Western Bua Resilience Survey 2012 Report

YASHIKA NAND, AKUILA CAKACAKA, REBECCA WEEKS AND STACY JUPITER

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Introduction

Marine resources are crucially important for coastal communities in Fiji for the ecosystem services that they provide, such as food, income and shoreline protection (Laurans et al. 2013). Both local threats (e.g., land-based pollution, overfishing) and global threats (e.g. coral bleaching from elevated sea surface temperatures) are increasingly eroding coastal ecosystem services from coral reefs and causing negative impacts on human livelihoods. To address these challenges, it is important to understand how coral reef ecosystems are likely to respond in order to prioritize areas for management that might be more able to either resist disturbance or recover more quickly from impact. We call these areas "resilient" (Obura and Grimsditch 2009).

In Bua Province, Fiji, the Wildlife Conservation Society (WCS) developed a ridge-to-reef management model using ecosystem-based management (EBM) tools to assist local communities to sustainably manage their natural resources. The model was first tested and adapted in Kubulau District, where WCS worked with the 10 villages to develop and subsequently refine a management plan that included provisions for management of a marine protected area (MPA) network within the Kubulau traditional fisheries management area (*i qoliqoli*; Clarke and Jupiter 2010).

The initial Kubulau MPA network design was informed by biological data, socioeconomic assessments and extensive consultation with communities. In 2009, management of these areas was formalised when village chiefs endorsed the Kubulau Ecosystem-Based Management (EBM) Plan, Fiji's first ridge-to-reef management plan that includes rules and regulations for all of the terrestrial and marine habitats in the district (Clarke and Jupiter 2010). By 2011, two factors motivated a revision of the Kubulau EBM Plan: the need to improve management effectiveness, and the desire to make the MPA network more robust to climate change impacts (Jupiter and Egli 2011; Weeks and Jupiter 2013). WCS suggested ways to change the size and shape of the existing MPA boundaries to make them more recognizable and also increase the opportunity to protect fish during their daily home range movements. In addition, WCS carried out new surveys of coral reef resilience indicators likely to be related to the ability of reef areas to resist or recovery from disturbance. These new field data, described below, were integrated with new habitat maps of coral reef regions in order to advise on further ways to strengthen the Kubulau MPA network to reduce likely impact from climate disturbance.

WCS subsequently applied these methods to advise the districts of Wainunu, Nadi and Solevu (Bua Province) and Wailevu (Cakaudrove Province) on options for developing resilient MPA networks. EBM plans have been endorsed for Wainunu and Wailevu, with endorsement for EBM plans in Nadi and Solevu anticipated by January 2014. This report describes data collection and analyses of resilience indicators from 5 districts in western Bua (Vuya, Dama, Bua, Lekutu, Navakasiga) in November and December 2012, as well as production of maps to be used in consultation with local communities to develop options for expanding their existing MPA networks.

Methods

In November and December 2012, WCS staff surveyed reef habitats across 5 districts of western Bua, including Vuya, Dama, Bua, Navakasiga and Lekutu (Figure 1). The team surveyed 86 sites in 5 weeks, using methods described in WCS (2010) and collected data on the following:

- *Site information* – a short summary on specific characteristics that included reef type, management efforts, survey techniques used, number of replicates for data collection, and any species of interest (sharks, turtles, bump-head parrotfish, hump-head wrasses).
- *Site description* – qualitative assessment of environmental and physical factors related to resilience, such as reef profile, visibility, local knowledge of current patterns, tidal flushing and potential natural shading effects.
- *Fish abundance and size* – abundance and size of different fish species.
- *Coral dominance* – relative abundance of different types of corals at the genus level
- *Juvenile corals* – corals smaller than 10 cm in 3 different size classes as a measure of potential for reef recovery.

- *Benthic data* – types of bottom cover and complexity of the reef structure.

