TECHNICAL REPORT: Development of a Network of No-take Zones Building on Community Based Management Initiatives for the Island Province of Kadavu, Fiji.

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1 Introduction

A combination of increased commercial fishing and larger local subsistence harvests has left most of Fiji's coastal waters overfished. Declining fisheries have been exacerbated by habitat decline caused by poor land-use practices, out-breaks of coral predators, and increased storm frequency and coral reef bleaching events. Rural Fijians, who constitute more than half (57%) of Fiji's rapidly-growing population of nearly one million (Fiji Islands Bureau of Statistics, 2008) , have suffered as most of these villagers still lead a traditional subsistence-based livelihood, communally utilizing local marine resources for at least part of their daily protein and income. Over the last nine years, a growing number of Fijian villages have begun to carefully regulate the use of their marine areas through the establishment of locally-managed marine areas (LMMAs). To date there are over two hundred of these LMMAs in operation in Fiji. These LMMAs have partner support of NGOs, government agencies and academic institutes which fall under the umbrella of the FLMMA network which in turn is part of the regional LMMA network (http://www.lmmanetwork.org/).

1.1 Community Based Management in Fiji

As the number of locally managed sites has increased, there has been an increasing focus on the management of these sites at the provincial level. The southern island province of Kadavu has been leading the way in this regard. Since 1997, a total of 60 no-take zones as part of a *iqoliqoli* (customary fishing ground)-wide LMMA, one gazetted marine protected area and four forest reserves have been established. Each *iqoliqoli* in Kadavu is now under some form of management with many having at least one no-take zone within their boundaries. These management initiatives were established when the Kadavu Provincial Administration with support from the Institute of Applied Science of the University of the South Pacific (USP-IAS) through a decentralisation process established the Kadavu Yaubula (living-wealth) Management Support Team (KYMST). This support team was trained to do community-based adaptive management training and have now done so in all of the communities in Kadavu. The KYMST now has the provincial mandate to be the lead agency on all natural resource management initiatives.

Since its establishment, the KYMST has grown in importance. As part of the Provincial Council meeting held in 2007, it was agreed that resource management is one of the seven key areas identified and endorsed in the Provincial Council Strategic plan for 2007-2011. The results from the increasing and province-wide agreement to conserve the natural resources in Kadavu are impressive.

As this ground-swell of management has organically grown, so too has the location and underlying principles of the placement and content of the management interventions being undertaken. Accordingly, whilst many of these management interventions are having well-defined success of ensuring food security at the individual community level, they arguably lack the coordinated island-wide outcomes sought by the wider province and the biodiversity conservation benefits associated with an integrated network of no-take zones.

1.2 Kadavu Island

Kadavu is a volcanic island arc in the Fiji Melanesian Island group located in the Southwest Pacific (Nunn 1999) at 19.05º South and 178.25º East (Island Dictionary, 1998). The Fijian island province which is situated to the southeast of mainland Viti Levu (Figure 1) and is the fourth largest island in Fiji and is considered to be an area of great natural beauty and resource wealth. Kadavu consists of a main large island and several smaller islands, mainly to the northeast. The island has a land mass of 475km^2 and 31 registered *iqoliqolis* covering an area of 719 km^2. Under Fijian law these *iqoliqolis* are under a system of customary usage rights. Typically there will be many villages all sharing use rights over an *iqoliqoli*. In these case the *iqoliqoli* is further subdivided into *kanakana* (or grounds from which food can be caught). *Kanakana* are not however legally recognized nor are their boundaries documented and in many cases, may be disputed. It is estimated that there are 75 *kanakana* around Kadavu- approximately 1 per village. The project covers the main larger island of Kadavu which covers 29 inshore *iqoliqolis* with an area of approximately 408 km^2.

Kadavu is not the only province in Fiji. There are twelve other maritime provinces with LMMAs within their *iqoliqoli*. Accordingly, it is envisaged that the work done in Kadavu will lead to the learning of lessons underpinning the successful integration of a networking approach with community based marine resource management so that the approach may be expanded in the future to additional regions and finally to the national level in Fiji. The aim is that this will assist the National government of Fiji to implement its commitment to the effective conservation of 30% of its marine resources as part of the 'Melanesia challenge' made at the Mauritius SIDs meeting in 2005.

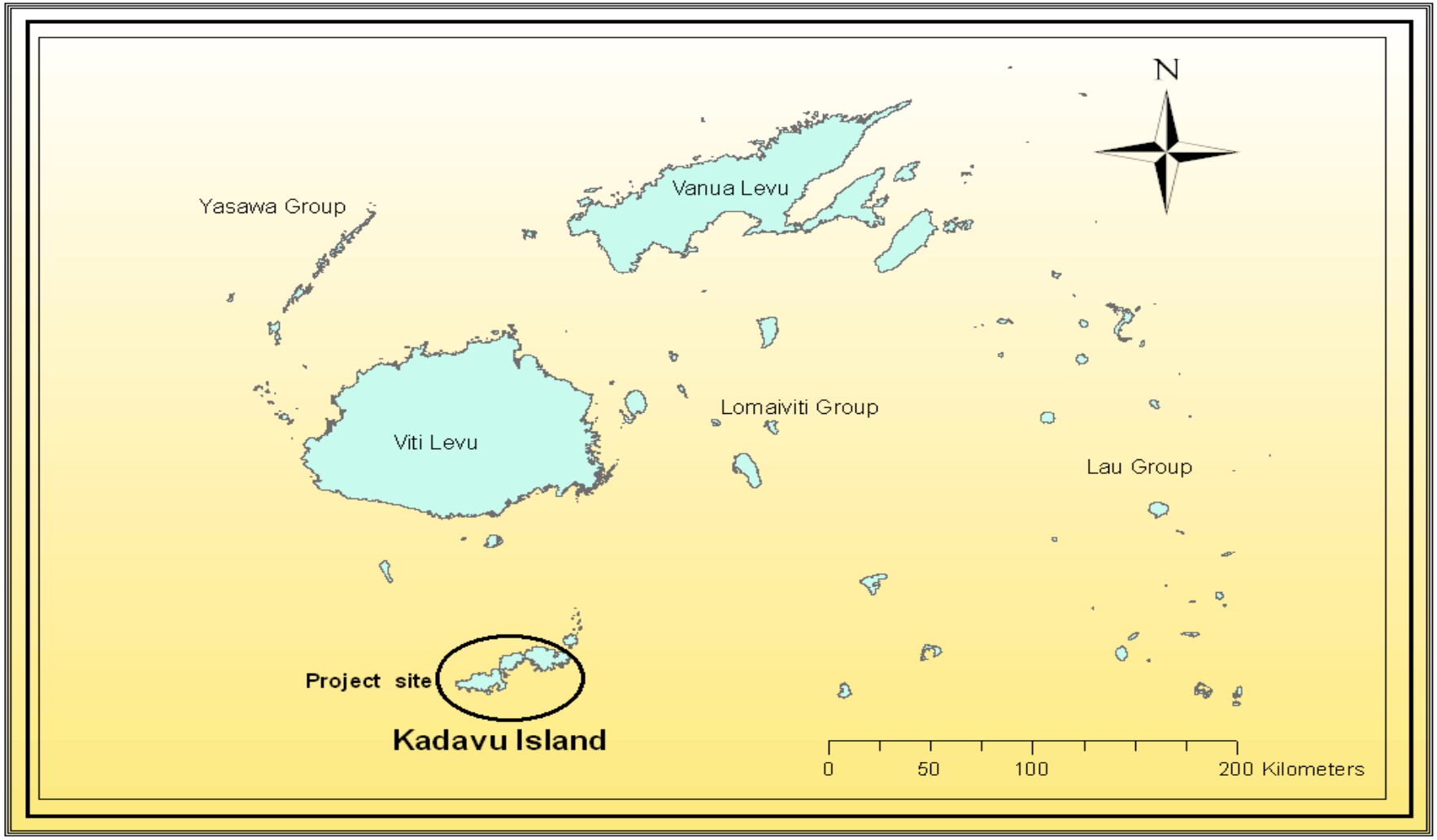


Figure 1: Kadavu Island south of Viti Levu, Fiji.

2 Methods and Results

2.1 Developing the Provincial Vision- and contextualizing networking criteria

The conservation target set by communities was to protect 30% of each habitat features. An additional target was to protect 100% of significant sites such as Spawning Aggregations, cultural sites and turtle nesting areas.

In early September 2007, a visioning exercise was conducted as part of a workshop facilitated by individuals from the National Ocean Service of NOAA. This workshop brought together government representatives, local community leaders and individuals instrumental in the development of the Kadavu Yaubula (living-wealth) Management Support Team. The workshop again re-confirmed the province-wide principles of marine resource management. However, perhaps the most important concept was that the workshop went as far as to explore the potential for trans-*iqoliqoli*-boundary no-take zone networks if these were likely to have a greater management potential than the sum of the single pre-existing no-take zone.

The island province expressed a commitment to undertaking an island wide exercise towards a network of interconnected no-take zones across the Province to maximise fisheries benefits. Their goal was to protect 30% of their *iqoliqoli* shallow reef habitats and to design a network of no-take zones that included, where possible, the International Union for Conservation of Nature (IUCN) criteria for marine protected areas (MPAs) (Table 1). However, the communities stressed it was crucial that site-based traditional governance and ecological knowledge be considered in the design of the network.

Table 1: IUCN scientific networking criteria for MPAs that were considered for Kadavu (Reference: IUNC-WCPA 2008)

Criteria	**Description**
Representation	a) Need to have all the different types of habitats managed/protected b) Need to protect all different kinds of fish and inverts (maintain the food web - Strength through diversity). c) Should also include 'special' places – spawning sites.
Replication	Need to have several similar areas protected. Lose one house, need another one to go to.
Resilience and Resistance	Protect areas that may be more resistant to bleaching and cyclones (and other hazards – natural or man made).
Ecological significant areas	Protect foraging or breeding locations in No-take zones network to ensure that there are enough resources are sustained for future generations. Protection of important sites for reproduction (spawning areas, egg sources).
Ecological linkages	Need to have areas that are big enough to protect the fish and inverts home area. Need to have areas of seeding and spill-over, eggs, babies, and adults.
Maintain long-term protection	No-take zones should include some permanent sites, if possible.
Maximum contribution of individual no-take zone to the network	It is important to consider size, spacing and shape that allow maximum contribution of individual MPAs to the overall network.

2.2 Habitat characterization and mapping

Mapping work was done in partnership with the Center for Spatial Environmental Research (CSER) (http://www.gpem.uq.edu.au/cser)

2.2.1 Collection of ground - truthing field data

Field assessment was conducted in two periods; one in June-July and one in October-November 2009 to collect GPS-photo linked photographs of the coral reef habitats. Areas of spatially heterogeneous habitats had previously been identified from satellite imagery and these areas received special attention.

Using this reference guide of marine resource habitat types for Kadavu, extensive fieldwork around the island were undertaken to collect photos from identified areas of interest. Each station of interest was found using a handheld GPS and swam on compass bearing from GPS start (one station) to end point (another station) using snorkeling gear. Photos of benthic habitats were taken after each 5 fin kicks using an Olympus and Canon cameras at 5 mega pixel resolution (figure 2). A total of 211 transects were surveyed where 8,143 georeferenced photographs of the reef communities were taken in these periods covering all areas around the island.

Figure 2: Field data collection method and interpretations (source Roelfsema)

Using GPS-Photo Link software (version 4.3.0 GIS Pro) photographs were linked to the GPS and overlaid onto the satellite imagery together with the GPS coordinates of where the photos were taken. The software downloaded the photos from the camera and the GPS tracklog from the GPS receiver and matched the timestamp from the photo to the closest timestamp in the GPS. The output shape file was named according to the date the photos were taken, the *iqoliqoli*ID and the camera used (date_*iqoliqoli*id_camera).

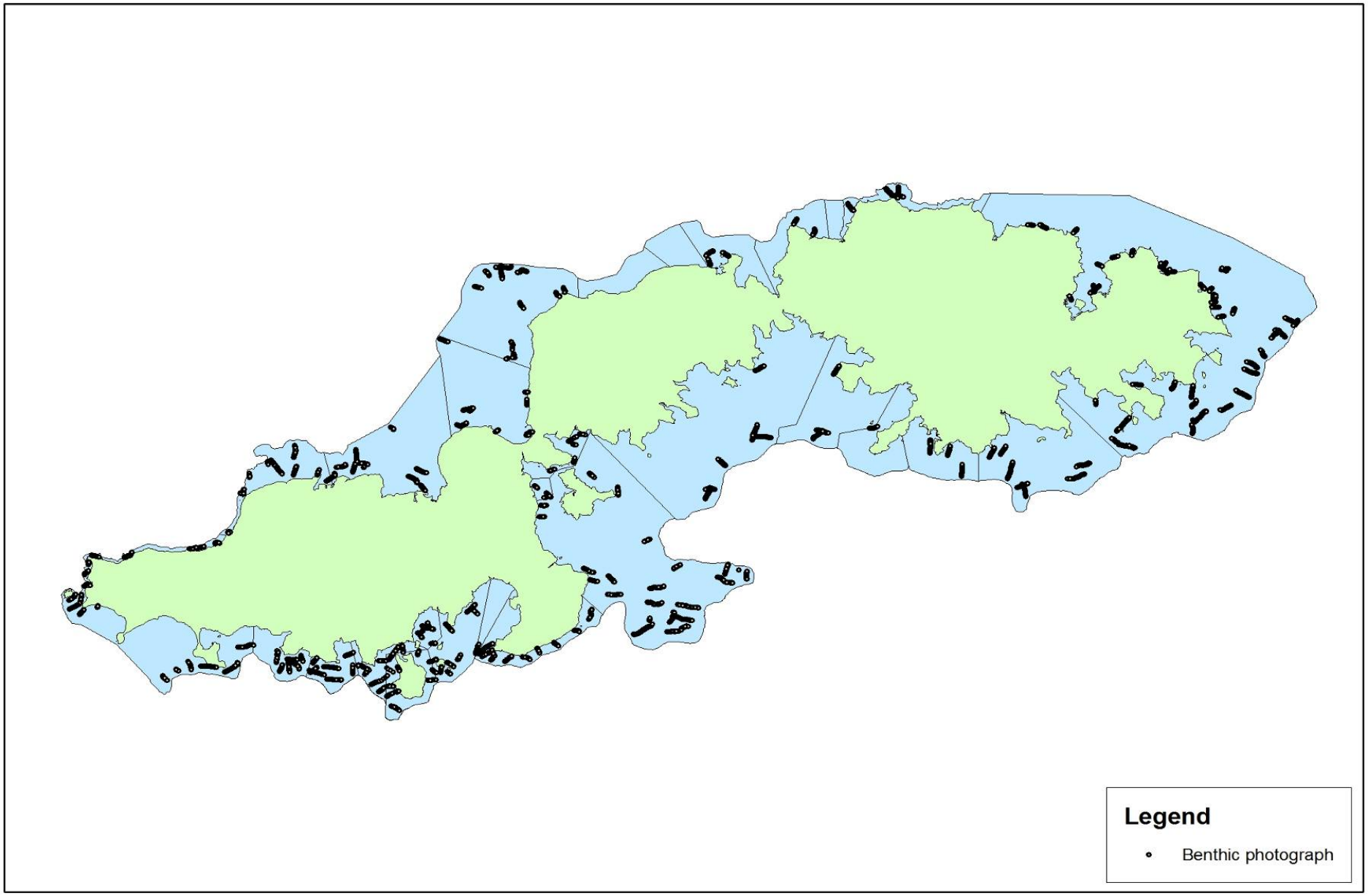


Figure 3: Benthic photographs on transects in areas of interest on coral reef habitats across Kadavu.

