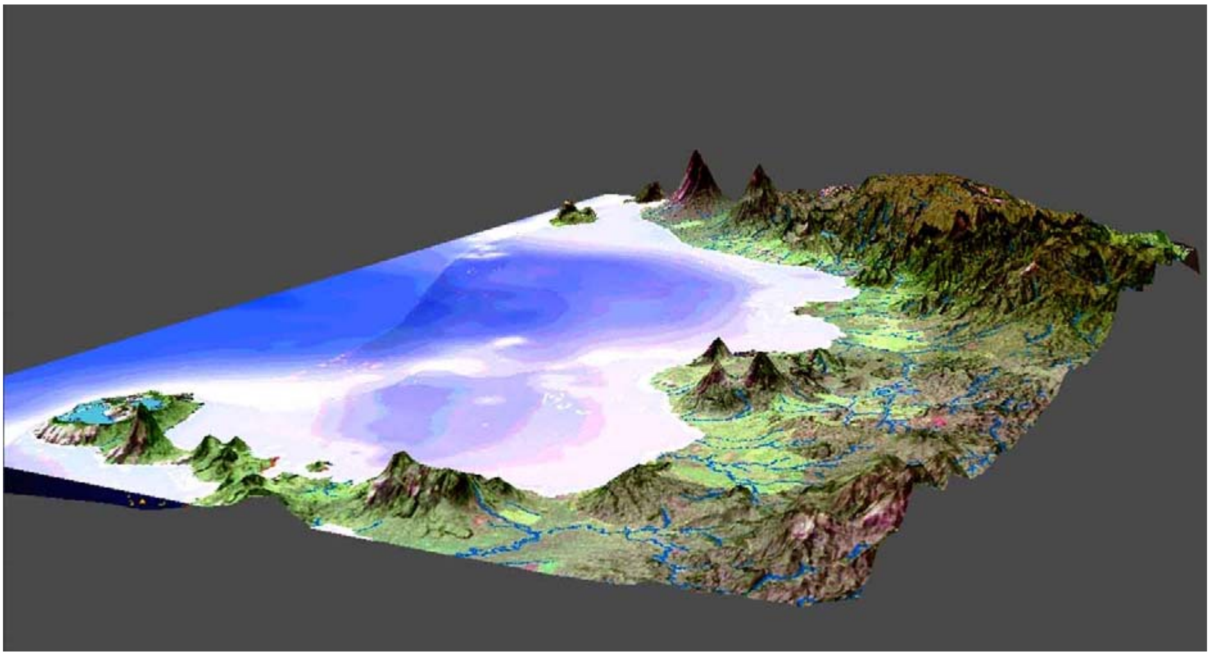
Rapid Ecological Assessments have described healthy coral reefs with high biodiversity, (Holthus 1994, Beger 2002, Turak and Aitsi 2002), particularly on the eastern and mid to outer portions of the bay. These reefs are considered part of the global centre of marine biodiversity known as the Coral Triangle (Figure 1). Field surveys have also described ecologically significant mangrove forests and seagrass communities in the bay, with reasonably high biodiversity (Sheaves 2002, Aitsi and Sapul 2006, Keu in prep.). Nesting areas for leatherback, green and hawksbill turtles have also been reported (Rei and Galama 2004, Aitsi 2006).

Kimbe Bay also supports extensive deepwater habitats including seamounts, which are likely to have high conservation value for pelagic species (whales and fishes) and benthic communities. To date, twelve species of marine mammal (including sperm whales, orcas, spinner dolphins and dugong: Visser 2002a,b, 2003) and other rare and threatened species (including sea turtles and seabirds) have been recorded in the bay (Rei and Galama 2004, Aitsi 2006). The close proximity of shallow and deepwater habitats provides an excellent opportunity to protect a wide range of high diversity marine habitats in one location.

Kimbe Bay is also an integral component of the Bismarck Sea (Figure 2), which is the home of one of the most extensive coral reef systems in PNG. As part of the Coral Triangle (Figure 1), the Bismarck Sea supports some of world's highest marine biodiversity. It also provides important habitat for sperm and blue whales (Kahn 2003, 2006), access to two crucial cetacean migratory corridors either side of the island of New Britain (Kahn 2003, 2006), important nesting and feeding areas for sea turtles (Spring 1979, WWF 2003), and one of the most productive tuna fisheries in the Western Pacific (Langley et al 2006). In 2003, the East Bismarck Sea was recognised as a globally significant area for pelagic fishes (particularly tuna) and toothed whales (WWF 2003). Kimbe Bay was also recognised as an ecoregionally outstanding area for its well-developed inshore reefs and unique offshore pinnacles rising from deep water, its rich coral and fish communities and frequent whale sightings (WWF 2003).

The PNG Conservation Needs Assessment (Swartzendruber 1993) also identified 30 high priority marine areas, half of which are in the Bismarck Sea. One of these, Talasea, is located along both sides of the Willaumez Peninsula (Figure 5), which includes the southwest corner of Kimbe Bay. This area was nominated for reef and soft bottom marine habitats, and nesting beaches for leatherback turtles. As part of these globally and ecoregionally significant areas, Kimbe Bay is a high priority for marine conservation and an excellent candidate for an MPA network to anchor a larger scale network in the Bismarck Sea.

[6] Functional seascapes are defined as "Areas within a wider ecoregion within which there is some geographical or ecological distinctiveness, but over a smaller area that maybe more suitable for the application of management measures such as MPA networks"



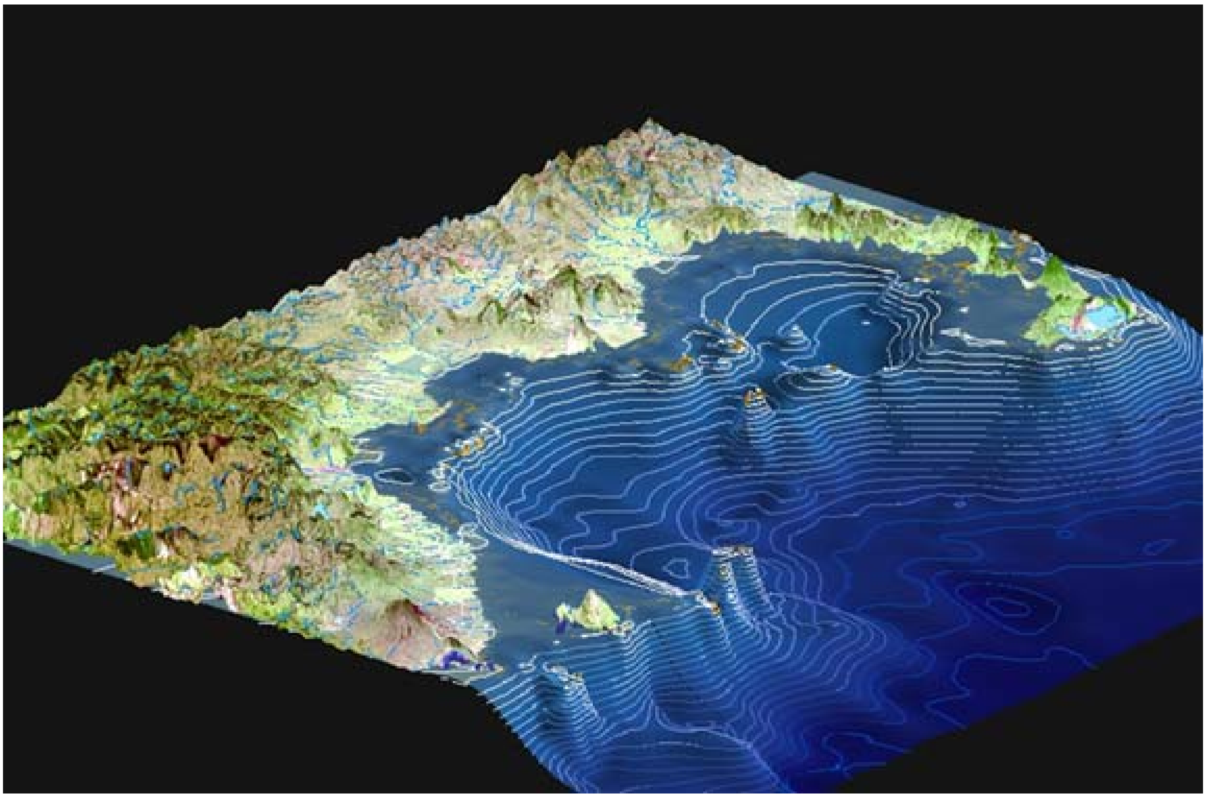


Figure 3. Topography of Kimbe Bay[7] (top) showing volcanic peaks rising to >2000m close to shore; and bathymetry[8] (bottom) showing the narrow coastal shelf (maximum depth 200m) plunging to deep ocean depths of >2000m.

1.3.2 Socioeconomic Characteristics

The socioeconomic characteristics of Kimbe Bay provide an excellent opportunity for establishing a network of MPAs. Levels of marine resource use are low, and there is widespread interest in conservation activities

[7] Based on the Space Shuttle's Radar Topography Mission (90m digital elevation model: NASA 2003).
[8] Interpolated from best available bathymetric data (Navigation Charts and the General Bathymetric Chart of the Oceans) overlaid with IMaRS 2004 geomorphology for the coastline and reefs. Contour intervals are approximately 100m

by local communities (Cinner et al 2002, Koczberski et al 2006). However, some challenges to marine conservation exist, which are likely to increase in future.

Coastal village communities rely on both land and marine resources to meet their everyday subsistence and cash income needs, and much of their cultural identity, beliefs, and ancestral stories are drawn from elements of the marine environment (Koczberski et al 2006). Despite a decreasing reliance on a subsistence-based economy, fish and shellfish remain major dietary items for coastal communities (Koczberski et al 2006). Shellfish meat in particular is a vital part of the subsistence diet.

Approximately 100,000 people[9] live in the Kimbe Bay watershed, of which more than one-third migrated to the area from elsewhere in the province and mainland PNG. Excluding the densely populated offshore islands of Bali Witu[10] and Arawe [11], the coastal plain between Kimbe town and Bialla (Figure 5) has the highest population density in the New Britain province at 130 persons/km (Hanson et al 2001). As a result, resource owners are facing several challenges including changing village socio-political systems, high population growth rates (both urban and rural), poaching of marine resources, the use of destructive fishing methods, rising cash needs, and in some areas, the loss of traditional income sources like cocoa and copra (Koczberski et al 2006).

With the growth of the agriculture industry and the rapidly growing population of the bay (through birth and migration), coastal ecosystems are facing increasing pressures resulting from clearance of coastal forests and mangroves (Beger 2002, Sheaves 2002), changes in land use practices (Sheaves 2002) and elevated sedimentation rates on inshore reefs (Munday 2004). Many local communities are aware that the growing pressures are having detrimental effects on the marine ecosystems in Kimbe Bay, and are receptive to ideas of how to better manage their marine resources. Koczberski et al (2006) reported that throughout all of the villages they surveyed, there was a common perception that there had been a reduction in the abundance of commonly harvested marine resources throughout the bay, which communities attributed to the over-exploitation of marine resources, the use of destructive fishing methods, and changes to marine habitats.

At present, apart from the commercial sale of beche-de-mer (Class Holothuroidea), trochus (*Trochus niloticus*), and shark fin, there are no commercial fishing[12] operations within the bay. Most of the invertebrate catch comes from just a few areas (particularly around Hoskins and Talasea: Figure 5), and catches have increased rapidly in recent years (National Fisheries Authority unpubl. data). Unfortunately, some of the target species (particularly beche-de-mer and sharks) are vulnerable to overexploitation due to their life history characteristics, and declines in stocks of these species have been noted in some areas.

There is no commercial fishery for finfish or crayfish at present, although fishing for these species does occur at subsistence or artisanal[13] levels. This is fortunate, because stocks of these species are considered low due to the relatively small area of coral reef habitat in the bay. Consequently, it is important that no commercial fisheries for these species become established, since these stocks would be vulnerable to overexploitation. This low level of marine resource use provides an excellent opportunity to establish an MPA network, reinforced by a marine resource use strategy, before fishing pressure becomes a more serious problem (see 1.3.4 Key Threats and Conservation Strategies).

Nature based tourism is the only non-extractive industry in West New Britain. In Kimbe Bay, most marine tourism activities originate from Walindi Plantation Resort on the western side of the bay (Figure 5). The resort offers day trips on the south-western side of the bay, and operates two live aboard vessels both inside and outside the bay. Activities include diving, snorkelling, underwater photography, bird, dolphin and whale watching. All activities are conducted in an environmentally friendly way, and impacts are minimal. For example, the dive boats have a strict "look but don't touch" policy and moorings have been installed at dive sites to avoid anchor damage. In 2004, a sports fishing lodge opened at Baia village in eastern Kimbe

[9] 113,120 (PNG Census 2000).
[10] Located in the Witu Islands, northwest of Kimbe Bay.
[11] Located on the southwest side of the island of New Britain.
[12] Catch is exported out of the local area.
[13] Catch is sold in markets and stores for local consumption.

Bay (Figure 30), and is attracting international visitors interested in black bass and blue water fishing. Coastal villagers are keen to see tourism development in their villages and in the wider Kimbe Bay.

Tourism activities, while highly localised, provide a positive contribution to the economy of Kimbe Bay. Most of the related expenditure flows to local businesses, businesses elsewhere in PNG, and communities immediately adjacent to the tourist operations. While on a small scale, this industry provides significant positive economic benefits for some communities, and represents an important sustainable source of income for these communities. Given the minimal impact of this industry, and its value to local communities and businesses, tourism plays an important role in the development of sustainable industries in the bay.

Other marine industries in Kimbe Bay include shipping, which has well defined harbours and areas of use (wharfs, pilotage channels, and anchorages). While shipping may pose a threat to marine ecosystems through ship groundings, pollution, and the introduction of invasive species, impacts appear to have been localised to date.

Land use, particularly large scale agriculture and forestry, are major industries in Kimbe Bay (Figure 4). Runoff from these activities and others (community gardens and urban areas) appears to be causing significant impacts on nearshore ecosystems in some parts of the bay (see 1.3.4 Key Threats and Conservation Strategies). Although arising from outside the marine environment, these threats are significant and will be addressed through a collaborative partnership with industry.

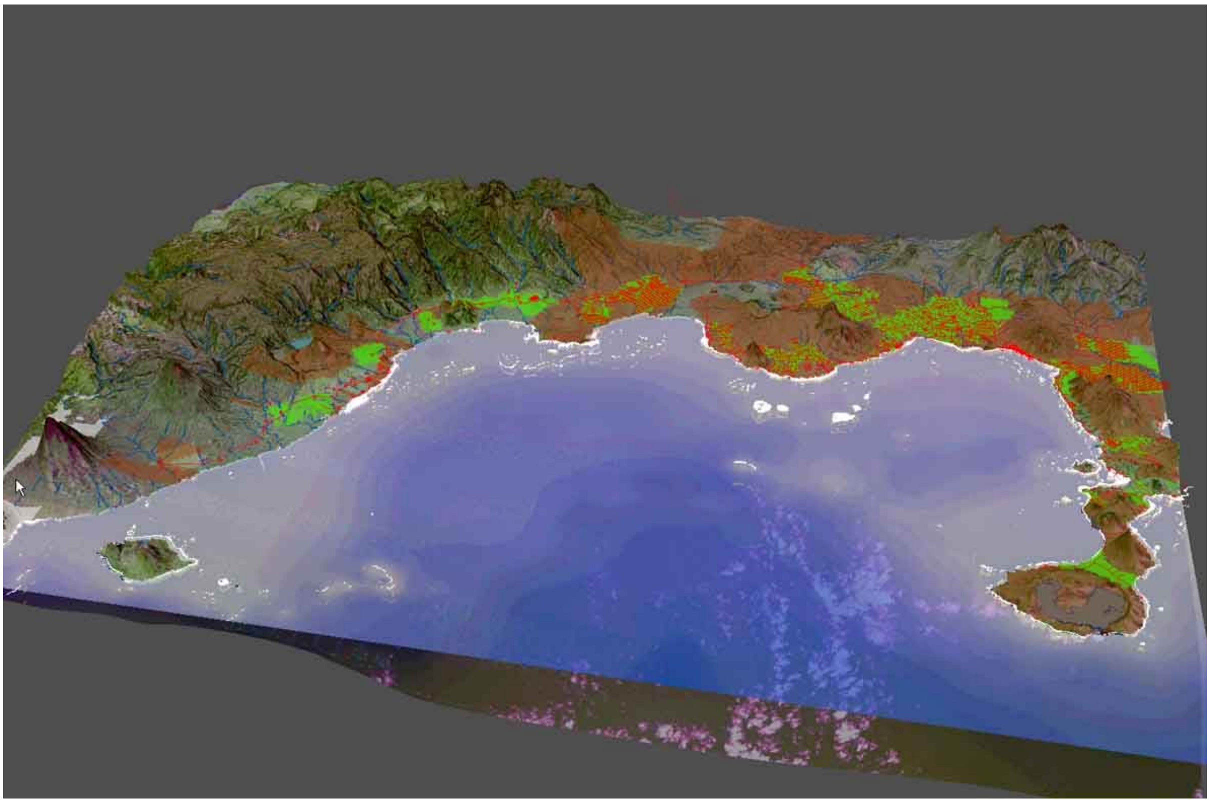


Figure 4. Major areas of land use in Kimbe Bay watershed (red= logging and green=oil palm plantations)

1.3.3 A Strong Basis for Conservation

The Nature Conservancy has been working in Kimbe Bay, and elsewhere in the Bismarck Sea, for over a decade. This work has focused on building a strong basis for marine conservation, and has included:

- Building the capacity of our local partner, Mahonia Na Dari (MND[14]), which has worked with the Conservancy and other partners to establish the Kimbe Bay Marine Conservation and Research

[14] The local translation of Mahonia Na Dari is "Guardians of the Sea".

Centre, and help communities create Locally Managed Marine Areas (LMMAs[15]). They have also conducted a successful education program for local communities and schools, focusing on marine conservation and addressing key threats (particularly destructive fishing practices).

- Providing technical support for LMMAs by drafting legislation for Local Level Governments (LLGs) to assist communities in protecting these areas, and by supporting a scientific monitoring program (by James Cook University) to monitor their success. The LLG legislation has now been passed by all three LLGs that encompass marine areas in Kimbe Bay (Talasea, Hoskins and Bialla), and has already been used to enforce LMMA rules and regulations.
- Assessing the biodiversity of Kimbe Bay through a series of Rapid Ecological Assessments. To date, these surveys have focused on corals, reef fishes, mangroves forests, seagrass beds and cetaceans.
- Supporting research into coral reef ecology by partner institutions, particularly James Cook University and the University of PNG.
- Participating in ecoregional planning for the Bismarck Solomon Seas Ecoregion (led by World Wildlife Fund), and conducting a more detailed Ecoregional Conservation Assessment for the Bismarck Sea.
- Undertaking Conservation Area Planning for Kimbe Bay to identify conservation targets, their current status and long term viability, threats and sources of threats to these targets, and strategies for addressing these threats.
- Addressing threats to marine ecosystems from land use practices in partnership with industry.
- Working with local dive operators and the PNG Dive Association to establish an environmentally sensitive mooring system in Kimbe Bay and throughout PNG.
- Supporting local communities in identifying, protecting and monitoring reef fish spawning aggregations.
- Expanding the Conservancy's conservation activities in the Bismarck Sea with a focus on management of the live reef food fish trade and protecting reef fish spawning aggregations.
- Supporting aerial surveys of leatherback nesting beaches.

The success of these programs has ensured that The Nature Conservancy is well respected and has a good working relationship with local communities, conservation groups, scientists, government and sustainable industry (particularly tourism). This has provided a strong basis for expanding our conservation activities in the bay.

While our work to date has been an important first step in engaging local communities in conservation and building partnerships with sustainable industries, non-government, government, and academic institutions, a larger-scale approach is now required to achieve lasting protection for Kimbe Bay. In areas where we are already working, local communities are very supportive of coral reef conservation and management, and have a strong desire to engage in marine resource management, as demonstrated by the establishment of LMMAs. The success of the LMMAs, which operate on a small scale, has ensured that these communities are well disposed towards supporting a large scale network of MPAs (including LMMAs and other protected areas). However, further education and awareness-raising is still required in other areas. Our goal is to consolidate our learning in Kimbe Bay and create a lasting, well-designed resilient MPA network that produces conservation results, before expanding to other high priority areas in the Bismarck Sea.

1.3.4 Key Threats and Conservation Strategies

The marine ecosystems in Kimbe Bay, like most places in the world, are threatened by an increasing human population and associated uses and threats (Koczberski et al. 2006). Overfishing is not a serious problem as yet (see 1.3.2 Socioeconomic Characteristics), since the human population and associated fishing pressure is still low. However, this is likely to change as the population increases, and there have already been some

[15] As defined by the LMMA Network, an LMMA is an area of nearshore waters actively being managed by local communities or resource-owning groups, or being collaboratively managed by resident communities with local government and/or partner organizations. Consistent with international usage (Kelleher 1999), Locally Managed Marine Areas are considered Marine Protected Areas (see Footnote 3).

problems with overfishing of commercially valuable invertebrates (particularly beche-de-mer), which provide a valuable source of income for local communities (Koczberski et al. 2006). Fishing pressure could also increase in future if alternative sources of livelihood (Koczberski et al 2001, Cinner et al 2002), particularly from subsistence and cash crop agriculture, are reduced.