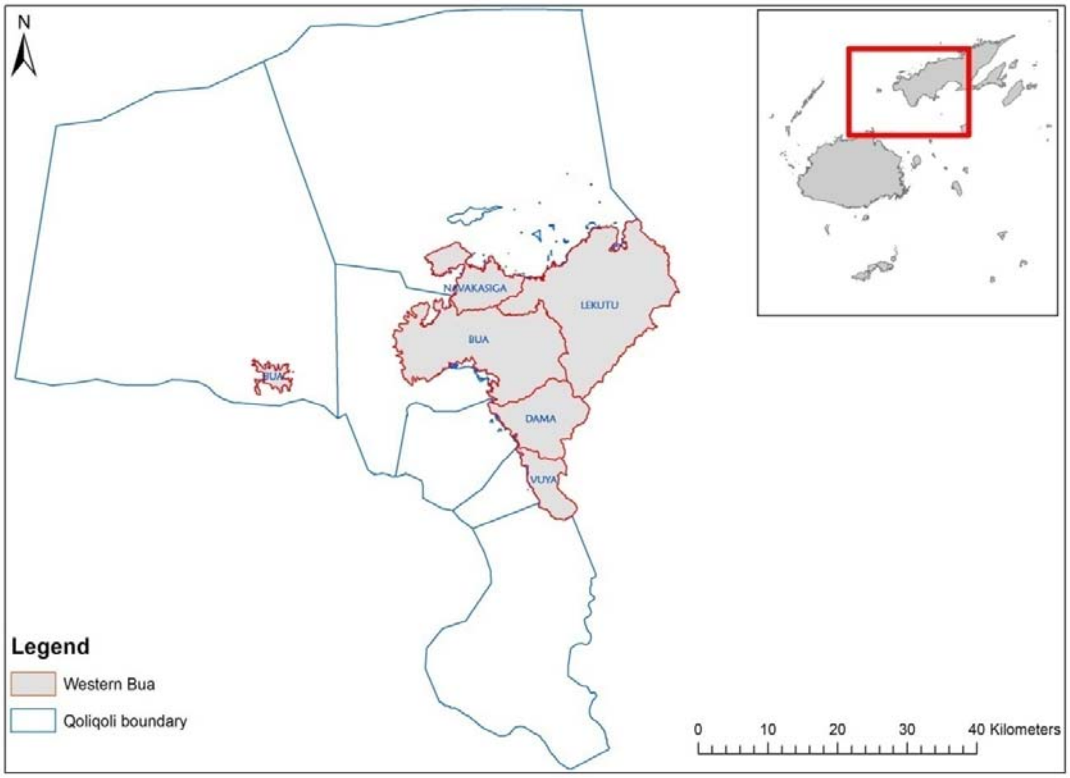

Figure 1: Map of Bua province with the five districts that were surveyed.

We used the above data to calculate four potential indicators of reef resilience. Each of these is described briefly below:

Herbivory Potential

Herbivores are animals that eat plants and algae. On coral reefs in Fiji, there are different types of herbivores, including some groups of fish and sea urchins. We restricted our assessment of herbivory potential (i.e., the relative amount of clearing of micro- and macroalgae from the reef) to groups of herbivorous fish only. This is a very important function on coral reefs as it clears space for new coral recruits to settle and reduces harmful interactions between corals and algae (Obura and Grimsditch 2009; Rasher and Hay 2010). This indicator is important because it enable us to understand if a reef system will come back to its functional state from a damaging event (Green & Bellwood, 2009).

Green and Bellwood (2009) describe four different groups of herbivorous fish found on tropical coral reefs in the western Pacific, including: (1) scrapers and small excavators; (2) large excavators; (3) browsers; and (4) grazers and detritivores. We calculated herbivory potential at each site surveyed based on the relative (standardised) amount of biomass of all herbivorous fish recorded and the average number of different herbivore functional groups observed at that site.[1]

Coral-Algal Balance

The balance between the amount of corals and algae describes the current health of the reef site and also may be a good predictor of the ability of reefs to recover from disturbance (McClanahan et al.

[1] Herbivore potential was calculated as the standardized average total herbivore biomass score plus the standardized average number of herbivore functional groups, divided by two to downweight the impact of number of functional groups.