2.2.2 Classifying field data

Collected field data were classified through visual interpretation in Coral Point Count with Excel extensions (CPCe) using a developed hierarchical classification scheme (figure 4) for the coral reefs of Kadavu to identify the percentage cover of benthic habitats around the whole coral reef areas of Kadavu. The scheme included both geomorphological and ecological features in the definition of the habitat classes. It was developed by examining schemes previously made for other coastal tropical regions and adapted to meet shallow water marine ecosystem environment characteristics.

Habitat types were defined by the geomorphological zone and the predominant benthic structure or biological cover. The scheme included unconsolidated (e.g. sand and mud) and consolidated habitats (eg. bedrock and rubble) with the percent cover of the dominant substrate identified as shown in figure 4. This task was carried out at the end of the field work period where images were analyzed for the benthic community and assigned to one of the mapping categories.

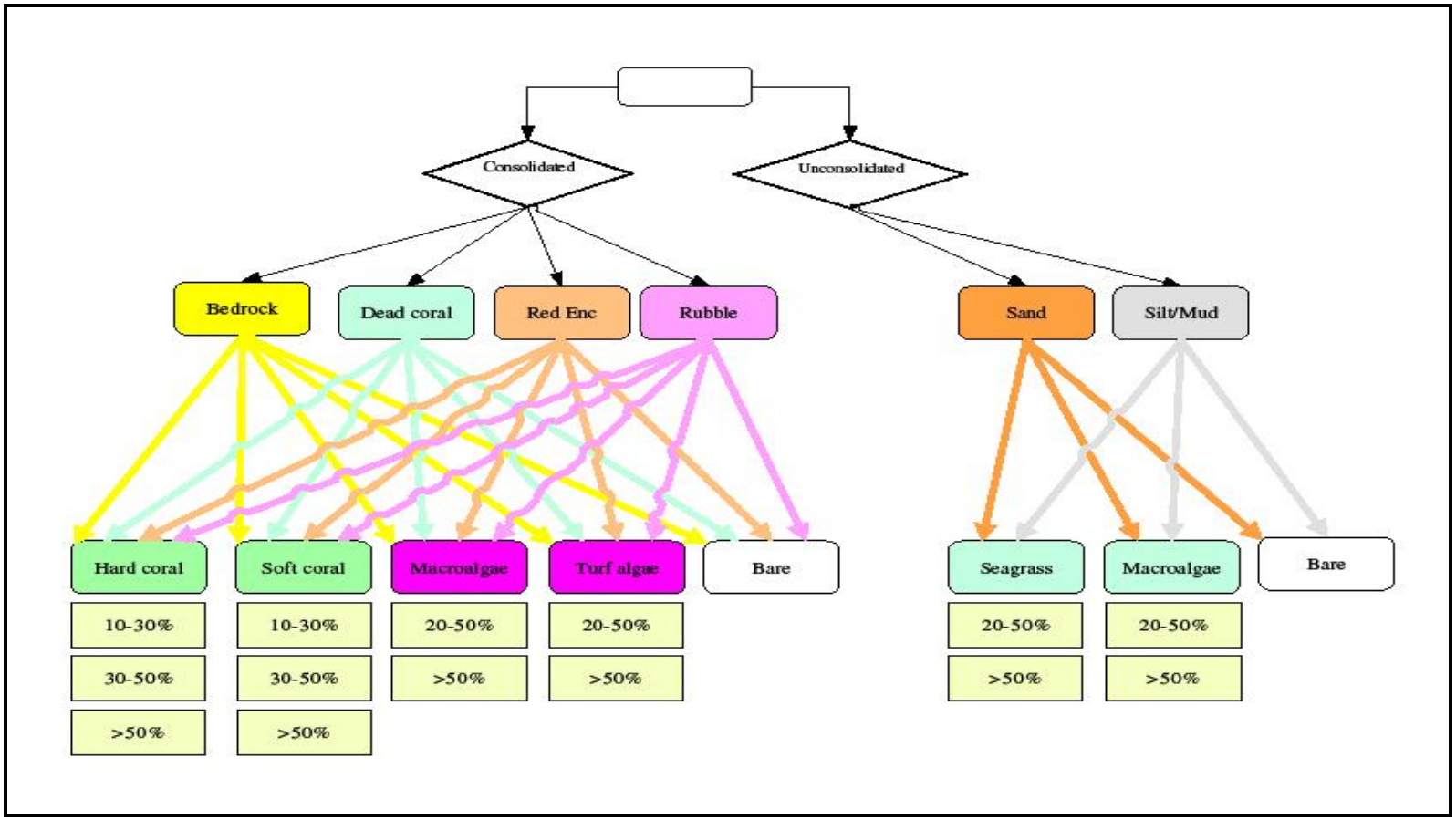


Figure 4: Kadavu classification scheme used for this project

2.2.3 Image data

High resolution satellite imagery (figure 5) was acquired covering all of the fishing grounds and land areas of Kadavu. The satellite imagery used was a composite of archived Ikonos (4 m pixels) and Quickbird (2.4 m pixels) satellite imagery. The satellite image data sets were corrected for radiometric and atmospheric distortions to at-surface reflectance (Phinn et al. in press). A mosaic of Quickbird and Ikonos images dated from September 2003 to June 2005 were selected to give the least cloud-affected coverage.

2.2.4 Creating habitat maps

Using Definiens Developer 7.0, four hierarchical spatial scales of habitat maps for the study site were created based on object based image analysis (Roelfsema et al. 2010).

There were two steps in object based image analysis: 1) image segmentation and 2) image segment classification (Blaschke 2010). The first step was applied initially on the whole mosaic image. The segments for a required spatial scale were determined by this image segmentation step depending on the colour and shape of groups of pixels and the spatial resolution of mapped features. Later sub-segmentation was applied on mapping categories of higher level map scale. The second step used membership rules to manually or automatically assign mapping categories to the segments. This included the segment: colour, shape, texture, position or biophysical properties and basically repeated for each of the mapping scales. The membership rules for this study were developed from previously developed rule sets (Phinn et al. in press) which mostly required thresholds adjustments for a similar reef type, geomorphic zone or benthic community mapping category (Roelfsema et al. 2010).

For the first three mapping scales, the segmentation scales and membership rule sets were mostly determined by image interpretation and expert knowledge whereas the benthic community scale was mostly based on field data (Roelfsema et al. 2010).

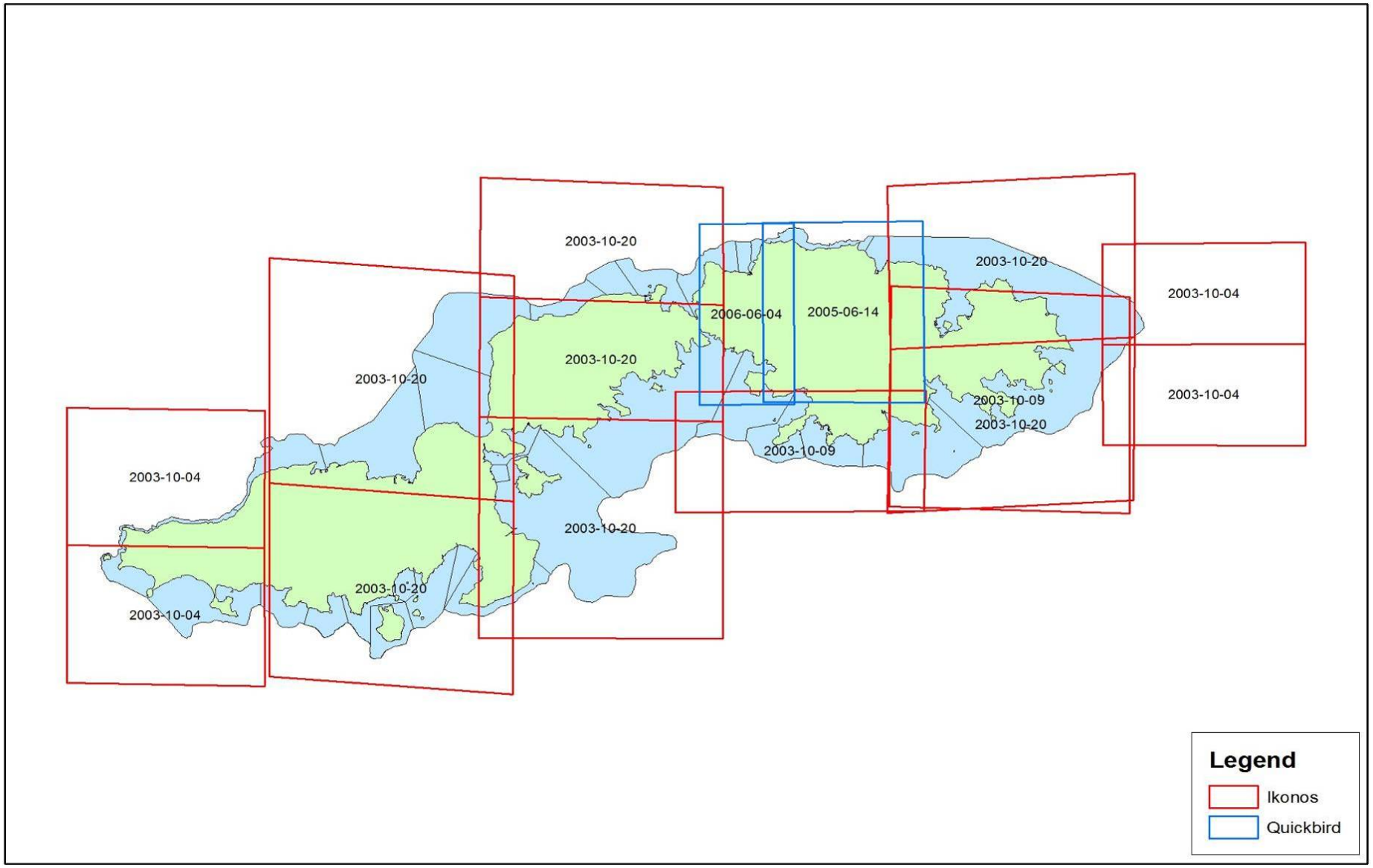


Figure 5: Mosaic of Quickbird and Ikonos images dated from September 2003 to June 2005

2.2.5 Accuracy assessment of habitat maps

To assess for accuracy assessment of the habitat maps produced at geomorphic and benthic community scale, error matrixes were determined. These error matrixes were based on classified image and reference data for the individual maps and they were used to calculate commonly used: 1) map accuracy, 2) Overall and Kappa, and 3) the mapping category accuracies, user and producer (Congalton and Green 1999). Based on expert knowledge, the geomorphic reference dataset was extracted by manually assigning geomorphic mapping category to randomly distributed points within each geomorphic zone. On the other hand, the benthic community reference dataset was derived from field data set not used for calibration by comparing the filed data with the underlying segment from the benthic community scale map (Roelfsema et al. 2010).

2.2.6 Final habitat map for Kadavu

The final shapefile of the habitat map produced by the Center for Spatial Environmental Research (CSER) was further categorized to reflect the CCMA-NOAA shallow water benthic habitats for the Republic of Palau (http://ccma.nos.noaa.gov/products/biogeography/palau/htm/refer.html). The classification scheme for Palau was adopted because the reef system was similar to that of the project site; Kadavu and the class names used were simple. The mapping scales were further divided into three habitat categories: 1) NOAA zone, 2) NOAA structure and 3) NOAA cover. The first category included identified zones from land to open ocean corresponding to a coral reef geomorphology. These zones included: intertidal, lagoon, back reef, reef flat, reef crest, fore reef, bank, channel, unknown, and land. The second category included geomorphological structures that could be mapped and these included: individual patch reef, aggregated patch reef, aggregate reef, scattered coral/rock in unconsolidated sediment, pavement, reef rubble, unconsolidated sand, unconsolidated mud and unknown. The biological cover category included: coral, seagrass, coralline algae, emergent vegetation, uncolonized, and unknown.

The cover types were defined in a collapsible hierarchy ranging from six major classes (coral, seagrass, coralline algae, emergent vegetation, uncolonized, and unknown), (figure 6) combined with a density modifier representing the percentage of the predominate cover type (10% - <50% sparse, 50% - <90% patchy, 90% - 100% continuous). Substrates not covered with a minimum of 10% of any of the live biological cover types are classified as uncolonized. Unknown areas included data that could not be interrupted due to turbidity, cloud cover, water depth, or other interference.

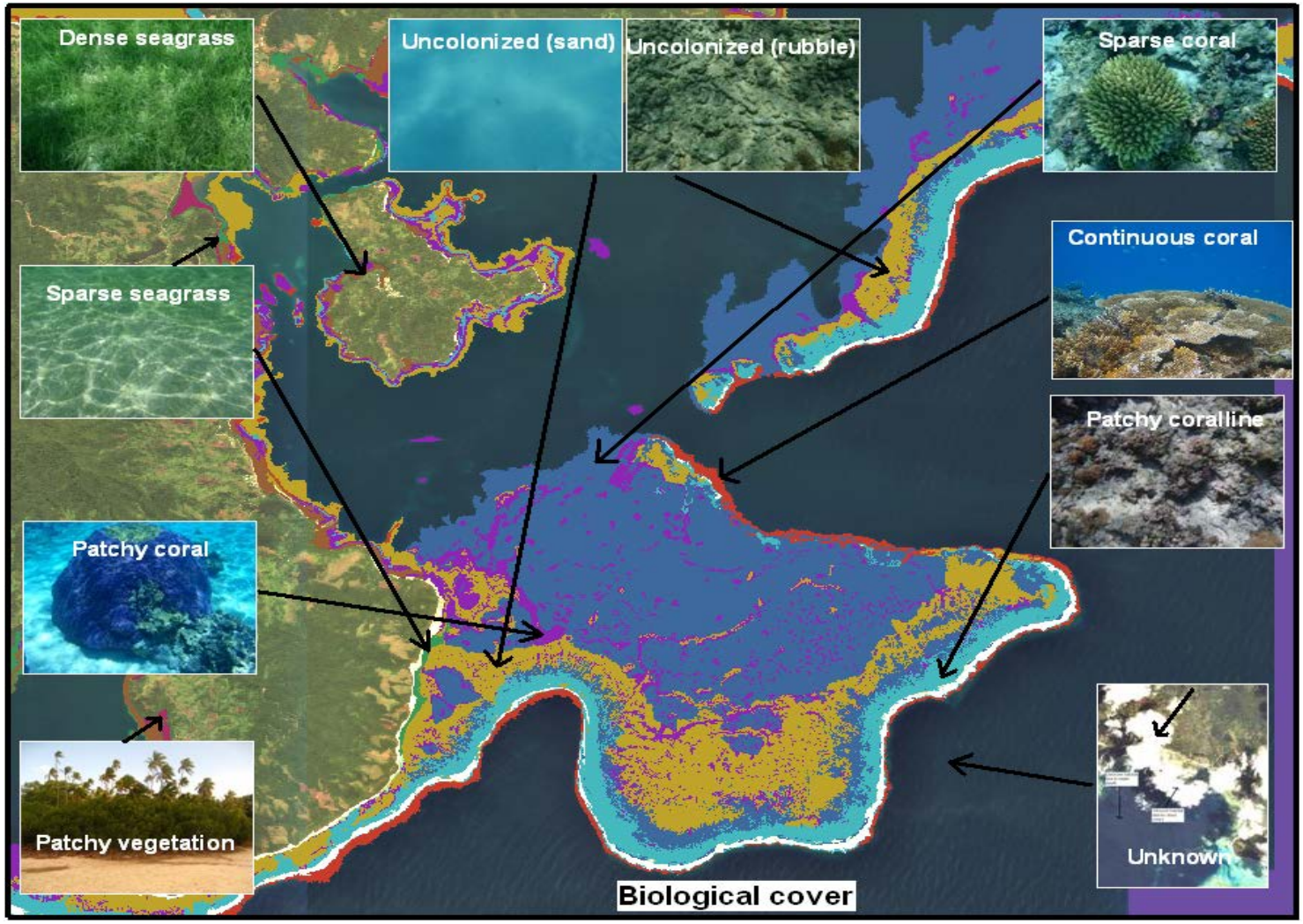


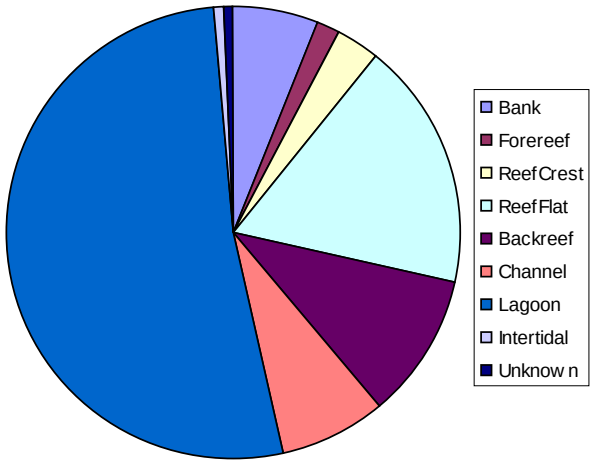
Figure 6: Benthic habitat map of Kadavu Island

There were 6 major and 9 detailed biological covers, 3 major and 9 distinct structures and 9 exclusive zones identified across the entire *iqoliqoli* and mapped in GIS.