The use of destructive fishing methods, primarily the use of poisons including insecticides and a traditional method called poison rope, has been a problem in the past. These methods are still used (Koczberski et al. 2006), but their use has declined following a successful education and awareness program by Mahonia Na Dari and The Nature Conservancy. Hunting of rare and threatened species, particularly sea turtles, is still a concern in some areas.

Of greater concern is runoff of sediment and other pollutants from poor land use practices associated with large scale agriculture and forestry (Munday 2004, Jones et al 2004). Runoff from these activities and others (community gardens and urban areas) appear to be causing significant impacts on nearshore ecosystems in some parts of the bay. While these activities are widespread, runoff from poor land use practices is more of a concern on inshore reefs in the south western corner of the bay, which is most protected from ocean waves and currents. As a result, pollutants tend to remain on the reef for extended periods of time causing a serious threat to coral reef health. In contrast, this is less of a concern in the rest of the bay which is more exposed to ocean waves and currents.

One of the biggest threats to marine ecosystems in future will be from climate change. Climate change represents a serious and increasing threat to the tropical marine ecosystems of the world, including Kimbe Bay. Over the coming decades, water temperatures and sea levels will rise, which will have profound effects on coral reefs and associated ecosystems (Grimsditch and Salm 2006, McLeod and Salm 2006). Elevated sea surface temperatures are a major threat to coral reefs, and have already caused serious impacts to reefs around the world (Wilkinson 2000), including some parts of Kimbe Bay[16]. These warm water events are expected to occur with greater frequency and intensity in the coming decades, leading to an increase in the frequency and severity of mass coral bleaching events (Hoegh-Guldberg 1999, Hughes et al 2003). Sea level rise also represents a serious threat to coastal ecosystems, particularly mangrove forests (McLeod and Salm 2006) and turtle and seabird nesting areas. Changing storm and current regimes are also likely to affect marine ecosystems.

The Kimbe Bay Project has three conservation strategies aimed at addressing these key threats:

- Establishing a resilient network of MPAs that is specifically designed to address the threat of climate change. This strategy will contribute towards both biodiversity protection, and the management of marine resources.
- Marine resource use strategy, which will address threats from overfishing, destructive fishing and hunting of rare and threatened species (dugong and sea turtles).
- Land use strategy, which will address the threat of runoff from poor land use practices.

This report focuses on a critical step in the first strategy – designing a resilient network of MPAs for Kimbe Bay.

1.4 DESIGNING A RESILIENT NETWORK OF MARINE PROTECTED AREAS

Climate change represents a major threat to the long term future of coral reefs and associated ecosystems around the world (see above). In recent years, principles for designing and managing MPA networks that are

[16] Srinivasan (2000) and Jones et al (2004) reported several incidences of low to high rates of coral bleaching on the west side of the bay over the last 20 years, with inshore reefs most severely affected. In contrast, coral bleaching has not been reported from the east side of the bay, and Turak and Aitsi 2002 found no evidence that these reefs have suffered from coral bleaching events.

resilient to the threat of climate change have been developed (West and Salm 2003, TNC 2004, Grimsditch and Salm 2006, McLeod and Salm 2006). They include:

- **Spreading the risk through representation and replication:** There is a lot of uncertainty regarding the changes that will occur as a result of climate change, so it is important to spread the risk by protecting several examples of each type of habitat, and spreading them out so the chances that they will all be affected by the same disturbance are reduced.
- **Protecting special and unique sites:** Some sites are of particularly high conservation value and should be included in the MPA network. They include sites that support critical life history phases of marine organisms (such as fish spawning aggregation sites and turtle nesting areas), and areas that may be naturally more resistant or resilient to the threat of climate change.
- **Incorporating patterns of connectivity:** For MPA networks to be successful, they must function as mutually replenishing networks to facilitate recovery after disturbance. Therefore, it is important to understand and incorporate biological patterns of connectivity among coral reefs and associated habits in MPA network design.
- **Effective Management:** It is important to ensure that reefs and associated ecosystems are as healthy as possible so they are naturally more resilient to change. This will require addressing key threats such as overfishing, destructive fishing and runoff from poor land use practices.

Once MPA networks have been designed, it is essential that they are effectively managed and sustainably financed to ensure long term success.

The scientific design of the Kimbe Bay MPA network represents one of the first attempts to design a network of MPAs that is resilient to the threat of climate change, based on these principles.

2. METHODS AND RESULTS

The scientific design of the Kimbe Bay MPA network was developed via a six step process, which comprised a series of three scientific workshops, targeted research, data processing and analysis (Table 1).

Table 1. Kimbe Bay MPA network scientific design process.

Steps	Timing	Outputs
1. First scientific workshop	February 2004	MPA network objectives, conservation targets, boundaries, network design principles and research priorities.
2. High priority research	2004–2005	Minimum information required for MPA network design.
3. Data processing	Jan–April 2006	Best available information summarised in GIS data layers.
4. Second scientific workshop	April 2006	Revised and refined GIS data layers.
5. Data analysis using analytical design software (MARXAN)	May-June 2006	MPA network design options.
6. Third scientific workshop	July 2006	Scientific design of MPA network.

The following is a detailed description of this process.

2.1 SETTING OBJECTIVES, CONSERVATION TARGETS, BOUNDARIES AND NETWORK DESIGN PRINCIPLES

The first step in designing a resilient network of MPAs for Kimbe Bay was to clearly define what we were aiming to achieve, and to establish a process for achieving it. This was conducted during the First Scientific Design Workshop held in Townsville in February 2004 (Green and Lokani 2004). Approximately 30 scientists, partners, staff and local representatives participated in the meeting, where the MPA network objectives, conservation targets, boundaries, and network design principles were defined. These definitions provided the guiding principles for the MPA network design, and are summarised below.

2.1.1 Objectives

The Kimbe Bay MPA network has two objectives:

- To conserve marine biodiversity and natural resources of Kimbe Bay in perpetuity, and
- To address local marine resource management needs.

2.1.2 Conservation Targets

Conservation targets include the full range of marine biodiversity in the bay, including key habitats and associated flora and fauna:

- Shallow water habitats: coral reefs, seagrass beds, mangrove forests and estuaries;
- Deepwater habitats: oceanic waters (epi, meso and bathypelagic), seamounts and other key features which may occur in the area but whose presence has not been confirmed (upwellings, canyons and hydrothermal vents);
- Islands and associated flora and fauna, particularly areas that represent important habitat for marine species (eg sea turtle and seabird nesting areas);
- Rare and threatened species, particularly cetaceans, sea turtles, seabirds and dugong;
- Species of very limited distribution, particularly the *Gobiodon* species only know to occur in one location (Wulai Lagoon) in the world (Munday 2004);
- Commercially important reef species that may be threatened by overexploitation (both fish and invertebrates); and
- Large pelagic fish.

2.1.3 MPA Network Boundary

The MPA network boundary was delineated based on the biophysical and socioeconomic characteristics of the area. The outer boundary was delineated to include all of Kimbe Bay and offshore islands and reefs (Figure 5), and was extended further offshore to include 52 fathom seamount, which is the most important feature in this globally significant area for oceanic species (WWF 2003, B. Kahn pers. comm.). The inner boundary coincides with highest astronomic tide to include coastal targets (mangroves and estuaries). This is a large area, encompassing 13,000km2, or 1,336,594 hectares (3,302,723 acres).

The eastern and western boundaries were delineated based on biophysical characteristics of the bay, and modified to take socioeconomic factors into account: the eastern boundary was moved east to coincide with the eastern boundary of West New Britain Province, while the western boundary was moved west to include all three villages surrounding Lake Dakataua on Willaumez Peninsula, which form part of the same community. Islands within the MPA network boundary, especially those that are uninhabited, were included in the network because of their importance as nesting habitat for marine species (particularly sea turtles and seabirds). A more detailed description of the boundary, and the rationale behind it, is provided in Green and Lokani (2004).

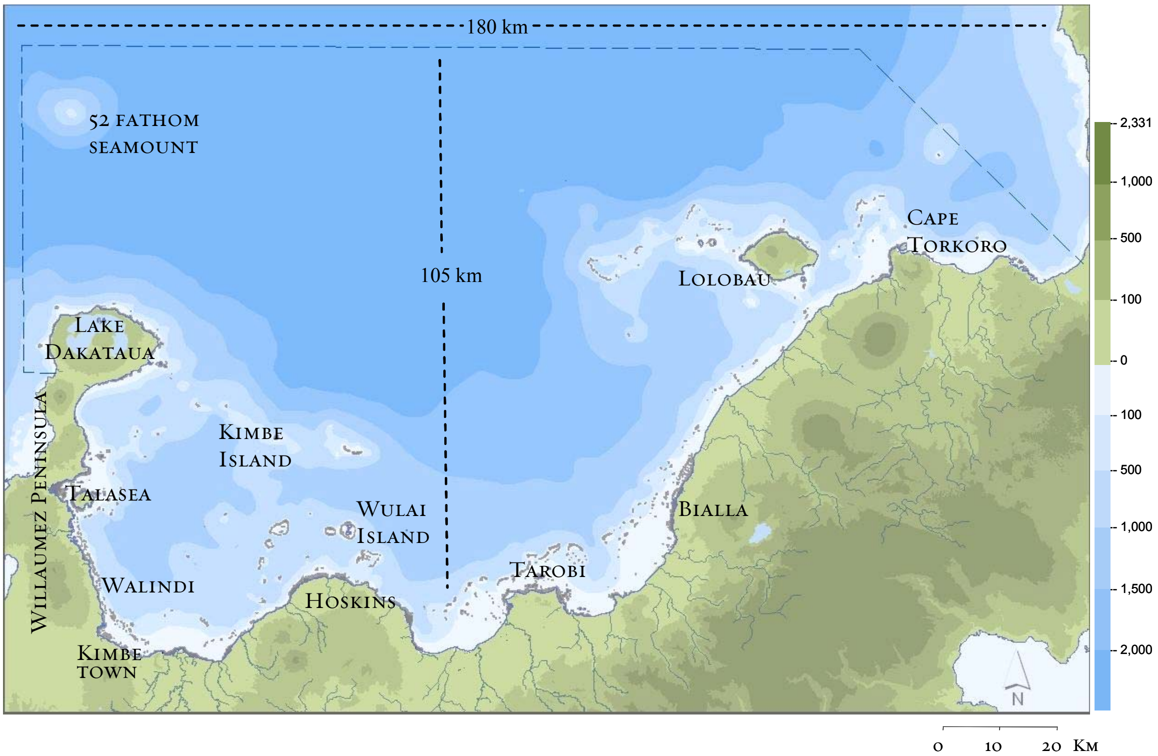


Figure 5. Kimbe Bay MPA network boundary.

2.1.4 MPA Network Design Principles

Once the objectives, conservation targets and boundaries had been defined, specific design principles were defined which were used to design the MPA network by taking into account both the biophysical and socioeconomic characteristics of the bay. While applying these principles during the design process, it became apparent that while most could be applied spatially for MPA network design, some would need to be addressed through other conservation strategies (marine resource use and land use). A complete list of the biophysical and socioeconomic design principles developed in the First Scientific Workshop, and a summary of which principles were used for the MPA network design (and how) and which ones will be addressed through other strategies, is provided in Appendices 1 and 4. The principles that were used for the MPA design are summarised below.

Biophysical design principles: These principles were aimed at maximising biological objectives by taking into account key biological and physical processes, including resilience to climate change.

Risk spreading (representation and replication):

- Conserve representative examples of each habitat type.
- Include a "sufficient" number and area of each habitat type, and spread them out geographically to reduce the chances that they will all be negatively impacted at the same time. Aim to include at least 3 areas and 20%[17] of the area of each habitat type.
- Where information is available, include a minimum amount (see above) of each ecosystem and community type within each habitat type (to ensure that all known communities and habitats that exist within each habitat type are protected).
- All else being equal, chose representative areas[18] based on knowledge (high biodiversity areas, complementarity) to maximise the number of species protected.

[17] This is lower end of the range recommended for protecting marine habitats (20-50%: Bohnsack et al 2000, Airame et al 2003, Fernandes et al 2005, World Parks Congress 2003), and was selected because threats are currently low and this was considered an achievable goal for Kimbe Bay.
[18] An area that is typical of a habitat type within which it is located

Protecting key sites:

- All else being equal, choose sites that are more likely to be resistant or resilient to global environmental change.
- Include special and unique sites including:
  - Areas that may be naturally more resistant or resilient to coral bleaching.
  - Permanent or transient aggregations of large groupers, humphead wrasse, and other key fisheries species (including invertebrates).
  - Turtle nesting areas (beaches and nearshore resting areas).
  - Cetacean preferred habitats (breeding, resting, feeding areas and migratory corridors).
  - Areas that support high species diversity.
  - Areas that support species with very limited distribution and abundance.
  - Areas that are preferred habitats for vulnerable species (eg sharks, and those on the IUCN red list).
  - Areas that contain a variety of habitat types in close proximity to each other.

Incorporating patterns of connectivity:

- Take a system wide approach that recognises patterns of connectivity within and among ecosystems.
- Where possible, include entire biological units (eg whole reefs, seamounts), including a buffer around the core area of interest.
- Where entire biological units cannot be included, chose bigger verses smaller areas.
- Maximise acquisition and use of environmental information to determine the best configuration, recognising the importance of connectivity in network design.

Effective management:
This will be largely addressed through other strategies (marine resource use and land use: see Appendix 1). These principles were designed to take into account existing and future patterns around the bay:

- Consider sea and land use, particularly proximity to threats and other protected areas.
- Consider if patterns (distribution and status of community types) are the result of natural processes or human impacts.

Socioeconomic design principles: These principles were aimed at maximising benefits and minimising costs to local communities and sustainable industries.

General

- Recognise and respect local resource owners and customary marine tenure systems.
- Recognise that local communities are the decision makers and custodians over marine resources.
- Understand and incorporate local knowledge and traditional fisheries management and conservation practices.
- Minimise negative impacts on existing livelihood strategies.
- Protect areas of cultural importance to traditional owners.
- Ensure costs and benefits are fairly distributed within and between communities.
- Minimise conflicting uses, such as tourism and extractive use.
- Consider current and future population trends and changing resource use.

Fisheries

- Ensure MPA supports sustainable subsistence and artisanal[13] fisheries for local communities by recognising diverse livelihood strategies, and spatial and temporal variations in resource use and value.
- Consider costs and benefits to local communities (and sustainable industries) in management of commercial fisheries[12].
- Conserve marine resources, which local communities identify as important to their livelihood.
- Conserve marine resources for local communities by prohibiting destructive fishing methods.

- Conserve marine resources for local communities by prohibiting unsustainable commercial fisheries, particularly the live reef food fish trade and other fisheries for species particularly vulnerable to overexploitation (sharks and rays).

Nature Based Tourism

- Protect high priority tourism sites from conflicting (extractive or destructive) uses.

Shipping

- Accommodate existing shipping infrastructure (wharves, channels) in MPA design (avoid placing highly protected areas in the vicinity of these areas)

2.2 IDENTIFYING AND COMPLETING HIGH PRIORITY RESEARCH

Once the guiding principles for the MPA network design had been defined, the information required to design the network was reviewed. Since only some of this information was available, a list of high priority research was identified which focused on providing the minimum amount of information required to provide a sound scientific basis for the design (Green and Lokani 2004). This included:

- Biological information: identifying biologically distinct habitat types and their location in the MPA network area, and identifying special and unique areas.
- Physical information: bathymetry and ocean currents.
- Socioeconomic and cultural information: how local stakeholders use and value their marine resources, traditional marine tenure systems, and knowledge of marine ecosystems.

High priority research was conducted over the next two years (2004-2006). During this time field surveys were completed of three shallow water habitat types (coral reefs, seagrass beds and mangrove forests), special and unique sites were identified (fish spawning aggregation sites, turtle nesting areas, and important nesting, wading and resting areas for birds), a hydrodynamic model was developed for the Bismarck Sea (including Kimbe Bay), and a detailed socioeconomic survey of six local communities was completed to provide an understanding of the various socioeconomic settings in the bay.

2.3 COMMUNITY ENGAGEMENT

The PNG constitution recognises indigenous Papua New Guineans own land and sea resources, and also own user rights in areas where the state owns the sea on behalf of the people. Land and sea resources are generally communally owned by families, sub-clans, clans or communities. It is therefore critically important to engage communities in all conservation and resource management activities in order to successfully implement conservation and management strategies.

Community engagement has been an integral part of the process of planning and developing the MPA network in Kimbe Bay. Initial community engagement conducted by Mahonia Na Dari, and to a lesser extent by TNC, focused on environmental awareness, destructive fishing practices, and the need for conservation and management of marine resources.

During the planning phase for the MPA network design, several options were considered for expanding community awareness programs and engaging communities in the scientific design process. Options included full engagement in all aspects of the design, limited engagement on specific issues (of strategic importance), and engagement after the scientific design process had been completed. It was decided to engage the communities after the scientific design had been completed, based on the following rationale:

- Communities focus on areas they own immediately around their communities and would push for the inclusion of their areas in the MPA design. They would be motivated by a perceived benefit that could accrue if their area was included in the MPA network. Given limited staff and resources, the Conservancy did not have sufficient resources to manage this expectation on the ground.

- Not accommodating communities' expectations in the MPA design would cause problems both within and between communities.
- It was important not to raise community expectations well beyond our capacity to deliver. There is widespread interest in support for conservation activities around the bay, and if we entered into a full community engagement process, it was likely that the Conservancy would be asked to support conservation activities in many locations outside key biodiversity areas of interest.
- There are over 100 culturally diverse communities in Kimbe Bay, all of which hold complex and often overlapping traditional rights to sea resources. Fully engaging all these communities, and adequately capturing all of their views and opinions in the scientific design process, was considered logistically and financially unrealistic.
- The scientific design process was highly technical, and it was not considered practical for community members to participate in this process.

Therefore, it was agreed that the most effective strategy would be to engage communities after the scientific design had been completed, and priority areas for conservation had been identified. The Conservancy would then seek to work with communities that own and manage marine resources within priority areas through a detailed community-based planning process (see 3.1 Implementation).

While a full community engagement process was not undertaken during the scientific design process, several steps were taken to understand and incorporate the needs and interests of communities as far as practicable in the design:

- Considerable community engagement was undertaken in informal settings in the areas field staff visited while collecting biological data required for the MPA design process. For example, when TNC field staff were collecting biological information on spawning aggregations, mangrove areas and turtles nesting beaches, they also documented local knowledge of rare and threatened species, and special and unique areas that communities expressed an interest in protecting, including areas of biological and cultural significance (eg *masalai*[19] and *tambu*[20] areas). Field staff also documented the level of interest that the communities they visited expressed in conservation, and if they appeared to have the ability to manage their marine resources at a community level. Likewise, areas that seemed to be poor choices for conservation, due to the social and political landscape in which they were located, were noted.
- A detailed socioeconomic study was conducted of six communities to provide an understanding of the variety of socioeconomic situations in the bay. This study provided important background information including information regarding marine tenure systems, customary and modern perceptions of MPAs (based on traditional *tambu* areas and more recent LMMAs), local knowledge of special and unique areas for protection (including areas of biological and cultural significance, such as *masalai* and *tambu* areas), rare and threatened species and physical processes in the bay, issues of concern for marine resource use, patterns of marine resource use and value, and long term trends in the condition of major habitats and key resources and why (Koczberski et al 2006). The study also provided specific information on marine tenure systems in these communities, each community's interest in conservation, and specific issues that might advance or hinder conservation efforts in these areas (Koczberski et al 2006).
- A full set of socioeconomic design principles was also developed and implemented for the MPA network (see 2.1.4 MPA Network Design Principles), which were specifically designed to address the needs and interests of local communities and other stakeholders.

2.4 DATA PROCESSING

Once the high priority research was completed, the best available information for Kimbe Bay was digitized into GIS layers (where possible), which could be used for spatial data analysis. Primary layers of information included conservation targets and socioeconomic information. Important information that could

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[19] Permanent closures usually applied to sites which are considered sacred or *tambu* because they are spirit-dwelling areas.
[20] Traditional closures, either permanent (*masalai* areas) or temporary (usually following a death).

not be represented spatially was also recorded so it could be taken into account manually during the design process (see 2.6 Designing the MPA Network).

Once the GIS data layers had been assembled, a Second Scientific Workshop of core technical experts was held in Brisbane in April 2006 (see Contributors) to review and refine the data layers for the analysis. Additional information requirements to finalise the data layers were identified, and addressed in the weeks following the workshop.

2.5 DATA ANALYSIS

Data analysis was conducted in May-June 2006 at the Conservancy's Indo-Pacific Resource Centre in Brisbane, Australia using marine reserve design software (MARXAN). The following is a brief description of the software, how it was used, and details of the analysis.

2.5.1 Marine Reserve Software

MARXAN was developed to aid in the design of the Great Barrier Reef Marine Park. Planning units are the fundamental unit of selection, and MPA planning requires the consideration and comparison of an enormous number of potential planning units. Protected area design requires the selection of those planning units that satisfy a number of ecological, social and economic criteria (in this case our design principles, based on our biodiversity goals for each target layer and a cost layer that incorporates socioeconomic considerations). It is also designed to help automate the selection process so that many different scenarios can be developed and explored. One way of dealing with often conflicting biodiversity and socioeconomic criteria is to have well defined goals for all of the conservation targets and well defined measures of the likely impact of the reserve system. The conservation goals are then sought in a way that the protected areas network results in maximum benefit and minimal cost to local communities and sustainable industries. The selection process uses an objective function whereby any collection of planning units is given a score. The analysis is based on a spatially explicit simulated annealing procedure that attempts to find protected areas networks (i.e. collections of planning units) which have the lowest scores (socioeconomic cost) and highest biodiversity benefit. This means that the scenarios produced try to meet the most conservation goals while simultaneously having the least negative impact on socioeconomic values. For a full description of MARXAN see Ball and Possingham (2000) and Possingham et al. (2000).