2012). Macroalgae can limit recovery of corals by increasing competition for space for coral larvae to settle, attacking corals with chemical defences (called "allelopathy"), and by trapping sediment that smothers coral larvae when they settle (Kuffner et al. 2006; Mumby et al. 2007; Rasher and Hay 2010). The presence of high amounts of macroalgae may also stress corals and reduce their ability to resist disturbance. For example, coral may have reduced growth rates in the presence of macroalgae and disease transmission from algae can weaken coral health, making it potentially more susceptible to coral bleaching (West and Salm 2003; Mumby et al. 2007). We calculated coral-algal balance as the standardised site average of coral cover minus the standardised site average of macroalgal cover.

Site Susceptibility Index (SSI)

The site susceptibility index focuses on the differing ability of different types of corals to resist or tolerate thermal stress which can lead to coral bleaching (Obura & Grimsditch, 2009). For example, massive boulder corals tend to be more tolerant of stress and a high abundance of these types of corals would indicate that a site overall is more resistant to disturbance (Loya et al. 2001). We calculated an index of site susceptibility based on the relative dominance of each coral genera at each site multiplied by its predicted tolerance to thermal disturbance, and then divided by the total number of taxa per site. Higher scores indicate sites that are likely to be the most resistant to disturbance from anomalously high or low sea surface temperatures.

Recruitment Potential

The term "recruit" refers to a coral that has newly arrived on the reef after settling from its larval stage in the plankton. The amount of coral recruitment may indicate how fast a reef system is able to recover after a major disturbance (Colgan 1987; Mumby and Harbourne 2010). Because new coral recruits tend to be too small to observe with the naked eye during underwater visual census during the day, we measured small coral colonies (<5 cm), which indicate not only that corals successfully recruited, but that they were able to survive and grow at that site for a couple of years. Recruitment potential also depends on the amount of suitable space on which coral larvae can settle: they prefer to settle on certain species of crustose coralline algae while avoiding turf algae (Harrington et al. 2004). We therefore calculated recruitment potential of a site as the relative amount of available settlement space (standardized site average of crustose coralline algal cover minus the standardised site average of turf algal cover), plus the relative coral survivorship potential (standardised juvenile coral density).

District surveys and results

The five districts of western Bua comprise 66% of Bua Province's land area and 16% of the land area of Vanua Levu. They additionally include 78% and 28% of the coral reef habitat of Bua Province and Vanua Levu, respectively. Bua Province is one of Fiji's least developed regions, with high poverty levels and dependence on natural resources. Communities, comprised mostly of indigenous Fijians, are fairly sparse (5-22 people per km^2) and isolated from markets and urban centres due to poor transportation infrastructure. Local communities hold customary rights to the resources in their forests and fishing grounds, which are managed in practice through traditional systems of governance. Primary means of livelihoods include farming, logging, and sale of sea cucumbers.

WCS's reef surveys indicated generally high levels of mean coral cover (37-48%) and reasonable levels of fish biomass (721-1,303 kg/ha; Table 1). As these are the first comprehensive surveys of reefs in the region, we are unable to assess trends; however, the values fall well within range of sites open to fishing that were surveyed in the nearby Kubulau District between 2007 and 2009 (Jupiter and Egli 2011). On December 17, 2012, following the field surveys, coastal villages and adjacent habitats were hit by Category 4 Tropical Cyclone Evan, which caused extensive damage to housing infrastructure and may have impacted reef habitats.

Table 1. Summary statistics for district population size, number of households, land area, fisheries management area, reef area within qoliqoli boundaries, mean live hard coral cover and mean total fish biomass.

District	Pop.	# house-holds	Land (km^2)	Fisheries management area (km^2)	Reef area (km^2)	Mean coral cover (% ± 1 SE)	Mean fish biomass (kg/ha ± 1 SE)
Vuya	1046	202	65	2742	110	45.7 ± 3.3	1079 ± 440
Dama	2417	433	109	209	24	39.6 ± 4.3	721 ± 104
Bua	1354	265	288	383	36	37.4 ± 3.3	1303 ± 223
Lekutu	3167	152	359	1821[a]	155	48.1 ± 2.9	987 ± 98
Navakasiga	624	196	78				

[a] Lekutu and Navakasiga districts share the same traditional fisheries management area (qoliqoli).

Bua District

Mangroves, mudflats and other reef types cover essential habitat that support marine life (corals, fish and invertebrate) and protect shoreline protection. Deep lagoons cover the majority of the qoliqoli area, while there are small portions of mangroves and mudflats inshore. There are 7 existing community managed tabu area within the qoliqoli.