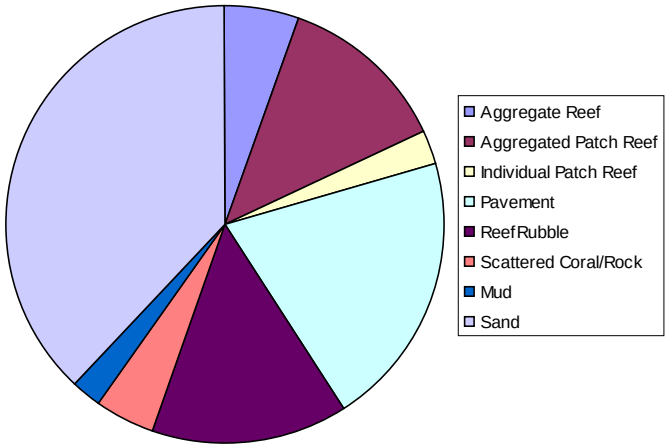
Tables 2 shows the summary results of habitat mapping classes used for this study. For instance, live corals were dominated by sparse corals which covered an area of 54 km^2 and this equals 28% of known habitat types. Coralline algae covered an area of 19 km^2 whereas emergent vegetation (mangroves) covered 4 km^2 along the intertidal zone of the main island. The largest area of major structures was constituted by sand and unconsolidated sediment occupying 74 km^2. For coral reef and hard bottom structures, pavement covered the biggest area across all *iqoliqolis* (39 km^2) whereas lagoons covered the biggest zone with an area of 209 km^2.

Table 2: Summary results for zone, structure and cover

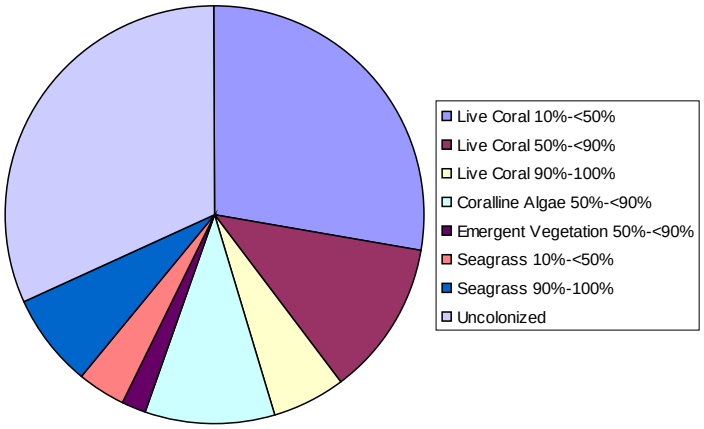
	Zone	Polygons	Area (km^2)	% of total
	Bank	49	24	5.97
	Forereef	1,312	7	1.69
	ReefCrest	985	12	3.1
	ReefFlat	8,030	71	17.61
	Backreef	20,281	41	10.24
	Channel	170	30	7.54
	Lagoon	3,644	209	52.25
	Intertidal	179	4	1.12
	Unknown	92	2	0.49
	Total	34,742	401	



Major structure	Structure	Polygons	Area (km^2)	% of total
Coral Reef and hard bottom	Aggregate Reef	1,149	11	2.78
	Aggregated Patch Reef	556	24	6.08
	Individual Patch Reef	1,031	5	1.21
	Pavement	12,308	39	9.79
	Reef rubble	13,426	28	7
	Scattered Coral/Rock	1,732	9	2.31
Unconsolidated sediment	Mud	155	4	1.08
	Sand	3,553	74	18.51
Unknown	Unknown	834	205	51.26
	Total	34,744	401	



Major Cover	Detailed Cover	Polygons	Area (km^2)	% of total
Live Coral	10%-<50%	13,893	54	13.57
	50%-<90%	8,279	23	5.85
	90%-100%	1,452	11	2.73
Coralline Algae	50%-<90%	3,365	19	4.72
Emergent Vegetation	50%-<90%	155	4	1.08
Seagrass	10%-<50%	312	7	1.75
	90%-100%	960	14	3.58
Uncolonized		5,496	62	15.47
Unknown		832	205	51.25
	Total	34,744	401	



2.3 Reserve design planning

The Hexgen command within TNC Protected Area Tools (PAT) v. 2.1 was used to create a layer of hexagonal Planning Units (PUs) covering the entire inshore fishing ground areas of Kadavu. The planning units were 1.5 hectares in area and a total of 29,728 were needed to cover the design area.

2.4 Mapping socio-cultural variables and resource use pattern

One day workshops were conducted in 8 districts around the main island of Kadavu with invited key representatives from each district to gather information on marine resource use and traditional knowledge. The workshops used participatory mapping techniques. The maximum number of attendees per district workshop was 25 including different stakeholder groups based on the following criteria:

- 3 chiefs from villages within the district
- 3 representatives from District Environment Committees
- 3 village headman from the district
- 3 village fishermen from the district
- 2 commercial fishermen from the district
- 2 members of the KYMST from that district
- 3 community representatives who conduct biological monitoring
- 3 *iqoliqoli* owners
- 3 fisherwomen representatives

Figure 7: Socio-cultural and resource-use patterns mapping workshop

The workshops covered a wide range of age groups (including elders and chiefs) and focused on both former and current marine resource users.

During the workshop, four copies of A2 size laminated maps showing satellite imagery, *iqoliqoli* boundaries and planning units were provided to participants. An A4 response-sheet showing the *iqoliqoli* boundaries, coastline and planning units was provided in black and white format to record the response of participants.

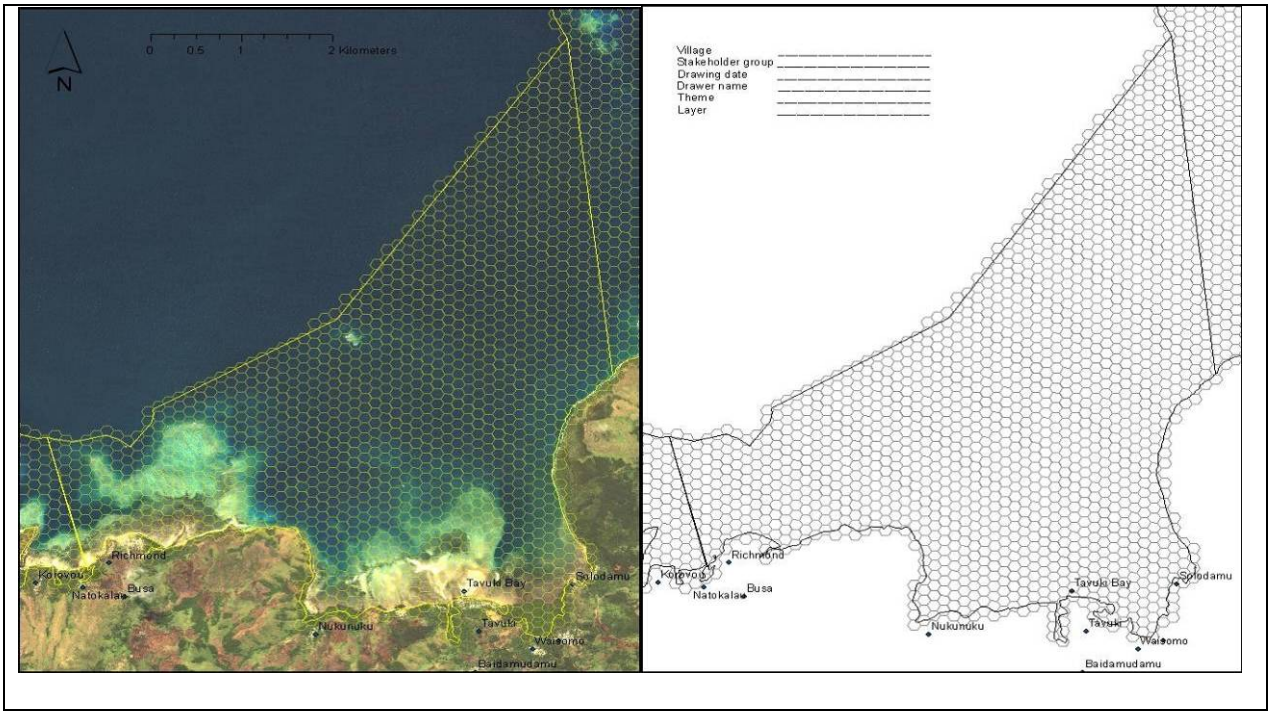


Figure 8: Map showing satellite imagery, *iqoliqoli* boundaries with overlaid hexagonal grids and answer-sheet provided during the resource use

Table 3: List of questions used to elucidate GIS and Marxan layers

Session 1: Important Fishing and Resource Use

1. What are the 5 most important gears you use for subsistence, artisanal and commercial fishing respectively? Please map where these gears are used in your *iqoliqoli*?

Example:

Handline
Speafishing
Spear fishing, etc

Session 2: Governance Issue

2. Are the *iqoliqoli* boundaries by Native Lands and Fisheries Commission correct? If not, please mark out the boundaries that you know.
3. Are there any areas in your *iqoliqoli* that is disputed? Please map these disputed areas.
4. Are the no-take zone boundaries you see correct? If not, please mark out the changed/current boundaries that you know.
5. Are you able to enforce no-take zones that are not within line-of-sight or far offshore?

Session 3: Mapping significant sites

6. Are there any significant sites in your *iqoliqoli*? For example spawning aggregation sites (SPAGs)? Are these sites fished or not?

2.4.1 Storing collected data

The black and white A4 response maps were collected at the end of the workshop. Columns were added to the PU layer attribute table relating to each of the questions asked in the workshop and areas indicated on the response maps were attributed with '1' in the respective column. For example, for Handline = 1, this grid was identified as being important for handling.

2.4.2 Validation and standardization of fishing use layers

It was clear that in some instances, areas shaded on the map were greater than the true extent. An example was handling which is only carried out in shallow water. A set of decision rules was made to validate and where necessary correct the assignment made to each grid. The decision rules were:

Factor	Rule
Handling	Only done in areas where depth <20-30m
Spear	Only done in areas where depth <10-15m
Handspear	Only done in areas where depth <10m
Glean	Only done in areas where depth <5m
Netting	Only done in areas where depth <5-10m
Troll	Only done in deep water
Duva	Only done in areas where depth <5-10m
Fish drive	Only done in areas where depth <5-10m

Using these decision rules the grid layer was examined gird by grid and areas where the decision was violated were manually recoded to zero.

The sum of fishing efforts over the entire *iqoliqoli* was calculated by adding all fishing layers in one shapefile. Assuming that fishing pressure is equal across *iqoliqoli*'s in Kadavu and all *iqoliqoli*'s have the same lost opportunities, there was a need to standardize the fishing layers. To standardize the fishing layers, first it was assumed that the workshop participants were only told to shade 100 grids in their *iqoliqoli*'s. The total number of grids that fall in a *iqoliqoli* was divided by the standard 100 grid value to get a weighting factor for each *iqoliqoli*. The sum of fishing efforts was then divided by the weighting factor for each *iqoliqoli* to get a corrected fishing layer for all fishing efforts. Finally in order to express this value on a scale from 0-1, each value was divided by the maximum value of the corrected fishing layer. The corrected fishing layer (figure 9) was used as a fishing use intensity cost layer in the reserve design analysis. This basically means that putting a no-take zone in such an area causes a lost of fishing ground in that particular *iqoliqoli*.

2.4.3 Creating an enforceability distance layer

In addition to the variables outlined in the workshop, an additional factor of enforceability was created. In most of the villages in the study area the ability of communities to enforce any no-take zone is limited. Few have access to boats and those that do have limited access to fuel to undertake enforcement patrols. Therefore

it is important that any no-take area be established within a relatively short distance from the village and certainly within line-of-sight.

In order to create this layer, a ‘straight line’ analysis using ArcGIS Spatial Analysis was undertaken to assign a distance of each PU from the nearest village (figure 10).

2.4.4 Creating a disputed areas layer

Disputed areas included areas of *iqoliqoli* where there have been disputes over the years regarding traditional ownership (figure 11). The communities identified these areas at the resource use and traditional knowledge workshop. The identified areas were spatially recorded in GIS and the areas were calculated in square meters to be used as disputed areas layer in the analysis.