MARXAN provided an excellent tool for processing the enormous amount of information used in this analysis - 32,834 planning units, 51 conservation targets, 51 goals (percentage of targets to be protected), and 10 socioeconomic values (cost layers). However, it was important to remember that this software is a decision support tool, and not the decision maker. Final decisions regarding the scientific design for the MPA network were made manually during the Third Scientific Workshop (see 2.6 Designing the MPA Network), using MARXAN as an accounting tool (to ensure we had achieved our goals). It should be noted that the results of this analysis represent the views of scientists as to those areas most likely to meet biodiversity targets and least likely to impact local communities and other stakeholders. These views still require direct input from local communities and other stakeholders (see 2.3 Community Engagement and 3.1 Implementation).

2.5.2 Planning Unit Layer

Planning units provide the individual unit of choice for selection. We generated a planning unit layer that consisted of 32,834 hexagons across the areas to be included in the MPA network (Figure 6)[21]. Hexagons were 10 ha in size, which provided a fine enough scale to allow the development of refined areas while simultaneously keeping the number of planning units constrained to a number where the processing time in MARXAN was manageable. Hexagons were used because they share a boundary with all adjacent units. For this analysis, the planning unit layer was primarily limited to shallow water habitats and special deepwater

[21] Open ocean was explicitly excluded from the MPA network design, since these areas will be more adequately protected through marine resource management (fisheries policy) than by spatial closures in the MPA network.

features (52 fathom seamount: Figure 5), because other strategies will be used to protect other deepwater habitats (Appendix 1).

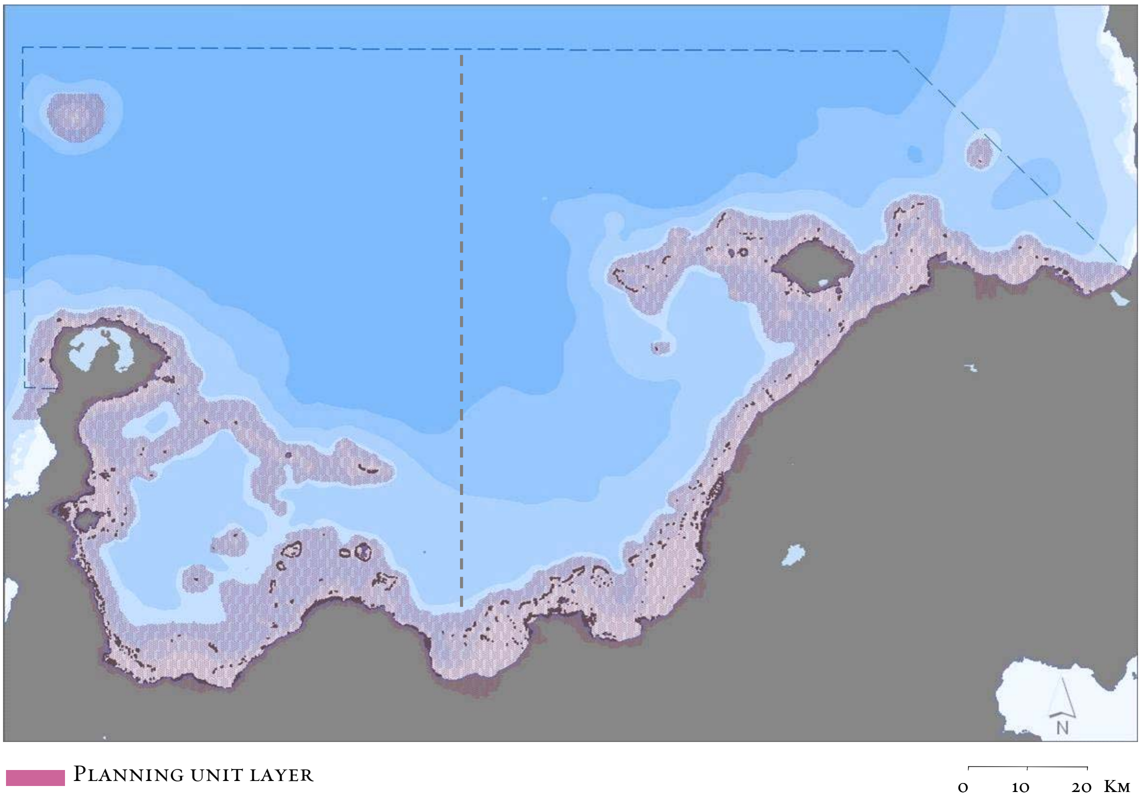


Figure 6. Planning unit layer showing areas included in the MARXAN analysis, and the east and west stratification units (either side of the dotted line).

2.5.3 Cost Layer

The cost surface layer was derived from the socioeconomic information, and special and unique areas that were a high priority to include in the network. Some layers were considered high cost (not good areas for selection), while others were considered low cost (good areas for selection). They included:

High cost layers:

- Areas adjacent to major towns (Figure 7) based on local knowledge (TNC unpubl. data);
- Areas adjacent to large river mouths with industry (Figure 7) based on local knowledge (TNC unpubl. data); and
- Ports and shipping channels (Figure 8) based on Australian and Admiralty Publication 1991 (Chart #AUS547 Lolobau to Willaumez Peninsula).

Low cost layers:

- Community interest in marine conservation (Figure 9) based on local knowledge (TNC unpubl. data);
- Cultural sites: *masalai* (spirit) areas[19], which are already protected through traditional beliefs (Figure 10: Koczberski et al 2006);
- Existing protected areas, including LMMAs and the Pokili Conservation Area (Figure 11) based on local knowledge (A. Sapul and J. Aitsi pers. comm.) and World Conservation Monitoring Centre-World Database on Protected Areas (2006);
- Dive sites which already receive some degree of protection by the tourism industry (Figure 12) based on information provided by Walindi Plantation Resort;
- Special and unique areas (Figure 13) based on local knowledge (TNC unpubl. data);
- Areas recommended as good candidates for marine conservation by the Kimbe Bay Rapid Ecological Assessments (Figure 14: Holthus 1994, Beger 2002, Turak and Aitsi 2002); and

- Villages visited during the Rare Education and Awareness Campaign (Figure 15: P. Lahui pers. comm.).

Spatial data layers were assigned a specific value (rating) and values from all layers were summed for each hexagon to provide a total cost for each hexagon (Figure 16). The higher the cost, the less desirable that hexagon was for selection.

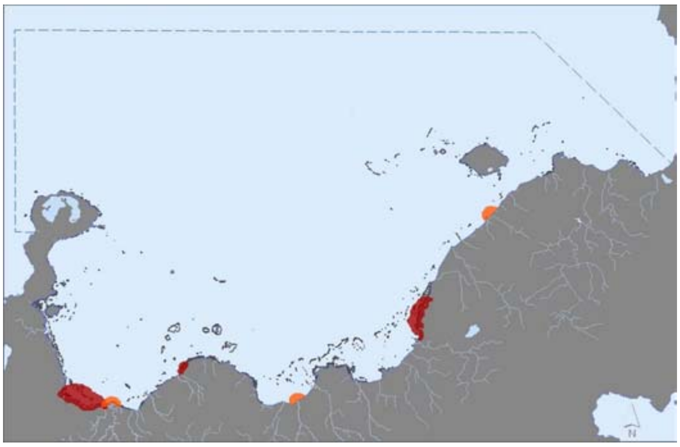


Figure 7. Areas near major towns or river mouths with industry.

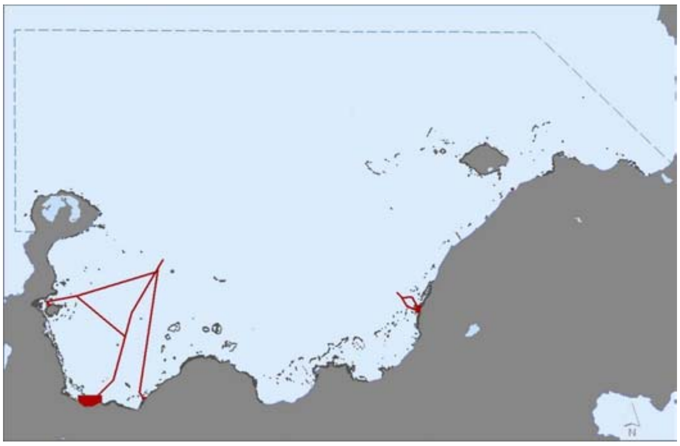


Figure 8. Ports and shipping channels

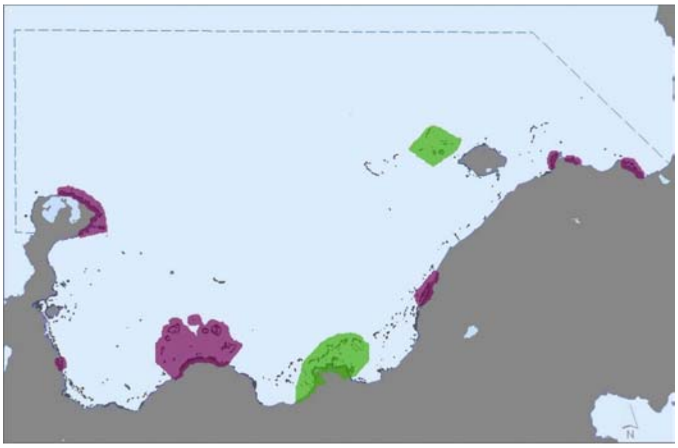


Figure 9. Community interest in conservation.

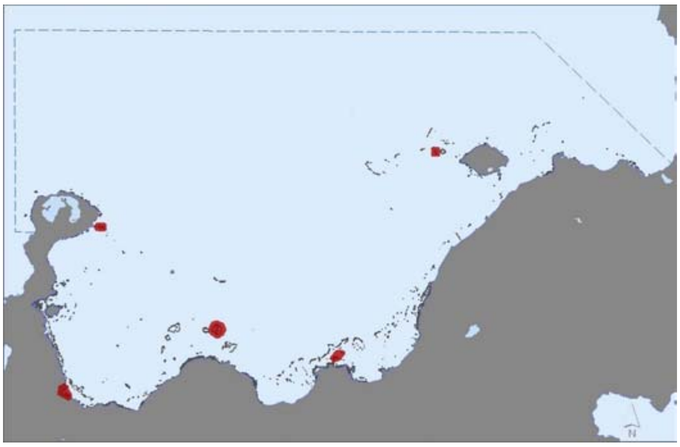
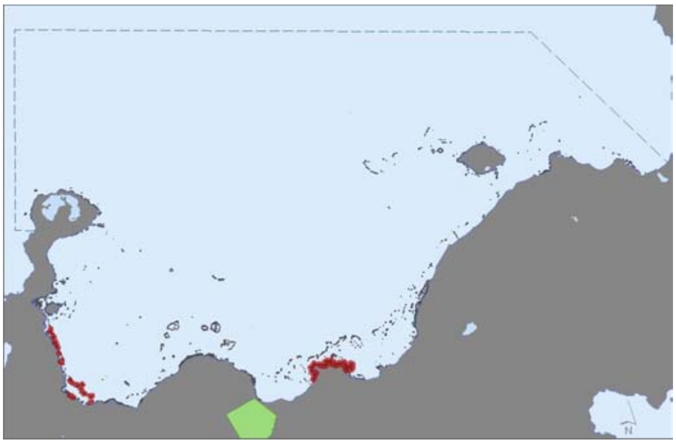


Figure 10. Cultural sites.

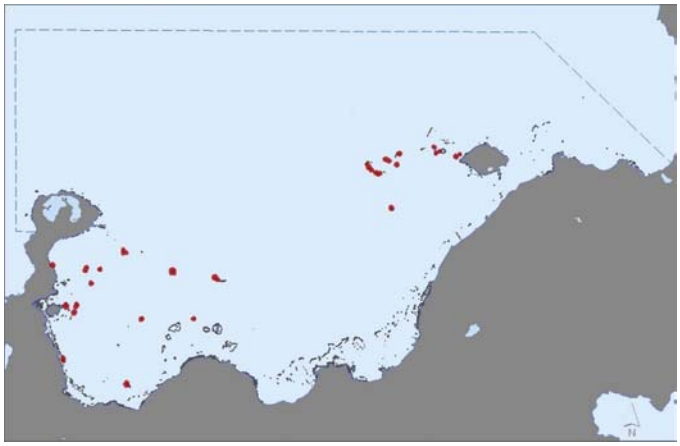
0 10 20 30 40 Km



Pokili Wildlife Management Area

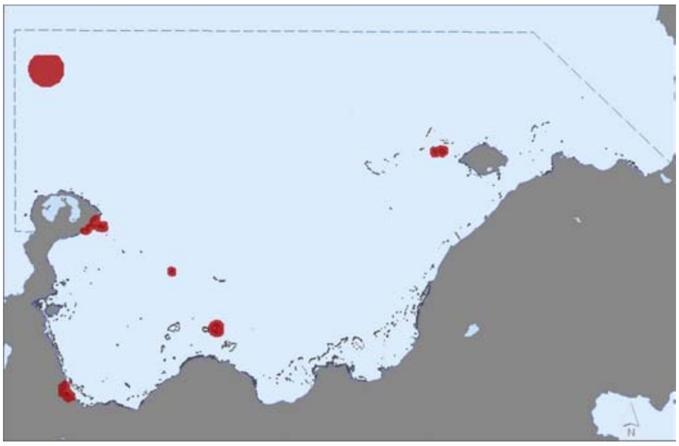
Existing Locally Managed Marine Area

Figure 11. Existing protected areas.



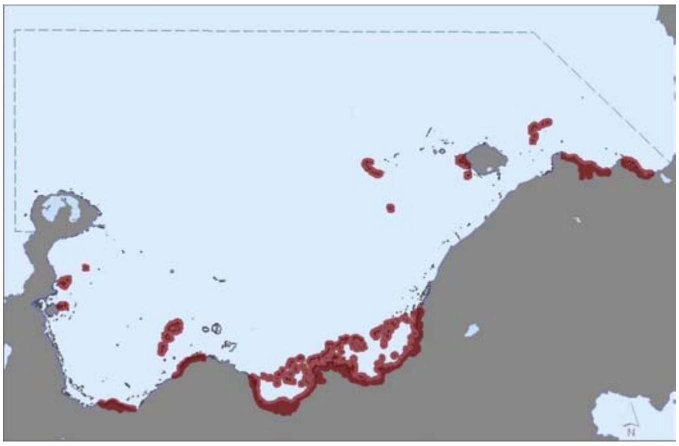
Dive Site

Figure 12. Dive sites.



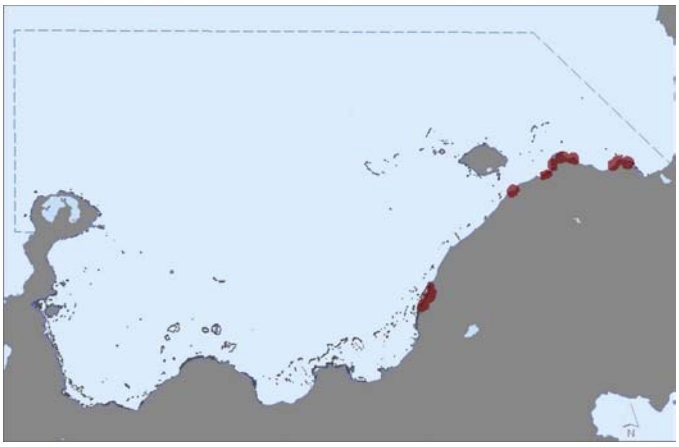
Special and unique areas

Figure 13. Special and unique areas.



Conservation areas recommended by REAs

Figure 14. Conservation areas recommended by REAs



Coastal communities visited by RARE Campaign

Figure 15. Villages visited during the RARE campaign.

0 10 20 30 40 Km

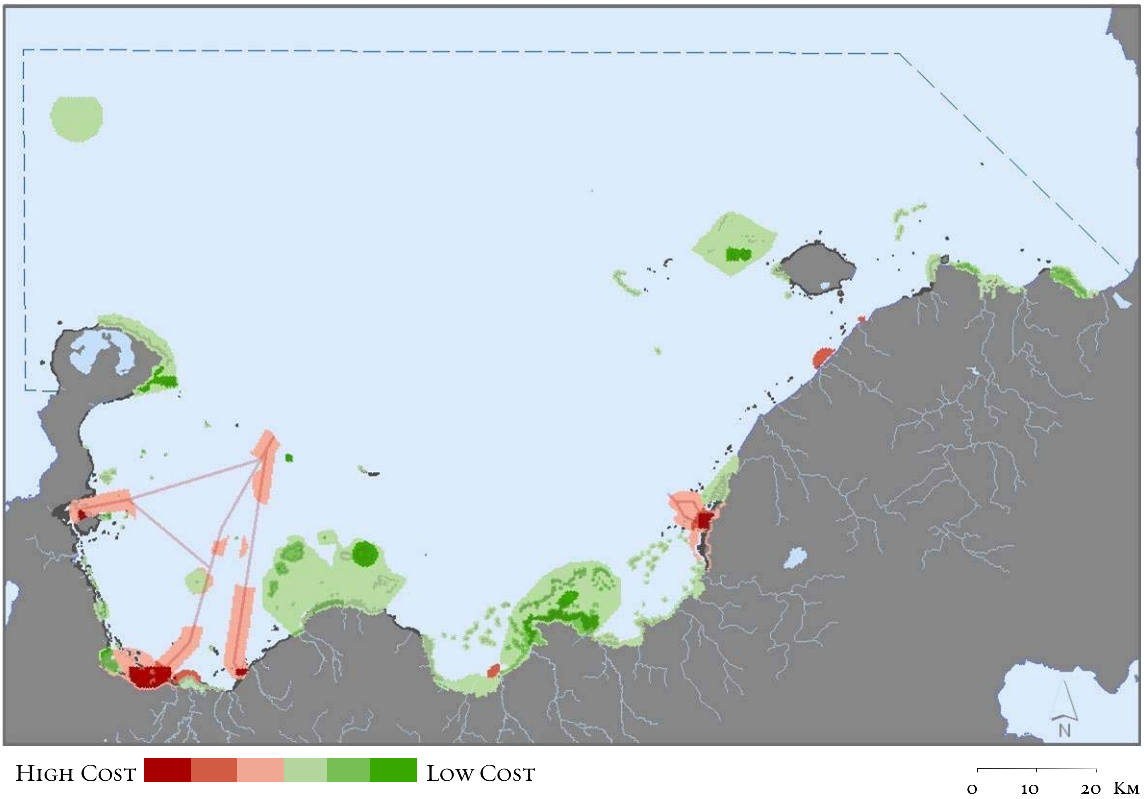


Figure 16. Total cost layer.

2.5.4 Key Inputs

- Total number of planning units (hexagons) = 32,834
- Area of each planning unit = 10 ha
- Boundary Length Modifier = 1.5 [see 2.5.7 Generating Scenarios)
- Penalty Factor = 50 [The penalty factor is a measure of the relative worth of a conservation feature i.e. how important it is to represent the feature. This was set equally across all conservation targets.]
- Simulated annealing was used.
- Adaptive annealing was turned "on" with:
  - Temperature decreases 10,000; and
  - 100 runs per scenario, where each run = 10,000,000 iterations

For further information, please consult the MARXAN manual (Ball and Possingham 2000).

2.5.5 Data Analysis

Data analysis was based on the following:

2.5.5.1 MPA Network Design Principles

The MPA network design principles are the overarching guidelines or criteria that detail important design considerations for developing the MPA network (see 2.1.4 MPA Network Design Principles).

2.5.5.2 Conservation Targets

The conservation targets represented the spatial distribution of the major biodiversity features under consideration. They included:

- Coral reef habitat types (Figure 17) based on IMaRS (2004) reef geomorphology.
- Coral reef fish communities (Figure 18: Beger unpubl. data) based on rapid ecological assessments (Allen and Munday 1994, Beger 2002).
- Seagrass communities (Figure 19) based on a seagrass survey (Aitsi and Sapul 2006).
- Mangrove communities (Figure 20) based on a mangrove survey (Keu in prep.).
- Estuarine communities (Figure 21) based on satellite imagery interpretation (TNC unpubl. data).
- Fish spawning aggregation sites based of surveys of traditional knowledge and spawning aggregation sites (Hamilton et al 2005) [Note: this data layer is not presented here due to the sensitive nature of this information.]
- Nesting areas for leatherback, hawksbill and green turtles (Figure 22) based on an aerial survey (Rei and Galama 2004) and local knowledge (Aitsi 2006).
- Important nesting, wading and resting areas for seabirds, waders and pigeons (Figure 23) based on local knowledge (TNC unpubl. data).
- Seamount (52 fathom seamount: see Figure 5), based on Australian and Admiralty Publication 1991 (Chart #AUS547 Lolobau to Willaumez Peninsula).

Since these targets were stratified on the east and west sides of the bay (see 2.5.5.5 Stratification below), a total of 51 conservation targets was used in the analysis (Appendix 2).

2.5.5.3 Conservation Goals

The conservation goals defined how much of each target was necessary to include in the network. For this analysis, our goal was 20% of each target (see 2.1.4 MPA Network Design Principles), except for confirmed reef fish spawning aggregation sites and seamounts which were 100%.