We surveyed resilience factors and calculated resilience indices at 15 sites across different habitat types in the qoliqoli. Figure 2 shows the results for herbivory potential. Larger green dots on the map indicate that there were greater numbers, sizes and types of herbivorous fish (e.g. many species of parrotfish and surgeonfish) at those sites. Total average herbivore fish biomass varied from 193 – 2243 kg ha^{-1} across sites.

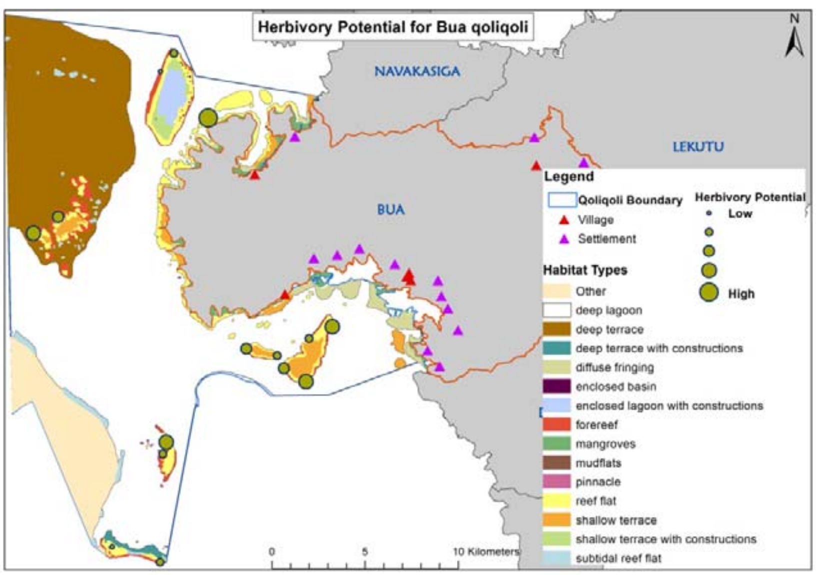

Figure 2: Map of herbivory potential for Bua qoliqoli. The size of the green dots at the survey sites indicate the predicted relative amount of herbivory based on the abundance, size and types of herbivorous fish present.

Figure 3 indicates the relative present "health" of the reef as defined by the balance between live hard coral and macroalgae. Larger blue circles on the map are sites with relatively higher live coral cover and less macroalgae. Average live hard coral cover varied from 17-56%, while average macroalgal cover varied from 0-28%.

Figure 4 shows the relative coral susceptibility to bleaching at each site. The sites with the largest orange dots indicate the most thermally tolerant coral communities that are less likely to experience bleaching from heat stress. The smaller dots represent coral communities that are primarily composed of coral genera that may easily get stressed if sea surface temperatures are above mean summer temperatures for a prolonged period.

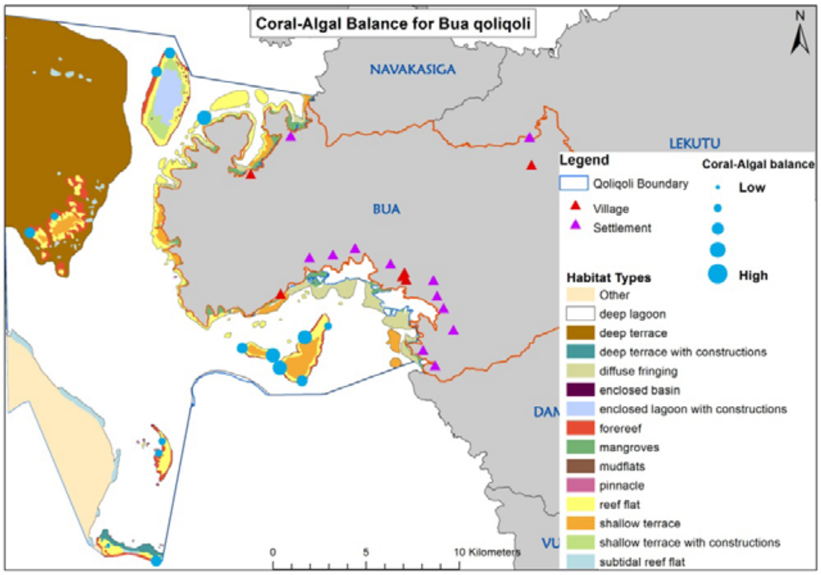

Figure 3: Map of coral-algal balance for Bua qoliqoli. The size of the blue dots at the survey sites indicate the relative amount of live coral minus macroalgal cover.