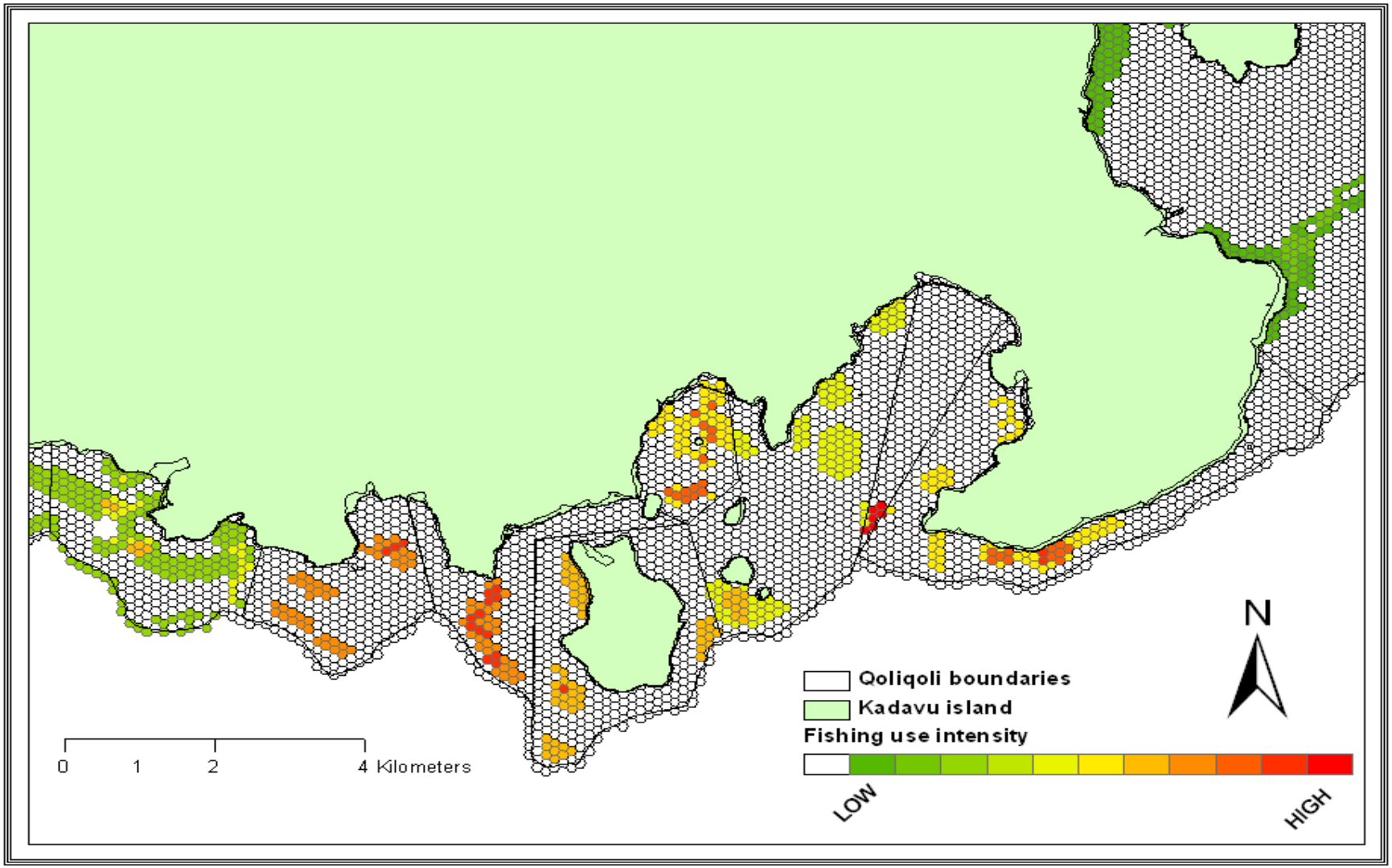


Figure 9: Fishing use intensity cost layer

Figure 10: Enforceability distance cost layer

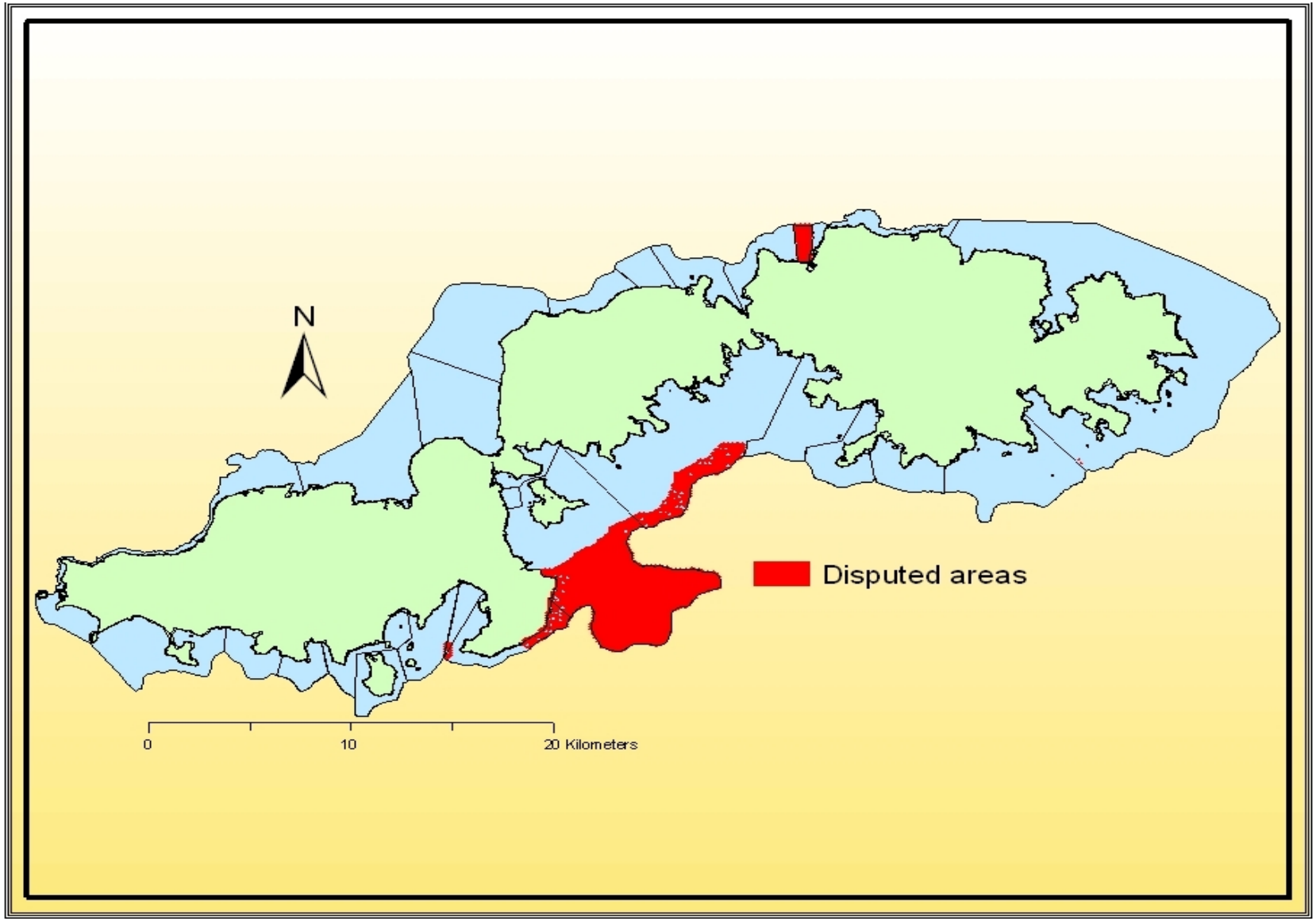


Figure 11: Disputed areas cost layer

2.5 Assessment of the pre-existing network and gap analysis

The pre-existing no-take zone network as of December 2010 included 60 individual community-based no-take zones (figure 12). The network protected a total area of 29.4 km^2 (12%) of shallow reefs areas and 0.5 km^2 (17%) of significant sites across the network.

Using the IUCN stated MPA networking principles, habitat maps and the community resource use maps, a feasibility assessment was undertaken to assess which pre-existing no-take zones fulfil the network design principles and which do not fulfil some or all of these principles.

2.5.1 Representation

There are two ways in which representation of habitats within the existing no-take zone network were assessed.

Percentage habitat representation per no-take zone area and across the network

To quantify the habitat coverage in each no-take zone, the spatial join performed previously and the calculated areas of each habitat polygon was used to calculate the area of each habitat type within each no-take zone. After performing no-take zone specific calculations it was then possible to sum habitat areas across all no-take zones and therefore calculate the percent representation of each habitat within the no-take zone network.

Diversity of habitats within each no-take zone

To assess the number of distinct habitat types in each no-take zone a spatial join between the habitat maps and the no-take zone boundaries was created. Using this spatial join allows for the number of distinct habitat types present in each no-take zone to be enumerated.

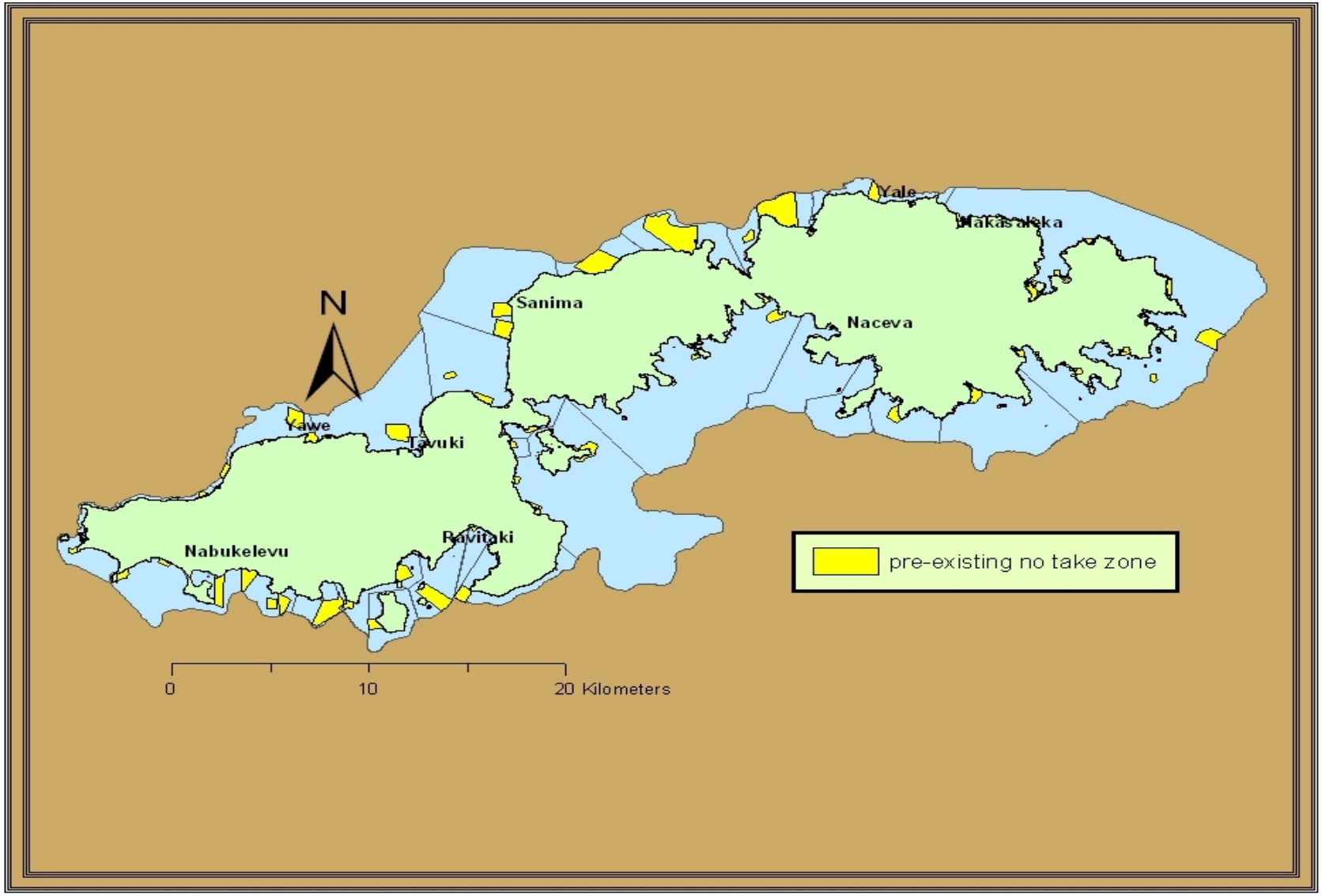


Figure 12: Pre-existing no-take zone as a network around the island of Kadavu.

Habitat complexities

The number of distinct habitat patches in each no-take zone was first assessed using a spatial join between the habitat map and the no-take zone boundaries were created. Using this spatial join allows for the number of distinct habitat types present in each no-take zone to be enumerated. This was then later compared across all no-take zones in the pre-existing network.

2.5.2 Replication

To assess replication of habitats within the existing no-take zone network, the different habitat types present in each no-take zone were identified and labelled. After performing no-take zone specific enumerations it was then possible to calculate the number of no-take zone within the network where these distinct habitat types exist. The number of no-take zone that covers the major habitats for managing and protecting fish and invertebrates were also noted.

Significant sites such as spawning aggregation sites, cultural areas and turtle nesting sites were also assessed against representation and replication networking principles.

Table 4 shows the percent of each feature (zone, habitat, significant sites) around Kadavu that is already protected by no-take zone. It also shows the number of no-take zone each feature occurs in (replication) and the number of distinct habitat patches protected by no-take zones.

Table 4: Feature representation, occurrence and number of habitat patches across the re-designed network on Kadavu before the project

Feature	% protected	% (number) of no-take zone s in which feature occurs in	Number of patches protected
	Geomorphic zone		
Back reef	2	5 (3)	279
Channel	8	23 (14)	21
Fore reef	5	17 (10)	39
Intertidal	15	20 (12)	21
Lagoon	13	50 (30)	569
Reef crest	5	13 (8)	63
Reef flat	18	97 (58)	1,344
	Habitat		
Continuous coral	12	60 (36)	268
Patchy coral	12	77 (46)	570
Sparse coral	6	57 (34)	272
Dense seagrass	16	53 (32)	187
Sparse seagrass	15	42 (25)	53
Patchy coralline	6	27 (16)	148
Patchy vegetation	16	18 (11)	19
	Significant sites		
Spawning aggregations sites	41	12 (7)	
Turtle nesting sites	24	3 (2)	
Cultural areas	7	15 (9)	

These results (Table 4) showed that the most represented and replicated geomorphological zone in the pre-existing network was reef flat. It had the highest percent protected with 18% in no-take zones and the most occurred feature across the network in 58 (97%) no-take zones. Reef flat patches were also the most protected with 1,344 of them in no-take zones across the network. In addition intertidal zone was the second most protected class with 15% in no-take zones. This however was replicated in only 12 (20%) no-take zones with 21 patches protected, the least across the network. Half the no-take zones had lagoon within them; representing 13% of the total lagoon area and 569 lagoon patches. The network was also protecting 8% of channel, 5% of reef crest and fore reef areas. Back reef was the geomorphological zone that was least protected with only 2% in no-take zones occurring in 3 no-take zones.

The fact that communities put more no-take zones in reef flat and intertidal zones were evident in the high percent of seagrass and mangrove vegetation habitat

protected. Table 4 shows that patchy vegetation and dense seagrass habitat was the most protected habitat feature with 16% of dense and 15% of sparse seagrass in no-take zone. Dense seagrass was replicated in over 50 no-take zones; patchy vegetation however was replicated in only 11 (18%) no-take zones. There were only 19 patches of patchy vegetation protected in this case whereas over 150 patches of dense seagrass were protected. In addition the network also protected 12% of continuous coral and 12% patchy corals in no-take zones with patchy coral being the most replicated feature in 46 no-take zones and most number of patches protected with 570 of them in no-take zones. Patchy coralline algae and sparse coral were the least protected habitat with only 6% in no-take zones.

Community significant sites were also found to be protected by the pre-existing network when assessed. It was protecting 41% of spawning aggregation (SPAGs), which was replicated in 7 no-take zones (Table 4). The network also protected 24% of turtle nesting sites in 2 no-take zones and 7% of culturally important areas were protected by 9 no-take zones in the network.

When pre-existing network was assessed against habitat diversity, 7 distinct habitat types had been protected across Kadavu. Figure 13 shows the percentage of no-take zones and the number of distinct habitat types they protect. Diversity of habitats within pre-existing no-take zones ranged from one to six distinct habitats per no-take zone. Most no-take zones protected four to five distinct habitat types across the pre-existing network. Only 3% of no-take zones protected six out of seven distinct habitat types whereas 10% of no-take zones protected one habitat type.