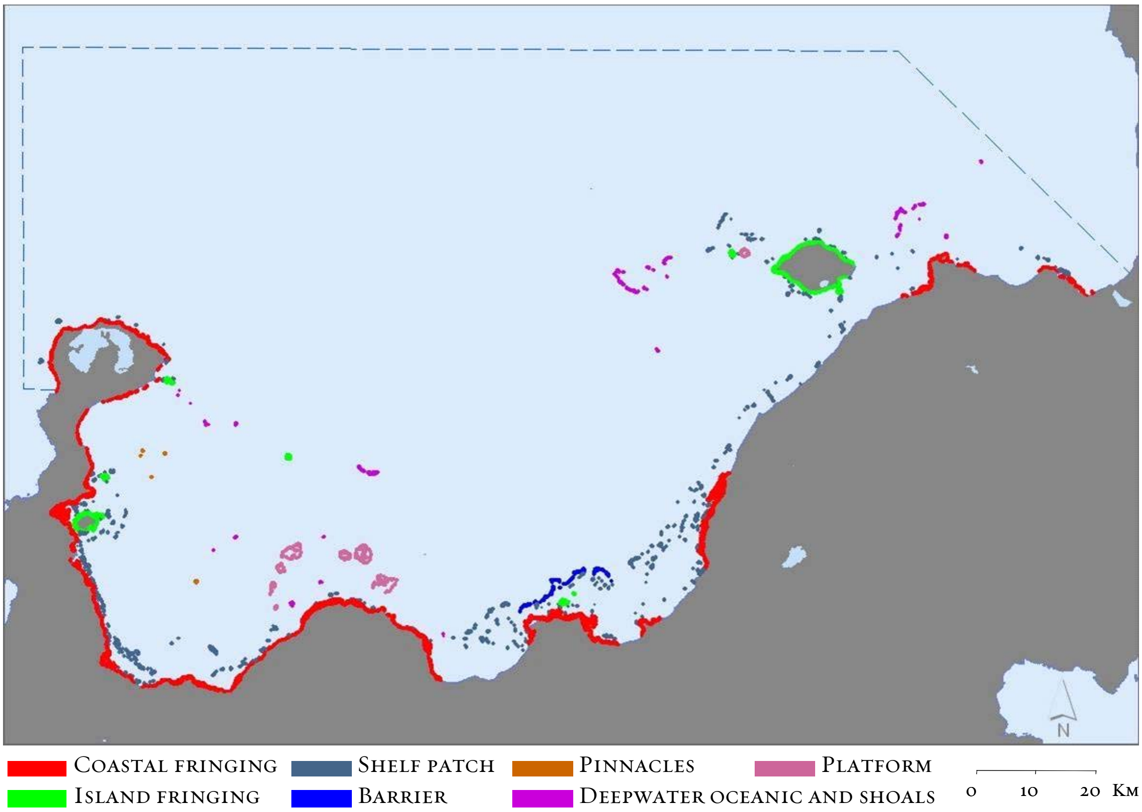


Figure 17. Coral reef habitat types.

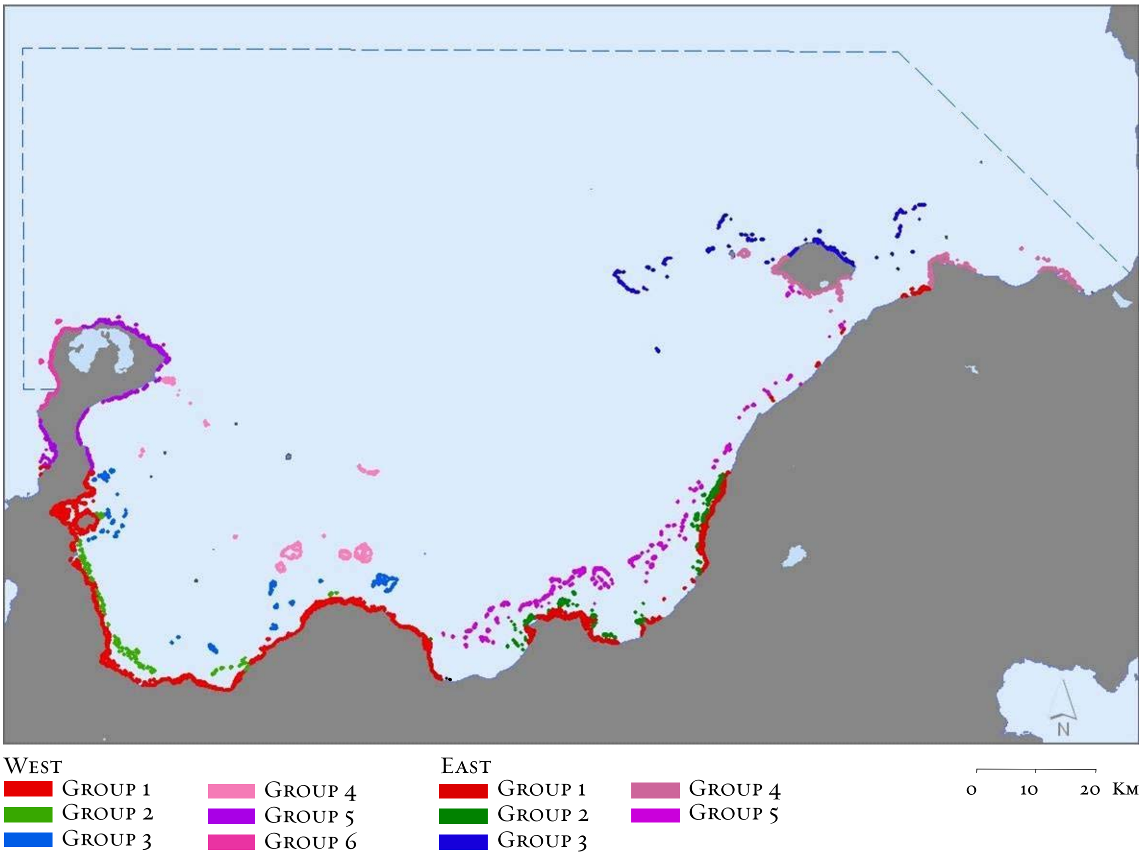


Figure 18. Coral reef fish communities.

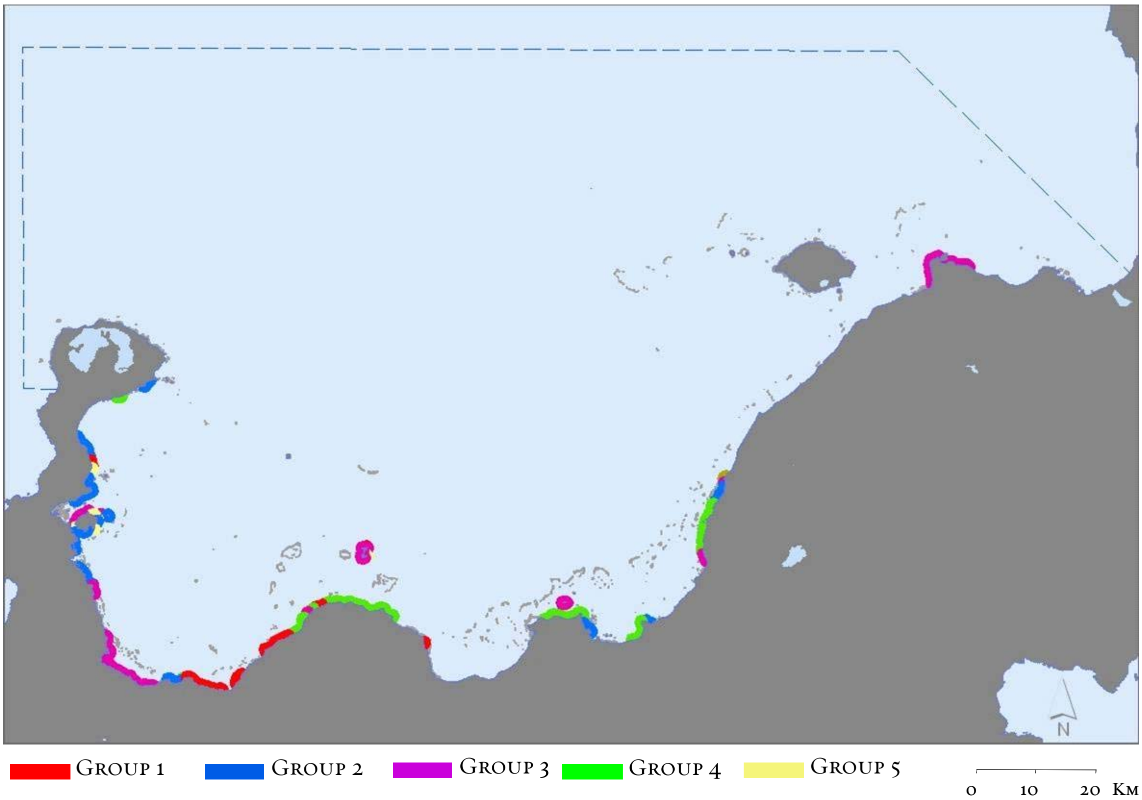


Figure 19. Seagrass communities

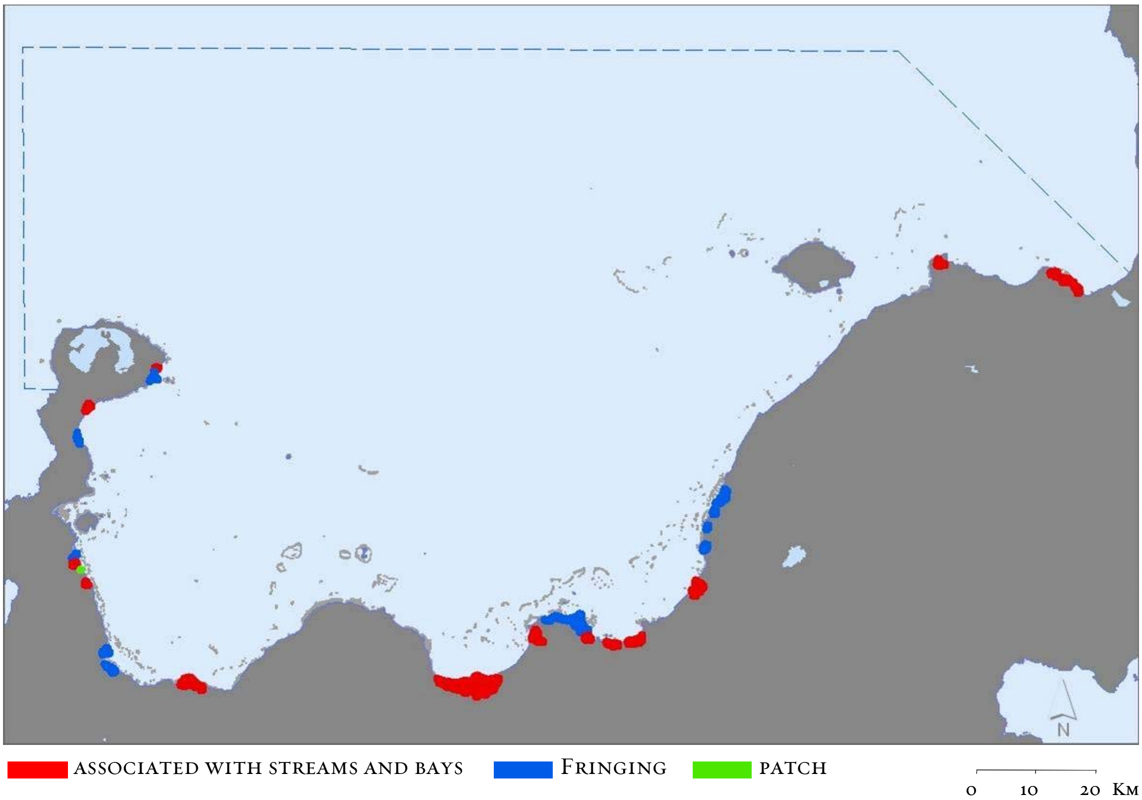


Figure 20. Mangrove communities.

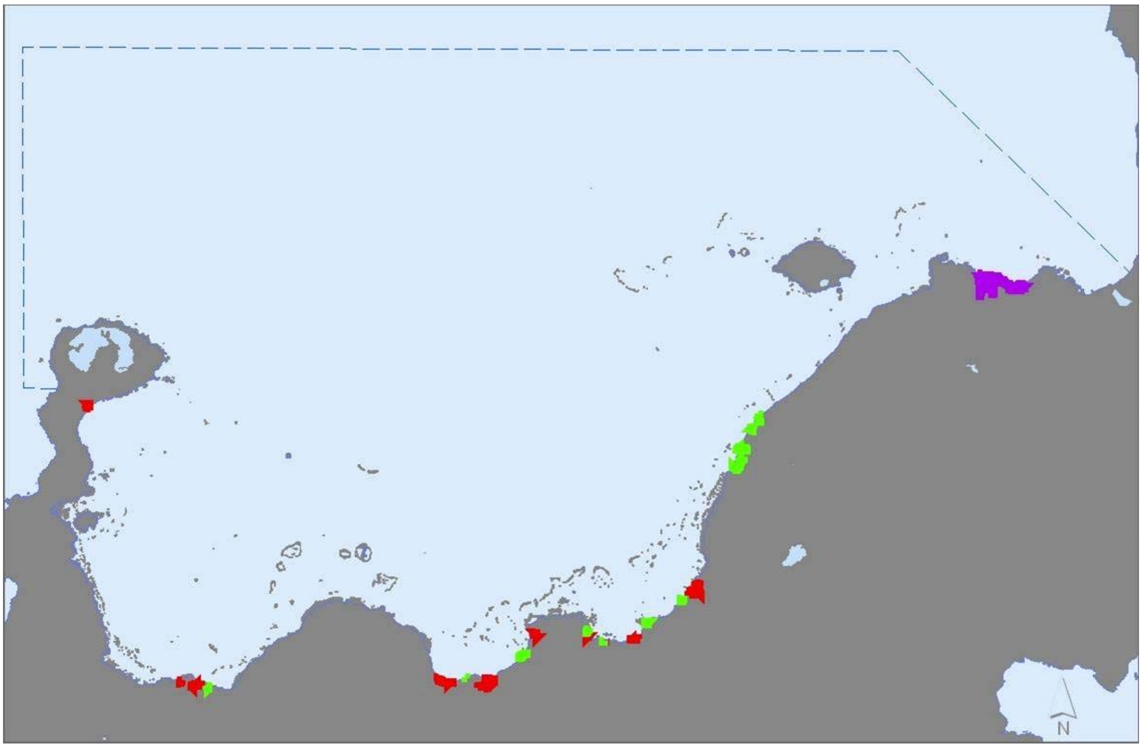


Figure 21. Estuarine communities**.**

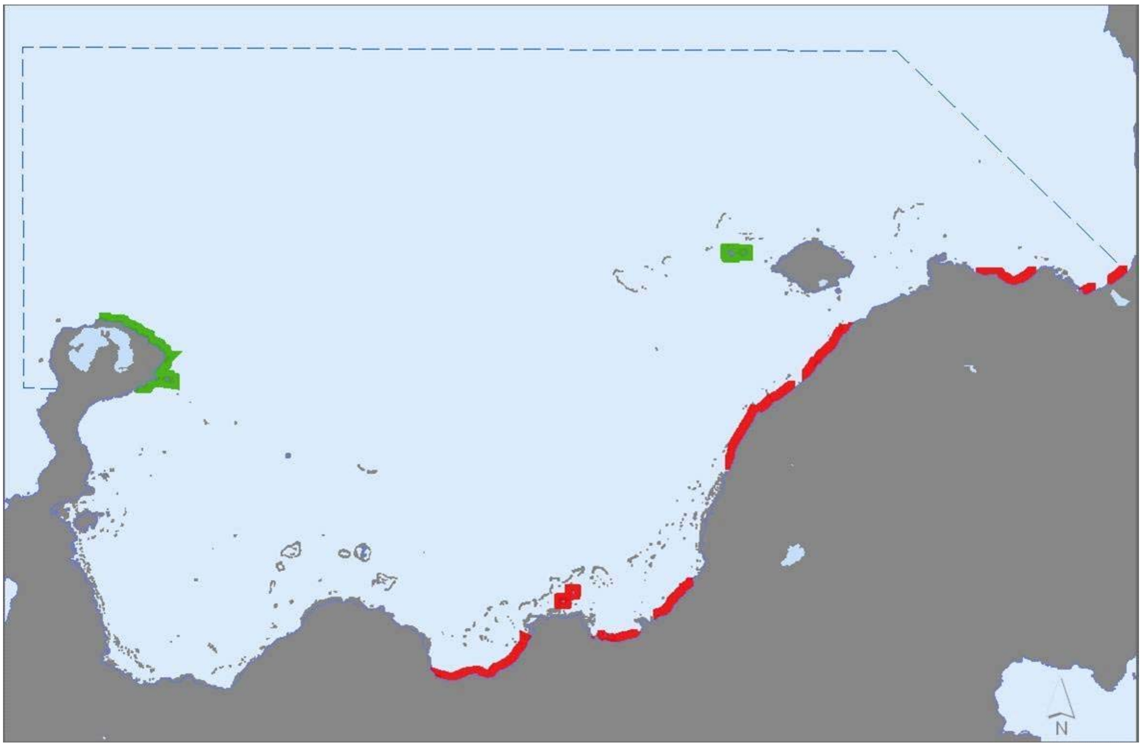


Figure 22. Sea turtle nesting areas.

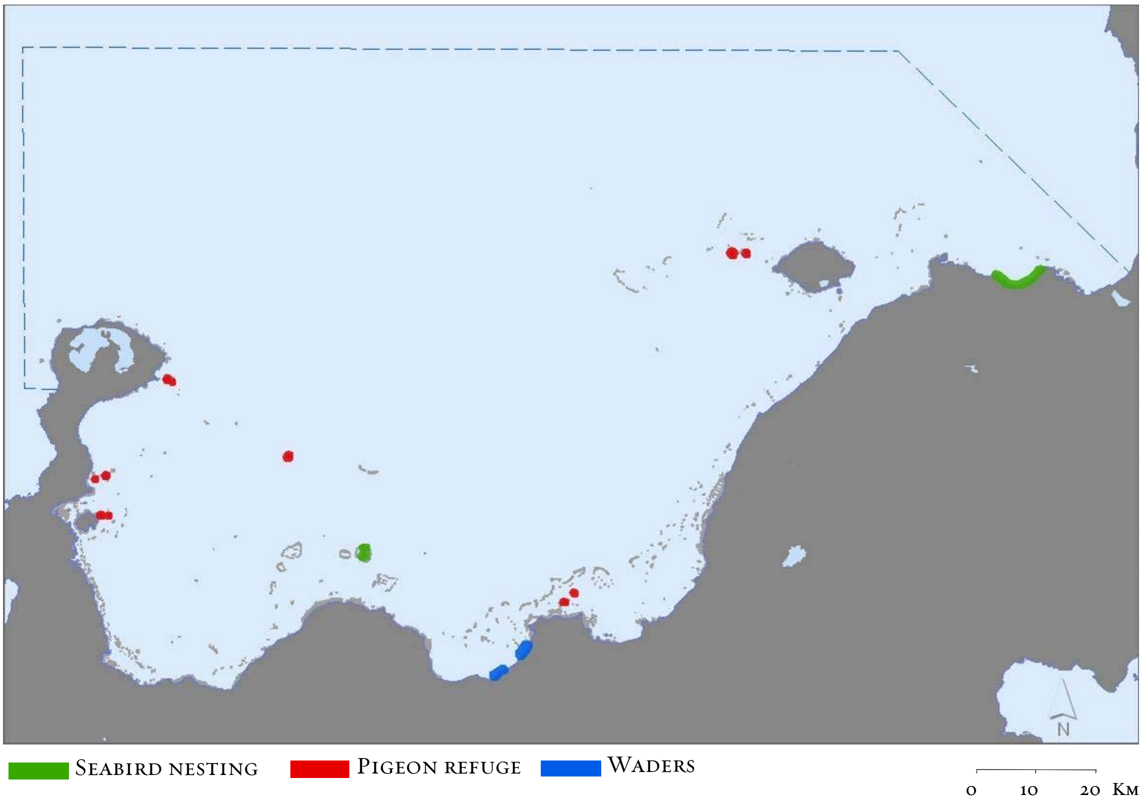


Figure 23. Important nesting, wading and resting areas for birds.

2.5.5.4 Cost Surface

The cost surface represented those areas likely to have a positive or negative affect on conservation (i.e. the success of the network: Figure 24). These were largely derived from socioeconomic and existing threat data layers (see 2.5.3 Cost Layer).