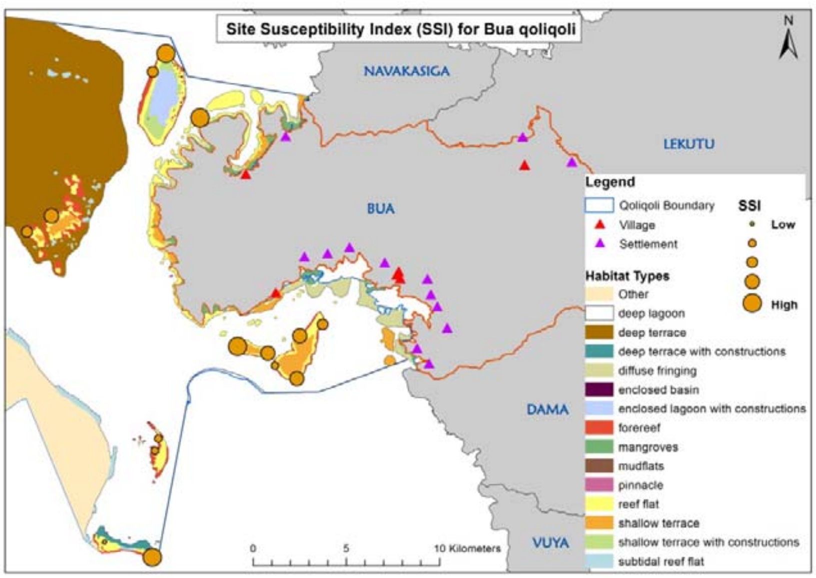

Figure 4: Map of relative site susceptibility to coral bleaching in Bua qoliqoli. Larger orange dots indicate more tolerant coral communities.

Figure 5 shows the spatial distribution of relative potential for coral recruitment across Bua qoliqoli. There were 3 sites with high potential for coral recruit settlement and survival (larger yellow dots) and 2 of these sites were inside tabu areas.

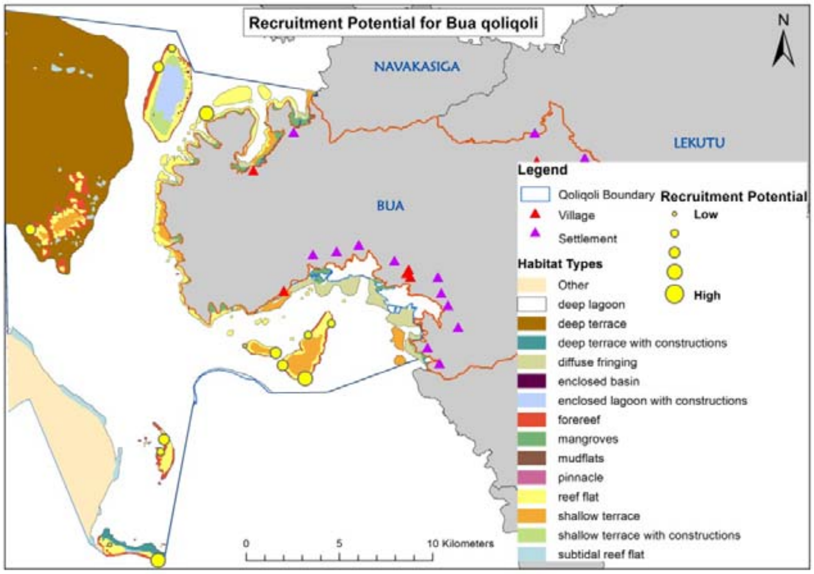

Figure 5: Map of relative coral recruitment potential for Bua qoliqoli. Larger yellow dots indicate higher potential for recruit settlement and survivorship.