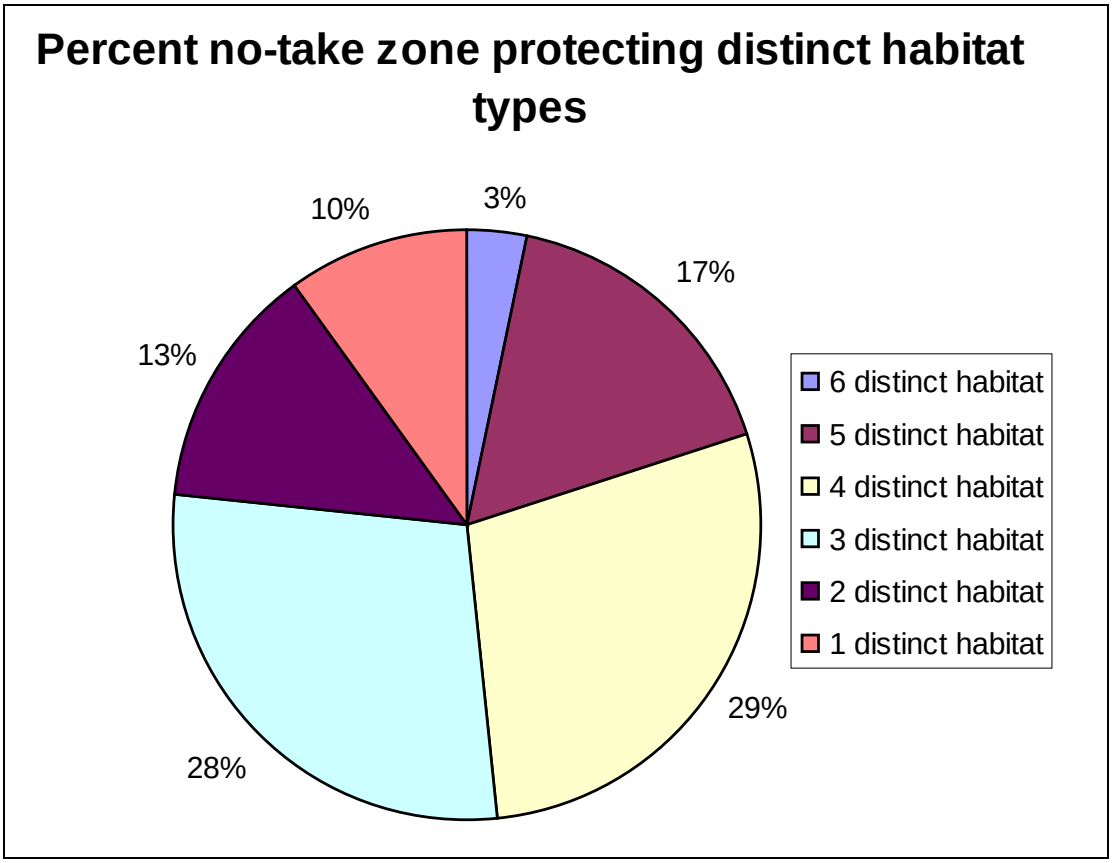


Figure 13: Percentage of no-take zones protecting different habitat types

2.5.3 Ecological linkages

There are two ways in which ecological linkages within the pre-existing no-take zone network were assessed.

Larvae settlement

With the assumption that larvae settlements tend to be on coral reefs and not sand, seagrass or other habitats, this parameter was assessed by calculating the percentage of each no-take zone classified as hard substrate.

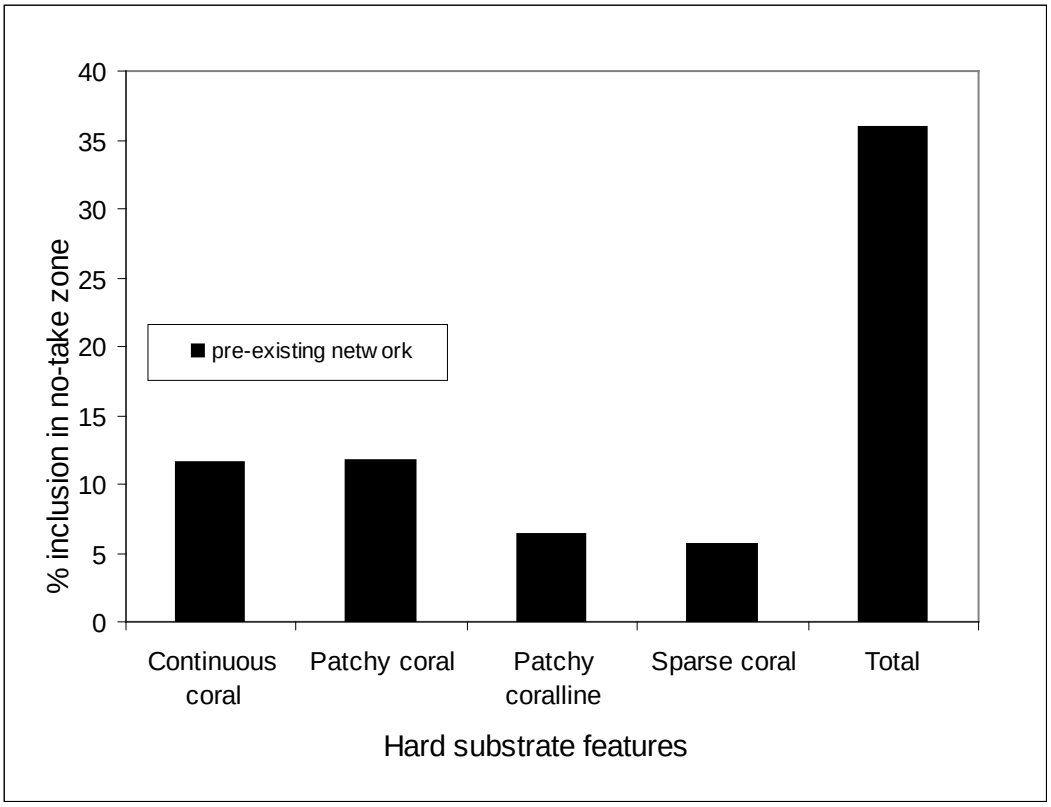


Figure 14: Percent hard substrate features protected by pre-existing network

The four detailed hard substrate habitats (continuous coral, patchy coral, sparse coral and patchy coralline) were used to assess larval settlement across the pre-existing network. The percentage covers of these hard substrate features in figure 14 are well presented in Table 4. Hard substrate calculation showed that the total hard substrate features protected by the pre-existing network available for larval settlement was 35% in total (figure 14).

No-take zone spacing

To assess the distance between no-take zones in the network, the linear distances from one no-take zone to another was measured and average distance before and after project was recorded.

Table 5: No-take zone spacing distance in the pre-existing network

Spacing parameter	Pre-existing network (meters)
Maximum spacing distance	10,456 m
Minimum spacing distance	329 m
Average spacing distance	3,131 m

The maximum spacing distance between no-take zones in the pre-existing network before the project was 10,456 meters and the minimum spacing distance was 329 meters. The average spacing distance between no-take zones was 3,131 meters (Table 5).

2.5.4 Long - term protection

Years in existence

Long-term protection of no-take zones within the existing network was assessed by calculating the year's individual no-take zone has been in existence since establishment (figure 15).

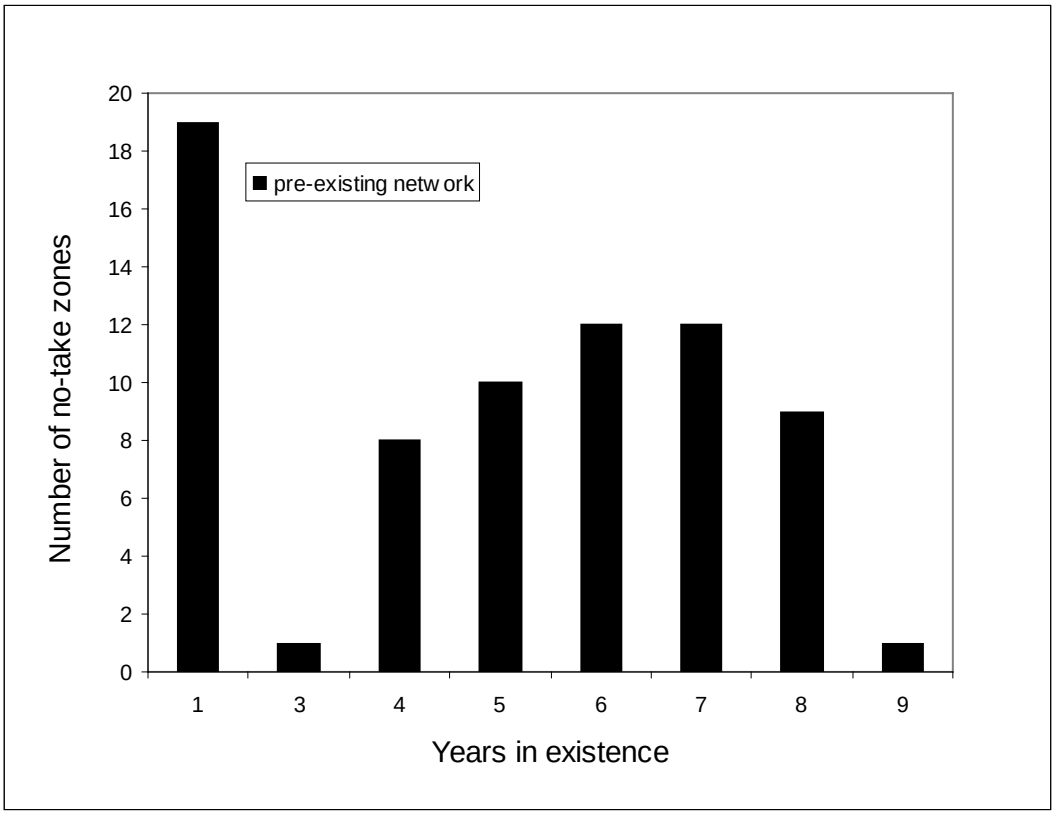


Figure 15: Number of years pre-existing no-take areas had been established

The pre-existing network included no-take zones that were initiated between the 2001 and 2009. The average age of the existing no-takes was 4.6 years. Across the network, only a single no-take zone had been in existence for nine years (initiated in 2001). Figure 15 shows that nineteen no-take zones had been in existence for just 1 year (initiated in 2009). Nine no-take zones were 8 years old and twelve no-take zones were established in the 2003 and twelve in 2004 which were 7 and 6 years in existence respectively. Ten no-take zones were 5 years old and 8 were four years on the ground. On average, the network had been 4 years in existence.

2.5.5 Maximising the contribution of individual no-take zones to the overall network

To assess if the contribution of individual no-take zone to the current network is maximised, the size of the no-take zones were calculated and compared to the home range of Lethrinidae fish family, one that is commonly used by communities in Fiji. The size was calculated by using a spatial tool in GIS to find out the maximum dimension of no-take zones.

Recent studies done in the Coral Coast of Fiji and funded by NOAA showed that the average movement of Lethrinidae fish was less than 900 meters. For this the numbers of no-take zones that have their size greater than 900 meters were recorded.

Table 6: Maximum dimension results for the pre-existing network

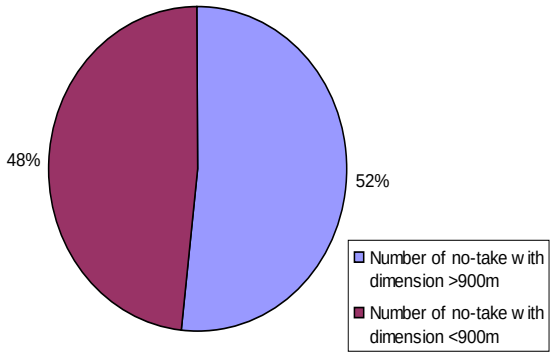
Long axis parameters	Pre-existing network	Pie graph
Maximum no-take dimension	3,493 m	
Minimum no-take dimension	242 m	
Average dimension	983 m	
Number of no-take with dimension >900m	31	
Number of no-take with dimension <900m	29	

Table 6: above showed that the maximum dimension of a no-take zone in the pre-existing network was over 3,000 meters and the minimum dimension was 242 meters. The average dimension across the network was 983 meters which was higher than the travel distance of Lethrinidae fish species.

2.6 Reserve design planning

2.6.1 Marine reserve software

Marxan with zones (Marxan Z) was the marine reserve software that was used for the analysis of this study. It is decision support tool and has been used in the design of marine reserves worldwide (Airame et al. 2003; Leslie 2005). In this study, the software was used and provided decision support in the scaling up of an individual community based no-take zone on Kadavu into a province-wide network of ecologically functioning no-take zone network to maximize fisheries and conservation benefits. It was used with Zonae Cogito (ZC), another software tool as a decision

support system and database management system for Marxan software. GIS software components were also integrated in ZC which makes work easier. The design of ZC is simple and strong making it easier to run Marxan analyses and viewing the results after each analysis.

For further information, please consult the Marxan with Zones manual v1.0.1 (Watts et al. 2008) and more information can be found at http://www.uq.edu.au/marxan/zonae-cogito-software.

2.6.2 Assembling primary input files

Once the GIS data layers had been created, the next step was to create input files needed for Marxan with Zones analysis. These input data files were created using ArcGIS, Jump statistical software, Microsoft Excel and Access. There were seven fundamental input files that were required to run Marxan. In addition, there are optional files that facilitate additional function.

Table 7: Descriptions of the input files created and used in the Marxan analysis

Input files	Required/Optional	Default name	Description
Planning Unit	Required	pu.dat	This file contained a unique ID for each hexagon and the individual cost of each hexagon assigned to a particular zone.
Feature	Required	spec.dat	This file contained a positive numeric identifier and the overall targeted amount to include in protected zone. The spatial features were included from ecological and socioeconomic data collected.
Planning Unit versus Feature	Required	puvspr^2.dat	This file included information on the distribution of features across the planning units. It contained the feature identifier, planning unit identifier and the amount of feature in the planning unit.
Zones	Required	zones.dat	This file contained a list of zone names and the numeric identifier for all possible zones.
Costs	Required	costs.dat	This file contained each cost name in the planning unit file assigned with a unique numeric identifier.
Zone cost	Required	zonecost.dat	This file contained a weighting factor for each cost in each zone
Boundary Length	Optional	bound.dat	This is optional file. This file contained information on the boundary “costs” of planning units. Required if the boundary length modifier is greater than 0 in the input.dat file.
Planning unit lock	Optional	pulock.dat	This is an optional file and was used to restrict certain planning units to a zone.
Zone target	Optional	zonetarget.dat	This is an optional file and was used to allow zone based targets to be set in Marxan Z.
Input parameter file	Required		The file is needed to run Marxan Z. it contained all the main parameter definitions that controlled the way Marxan Z worked.

2.6.3 Community targets

To protect 30% of each habitat features and 100% of significant sites (Spawning Aggregations, cultural sites and turtle nesting areas).

2.6.4 Conservation features

The conservation and fisheries targets represented the spatial distribution of the major biodiversity features that were considered. Conservation feature targets included:

- Continuous coral reef habitat types based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Patchy coral reef habitat types based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Sparse coral reef habitat types based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Patchy coralline red algae habitat types based on based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Dense seagrass communities based on field assessment survey based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Sparse seagrass communities based on field assessment survey based on field assessment survey (2009) and habitat map produced by UQ (2010).
- Patchy emergent vegetations cover (mangroves) based on digitized mangrove areas on Google image 2010.
- Spawning aggregation sites (SPAGs) based on survey of local traditional knowledge and resource use in Kadavu (2009).
- Cultural areas based on survey of local traditional knowledge and resource use in Kadavu (2009).
- Turtle nesting sites based on survey of local traditional knowledge and resource use in Kadavu (2009).

2.6.5 Planning Units and costs

The same hexagonal grids that were created for mapping community resource use and traditional knowledge were generated as a planning unit (PU) file (Figure15) for Marxan analysis. The PU file consisted of a number of unique identifiers and the cost

layers that were derived from the socioeconomic information collected from the communities in 2009. These identified cost files included:

- Loss of fishing grounds for fishing
- Enforceability distance from each village and settlement
- Disputed areas across the *iqoliqolis*

High costs were associated with these areas through various socio-cultural reasons if they were to be placed into no-take zone. These areas were considered not good for selection in Marxan Z. The standardized fishing layers, enforceability distance layer, disputed areas layer and planning unit area were used as zone costs in Marxan Z analysis.