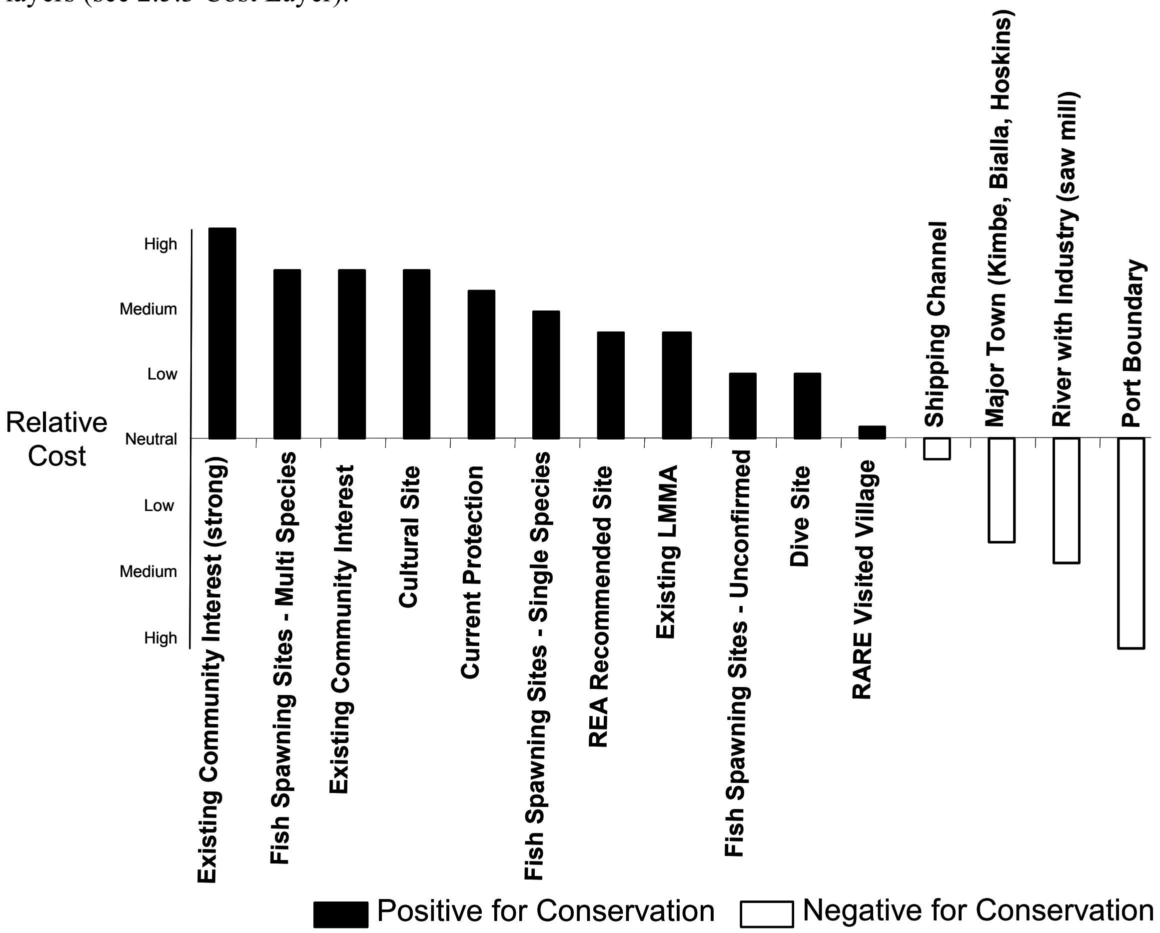


Figure 24. Cost surface.

2.5.5.5 Stratification

The stratification units showed how it was necessary to divide the MPA network area to represent the full range of environmental and geographic variation that exists within the study area. The MPA network was stratified into two strata (east and west sides of the bay: Figure 6), since best available data suggested that these areas are different in terms of their exposure to ocean currents and waves (Steinberg et al 2006, and local knowledge), and their biological communities (Beger unpubl. data).

2.5.6 Primary Input Files

MARXAN has four primary input files required to run the analysis. Please note that there are slight differences in terminology between MARXAN and TNC conservation planning. The main differences are:

- TNC target = MARXAN conservation feature; and
- TNC goal = MARXAN target.

TNC terminology has been used throughout this report.

2.5.6.1 Planning Unit File

The planning unit file is the hexagon layer (Figure 6). This is the GIS data layer where desired units are either locked in or locked out. This file contains a unique ID for each hexagon, the individual cost of each hexagon (identified above) and status of each hexagon, that is, whether it is a seed for a new reserve system (locked in), or whether it is unavailable for consideration (locked out).

2.5.6.2 Conservation Target Occurrence File

This table references the area of each target within each hexagon. It contains: a unique ID for each target and the amount (in hectares) present within the planning unit.

2.5.6.3 Conservation Goals File

This file contains the individual conservation goal for each target (i.e. the % to be protected), and the Penalty Factor for that conservation value (see 2.5.4 Key Inputs).

2.5.6.4 Boundary Length File

This file contains information on the boundary costs of adjacent planning units. A boundary length modifier was then applied to adjust the relative importance of clumped or dispersed protected areas for any given scenario (see below).

2.5.7 Generating Scenarios

A number of scenarios were developed using different boundary length modifiers to determine which one produced the desired degree of clumping. A boundary length modifier of 1.5 was selected, since it provided a moderate degree of clumping that produced compact areas of moderate size which satisfied both our biophysical and socioeconomic design principles (see 2.1.4 MPA Network Design Principles).

Several scenarios were also generated where different areas were locked in or out, which allowed the scenario that was most successful in capturing our goals to be identified. Four scenarios were developed where all conservation goals were met:

1. **Unconstrained** – where no areas were locked in or out.
2. **Special and unique areas** – where special and unique areas were locked in. These were areas that were a high priority for inclusion because they were either unique features (eg seamount, mangrove island, offshore coral cay, or platform reef with lagoon), or areas of high conservation value (eg high diversity sites).
3. **Existing protected areas** - where all existing LMMAs were locked in.
4. **Existing protected areas, traditional areas and dive sites** – where all areas that currently receive some form of protection (LMMAs, spirit areas and dive sites) were locked in.

For each of the above scenarios, where areas are "locked in", a proportion of the conservation goals are met in those areas and the remainder of the goal is sought elsewhere in the study area. Each scenario comprised 100 runs of 10,000,000 iterations.

Of these four scenarios, **Scenario 2 – Special and unique areas** was selected, because these areas were considered a high priority for inclusion in the MPA network. Existing protected areas (LMMAs) were not locked in (Scenario 3) because while they may be good choices for inclusion because they are already protected, it was important that they were selected due to their contribution to the overall goals. Furthermore, locking in the existing LMMAs (Figure 11) would have resulted in over-representation of a few coastal habitats (fringing reefs, patch reefs and mangroves: Figure 17 and Figure 20) in the design, including some areas that were not in good condition (Jones et al. 2004). So rather than "locking them in" and designing the network around them, they were allocated a medium weighting in the cost layer, so they were considered of mid level importance to include. A similar approach was used for the dive sites. Spirit areas were not assigned a weighting in the analysis, since all but one (off Tarobi, Figures 5 and 10) were located in special and unique areas (Figure 13), which were already locked into the analysis. The remaining spirit area was included during manual accounting at the end of the analysis (see 2.6.3 Refining Areas of Interest Using Manual Accounting).

2.6 DESIGNING THE MPA NETWORK

The scientific design of the Kimbe Bay MPA network was produced at the Third Scientific Workshop in Kimbe Bay in July 2006, with the Kimbe Bay Project Team and a multidisciplinary team of technical advisors (see Contributors). The following is a description of the process used to develop the design.

2.6.1 Refining the Process

The results of the data analysis demonstrated that there are many ways to design an MPA network in Kimbe Bay that will achieve our goals, and that there is lots of room to move in choosing specific areas to include. For example, the results of three of the 100 runs from Scenario 2 (see 2.5.7 Generating Scenarios) are presented below. Each of these examples achieves our goals, but they each do it in different ways:

- Best (lowest) total score (Figure 25);
- Lowest cost (Figure 26); and
- Shortest boundary length (most clustered: Figure 27).

In Kimbe Bay, local communities are the resource owners and decision makers. For that reason, the most effective approach was to use the results of the analysis and the full range of our knowledge and experience in the bay[22], to identify broad Areas of Interest (AOIs) that are good choices for biodiversity conservation where local communities can consider opportunities for the development of protected and managed areas. Once these areas are identified, the Conservancy will seek to work with communities that own and manage marine resources within these areas through a detailed community-based planning process.

2.6.2 Selecting Areas of Interest

The results of the MARXAN analysis, and the full range of our knowledge and experience in Kimbe Bay[22], were used to identify AOIs for inclusion in the MPA network. The data analysis summarised the cumulated results of 100 runs from Scenario 2 (the sum result: Figure 28), each of which achieved our goals. In this analysis, red areas were selected most of the time (>90% of runs) and were a high priority for inclusion in the network, because they were either locked in by the analysis (special and unique areas) or because they were particularly efficient to include. By comparison, the orange and yellow areas were selected more than half of the time, and the green areas were selected less than half of the time. This means that while it was important to include the red areas in the MPA network, there was lots of room to move in selecting the other areas. Where possible, more orange and yellow areas and less green areas were included, depending on where the communities are interested in working (since that will maximise our chance of success). The greatest number of options was available in the green areas, and the least number of options available in the red areas.

AOIs were selected using the red areas from the sum analysis as core areas, and expanding into areas where local communities have demonstrated the strongest interest and ability in conserving their marine resources.

2.6.3 Refining Areas of Interest Using Manual Accounting

Once the AOIs were selected, the results of the analysis were used as an accounting tool to ensure that the design principles and goals had been applied successfully, and to confirm that the network objectives would be achieved by working in these areas. This was an iterative process that required moving AOI boundaries, and including new AOIs, until the design principles and goals were met. In particular, boundaries were modified to ensure that biological, socioeconomic and cultural interests had been taken into account. Particular attention was paid to marine tenure boundaries where this information was available. AOIs that occurred within marine tenure estates that were owned by only one or two communities, and had locally recognised boundaries, were identified as prime locations to work because implementation will be easier in those areas. The AOIs, overlaying the sum result, are presented in Figure 29. It is noteworthy that at this

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[22] This included information that could not be included in the data analysis because it was not available for the entire bay (including unmapped land use and sensitive marine tenure information). Where this information was available for some areas (eg local knowledge of land use or marine tenure), it was taken into account manually while refining the design (see 2.6.3 Refining Areas of Interest Using Manual Accounting). These issues will require further consideration and refinement during the community-based planning process for each AOI (see 3.1 Implementation).

stage not all of the AOIs have been endorsed by local communities. Thus, the boundaries of the AOIs, or even the AOIs themselves, may shift in future as a result of the community-based planning process (see 3.1 Implementation).

The outcome was the scientific design of an MPA Network for Kimbe Bay (Figure 30). Fifteen AOIs were identified, where the Conservancy will seek to work with communities that own and manage marine resources within these areas through a detailed community-based planning process (see 3.1 Implementation). Depending on community interests, AOIs may be either large scale LMMAs or comprised of a number of smaller LMMAs within a broader area. This will be determined during the community-based planning process for each AOI. Manual accounting confirmed that if these areas are effectively conserved, the MPA network design principles will have been applied successfully and the network objectives will be achieved (Appendices 2-3).

These areas, together with other areas already under some form of protection (LMMAs and dive sites: Figure 31), will form a comprehensive MPA network that will achieve the network objectives. In fact, if all of these areas are effectively conserved, many of the targets will be over represented (see Appendix 2). This provides room to move when working with the communities to refine the network (see 3.1 Implementation).

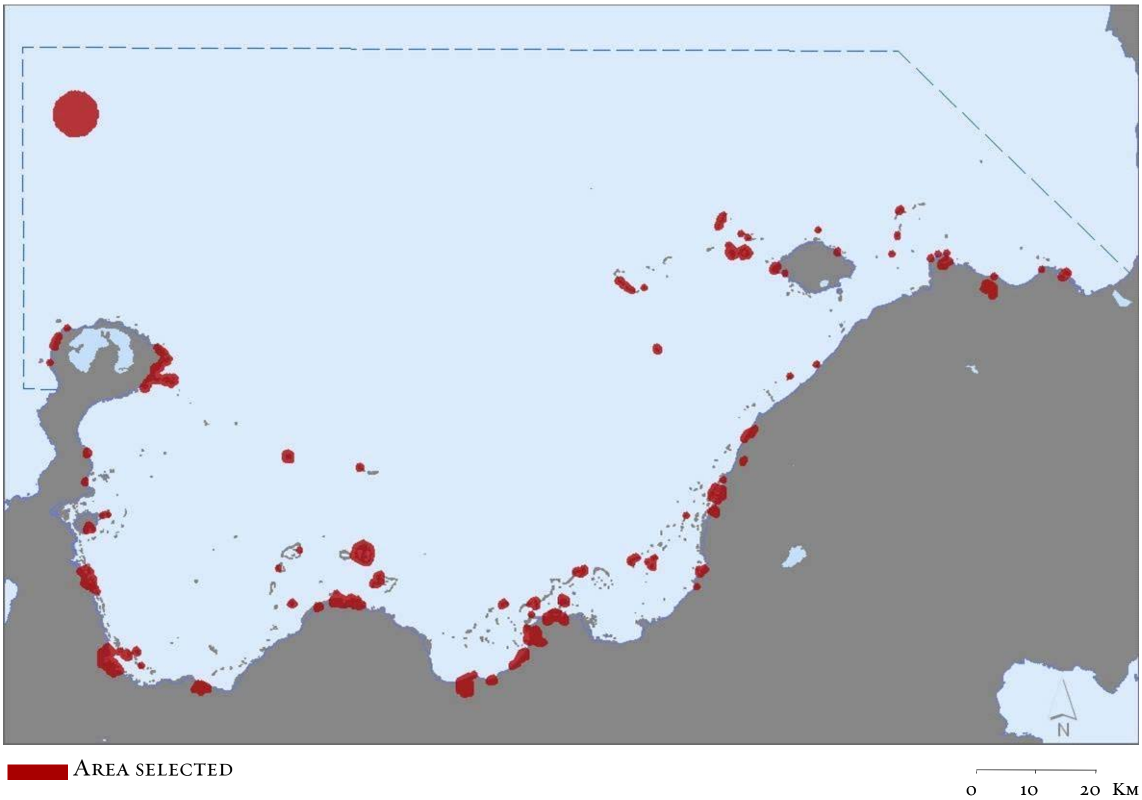

Figure 25. MARXAN results representing best of 100 runs based on best (lowest) total score.

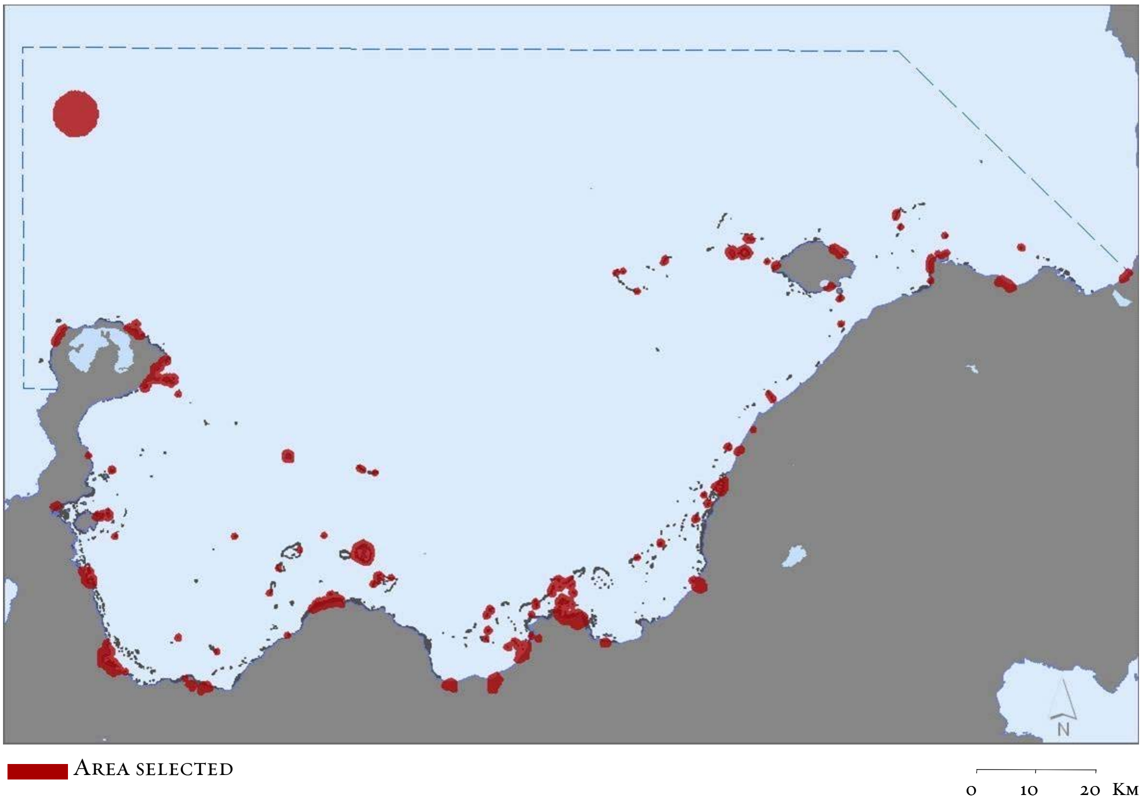

Figure 26. MARXAN result representing best of 100 runs based on lowest cost.

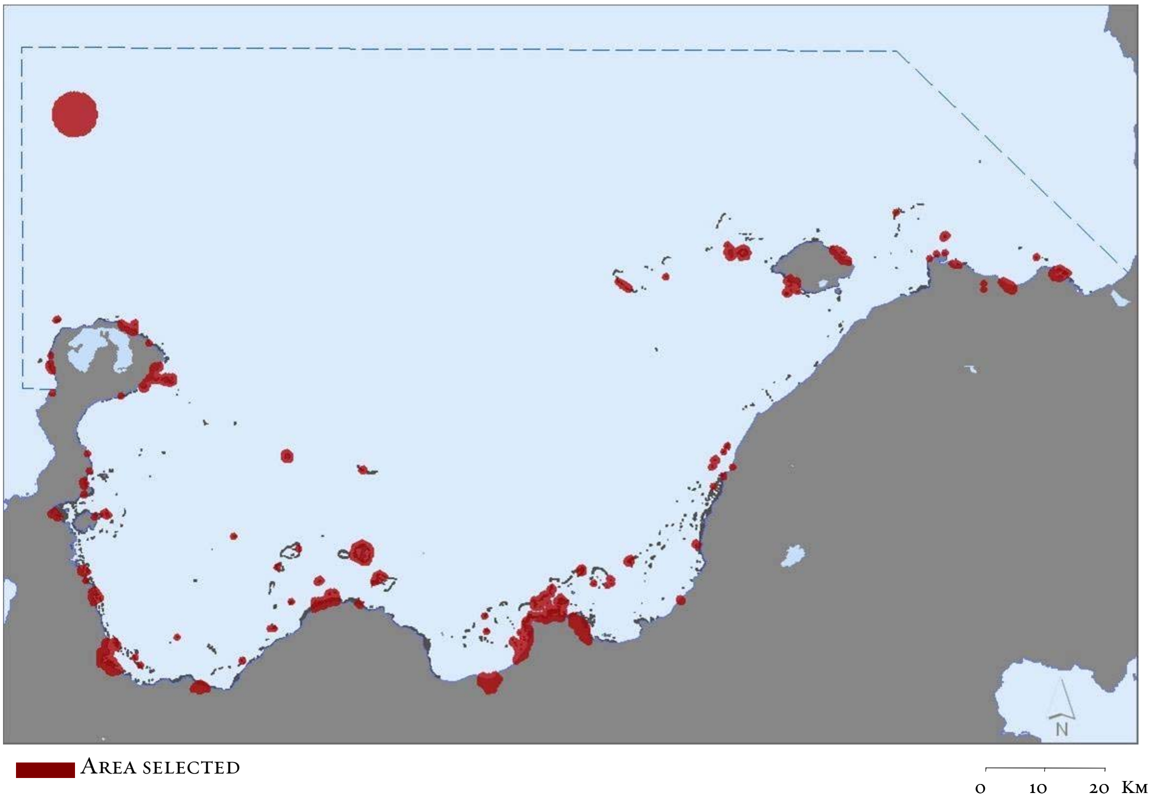

Figure 27. MARXAN result representing best of 100 runs based on shortest boundary length (most clustered).

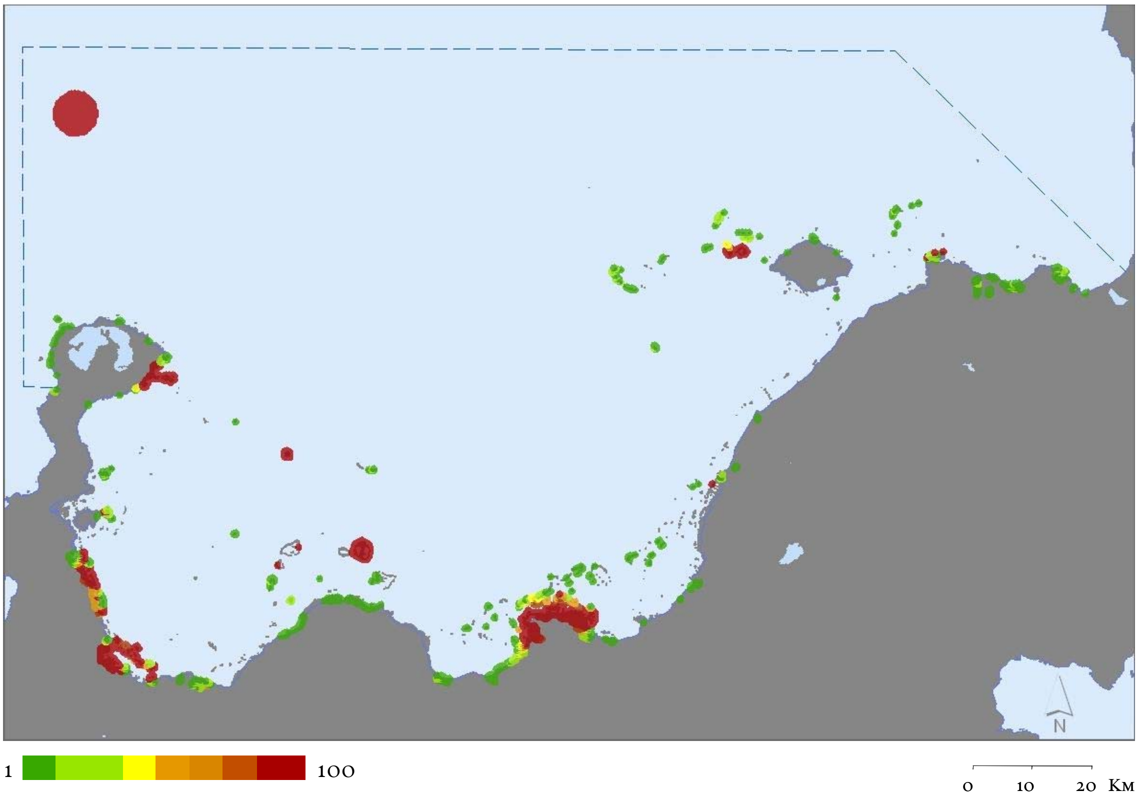

Figure 28. MARXAN sum result representing the number of times each hexagon was included in a "best" solution in 100 runs.