Dama District

There are 12 major coral reef geomorphic habitat classes in Dama qoliqoli, as well as substantial amounts of mangroves and mudflats. Dama has a large tabu area that covers ~13.25 km^2 of forereef, reef flat and shallow terrace (Appendix 1).

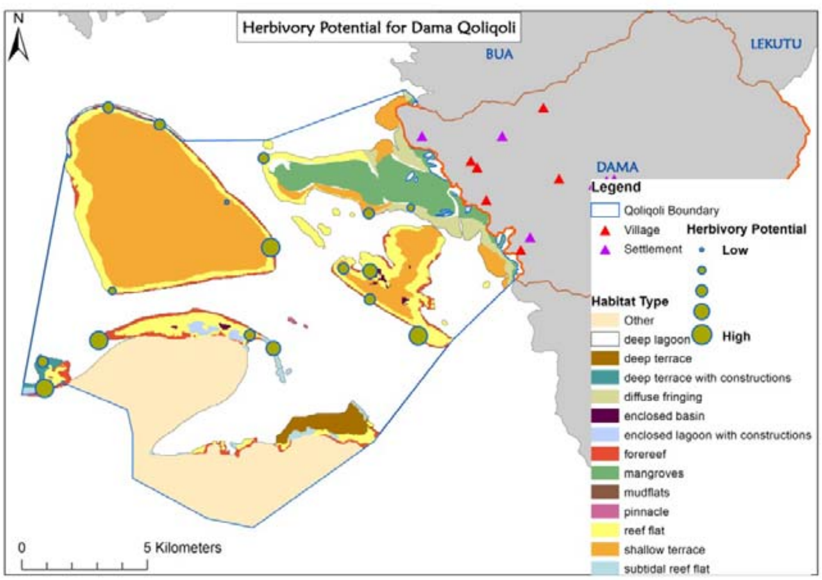

Figure 6: Map of herbivory potential for Dama qoliqoli. The size of the green dots at the survey sites indicate the predicted relative amount of herbivory based on the abundance, size and types of herbivorous fish present.

We surveyed resilience factors and calculated resilience indices at 17 sites across different habitat types in the qoliqoli. Figure 6 shows the results for herbivory potential. Total average herbivore fish biomass varied from 0 – 1054 kg ha^{-1} across sites.

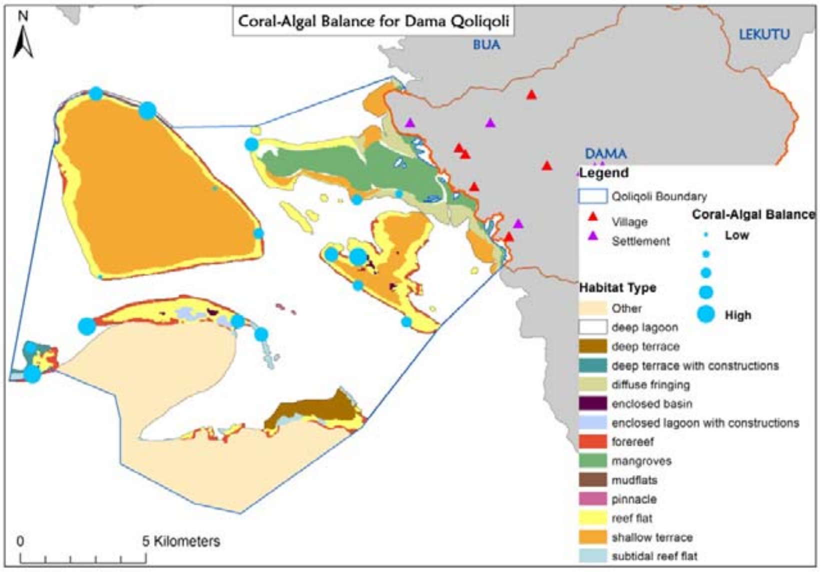

Figure 7: Map of coral-algal balance for Dama qoliqoli. The size of the blue dots at the survey sites indicate the relative amount of live coral minus macroalgal cover.