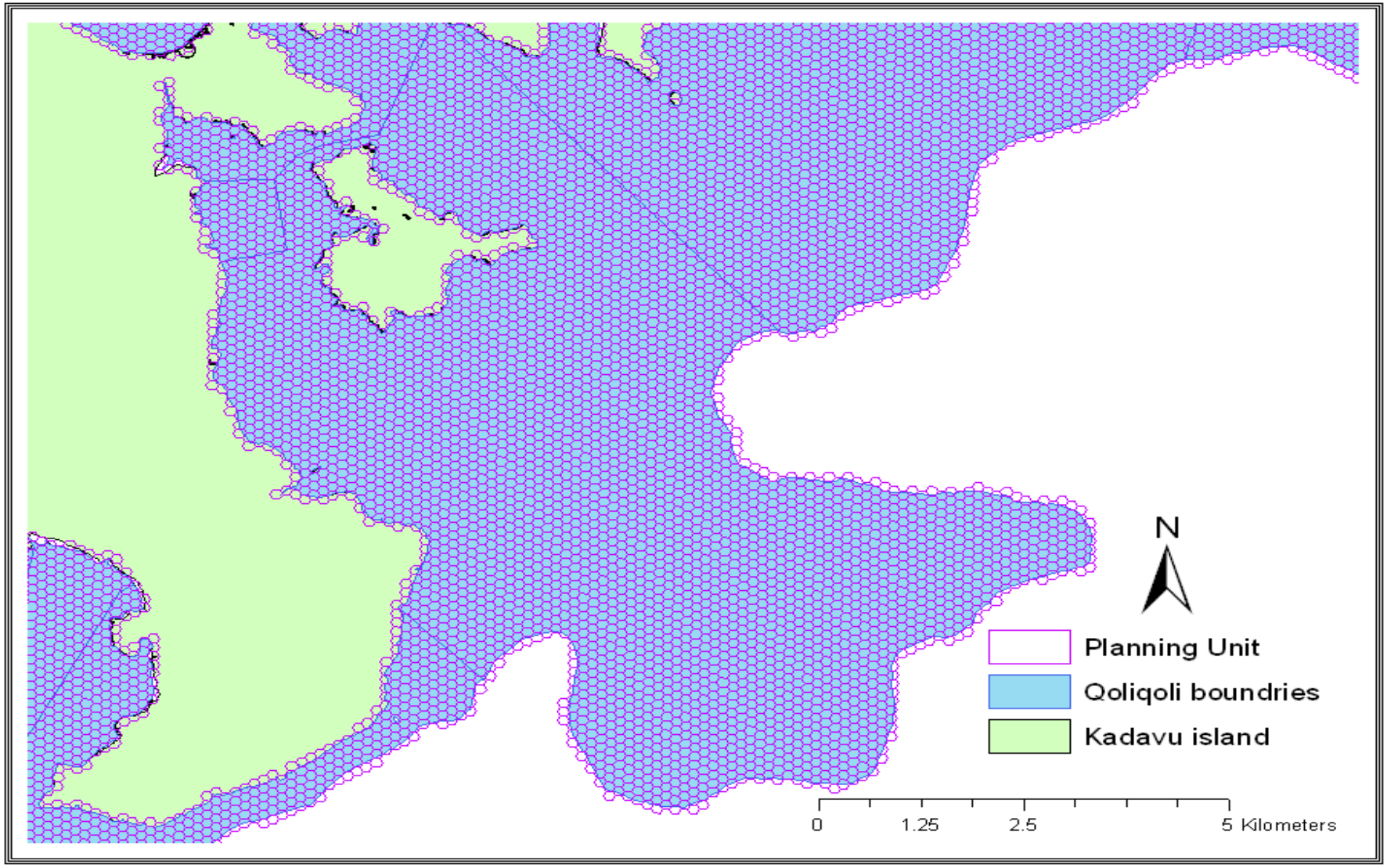


Figure 16: Marxan planning unit layer.

2.6.6 Zones

The two zones included in the zones file were zone 1 = fished and zone 2 = no-take zone. In the zone target file each feature and *Iqoliqoli* target was set for each zone. The targets represent major ecological habitats and *Iqoliqoli* areas that communities wished to protect or leave them out to fishing.

2.6.7 Planning unit lock

This file was used to restrict certain planning units to a zone. In the analysis, there were some instances where the pre-existing no-take zone were locked in or restricted to zone 2 and other runs where the re-designed no-take zones were locked in.

2.6.8 Summary input files

A summary of the input files used for re-designing the no-take zone network are outlined below:

- Planning unit file "pu.dat" = 29,728 hexagons
- Feature file "spec.dat" = 8 unique habitat features, 29 inshore *iqoliqoli* targets, 29 offshore *iqoliqoli* targets and 3 ecological significant sites
- Zone target "zone target" = 30% habitat features in no-take zone , 60% inshore reefs of each *iqoliqoli* in fished and 100% of ecological significant sites in no-take zone
- Area of each planning unit = 14,997 square meters
- Boundary Length Modifier = 60 (the BLM is a parameter that directs the assignment of planning units to zones in a cluster formation rather than selecting several disconnected planning units. BLM 60 provided a moderate degree of clumping that produced compact areas of similar size to that of pre-existing no-take zones).
- Penalty Factor = 1,000 (the penalty factor is a measure of the relative worth of a feature and how important it is to represent that feature. This was set equally across all conservation targets).
- Annealing Parameters

- ✓ NUMITNS = 10,000,000 (the number of times Marxan with zones tries to generate a solution for each run).
- ✓ NUMREPS = 100 (the number of separate runs with the same starting condition).

2.6.9 Running Marxan

Zonae Cogito interface was used to run Marxan Z. This made the analysis easier because of the editable nature of the software and a view of the result after each run. The Marxan input data files were added into ZC together with a Planning Unit shapefile for GIS display. In the process the input parameter files were edited according to the desired targets.

Two Marxan runs were made based on two different scenarios

1. **With** pre-existing no-take zones locked in- that the contribution already made by the existing no-take zone area is recognized by Marxan and only additional areas to comprise the shortfall between existing protection and the overall target are identified
2. **Without** pre-existing no-take zones locked in: It was decided early on in the project that as many of the no-take zones have been established for many years, the conservation cost associated with relocating them would be considerable.

2.6.10 Examining runs

The output dendrogram produced via the R plug-in in Zonae Cogito (Figure 16) was examined to identify two of the least similar of the total 100 solutions produced.

Solutions 48 and 10 were the least similar; with a Bray-Curtis dissimilarity of 0.068. This level of dissimilarity is low and suggests that the difference in spatial configurations of the two most ‘different’ solutions is actually very similar.

In order to examine this, the no-take zone configurations of the two least similar solutions were overlaid in ArcGIS. 5.6% of the PUs selected as no-take zones in solution 48 were not selected in solution 10; and 4.3% of PUs selected as no-take zones in solution 10 were not selected in solution 48.

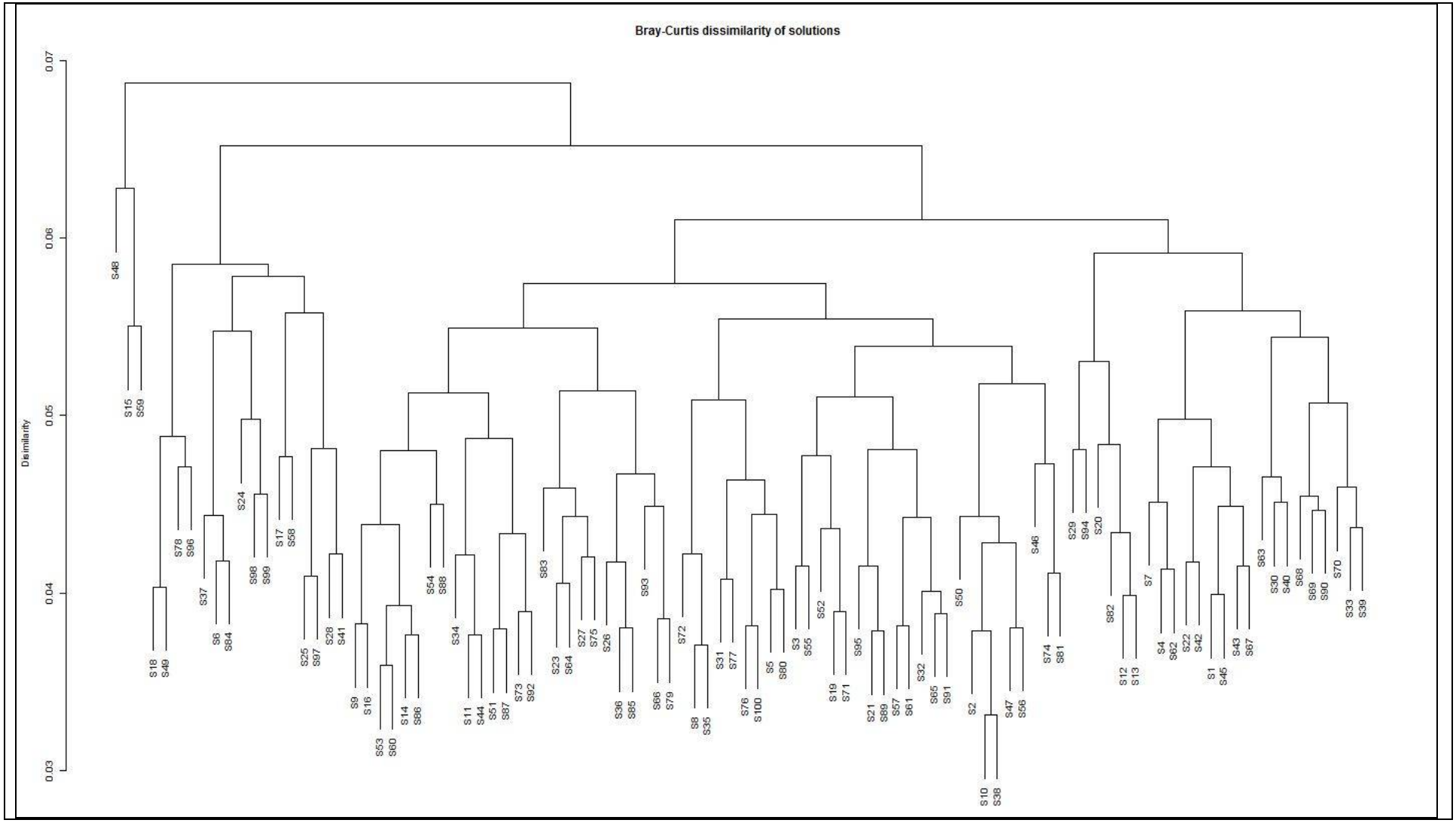


Figure 17: Output dendrogram produced via the R plug-in in Zonae Cogito with Bray-Curtis dissimilarity of solutions

2.7 Supplementing the existing- communicating design results

Four community level workshops were conducted for the 8 districts on the main island. Similar criteria to select participants from the initial socio-cultural workshop in 2009 were used including the Chiefs and *iqoliqoli* owners. The programme of these workshops is shown below.

Communicating design- workshop programme

9:00 Introduction to workshop

- History of project
  - Current status of no-take areas
  - Kadavu process and visioning
  - Development of this project
- NOAA Kadavu project goals and objectives

10:00 Session 1

- *Recap on this project*
  - how the project started
  - visioning workshop in 2007
  - Introduce MPA and MPA networks
  - Recap of the fieldwork and data collection processes
  - Community feedback

11:30 Session 2

- *Present the results back to the communities (to familiarize the communities with the maps)*
  - Basemap *(Current no-take zone and verify them with the communities, discuss where there is still conflict)*
  - Habitat map *(Discuss how habitats fits into existing no-take zone s – network principles)*
  - *Present status of MPAs*
  - % habitat represented in the current
  - Community feedback

2:00 Session 3

- *Re-Design no-take zone Network*

First present outlines

  - Marxan output (the different scenarios)
  - Adding to existing - **Best Run** (Best locked offshore excluded)
  - Modify existing - **Selection Frequency** (No-take zone unlocked-offshore excluded *(Present recommended areas to fill the Gap)*

4:00 Session 4:

- Moving towards an island-wide network of MPAs
  - Did we miss any important considerations
  - Discussion of influence of governance issues to NTZ network-obstacles, value, opportunities
  - Questions

5:00 Workshop close

Figure 18: Result dissemination workshop

2.7.1 Presenting results back to communities

The status of the pre-existing no-take zone network was presented and explained to communities in facts and figures and how the MPA network principles were reflected in the network. The A3 sized maps were then presented to familiarize the communities with the different types of maps. The two types of designs produced by Marxan were also presented and explained to communities at this stage.

2.7.2 Re-designing the network

A3 base maps of the satellite imagery with *Iqoliqoli*, existing no-take boundaries and village locations were produced for each workshop. Tracing paper overlays of the Marxan outputs were used to assist in the community discussions.

Marxan outputs from two scenarios were used in the workshop:

The ‘best’ run (figure 20) output overlay was used from the first scenario in which existing no-take zone areas were locked in

The selection frequency (figure 19) overlay was used from the second scenario in which the existing no-take zone areas were not locked in

In some instances communities wanted to retain the existing no-take areas, and wished to add additional areas. Where this was the case the best run maps were most frequently used.

In other instances, some communities expressed a desire to move the location of the existing no-take areas within their fishing ground. In these cases the selection frequency maps were of most value in identifying ecologically important areas.

Some villages that did not have any no-take areas prior to this project used the best run and the selection frequency maps together.

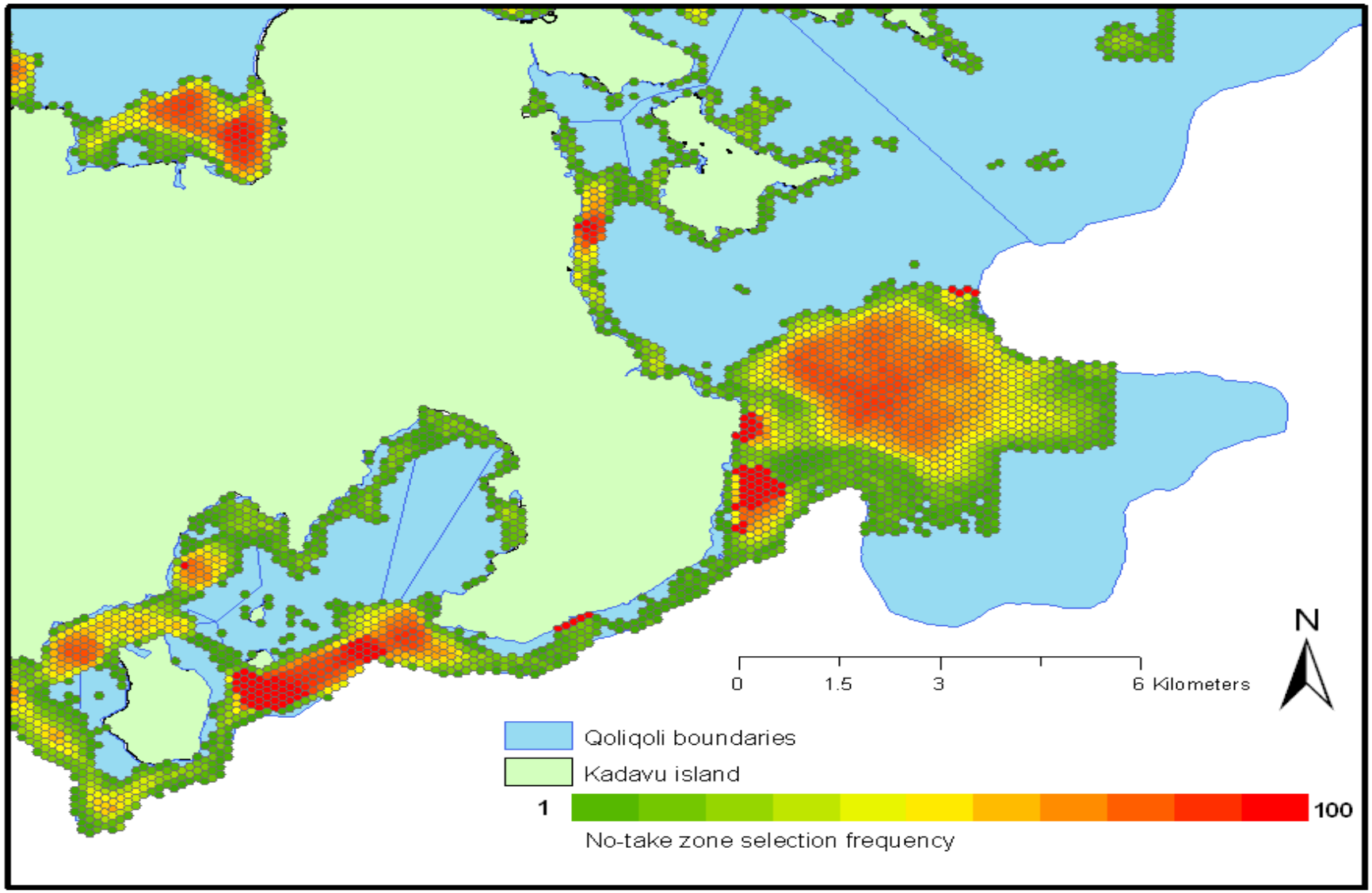


Figure 19: Marxan selection frequency without pre-existing no-take zones locked in (100 reps).