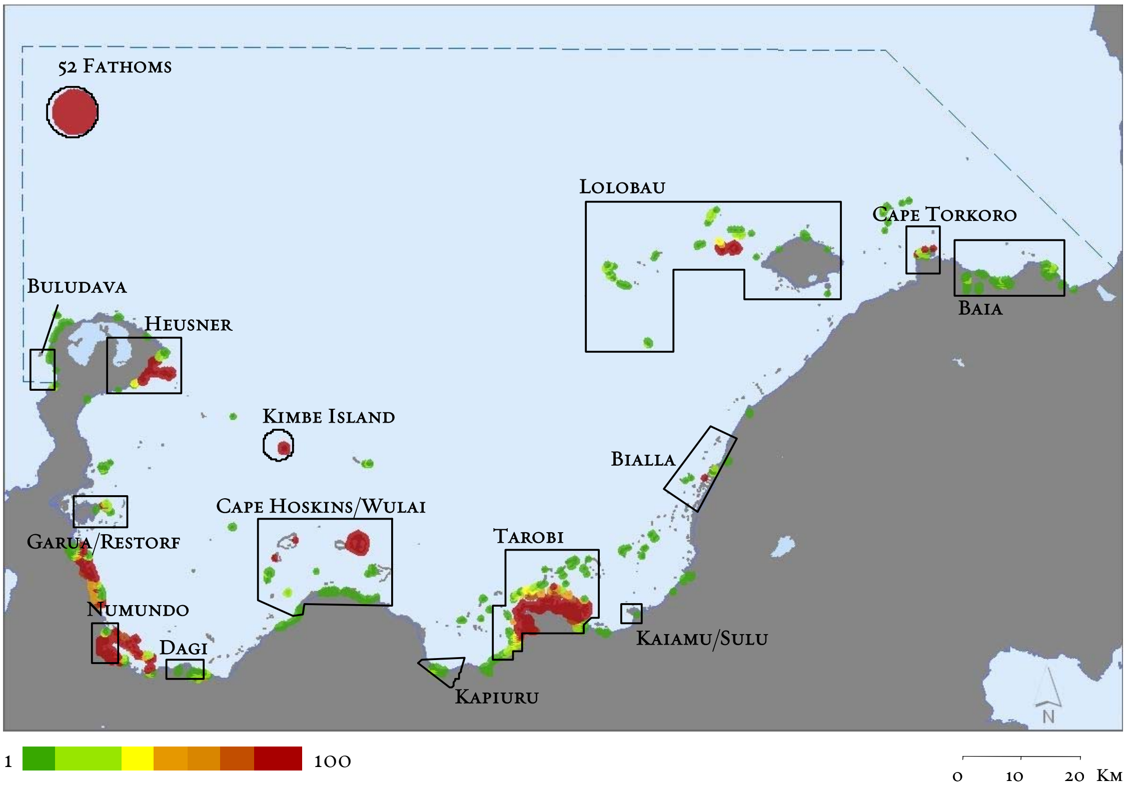

Figure 29. Areas of Interest overlaying the sum result from the data analysis.

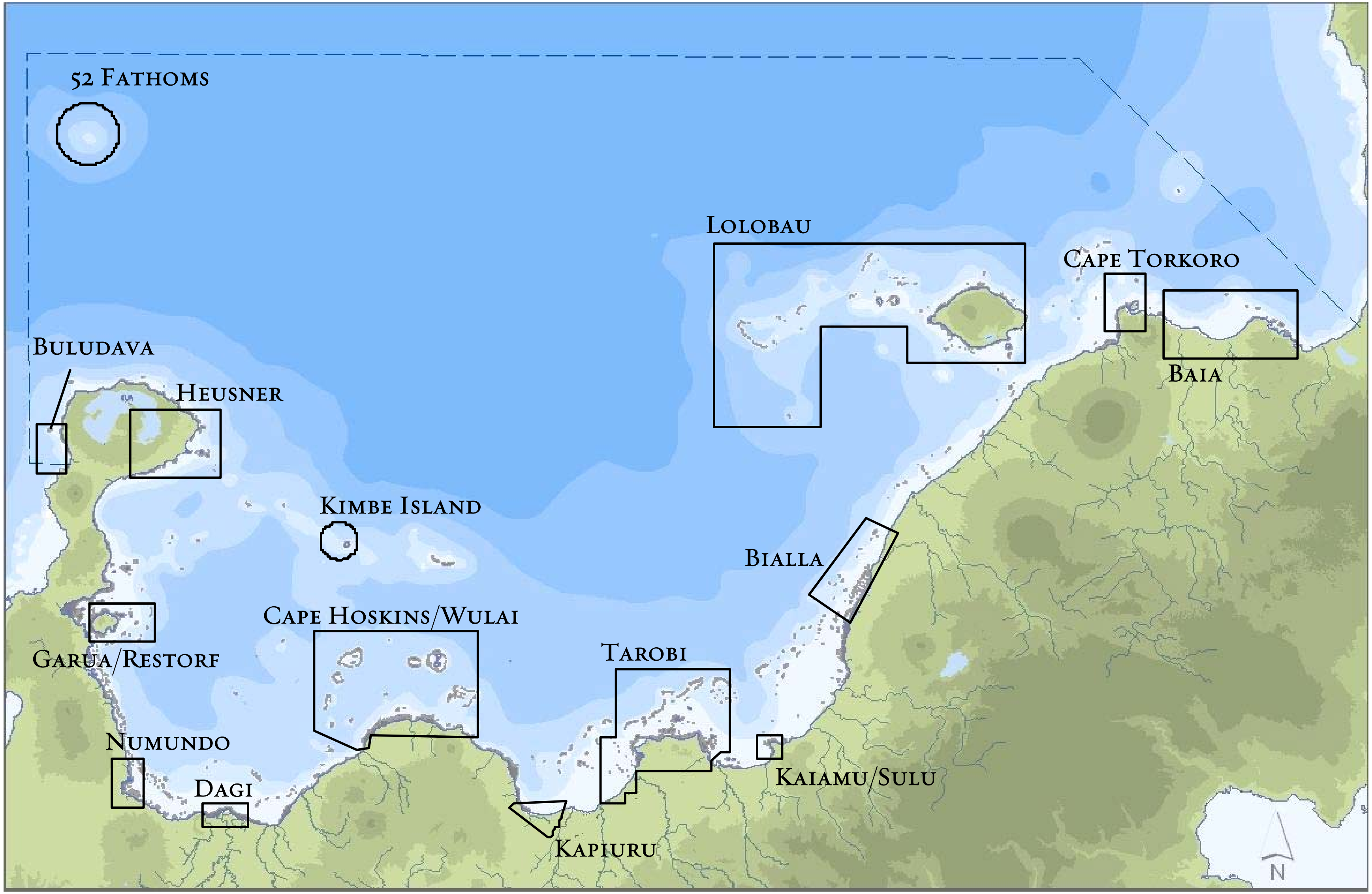

Figure 30. Scientific design of an MPA network for Kimbe Bay, Papua New Guinea, showing Areas of Interest (boxed areas) for biodiversity conservation.

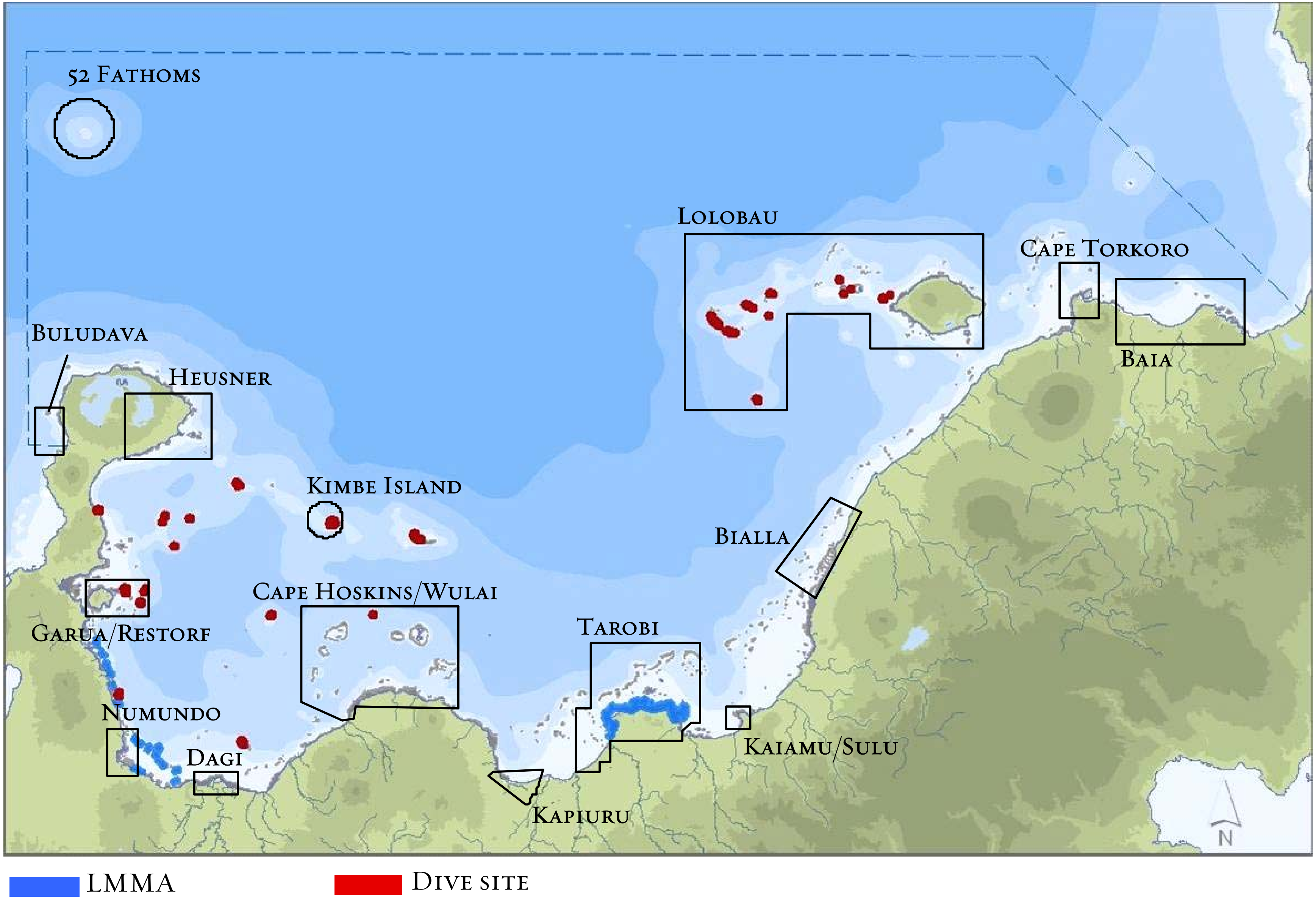

Figure 31. Scientific design of an MPA network for Kimbe Bay, Papua New Guinea, showing Areas of Interest (boxed areas) for biodiversity conservation, existing LMMAs and dive sites.

3. DISCUSSION

The Nature Conservancy's vision for Kimbe Bay is to *"Harness traditional and community values to protect and use land and sea resources in ways that maintain the exceptional natural and cultural heritage of the bay"*. This will be achieved by working with local communities, governments and other stakeholders to establish a resilient network of Marine Protected Areas (MPAs), and develop strategies for improved management of marine resources and land use practices.

The scientific design of the MPA network represents a major milestone for the Kimbe Bay Project, since it provides an excellent blueprint for biodiversity conservation in the bay. This design will form the basis for working with local communities and other stakeholders to refine and implement the design over time. However, since communities are the marine resource owners and decision makers, final decisions regarding the design will be at their discretion.

The next challenges will be: working with communities and other stakeholders to refine and implement the design; addressing high priority science needs for resilient MPA network design; and using lessons learned in the scientific design process, and lessons we are still learning in the implementation process, to inform other MPA design processes in the Bismarck Sea and elsewhere in the Coral Triangle.

3.1 IMPLEMENTATION

Implementing the design will require working closely with local communities and government at a range of scales. Locally managed marine areas (LMMAs) will be the primary strategy for nearshore areas, while other strategies will be required for offshore areas. Broader scale strategies will also be required for the entire MPA network area (Figure 5).

3.1.1 Locally Managed Marine Areas for Nearshore Areas

In PNG, local communities are the marine resource owners and decision makers (see 2.3 Community Engagement), and the primary implementation strategy for the Kimbe Bay MPA network will be to help communities manage their marine resources through LMMAs.

LMMAs are a well established strategy throughout the Pacific Islands, and the most effective strategy for conserving nearshore areas in line of sight of local communities (McClanahan et al 2006)[23]. The Conservancy is the country host and coordinator of the LMMA network in PNG, and works with local conservation partner Mahonia Na Dari to assist communities establish LMMAs. To date, six communities have established LMMAs, comprising 18 *tambu* reefs and 3 *tambu* mangrove areas on the western side of Kimbe Bay, and one community is in the process of establishing a large LMMA on the eastern side (Figure 11). Many more communities have requested assistance to establish LMMAs throughout the bay.

Kimbe Bay LMMAs have met with mixed success for two reasons:

1. Some areas were not good choices for marine resource management because they are either too small or in poor condition due to their proximity to poor land use practices and other threats (particularly coral bleaching: see Jones et al 2004).
2. Lack of effective management, particularly compliance and enforcement.

Despite these limitations, long term monitoring has demonstrated fisheries benefits for some species in these areas (Jones et al 2004).

The Kimbe Bay MPA network design provides a blueprint to focus conservation efforts in the bay. In the next few years, the Conservancy will work with communities that own and manage marine resources within

[23] Legal jurisdiction for LMMAs extends to 3nm offshore.

the Areas of Interest (AOIs) through a detailed community-based planning process (Lipsett-Moore 2006) to develop an approach that will ensure that good choices are made in selecting areas for protection, and that more effective management frameworks are established. Where possible, assistance will be also provided to communities whose marine resources lay outside the AOIs through the PNG LMMA network.

The community-based planning process will comprise five steps (Lipsett-Moore 2006):

- **Step 1. Community engagement** to introduce the concept of the MPA Network and the planning process to the communities.
- **Step 2. Community visioning** to develop consensus within communities regarding a realistic vision for managing their marine resources, and to identify boundaries for LMMA management areas.
- **Step 3. Participatory conservation planning** to identify biological or ecological systems that represent community priorities, and refine this information based on community knowledge.
- **Step 4. Community development of a LMMA plan and agreement** to help the community achieve their vision for the management of their area in the long term.
- **Step 5. Preparation of a draft LMMA plan and agreement**.
- **Step 6. Stakeholder consultation and finalisation of a LMMA plan and agreement** by the community.

This process is an amalgamation of key elements of the LMMA Process and the Conservancy's Conservation Area Planning Process, adapted for working with local communities based on successful examples from the Adelbert Mountains in PNG and Lore Lindu in Indonesia (Lipsett-Moore 2006). It will result in an LMMA plan and agreement for each AOI, and is already being trialled by the Conservancy and Mahonia Na Dari with communities in four AOIs in Kimbe Bay (see Figure 30):

- Tarobi Community, Tarobi AOI;
- Lolobau Community, Lolobau AOI; and
- Buludava Community, Buludava and Heusner AOIs.

These AOIs were selected because they comprise a wide range of conservation targets throughout the MPA network area, and each is owned by only one or two communities. The Conservancy also has a history of prior engagement with two of these communities (Tarobi and Lolobau), which have a strong interest in managing their marine resources and have demonstrated their ability to do so. The third community (Buludava) is a new area for the Conservancy, where the community has had less exposure to, and interest in, marine conservation. These communities offer a range of biophysical, socioeconomic and cultural situations to test this method. Lessons learned will be used to assist with work in other AOIs in the coming years. The implementation process is expected to take approximately five years to complete.

LMMAs rely on a combination of traditional and Local Level Government (LLG) laws for compliance and enforcement, which is the most effective mechanism for establishing and enforcing MPAs in PNG (McClanahan et al 2006). In Kimbe Bay, most local community members are likely to comply with traditional law, but some community members and outsiders are not, leading to problems with enforcement. For this reason, the Conservancy facilitated the establishment of LLG legislation to reinforce traditional laws for LMMAs. This legislation has now been passed in all three LLGs that encompass marine areas in Kimbe Bay (Talasea, Hoskins and Bialla), and has already been used to enforce LMMA rules and regulations. This legislation has also been enthusiastically received by local communities, and there have been several requests from other LLGS in PNG who wish to use it. A modified version of this legislation has already been passed by the Nali Sopat Penabu Local Level Government in Manus Province.

3.1.2 Strategies for Offshore Areas

While LMMAs are the best strategy for nearshore areas, other strategies will be required for offshore areas. For these areas, compliance and enforcement through other mechanisms will be required. There are several options available including:

- Resource user fees: Kimbe Bay is the home of a high end dive industry, which pays user fees to local communities to use specific reefs. This provides some degree of protection, since these reefs are not fished by local communities and are visited regularly by dive boats.

- Government protected areas: Offshore areas that are not dive sites may be protected by government declared protected areas, although some assistance to government agencies would be required for this to be successful (particularly regarding compliance and enforcement). Support for these protected areas by local communities would also be required.
- Closed fishing areas, including closure of most of the open ocean in the Kimbe Bay MPA network area (Figure 5) to all industrial tuna and pelagic fishing activities by the National Fisheries Authority (NFA). Under this arrangement, NFA would be involved in enforcement.

3.1.3 Broad Scale Strategies

To address threats at a broader scale (i.e. marine resource use and land use), it is important that the entire Kimbe Bay MPA network area (Figure 5) is declared an MPA. With this in mind, the Conservancy supported a review of legislative options for the National and Provincial Governments (Kwa 2004, 2006), which led to the Maritime Zones Bill being identified as the most practical option for providing a legal framework for MPAs in PNG. Recently, with support from the Conservancy, the Department of the Attorney General hosted a workshop to allow National, Provincial and NGO stakeholders to review the proposed Bill. The Bill will now be revised to provide for the establishment of MPAs. Once completed, it will undergo final stakeholder review and consultation with Provincial and Local Level Governments, before a final bill is submitted to the National Parliament.

In order for implementation to be successful, strong support will be required from local communities and all levels of government (Local, Provincial and National). Meetings with local communities have demonstrated that there is strong support for the MPA network in the areas where we already work, although a community engagement process is still required in other areas. The MPA network and scientific design have also been endorsed by all levels of government (key national government agencies include the Department of Environment and Conservation and the National Fisheries Authority). An ongoing commitment to working with local communities, government and other stakeholders will be required for this network to be successful in the long term.

Other priorities for implementation of the MPA network will include a sustainable financing plan for the establishment and long term management of the MPA network, and long term monitoring to measure success for adaptive management. For the MPA network to be successful it will also need to be embedded in broader marine resource use and land use strategies (see 1.3.4 Key Threats and Conservation Strategies).

3.2 SCIENTIFIC DESIGN OF A RESILIENT NETWORK OF MARINE PROTECTED AREAS

Climate change represents a major threat to the long term future of coral reefs and associated ecosystems around the world, including Papua New Guinea. The scientific design of the Kimbe Bay MPA network represents one of the world's first MPA networks specifically designed to address this threat. In recent years, principles for designing MPA networks that are resilient to the threat of climate change have been developed (see 1.4 Designing a Resilient Network of Marine Protected Areas). While most of these principles were applied successfully in Kimbe Bay, some aspects will require refinement over time as new scientific methods are developed and more information becomes available. The design will also be refined as implementation proceeds, with substantial input still required from local communities and other stakeholders. As this process proceeds, high priority science needs will need to be addressed, and MARXAN will used as an accounting tool to ensure that network objectives are achieved.

3.2.1 Application of Resilience Principles

Some resilience principles were easy to apply, because the data layers required were easily acquired and it was a straightforward matter to apply these principles using marine reserve software (MARXAN). They included:

- Risk spreading through representation[24];
- Protecting some key sites (eg fish spawning aggregation sites, turtle nesting areas, nursery areas etc); and
- Incorporating patterns of connectivity among adjacent habitat types (eg coral reefs, mangrove forests and seagrass beds)[25].