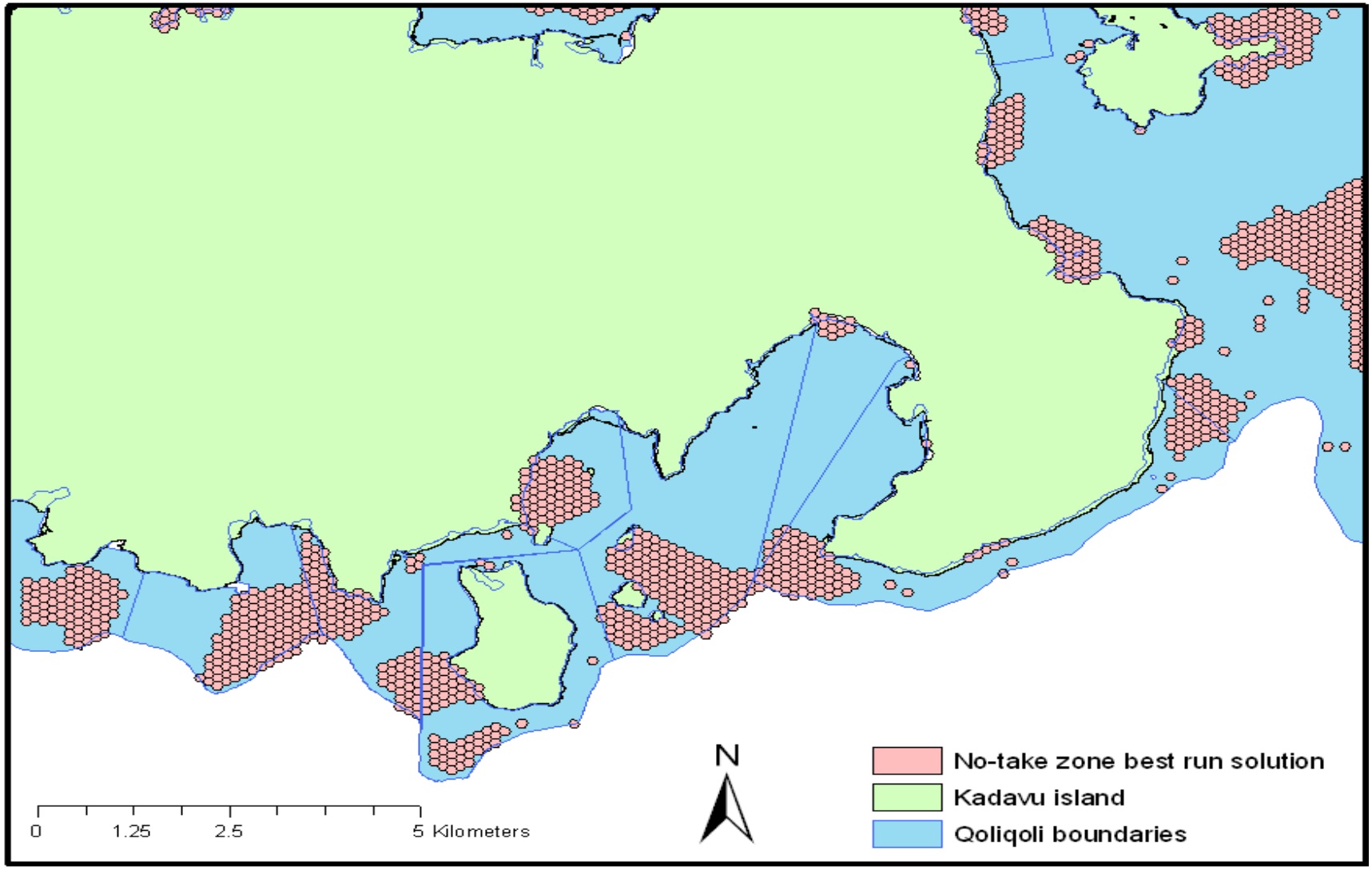


Figure 20: Marxan best run solution where pre-existing no-take zone were locked in (100 reps).

The two outputs above (Figures 19-20) were used to identify areas of interest for inclusion in the re-designed no-take zone network. Both designs showed important areas in each *iqoliqoli* to include in the network and achieve the overall provincial target of 30% to protect inshore habitats.

The best run design was used where communities wished to add to the pre-existing no-take zones. The selection frequency was used to modify the existing and to recommend areas to fill the gap where the best run cannot be used. At the end of the workshop the communities had re-designed an implemented network of no-take zones for the province of Kadavu. Maps of the re-designed network were created and sent to each community in Kadavu.

2.8 The modified network

Of the 60 existing no takes at the start of the project, 35 were not modified, whilst the remaining 25 were modified in some way (12 had additional areas added to them, 3 shrunk in size, 9 were moved and 1 large area was split into four smaller areas).

In addition, 14 new no-take areas were established through this project.

The total area under no-take zone increased from 29.4 km^2 to 50.1 km^2 as a result of the redesign project. . In addition, the re-designed network now protects an additional of 1 km^2 (38%) of significant sites.

There was an overall increase in protection in the community re-designed network when compared to the pre-existing network. There was an overall increase of 20.7 km^2 in total area protected by the re-designed network. Significant sites also increased by 21%. The re-designed network is 7% more compacted and the average social cost was 12.4% less than the pre-existing network. The re-designed network now protects 19% of shallow reef areas. There was an overall increase of 7% in features across network. Table 8 shows the percent of each feature around all of Kadavu after the project.

All modifications have been endorsed at the relevant village meetings and came into effect on the 1st of March 2011.

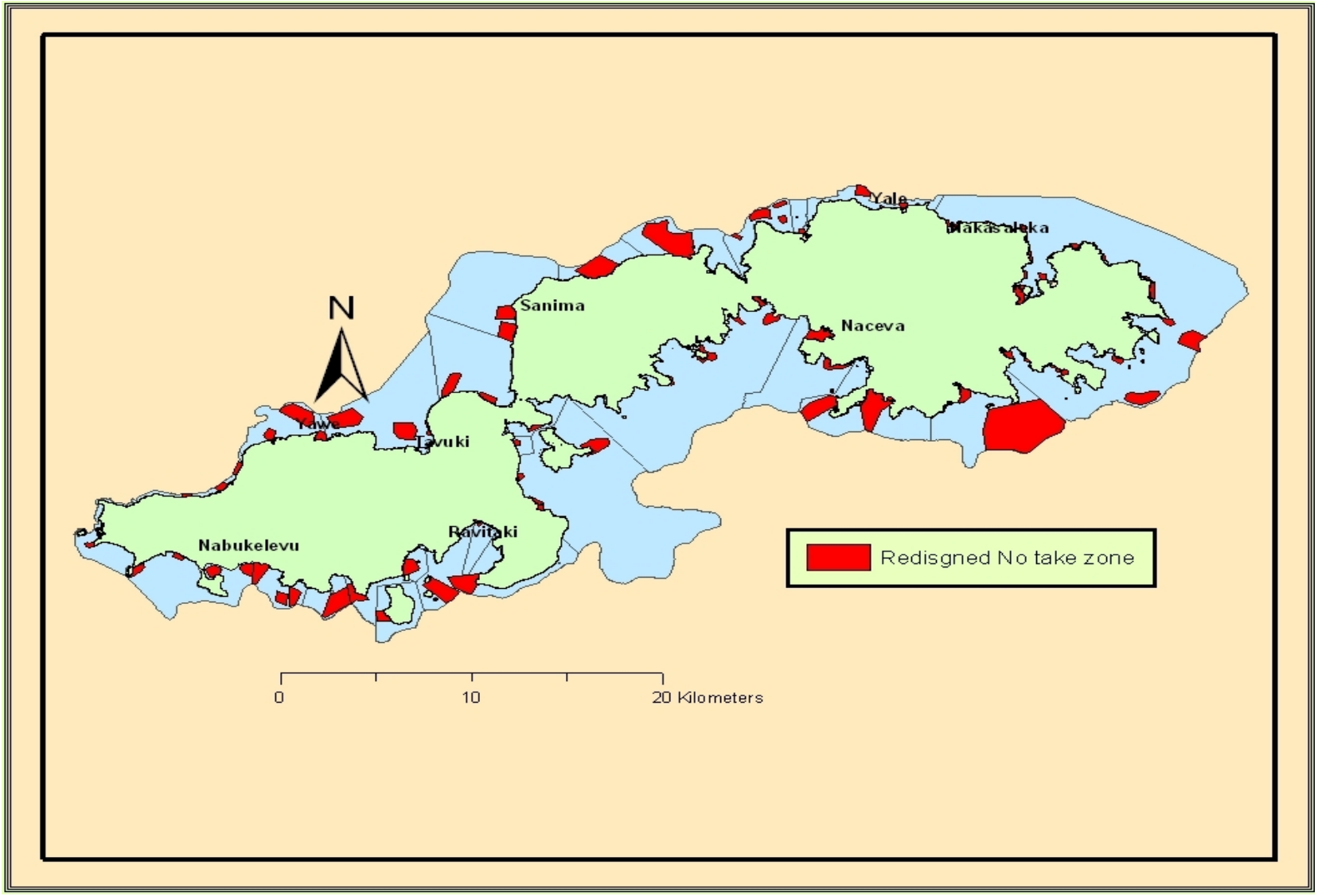


Figure 21: Community re-designed and implemented no-take zones network on Kadavu

2.8.1 Representation

There was an overall increase in geomorphological zone protected in the community re-designed network. After assessment, findings were communities had now put more channels into no-take zones which now resulted in 29% of channel being protected. This was an increase of 21% from the pre-existing network before the project started. Reef flat was the zone feature that was the most protected in the previous network and now protects 26%, an increase in 8%. Although back reef is still the least zone protected, it now protects 14%. This was a 12% increase from the previous network which protected only 2%.

The most represented habitat across the re-designed network was seagrass. In fact sparse seagrass was the only habitat feature target achieved, with 34% now protected (Table 8). Patchy vegetation and dense seagrass was the second most represented habitat feature in the re-designed network. There was an increase of 13% in the proportion of patchy coralline habitat protected from 6% to 19%. Sparse coral was the least represented habitat in the re-designed network with 15% protected by no-take zones. In terms of number of patches protected, sparse coral patches were the most protected with 1,911 was followed by patchy coral with 1,350. Over 700 patchy coralline patches were also protected however only 19 patches of patchy vegetation were included in no-take zones.

Table 8: Feature representation, occurrence and number of habitat patches across the re-designed network on Kadavu after the project

Feature	% protected	% (number) of no-take zone s in which feature occurs in	Number of patches protected
	Geomorphic zone		
Back reef	14	6 (5)	2,923
Channel	29	23 (18)	43
Fore reef	16	23 (18)	186
Intertidal	22	21 (16)	38
Lagoon	16	56 (43)	761
Reef crest	16	16 (12)	144
Reef flat	26	92 (71)	1,842
	Habitat		
Continuous coral	19	62 (48)	414
Patchy coral	20	79 (61)	1,350
Sparse coral	15	58 (45)	1,911
Dense seagrass	23	61 (47)	238
Sparse seagrass	34	36 (28)	82
Patchy coralline	19	27 (21)	743
Patchy vegetation	23	19 (15)	36
	Significant sites		
Spawning aggregations sites	80	23 (18)	
Turtle nesting sites	61	4 (3)	
Cultural areas	21	16 (12)	

2.8.2 Replication

Table 8 shows the number of no-take zones in which each feature occurs across the re-designed network. It shows that there was an overall increase in feature occurrence in no-take zones across the network. For example, reef flat was still the most replicated zone across the re-designed network. It occurred in over 90% of no-take zones with 1,842 reef flat patches protected. Back reef on the other hand only occurred in 5 no-take zones.

Generally live corals were the most replicated habitat feature across the re-designed network (Table 8). For instance, patchy coral was still the most replicated habitat feature across the network in 79% of no-take zones, continuous coral being the second most frequently occurring habitat feature in 62% of no-take zones and sparse coral in 58% no-take zones. Patchy vegetation was the least replicated habitat feature that occurred in 15 no-take zones.

Channels were the most protected significant sites across the re-designed network. In fact, channel was the most protected zone in the re-designed network (Table 8). Of the 100% Spawning Aggregation provincial target set, 80% was protected by the redesigned network. This was an increase of 38% protection for Spawning Aggregation sites. Over 60% known turtle nesting sites were also part of the re-designed network across 3 no-take zones. This was an increase of 37% in turtle nesting sites from the pre-existing network. Finally 21% cultural areas were included in 12 no-take zones in the re-designed network, a 13% increase from the 7% cultural areas protected by the pre-existing network.

Diversity of habitats across the re-designed network now range from one habitat type per no-take zone to seven distinct habitats per no-take zone. Figure 22 shows the percentage of no-take zones and the number of distinct habitat types they protect. Out of the seven distinct habitat types assessed, only 1% no-take zones protected all distinct habitat types, 5% of no-take zones protected six distinct habitats and 18% of no-take zones protected five distinct habitat types across the network. Most no-take zones (29%) protected four distinct habitat types and 22% of no-take zones protected three distinct across the network. Two distinct habitat types were protected by 13% no-take zones and finally one distinct habitat type was protected by 12% no-take zones.

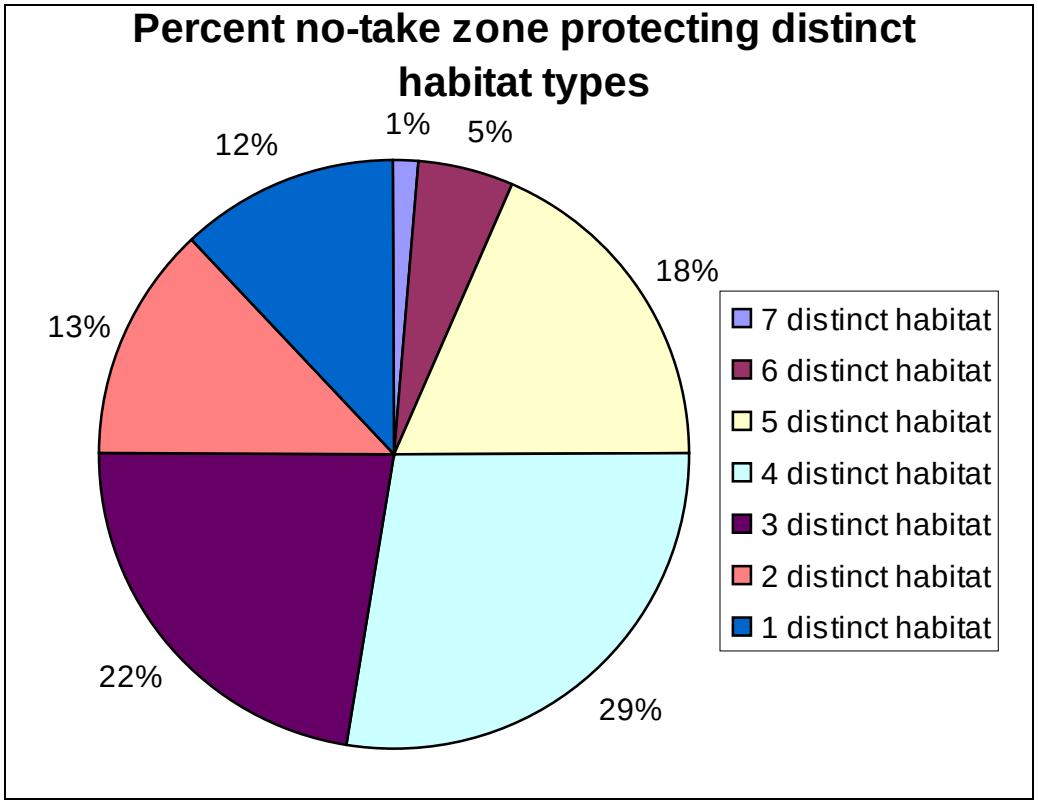


Figure 22: Percentage of no-take zones protecting different habitat types

2.8.2.1 Ecological linkages

Larval settlement and no-take zones spacing distance were used to assess ecological linkages before and after the project. They can create connection between no-take zones across the network. For larval settlement, there was an overall increase in hard substrate habitats in the re-designed network from the pre-existing network. Figure 23 below present graphs of the four detailed cover types (continuous coral, patchy coral, sparse coral and patchy coralline) and the total percent protected for larva settlement. The total hard substrate habitat now protected by the re-designed network is 42%, an increase of 7% over pre-project protection.