In contrast, some principles were not as straightforward to apply, although these difficulties could be easily overcome. For example, it was not a straightforward matter to apply the principle of risk spreading through replication and spread during the data analysis (the spreading function in MARXAN is time consuming and not very effective), but that was easily achieved using manual accounting after the analysis had been completed[26].

Other principles were difficult to apply in any detail, because the base level information required was not available (the science is still developing) and MARXAN is not yet designed to apply these principles. They include:

- Protecting some key sites, particularly areas that may be more resistant or resilient to climate change; and
- Incorporating patterns of connectivity within habitat types (eg among coral reefs), taking into account small and large scale patterns of connectivity through adult movement and larval transport.

In the absence of detailed information to identify specific areas that may be more resistant or resilient to climate change, this threat was addressed using two broad scale strategies:

- Addressing uncertainty by spreading the risk (through representation, replication and spread of each habitat type); and
- Using the best available information to:
    - Stratify the bay into two strata (east and west) to address the threat of rising sea surface temperatures, since best available information suggests that the west side of the bay may be more susceptible to coral bleaching than the east[16]. Different habitat types (including inshore and offshore reefs) were also included in the design, since best available information suggests that inshore reefs may be more vulnerable to bleaching than offshore reefs[16].
    - Address the threat of sea level rise on coastal targets (specifically mangroves and turtle nesting areas) based on best available knowledge of the topography of each area. However, this principle could not be applied in detail, because fine scale elevation information was not available that would allow for detailed predictions regarding sea level change in relation to climate change scenarios. However where possible, areas were selected with natural backdrops, which when compared with developed backdrops, may accommodate change more effectively. These predictions will be manually validated by visiting coastal targets selected in the network to assess their viability in regard to rising sea level, and this information will be used to refine the network during the community-based planning process.

In the absence of the detailed information required to incorporate fine scale patterns of connectivity among habitat types (e.g. coral reefs), connectivity was addressed at a broad scale using three strategies:

- Addressing uncertainty by spreading the risk (through representation, replication and spread of each habitat type);
- Stratifying the bay into two strata (east and west), since the best available information indicates that the east and west sides of bay are different in terms of their biological and physical characteristics (based on coral reef fish communities and ocean currents: Beger unpubl. data, Steinberg et al. 2006)
- Using rules of thumb for MPA network configuration that take into account the longest and shortest dispersal distances of targets. They include: including at least 20% of each habitat type in MPAs (20-50% recommended by Bohnsack et al 2000, Airame et al 2003, Fernandes et al 2005, World Parks

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[24]At least 20% of each habitat type (conservation target) was included in the MPA network design for 50 of the 51 targets (Appendix 2).

[25] Shallow water habitat types that have some degree of connectivity among them (coral reefs, mangroves forests and seagrass beds) were clustered as a function of the analysis, since that is what the software is design to do.

[26] Replication and spread was achieved for 40 of the 51 targets, where the number and spacing of targets allowed for this principle to be applied (Appendix 3).

Congress 2003), with a minimum size of $10km^2$ per MPA (10-20km in diameter: Mora et al 2006) and a maximum spacing distance of 15 kms between MPAs (Mora et al 2006). We were largely successful in applying these rules of thumb since:

- At least 20% of each habitat type is included in the AOIs for 50 of our 51 targets (Appendix 2). AOIs also include 57% of the coral reefs in the MPA network area, and 13% of the total area (Table 2), of which much is open ocean[21].
- AOIs range in size from 6 to $724km^2$, with only one (Kiamu/Sulu[27]) of the 15 AOIs smaller than the recommended size of $10km^2$ (Table 2)
- Minimum distance between AOIs was 2 to 35 kms, with only 2 of the 15 AOIs separated from others by distances greater than 15km (Table 2). One of these was 52 fathom seamount, which is a unique habitat type located in open ocean outside the bay, and the other was Garua/Restorf which was located 16km from the nearest AOI.

A detailed summary of how successful we were at applying all of the biophysical and socioeconomic design principles identified in the First Scientific Workshop (Green and Lokani 2004) is provided in Appendices 1-4.

Throughout the scientific design process, MARXAN provided a systematic procedure that was extremely useful for processing the large amounts of information used in the analysis. However, there are still some challenges to using this tool to apply resilience principles for MPA network design, particularly:

- New methods and functionality are required to implement some resilience principles, particularly regarding incorporating patterns of connectivity and a risk assessment to bleaching and other threats. Fortunately, these are being addressed by the software developers (University of Queensland Spatial Ecology Lab) and partners (including The Nature Conservancy).
- New methods and functionality are also required to easily apply risk spreading principles for replication and spread.

3.2.2 High Priority Science Needs

While there have been many scientific advances in MPA design in recent years, some information gaps still exist. High priority science needs to successfully apply resilience principles for MPA design include:

- Practical, low cost, low tech methods for identifying biological patterns of connectivity on an ecological scale.
- Further testing of resistance and resilience hypotheses, and methods for identifying resistant or resilient sites.
- Developing new MARXAN methods and functionality for applying resilience principles for MPA network design (see above).

High priority science needs to improve the base level information required to refine the MPA network design for Kimbe Bay include:

- Obtaining more detailed boundary delineations for marine tenure areas, spirit areas, and LMMAs.
- Conducting further field and traditional knowledge surveys to provide more information on key sites for rare and threatened species, particularly turtles, cetaceans, seabirds, dugong, dolphins, and large vulnerable reef fishes.
- Understanding more about biological patterns of connectivity in the bay.
- Identifying coral reef areas that may be more resistant or resilient to the threat of coral bleaching.
- Conducting a more detailed assessment of the threat of sea level rise on coastal targets, particularly regarding mangrove forests and turtle nesting areas.
- Conducting a field survey to ground truth estuarine communities delineated based on satellite imagery interpretation.

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[27] This area was added primarily to include an important seagrass community.

Table 2. Summary statistics for each Area of Interest and the entire MPA network area

Area of Interest (AOI)	Total Area (km^2)	Percentage of MPA Network Area (%)	Tropical Coast and Shelves (km^2 <200m deep)	Percentage Tropical Coast and Shelves (% <200m deep)	Coral Reef Area (km^2)	Percentage Coral Reef Area (%)	Minimum Distance to Adjacent AOI (km)
52 Fathoms	59.2	0.5	2.3	0.1	0.0	0.0	35
Baia	104.7	0.8	63.8	3.8	2.4	1.8	2
Bialla	60.9	0.5	54.9	3.3	6.5	4.9	14
Buludava	17.5	0.1	10.4	0.6	1.2	0.9	9
Cape Hoskins/Wulai	320.3	2.4	102.1	6.1	17.9	13.5	10
Cape Torkoro	32.7	0.3	28.2	1.7	2.0	1.5	2
Dagi	10.6	0.1	10.6	0.6	3.4	2.6	8
Garua/Restorf	42.1	0.3	33.5	2.0	4.0	3.0	16
Heusner	62.3	0.5	41.6	2.5	3.7	2.8	9
Kaiamu/Sulu	6.1	0.1	6.1	0.4	1.5	1.1	4
Kapiuru	9.5	0.1	9.4	0.6	0.6	0.5	5
Kimbe Island	21.7	0.2	10.5	0.6	0.4	0.3	10
Lolobau	724.3	5.5	207.5	12.3	11.2	8.4	11
Numundo	19.3	0.2	18.5	1.1	4.0	3.0	8
Tarobi	197.5	1.5	155.0	9.2	16.9	12.7	4
Total Inside AOIs	**168850.7**	**12.7**	**754.35**	**44.7**	**75.7**	**57.1**	
Total Outside AOIs	**1159999.5**	**87.3**	**933.76**	**55.3**	**57.0**	**42.9**	
Total MPA network	**1328850.2**	**100.0**	**1688.11**	**100.0**	**132.7**	**100.0**	

3.3 LESSONS LEARNED

This was one of the first attempts to design a resilient network of MPAs, and the first to design an MPA network for Melanesia. Therefore, it was necessary to develop a new process that was appropriate for the biophysical, socioeconomic and cultural situation in the bay. Many lessons were learned that may be useful to others undertaking a similar exercise. They include:

- **Have a clear plan for the design and a process for achieving it**: One of the most useful steps in our process was holding the First Scientific Workshop, which clearly identified the objectives, conservation targets, boundaries, design principles and research priorities for the MPA network. This provided a guiding framework early in the process, which resulted in a faster, more efficient design process.
- **Take implementation into account in the design**: It is very important to understand how the MPA network will be implemented, and to take this into account in the way the network is designed. In Kimbe Bay, it was important to recognise that local communities are the resource owners and decision makers, who will decide what and how to protect their resources. For that reason, identifying large AOIs to work with local communities on a community-based planning process is more likely to be an effective strategy than identifying individual features for protection (except for special and unique features that need to be included in the design).
- **Identify the most effective strategy for engaging stakeholders in the process:** Perhaps the most important lesson is that while the scientific design process is technical and time consuming, the biggest challenge is implementation. Therefore it is important to identify the most effective strategy for engaging local communities and other stakeholders. In Kimbe Bay, we made the strategic decision that the most effective strategy to engage local communities and other stakeholders in this process was after the scientific design had been completed (see 2.3 Community Engagement). The support for the MPA network and the design from communities where we already work and all levels of government suggests that this has been a successful approach for Kimbe Bay. However, more community engagement will be required before the MPA network design is finalised and supported by all local communities and other stakeholders.
- **There are still some scientific challenges for designing resilient networks of MPAs** which need to be addressed. In the interim, rules of thumb can be used to address these challenges (see 3.2.1 Application of Resilience Principles).
- **Use marine reserve software.** MARXAN is an excellent decision support tool, and a great way to process the large amount of information required for MPA network design. However, it is important to remember that it is a decision support tool, and is not the decision maker. Final decisions regarding the scientific design should be made using the full range of knowledge and experience of an area by local managers and other stakeholders, including much that will not be available in GIS layers for the data analysis. There are also still some limitations to using this tool (see 3.2.1 Application of Resilience Principles), which are currently being addressed by the software developers in partnership with the Conservancy and others.
- **The minimum amount of information required** includes the location of conservation targets (eg coral reefs, mangroves, fish spawning aggregation sites, turtle nesting areas etc), threats (eg major towns, industry, shipping etc) and opportunities (i.e. areas where there is the highest probability of success).
- **A multidisciplinary team with a wide range of expertise is required** including a marine scientist to lead the process who has experience in conservation planning (or is willing to give it a go), a specialist in GIS and analytical design tools, expert advisors for biophysical and socioeconomic sciences, managers who will be responsible for implementing the design, staff or other representatives who can contribute local knowledge and have a clear understanding of the culture, needs and interests of local communities and other stakeholders (or the stakeholders themselves, depending on the situation).
- **It takes time.** The scientific design process was technical and time consuming, and took just over two years to complete. The most time consuming part of the process was conducting the primary research required to assemble the data layers for the analysis, so identifying research priorities early in the process is important. Implementation also take time, and the fastest we could establish (design and implement) an MPA network in this part of the world is likely to be five years (if design and implementation proceed simultaneously)

- **Costs for the scientific design process were relatively low compared to those expected for developed countries.** Total cost was approximately $400,000USD, of which the majority was scientific research (54%), staff time (35%) and scientific workshops (10%). Costs per unit area were very low for the entire MPA network area (<$0.01 USD per ha: Figure 5), and for the shallow water habitats (<200m) that were the focus of the design ($2.39USD per ha: see Figure 6). These costs are relatively low compared to those expected for developed countries, because the minimum amount of information required by managers and stakeholders was low, and the costs of community engagement and implementation were not included.

Lessons learned in the scientific design process, and lessons we are still learning in the implementation of the Kimbe Bay MPA network, will be used to inform other MPA design processes in the Bismarck Sea and elsewhere in the Coral Triangle.

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5. GLOSSARY OF MARINE PROTECTED AREA TERMS

Areas of Interest: areas identified as a high priority for biodiversity conservation in the Kimbe Bay MPA network design (see Figure 30).

Kimbe Bay MPA Network: comprises 15 Areas of Interest within the Kimbe Bay MPA network area (see Figure 30). The MPA network will comprise both LMMAs and other types of marine protected areas (e.g. government protected areas).

Kimbe Bay MPA Network Area: the area delineated by the MPA network boundary (Figure 5), which includes the Kimbe Bay MPA network (Figure 30).

Locally Managed Marine Area (LMMA): as defined by the LMMA Network, an LMMA is an area of nearshore waters actively being managed by local communities or resource-owning groups, or being collaboratively managed by resident communities with local government and/or partner organizations. LMMAs are considered one type of MPA (see below).

Marine Protected Areas (MPAs): Consistent with international usage (Kelleher 1999), MPAs are defined as "any area of the intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment." This includes Locally Managed Marine Areas.

Marine Protected Area Network (MPA network): a portfolio of biologically connected MPAs that is fully representative of the range of target ecosystems, species, and processes.

Masalai Areas: permanent closures usually applied to sites considered sacred or *tambu* because they are spirit-dwelling areas (Koczberski et al 2006).

Resilience: the ability of a system to undergo, absorb, and respond to change and disturbance, while maintaining its functions (Carpenter et al. 2001).

Tambu Areas: traditional closures, either permanent (*masalai* areas) or temporary closures following a death (Koczberski et al 2006) or for other purposes.

6. APPENDICES

Appendix 1.Resilience principles, biophysical design principles (from Green and Lokani 2004), and how they were applied in the MPA network design. Also noted are where other strategies (marine resource use and land use) will be required to apply these principles.

Resilience Principle	Biophysical Design Principle	Application through MPA network design
Risk Spreading (representation and replication)	Conserve representative examples of each habitat type	Representative examples of each habitat type were included where spatial areas for protection were considered a good strategy. This included all shallow water habitats (coral reefs, mangrove forests, seagrass beds, and estuaries) and special deepwater features (52 fathom seamount). Other deepwater habitats (oceanic waters and benthic habitats) were not included in the MPA network, because the marine resource use strategy (fisheries policy) was considered a more appropriate strategy for their protection.
Risk Spreading (representation and replication)	Include a “sufficient” number and area of each habitat type, and spread them out geographically to reduce the chances that they will be negatively impacted at the same time. Aim to include at least 3 areas and 20%[28] of the area of each habitat type	Protecting 20% of each habitat type was a straightforward matter through the MARXAN analysis, which is designed to do this. Manual accounting confirmed that this was successful for most targets. At least 20% of each habitat type (conservation target) was included in the MPA network for 50 of the 51 targets (Appendix 2). Overall, AOIs accounted for 13% of the total MPA network area, of which much is open ocean (which was not included in the design: see above), and 57% of the coral reefs in the area. Selecting three replicate areas of each habitat type and spreading them was not a straightforward matter during the analysis (the spreading function in MARXAN is time consuming and not very effective). However, this difficulty was overcome using MARXAN as a manual accounting tool while finalising the scientific design. This principle was achieved for 40 of the 51 targets where the number and spacing of targets allowed for the principle to be applied (Appendix 3). Of the 11 conservation targets where this principle could not be applied, six had two replicate areas, four had 1 replicate area, and one had none (mangroves – patches west – see Appendix 2, this target was not included in network). In most of these cases, additional replicates were not included because there was considered to be adequate replication and spread within some of the larger Areas of Interest (AOI) or that increasing replication would require the expansion or addition of a new AOI which was not considered necessary based on the existing design (% representation and replication of the target).

[28] This is lower end of the range recommended for protecting marine habitats (20-50%: Bohnsack et al 2000, Airame et al 2003, Fernandes et al 2005, World Parks Congress 2003), and was selected because threats are currently low and this was considered an achievable goal for Kimbe Bay.

Resilience Principle	Biophysical Design Principle	Application through MPA network design
Risk Spreading (representation and replication)	Where information is available, include minimum area (see above) of each ecosystem and community type within each habitat type (to ensure that all known communities and habitats that exist within each habitat type are protected)	This principle was successfully applied through representation of each ecosystem and community type as conservation targets where this information was available (for coral reefs, coral reef fish communities, seagrass beds, mangrove forests and estuaries: see Appendix 2).
Risk Spreading (representation and replication)	All else being equal, choose representative areas based on knowledge (high diversity, complementarity) to maximise number of species protected	This principle was applied where information was available (eg coral reefs and seagrass beds with the highest number of species were included in the network). Complementarity was addressed by representation of each habitat and community type (where information was available eg for coral reefs, coral reef fish communities, seagrasses, and mangroves).
Protecting key sites	All else being equal, choose sites that are more likely to be resistant or resilient to global environmental change	This principle could not be applied at the site level for coral reefs, because sites that may be naturally more resilient to coral bleaching have not been identified. However, stratification of the bay into two strata (east and west) may contribute to this goal at a broader scale, since the reefs on the eastern side do not appear to have experienced bleaching as yet (Turak and Aitsi 2002), while those on the western side have experienced moderate to severe bleaching (Srinivasan 2000, Jones et al 2004), particularly on inshore reefs in the southwest corner. The effect of sea level rise on coastal targets (specifically mangroves and turtle nesting areas) was also considered based on best available knowledge of the topography of each area. However, this principle could not be applied in detail, because fine scale elevation information was not available that would allow for detailed predictions regarding sea level change in relation to climate change scenarios. Where possible, areas were selected with natural backdrops, which when compared with developed backdrops, may accommodate change more effectively. These predictions will be manually validated by visiting coastal targets selected in the network to assess their viability in regard to rising sea level, and this information will be used to further refine the network over time.
Protecting key sites	Include special and unique areas: areas that may be naturally resistant or resilient to coral bleaching	See above
Protecting key sites	Include special and unique areas: permanent or transient aggregations of large vulnerable reef fishes and other key fisheries species (inc inverts)	Spawning aggregations of large vulnerable reef fishes were included in the network, ranked relative to their importance: large, multi-species aggregations ranked highly (high priority); other verified sites ranked of moderate importance (moderate priority); and unverified sites ranked low (low priority) The marine resource use strategy (fisheries policy) will also be important for their protection. Unfortunately, it was not possible to apply this principle for other key fisheries species due to a lack of information

Resilience Principle	Biophysical Design Principle	Application through MPA network design
Protecting key sites	Include special and unique areas: turtle nesting areas (beaches and nearshore resting areas)	Information regarding turtle nesting areas is still preliminary, and will require refinement over time. Therefore, we aimed to protect 20% of the areas currently identified as turtle nesting areas, and these areas will be reviewed as more detailed information becomes available and important nesting areas are validated and refined. Other strategies including the marine resource use (to address hunting) and land use strategies (to protect areas behind nesting beaches) will also be required to protect sea turtles and their nesting areas.
Protecting key sites	Include special and unique areas: cetacean preferred habitats (breeding, resting, feeding areas and migratory corridors)	Where known, critical cetacean habitats (eg seamount, northern tip of Willaumez Peninsula) were included in the network. Other critical habitats have not been identified, and they will be considered for protection as more information becomes available. The marine resource use strategy (fisheries policy) will also be required to protect these species.
Protecting key sites	Include special and unique areas: areas that support high species diversity	Sites that support high diversity of coral reef fishes and seagrasses were included in the network.
Protecting key sites	Include special and unique areas: areas that support species with very limited distribution and abundance	The only known species with extremely limited distribution is a goby that only occurs in Wulai Lagoon (Munday 2004), which was included in the network (locked in as a special and unique area)
Protecting key sites	Include special and unique areas: areas that are preferred habitats for vulnerable species (e.g. sharks, and those on IUCN red list)	Areas of high importance for vulnerable reef fishes (fish spawning aggregation sites and *Bolbometapon* resting sites), cetaceans, turtles and seabirds were included in the network. Some protection will also be afforded to these species (and dugong) by protecting representative areas of each habitat type. The marine resource use strategy (fisheries policy) will also be required to protect these species.
Protecting key sites	Include special and unique areas: areas that contain a variety of habitat types in close proximity to each other	Areas that contained a variety of habitat types in close proximity were included as a function of the analysis, which tends to cluster areas (see also Incorporating Patterns of Connectivity below).
Protecting key sites	Conserve rare and threatened species; cetaceans, dugong, sea turtles, seabirds, and crocodiles	Key habitats were included in the MPA network where they were known (eg important areas for cetaceans, sea turtles and birds). Some protection will also be afforded by representation of each habitat type in the network (eg breeding areas for crocodiles, and feeding habitat for dugong, turtles etc). The marine resource use strategy (fisheries and hunting policies) will also be required to protect these species.

Resilience Principle	Biophysical Design Principle	Application through MPA network design
Incorporating patterns of connectivity	Take a system wide approach that recognises patterns of connectivity within and among ecosystems	Among habitat types: shallow water habitats that have some degree of connectivity among them were clustered as a function of the analysis (coral reefs, mangroves, seagrass), since that is what the software is designed to do. Within habitats: Information on biological patterns of connectivity was not available in sufficient detail to take connectivity among habitat types (eg coral reefs) into account at a fine scale. In the absence of this information, connectivity was addressed a broad scale through three strategies: • Addressing uncertainty by spreading risk (through representation, replication and spread of each habitat type); • Stratifying the bay into two strata (east and west), based on best available information that indicated that the east and west sides are different in terms of their biological and physical characteristics (based on fish community types and ocean currents: Beger unpubl. data; Steinberg eg al 2006). • Using rules of thumb for MPA configuration that recommend a minimum size of for MPAs of $10km^2$, and a minimum spacing distance between them of 15km (Mora et al 2006). A minimum area of $10km^2$ was achieved for 14 of the 15 AOIs, and AOIs were also located less than 15km apart for 13 of the 15 AOIs (see Table 2).
Incorporating patterns of connectivity	Where possible, include whole ecological units (eg whole reefs, seamounts), including a buffer around the core area of interest	Whole ecological units were included for discrete features (offshore reefs, seamounts etc), including a buffer zones around the core areas of interest.
Incorporating patterns of connectivity	Where entire biological units cannot be included, choose bigger vs smaller areas.	Where possible, larger areas of large continuous structures (eg coastal fringing reefs) were included.
Incorporating patterns of connectivity	Maximise acquisition and use of environmental information to determine the best configuration, recognising the importance of connectivity in network design	Best available information was acquired and used to recognise the importance of connectivity in network design by stratifying the bay into two sections (east and west), using rules of thumb for MPA network design and spreading the risk through representation, replication and spread of habitat types (see above).
Effective management	Consider sea and land use, particularly proximity to threats and other protected areas	Marine areas adjacent to developed areas (urban areas, industry, and ports/shipping channels) were given a high cost in the analysis. Marine areas adjacent to unmapped terrestrial threats (large scale agriculture, logging, roads etc) and natural or protected areas were taken into account manually while finalising the scientific design. Some priority was given to existing areas that are already protected to some extent, including spirit areas, LMMAs and dive sites (see 2.5.7 Generating Scenarios).
Effective management	Consider if patterns (distribution and status of community types) are result of natural processes or human impacts	Areas with significant human impacts were given a high cost in the analysis (eg near major towns or industry), because the likelihood of success is lower in those areas.

Appendix 2. Percentage area of each conservation target located within each Area of Interest (AOI), total percentage area of each conservation target included in the MPA network (all of the AOIs combined) and other forms of protection (LMMAs and dive sites outside the AOIs), and an assessment of whether the goal of protecting at least 20% of each target (except the seamount which was 100%) was achieved.

	Areas of Interest															**Other Protected Areas**		**Totals**	
Conservation Target	52 Fathoms	Baia	Bialla	Buludava	Cape Hoskins/Wulai	Cape Torkoro	Dagi	Garua/Restorf	Heusner	Kaiamu/Sulu	Kapiuru	Kimbe Island	Lolobau	Numundo	Tarobi	Dive Sites	LMMAs	**Total % Area of Target included in MPA Network**	**Achieved Goal**
Reefs - coastal fringing (east)		5%	18%			6%				4%					36%			**70%**	**yes**
Reefs - coastal fringing (west)				2%	15%		7%	0%	5%		1%			6%		0%	0%	**38%**	**yes**
Reefs - island fringing (east)													87%		13%			**100%**	**yes**
Reefs - island fringing (west)								47%	13%			7%						**68%**	**yes**
Reefs - barrier (east)															99%			**99%**	**yes**
Reefs - shelf patch (east)		7%	9%			0%				1%			15%		11%			**43%**	**yes**
Reefs - shelf patch (west)				2%	18%			9%	2%					7%		2%	15%	**54%**	**yes**
Reefs- deepwater oceanic and shoals (east)						6%							54%					**60%**	**yes**
Reefs - deepwater oceanic and shoals (west)					20%				1%							33%		**54%**	**yes**

Conservation Target	Areas of Interest															Other Protected Areas		Totals	
	52 Fathoms	Baia	Bialla	Buludava	Cape Hoskins/Wulai	Cape Torkoro	Dagi	Garua/Restorf	Heusner	Kaiamu/Sulu	Kapiuru	Kimbe Island	Lolobau	Numundo	Tarobi	Dive Sites	LMMAs	**Total % Area of Target included in MPA Network**	**Achieved Goal**
Reefs - pinnacles (west)																58%		**58%**	**yes**
Reefs - platform (east)													100%					**100%**	**yes**
Reefs - platform (west)					100%													**100%**	**yes**
Seagrasses - group 1 (west)					13%		23%	1%										**37%**	**yes**
Seagrasses - group 2 (east)			51%							12%					37%			**100%**	**yes**
Seagrasses - group 2 (west)							4%	11%	4%							3%	0%	**22%**	**yes**
Seagrasses - group 3 (east)			5%			54%									13%			**73%**	**yes**
Seagrasses - group 3 (west)					19%			14%						36%			0%	**69%**	**yes**
Seagrasses - group 4 (east)			13%							9%					41%			**63%**	**yes**
Seagrasses - group 4 (west)					75%		5%		6%									**86%**	**yes**
Seagrasses - group 5 (west)					33%			37%										**70%**	**yes**
Seagrasses - unique (east)			100%															**100%**	**yes**
Fishes – east group 1			16%							4%	2%				39%			**61%**	**yes**
Fishes – east group 2			26%							7%					44%			**77%**	**yes**

Conservation Target	Areas of Interest															Other Protected Areas		Totals	
	52 Fathoms	Baia	Bialla	Buludava	Cape Hoskins/Wulai	Cape Torkoro	Dagi	Garua/Restorf	Heusner	Kaiamu/Sulu	Kapiuru	Kimbe Island	Lolobau	Numundo	Tarobi	Dive Sites	LMMAs	**Total % Area of Target included in MPA Network**	**Achieved Goal**
Fishes – east group 3													80%					**80%**	**yes**
Fishes – east group 4		21%				17%							52%					**89%**	**yes**
Fishes – east group 5			7%										2%		42%			**52%**	**yes**
Fishes – west group 1					21%		7%	5%						7%			1%	**42%**	**yes**
Fishes –west group 2					4%			12%						13%		3%	30%	**62%**	**yes**
Fishes – west group 3					48%			16%								3%		**66%**	**yes**
Fishes –west group 4					72%				12%							8%		**92%**	**yes**
Fishes - west group 5									35%							0%		**35%**	**yes**
Fishes – west group 6				43%														**43%**	**yes**
Mangroves – fringing (east)			29%												60%			**89%**	**yes**
Mangroves – fringing (west)									24%					54%				**77%**	**yes**
Mangroves - assoc w streams and bays (east)		7%				3%					24%				9%			**44%**	**yes**

Conservation Target	Areas of Interest															Other Protected Areas		Totals	
	52 Fathoms	Baia	Bialla	Buludava	Cape Hoskins/Wulai	Cape Torkoro	Dagi	Garua/Restorf	Heusner	Kaiamu/Sulu	Kapiuru	Kimbe Island	Lolobau	Numundo	Tarobi	Dive Sites	LMMAs	**Total % Area of Target included in MPA Network**	**Achieved Goal**
Mangroves - assoc w streams and bays (west)							67%		5%									**73%**	**yes**
Mangroves – patches (west)																		**0%**	**no**[29]
Estuaries – with mangroves (east)											16%				9%			**25%**	**yes**
Estuaries – with mangroves (west)							58%											**58%**	**yes**
Estuaries – no mangroves (east)			47%							11%	3%				12%			**72%**	**yes**
Estuaries – no mangroves (west)							100%											**100%**	**yes**
Estuaries - large complex (east)		100%																**100%**	**yes**

[29] This target was not included because it is a small, isolated patch (2.8ha) that was not considered significant enough in terms of community type, size or viability to establish a new Area of Interest for its protection

Conservation Target	Areas of Interest															Other Protected Areas		Totals	
	52 Fathoms	Baia	Bialla	Buludava	Cape Hoskins/Wulai	Cape Torkoro	Dagi	Garua/Restorf	Heusner	Kaiamu/Sulu	Kapiuru	Kimbe Island	Lolobau	Numundo	Tarobi	Dive Sites	LMMAs	**Total % Area of Target included in MPA Network**	**Achieved Goal**
Fish spawning aggregation sites - multi species						50%							50%					**100%**	**yes**
Fish spawning aggregation sites - single species			17%		33%			33%							17%			**100%**	**yes**
Fish spawning aggregation sites – unconfirmed						50%									50%			**100%**	**yes**
Turtle nesting areas - leatherback and others		9%	4%								15%				18%			**46%**	**yes**
Turtle nesting area -hawksbill and green									50%				17%					**67%**	**yes**
Birds - pigeon refuges								9%	10%			19%	47%		7%			**93%**	**yes**
Birds - seabird nesting areas		81%			19%													**100%**	**yes**
Birds – wading area															62%			**62%**	**yes**
Seamount	100%																	**100%**	**yes**

Appendix 3. The number of replicate areas where each conservation target is represented, and an assessment of whether the risk spreading principle of protecting at least three examples of each target and spreading them out was achieved. Where the principle was not achieved, explanatory notes are provided.

Conservation Target	Number of Replicate Areas of Interest	Principle Applied Successfully?	Explanatory Notes
Reefs - coastal fringing (east)	5	Yes	At least 3 replicate areas with good spread.
Reefs - coastal fringing (west)	6	Yes	At least 3 replicate areas with good spread.
Reefs - island fringing (east)	2	Yes	100% of this target is captured in these two areas
Reefs - island fringing (west)	3	Yes	At least 3 replicate areas with good spread.
Reefs – barrier (east)	1	Yes	This area (Tarobi) includes all of this target. There are many replicate reefs within this large area, which are reasonably well spread out. So this goal is achieved as much as possible.
Reefs - shelf patch (east)	5	Yes	At least 3 replicate areas with good spread.
Reefs - shelf patch (west)	7	Yes	At least 3 replicate areas with good spread.
Reefs - deepwater oceanic and shoals (east)	2	No	There are only two Areas of Interest (AOIs) where this target exists (Lolobau and Cape Torkoro), and both are included in the network. One of these areas (Lolobau) provides many replicates and good spread over a large area. While it was possible to expand the Cape Torkoro area to include more of this target, it was not considered feasible for logistic reasons (there is already a lot of northeastern side of the bay included in the network)
Reefs - deepwater oceanic and shoals (west)	3	Yes	At least 3 replicate areas with good spread.
Reefs – pinnacles (west)	1	Yes	This target is captured in one AOI as well as in several other protected areas (dive sites), which provide good replication and spread.
Reefs – platform (east)	1	Yes	100% of this target is captured in this one area
Reefs – platform (west)	1	Yes	100% of this target is captured in this one area
Seagrasses – group 1 (west)	3	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 2 (east)	3	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 2 (west)	4	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 3 (east)	3	Yes	At least 3 replicate areas with good spread.
Seagrasses - group3 (west)	4	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 4 (east)	3	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 4 (west)	3	Yes	At least 3 replicate areas with good spread.
Seagrasses – group 5 (west)	2	No	Two replicate areas were included for this target, which are quite spread out. A third area was not considered necessary because there was already good spread in these two areas, and it would have been necessary to include a whole new area to include a third replicate, which was not considered necessary.

Conservation Target	Number of Replicate Areas of Interest	Principle Applied Successfully?	Explanatory Notes
Seagrasses – unique (east)	1	Yes	100% of this target is captured in this one area
Fishes – east group 1	4	Yes	At least 3 replicate areas with good spread.
Fishes – east group 2	3	Yes	At least 3 replicate areas with good spread.
Fishes – east group 3	1	No	There are many replicates within this AOI (Lolobau) spread over a large area. Therefore, it was not considered necessary to include new areas to protect this target.
Fishes – east group 4	3	Yes	At least 3 replicate areas with good spread.
Fishes – east group 5	3	Yes	At least 3 replicate areas with good spread.
Fishes – west group 1	5	Yes	At least 3 replicate areas with good spread.
Fishes – west group 2	5	Yes	At least 3 replicate areas with good spread.
Fishes – west group 3	3	Yes	At least 3 replicate areas with good spread.
Fishes – west group 4	3	Yes	At least 3 replicate areas with good spread.
Fishes - west group 5	1	No	This target occurs in three areas on the west, north and east side of Willaumez Peninsula. The area on the west side of the peninsula is outside the MPA boundary (further south) and was not included in the network. Two of the other areas are included in the Cape Heusner AOI, so there is replication and spread within this AOI to some extent. It would be possible to increase replication and spread by extending the southern boundary of the Cape Heusner AOI further south or establishing a new area further south, but neither was considered a good option for logistic reasons (the area would become too large, and it is difficult to work with communities further south).
Fishes – west group 6	1	Yes	100% of this target is captured in this one area
Mangroves – fringing (east)	2	No	These two replicates provide enough spread that it was not considered necessary to add a new area to include a third replicate (the only other choice is close by).
Mangroves – fringing (west)	2	No	These two replicates provide enough spread that it was not considered necessary to add a new area to include a third replicate (the only other choice is close by).
Mangroves - assoc w streams and bays (east)	4	Yes	At least 3 replicate areas with good spread.
Mangroves - assoc w streams and bays (west)	2	No	These two areas provide good replication and spread, and it was not considered necessary to add a new area to include a third replicate.
Mangroves – patches (west)	0	No	This target was not included in the network because it is a small, isolated patch (2.8ha) that was not considered significant enough in terms of community type, size or viability to establish a new AOI for its protection.
Estuaries - with mangroves (east)	2	No	These two areas provide enough replication and spread (e.g. two areas either side of Tarobi Peninsula)

Conservation Target	Number of Replicate Areas of Interest	Principle Applied Successfully?	Explanatory Notes
Estuaries - with mangroves (west)	1	No	While this target is only represented in one AOI (Dagi), there is good spread within that area. The only other area where this target could be captured is on the northern side of Willaumez Peninsula, and this target was not considered significant enough to establish a new area specifically for this purpose.
Estuaries - no mangroves (east)	4	Yes	At least 3 replicate areas with good spread.
Estuaries - no mangroves(west)	1	Yes	100% of this target is captured in this one area
Estuaries - large complex (east)	1	Yes	100% of this target is captured in this one area
Fish spawning aggregation sites - multi species	2	Yes	100% of this target is captured in these two areas
Fish spawning aggregation sites - single species	4	Yes	At least 3 replicate areas with good spread.
Fish spawning aggregation sites – unconfirmed	2	Yes	100% of this target is captured in these two areas
Turtle nesting areas - leatherback and others	4	Yes	At least 3 replicate areas with good spread.
Turtle nesting area - hawksbill and green	2	Yes	This target only occurs in these two areas. All of this target is included within one of these areas (Lolobau), and most of this target is included in the other (Cape Heusner).
Birds - pigeon refuges	5	Yes	At least 3 replicate areas with good spread.
Birds - seabird nesting areas	2	Yes	100% of this target is captured in these two areas
Birds – wading areas	1	No	There are only two areas close together southwest of Tarobi. One of these areas is included in the Tarobi AOI, and it was not considered feasible to expand this area any further to include the other.
Seamount	1	Yes	100% of this target is captured in this one area

Appendix 4. Socioeconomic category and design principles (from Green and Lokani 2004) and how they were applied for MPA network design. Also noted are where other strategies (marine resource use and land use) will be required to apply these principles.

Category	Socioeconomic Design Principle	Application through MPA network design
General	Recognise and respect local resource owners and customary marine tenure systems	Respect for local resource owners and their customary marine tenure systems were of primary importance for the MPA design. Where possible, areas were selected where local communities have demonstrated a strong interest in, and ability to, protect their marine resources (based on marine tenure and other considerations). Where available, information on customary marine tenure was also taken into account in drawing the boundaries of the Area of Interest (AOI).
General	Recognise that local communities are partners in the MPA network, and will be involved in all decision making processes	During this process it was recognised that local communities are more than partners - they are the decision makers and custodians over the conservation targets. Therefore, this principle was modified to "Recognise that local communities are the decision makers and custodians over marine resources." Community interest in conservation, and their ability to effectively manage their marine resources, was one of the primary layers of information used in the design.
General	Understand and incorporate local knowledge and traditional fisheries management and conservation practices	Local knowledge was used to help identify critical areas (eg fish spawning aggregation sites, dugong and turtle areas) for protection. The history of using *tambu* areas, which have fisheries benefits, for various reasons was also recognised. This provides an existing customary marine management structure which it may be possible to use to meet conservation objectives.
General	Minimise negative impacts on existing livelihood strategies	The process for selecting high priority areas for protection is stakeholder driven, since it is the communities that decide the areas that will or will not be protected
General	Protect areas of culture importance to traditional owners	The process for selecting high priority areas for protection is stakeholder driven, since it is the communities that decide the areas that will or will not be protected. Where we were aware of *tambu* or spirit areas, they were included in the network.
General	Ensure costs and benefits of the network are fairly distributed within and between communities	The MPA network is widely distributed around the bay, and will include 15 areas and many communities
General	Minimise conflicting uses, such as tourism and extractive use	Important areas for eco-tourism were included in MPA network (dive sites, and areas adjacent to the eco-lodge and important catch and release sports-fishing/estuary area in Baia).
General	Consider current and future population trends and changing resource use	Areas adjacent to towns and population growth centres, and areas with changing land use patterns (eg predicted expansion of agriculture or village based use) were avoided.

Category	Socioeconomic Design Principle	Application through MPA network design
Fisheries	Ensure MPA supports sustainable subsistence and artisanal fisheries for local communities by recognizing diverse livelihood strategies, and spatial and temporal variations in resource use and values	Local communities are decision makers and custodians of the conservation targets, and they have taken this into account. The results of the socioeconomic study and community engagement also provided information (eg areas that the community do and do not wish to be involved in marine conservation), which was taken into account in the design.
Fisheries	Consider costs and benefits to local communities (and sustainable industries) in management of commercial fisheries	As above
Fisheries	Conserve marine resources, which local communities identify as important to their livelihood	As above
Fisheries	Conserve marine resources for local communities by prohibiting destructive fishing methods	Some protection will be afforded by LMMAs in the MPA network. However, this will also need to be addressed at a broad scale through the marine resource use strategy
Fisheries	Conserve marine resources for local communities by prohibiting unsustainable commercial fisheries, particular the LRFFT and other fisheries for species particularly vulnerable to overexploitation (sharks, rays, trochus, beche-de-mer)	Some protection will be afforded by LMMAs in the MPA network. However, this will also need to be addressed at a broad scale through the marine resource use strategy
Fisheries	Recognise fisheries benefits of MPAs	This is not a design principle and is more relevant to communication, education and awareness for marine resource management. Key messages have already been developed through fish spawning aggregation work.
Fisheries	Specific fisheries strategies should include: • Enforcing NFA Section 32(1-7) that prohibits use of fishing with poisons or explosives, and working with local communities through education and awareness programs leading to eventual prohibition of other destructive fishing methods • Prohibiting commercial fisheries for LRFFT under national management plan • Conserving spawning aggregations of large commercial fish species, particularly those targeted by the LRFFT (also spatial/temporal closures) • Using closures to contribute to the management of commercial fisheries for invertebrates (particularly for trochus and beche-de-mer) • Designating special management area under Fisheries Act • Developing and implementing a provincial law that caters for fisheries management and conservation • Engaging in policy level discussions regarding fisheries policy in PNG, and WNB, which may benefit fisheries management	These are not design principles, and will need to be addressed through the marine resource use strategy at various levels of government (Local, Provincial and National).

Category	Socioeconomic Design Principle	Application through MPA network design
	• Prohibiting artisanal and commercial fishing for sharks and rays, and fishing or deliberate capture of cetaceans	
Nature Based Tourism	Use MPAs to provide opportunities for environmentally sound tourism to benefit local communities	This is not an MPA network design principle, but will be addressed indirectly through protection of sites that may provide opportunities for eco-tourism
Nature Based Tourism	Promote opportunities for sustainable tourism activities by local communities	This is not an MPA network design principle, but will be addressed indirectly through protection of sites that may provide opportunities for eco-tourism
Nature Based Tourism	Protect high priority tourism sites from conflicting (extractive or destructive) uses	Important areas for tourism (dive sites, areas adjacent to eco-lodge, and important catch and release sports-fishing/estuary area in Baia) have been included in the MPA network
Nature Based Tourism	Ensure tourism activities are environmentally sustainable	This is not an MPA network design principle, and will need to be addressed through the marine resource use strategy (by working with the tourism industry to establish best practices)
Nature Based Tourism	Develop and implement best environmental guidelines for diving, snorkeling, visiting islands, and swimming with whales	This is not an MPA network design principle, and will need to be addressed through the marine resource use strategy (by working with the tourism industry to establish best practices)
Nature Based Tourism	Ensure visiting tourism and recreational vessels are aware of MPA and regulations	This is not an MPA network design principle, and will need to be addressed through the marine resource use strategy (in partnership with the tourism industry)
Nature Based Tourism	Engage in discussions with PNG Tourism Promotion Authority, PNG Dive Association, local dive operators and Provincial Governments to develop a sustainable tourism network in PNG, and West New Britain (particularly for diving and bird watching)	This is not an MPA network design principle, and will need to be addressed through the marine resource use strategy (in partnership with the tourism industry)
Nature Based Tourism	Implement MPA management charges for the tourism industry to be used to support management of the MPA network	This is not an MPA network design principle but relates to sustainable financing, which will be addressed through the implementation plan
Shipping	Accommodate existing shipping infrastructure (wharves, channels) in MPA design (avoid placing highly protected areas in the vicinity of these areas)	Marine areas adjacent to port boundaries and shipping lanes (and 1.5km either side) were avoided in the design.
Shipping	Encourage the development of strategies to reduce the threat of marine resources from shipping related activities (ship groundings, pollution, and invasive species). This will include encouraging the development and implementation of improved navigational aids, incident response strategies, and a strategy for the management of ballast water	This is not an MPA network design principle, and will need to be addressed through the marine resource use strategy in partnership with stakeholders in the shipping industry
Mining and Drilling	Protect marine resources from pollution and habitat destruction by prohibiting mining and drilling activities	There are no mines in the area at present, so this was not considered in the MPA network design at this time. Some mines have been proposed for the area, but no leases have been granted. This may need to be re-visited if new mines are confirmed for the area in future, and will need to be addressed through the land use strategy

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ISBN 9980-9964-7-1