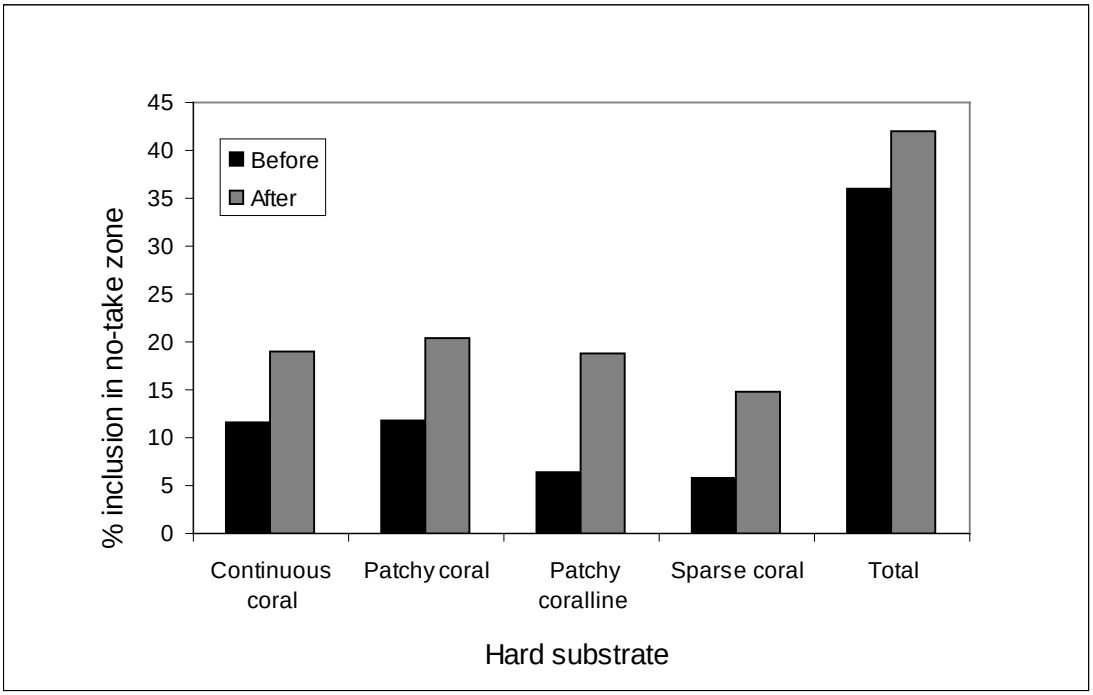


Figure 23: Percent hard substrate features protected by the pre-existing network before the project and the community re-designed network after the project.

The maximum spacing distance between no-take zones in the re-designed network is 10,543 meters (an increase of 87 meters) as shown in Table 9. The minimum spacing distance is now 136 meters, a reduction of 193 meters. The average spacing distance between no-take zones was 3,131 meters and is now 2,602 meters after the project (decreased by 529).

Table 9: No-take zone spacing distance before and after the project

Spacing parameter	Pre-existing network (meters)	Re-designed network (meters)
Maximum spacing distance	10,456	10,543
Minimum spacing distance	329	136
Average spacing distance	3,131	2,602

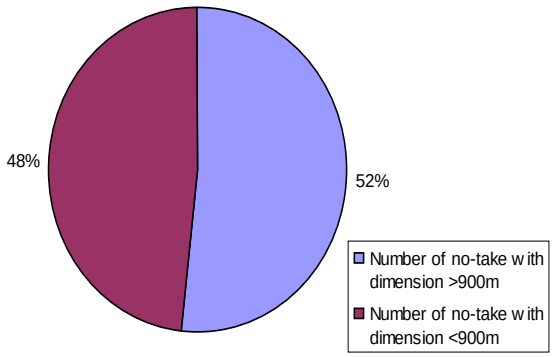
2.8.3 Maximising the contribution of individual no-take zones to the network

There are no upper limits on reserve size that are relevant to conservation goals but in general, upper limits are more likely to be set by practical considerations, cost or by user conflict than by biological considerations (Roberts et al. 2003). For fisheries benefits reserve size should not be too large (NRC 2000) and should depend on the target species involved and local oceanographic conditions (Roberts et al. 2003). An ecological network of moderately sized reserves is usually the favored option without compromising both fishery and conservation objectives (PISCO 2007; Roberts et al. 2001).

Individual reserves may be smaller if they are part of a network of reserves connected through dispersal of adults and larvae (Hastings and Botsford 1999). They must be large enough to capture the home-range sizes of many species, as well as allow for self-recruitment within the MPA by short-distance dispersers. In this case, the data of the study on the coral coast of Fiji on Lethrinidae fish was used. Findings suggest that on average Lethrinidae fish travels <900 m.

Table 10 showed that the maximum dimension of a no-take zone in the community re-designed network was over 4,500 meters and the minimum dimension was 89 meters. The average dimension across the network was over 1,000 meters which was also higher than the travel distance of Lethrinidae fish species. The number of no-take zones with dimensions greater than 900 meters was 40 out of 77 (52%) of the total no-take zones.

Table 10: Maximum dimension results for the pre-existing and the re-designed network

Long axis parameters	Pre-existing network	Re-designed network	Pie graph
Maximum no-take dimension	3,493 m	4,502 m	
Minimum no-take dimension	242 m	89 m	
Average dimension	983 m	1,073 m	
Number of no-take with dimension >900m	31	40	
Number of no-take with dimension <900m	29	37	

2.8.4 Social cost of the network

The sum of costs for the re-designed network was greater than the sum of costs for the pre-existing because the re-designed network had a greater number of planning units in no-take zones. However the average cost per planning unit graph below showed that there was a reduction in the individual costs in the re-designed network. For instance the average enforceability cost per planning unit was 0.00006 before the project and now 0.00004 after the project (a 13% decrease in cost). Fishing use intensity and disputed areas costs were also reduced by 12% and 10% respectively. On average the cost was reduced by 12.4% in the re-designed no-take zones network after the project.

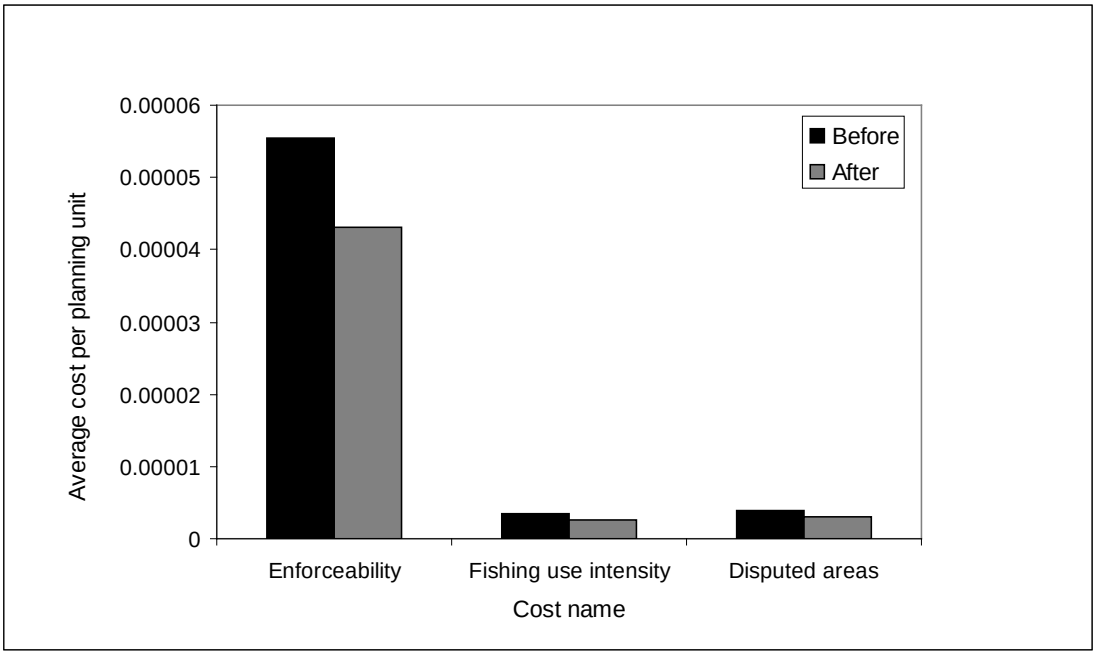


Figure 24: Average cost per planning unit before and after the project.

3 Discussion

3.1 Summarizing the effects of redesigning the no-take network

The following bullet points summarize parameter by parameter the effects of redesigning the no-take zone network. Most show that the redesigned network is likely to perform better ecologically than the existing.

- The number of no-take zones increased from 60 to 77 (increase by 17 no-take zones)
- The area protected increased from 29 sq km to 50 sq km (increase of 21 sq. km)
- The overall percentage of shallow areas protected rose from 12% to 19%

Protection of Geomorphological zone

Across all zones the average number of no-take zones each zone appears in has gone from 19 to 26.

- There has been a 12% increase in protection of back reef zone across all no-take zones.
- There has been a 21% increase in protection of channel zone across all no-take zones.
- There has been an 11% increase in protection of fore reef zone across all no-take zones.
- There has been a 7% increase in protection of intertidal zone across all no-take zones.
- There has been a 3% increase in protection of lagoon zone across all no-take zones.
- There has been an 11% increase in protection of reef crest zone across all no-take zones.
- There has been an 8% increase in protection of reef flat zone across all no-take zones.

Protection of habitat coverage

- There has been a 7% increase in protection of continuous coral habitat across all no-take zones.
- There has been an 8% increase in protection of patchy coral habitat across all no-take zones.
- There has been a 9% increase in protection of sparse coral habitat across all no-take zones.
- There has been a 7% increase in protection of dense seagrass habitat across all no-take zones.
- There has been a 19% increase in protection of sparse seagrass habitat across all no-take zones.
- There has been a 13% increase in protection of patchy coralline habitat across all no-take zones.
- There has been a 7% increase in protection of patchy vegetation habitat across all no-take zones.

Protection of Significant sites

- The area of spawning aggregations protected increased from 41% to 80%
- The area of turtle nesting sites protected increased from 24% to 61%
- The area of cultural sites protected increased from 7% to 21%

Diversity of habitats

The average number of distinct habitats in each no-take zones did not increase/decrease before and after the project. The average number of distinct habitat was 4 across all no-take zones.

Replication of habitats

Across all habitats the average number of no-take zones each habitat appears in has gone from 29 to 38.

- The number of no-take zones continuous coral appears in has gone from 36 to 48

- The number of no-take zones patchy coral appears in has gone from 46 to 61
- The number of no-take zones sparse coral appears in has gone from 34 to 45
- The number of no-take zones dense seagrass appears in has gone from 32 to 47
- The number of no-take zones sparse seagrass appears in has gone from 25 to 28
- The number of no-take zones patchy coralline appears in has gone from 16 to 21
- The number of no-take zones patchy vegetation appears in has gone from 11 to 15

Larval settlement

- There was an increase in total hard substrate features from 35% to 42% in the re-designed network (an increase of 7%)

Spacing

- Maximum spacing distance between two no-take zones was 10,456 (pre-existing) and 10,543 in the re-designed network (increased by 87 m).
- Minimum spacing distance between no-take zones was 329 in the pre-existing and 136 in the re-designed network (decreased by 193 m).
- Average distance between no-take zones decreased from 3,131m to 2,602 in the re-designed network.

Maximizing the contribution of individual no-take areas to the network

- The maximum dimension of the longest axis of no-take zones was 3,493 meters in the pre-existing and is now 4,502 meters in the re-deigned network (an increase of 1,009 meters).
- The minimum dimension of the longer axis of no-take zones was 242 meters in the pre-existing and is now 89 meters in the re-deigned network (a decrease of 153 meters).
- The average dimension of the longer axis of no-take zones was 983 meters in the pre-existing and now 1073 meters after the re-deigned network (an increase of 90 meters).

- Number of no-take zones with dimension greater than 900 meters was 31 in the pre-existing network and now 40 no-take zones in the re-designed network.

Cost

- On average the cost was reduced by 12.4% in the re-designed no-take zones network after the project.

3.2 Assessing the cost of the design approach

It is clear from the above summary of changes that there are likely ecological benefits that will result from the redesigning process. However, it is prudent to examine the financial costs associated with this process.

The total project implementation budget for this project was US$97,000 (approximately Fijian $170,000) The main costs included the acquisition of high resolution imagery (~US$26,000) and field work costs to collect both social use information and data used to subsequently derive habitat maps (~US$ 22,000).

Unpublished work done by the University of the South Pacific has estimated the cost of all pre-existing marine management work done in Kadavu including establishing the Kadavu Yaubula Management Support Team at Fijian $140,000.

In the coarsest sense, it is therefore possible to estimate the cost of establishing no-take zones per unit area. Performing these calculations, it is estimated to have cost Fijian $4,800 per km^2 to establish and maintain the existing no-take zones over an average of 4.6 years.

With an increase in protection of $21km^2$ during the redesign process, the average cost per unit area of the redesign process was approximately Fijian $8,100.

Interestingly, with most the expenditure being made on satellite imagery, it was felt by the project team that the main value of the project was in providing opportunities for communities to sit, assess their existing protection efforts and plan new and expanded no-take zones. Arguably with the cost associated with a scientific redesign, this could have been achieved at a far lower cost per unit area protected.

3.3 Lessons learned and recommendations

1. The inclusion of social cost layers is essential in the development of a no-take redesign- factors such as enforceability and local conflict are as important as lost opportunity cost of, for example, fishing.

2. The reserve design process used in this project was successful in promoting the inclusion of additional areas in protection; and contributed to better reflection of networking principles; and managed to achieve so at a lower lost opportunity cost (fishing, enforcement etc).

3. Community participation is essential- in many ways, Fiji lends itself to such a project where customary marine tenure dictates the implicit involvement of communities.

4. In many instances the stakeholders involved in the design and re-design of no-take zones in Fiji are few; there are not large commercial fishing fleets in inshore areas and tourism operations are, aside from in a few areas, sparsely distributed. Therefore some of the complexities of redesigning protected area networks found elsewhere are not applicable in Fiji.

5. The reserve design process used has proven expensive per unit area protected- arguably the value was in engaging with communities and similar results could have been achieved at a lower cost per unit area.

6. It is worth examining more cost-effective means to derive the input data used in the reserve design process. For example, it maybe possible to use community drawn maps instead of those derived from satellite imagery; or use a lower descriptive resolution based on geomorphological ecological proxies.

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