Figure 7 indicates the relative present "health" of the reef as defined by the balance between live hard coral and macroalgae. Average live hard coral cover varied from 1-77%, while average macroalgal cover varied from 0-9%.

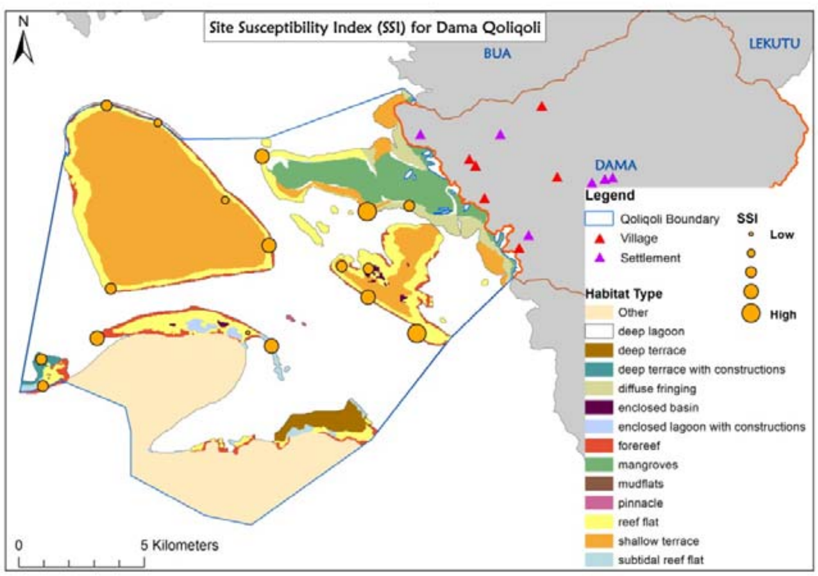

Figure 8: Map of relative site susceptibility to coral bleaching in Dama qoliqoli. Larger orange dots indicate more tolerant coral communities.

Figure 8 shows the relative coral susceptibility to bleaching at each site. The sites with the largest orange dots indicate the most thermally tolerant coral communities that are less likely to experience bleaching from heat stress. These tended to occur around fringing reefs that are accustomed to receiving high volumes of sediment. Figure 9 shows the spatial distribution of relative potential for coral recruitment across Dama qoliqoli. Three of the 4 sites surveyed inside tabu area showed high recruitment potential. Surveys conducted on other habitat types, such as shallow terrace and deep terrace with constructions, showed low recruitment potential except for one site that was closer to the tabu area.

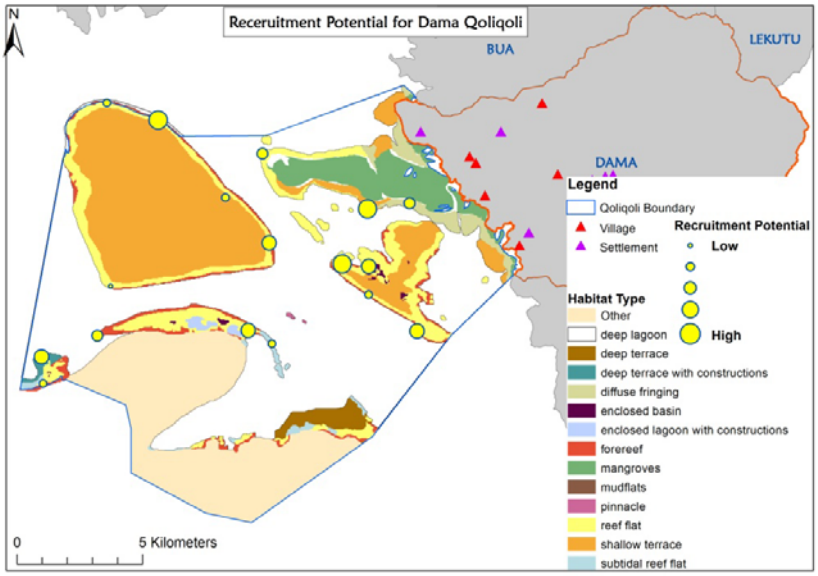

Figure 9: Map of relative coral recruitment potential for Dama qoliqoli. Larger yellow dots indicate higher potential for recruit settlement and survivorship.

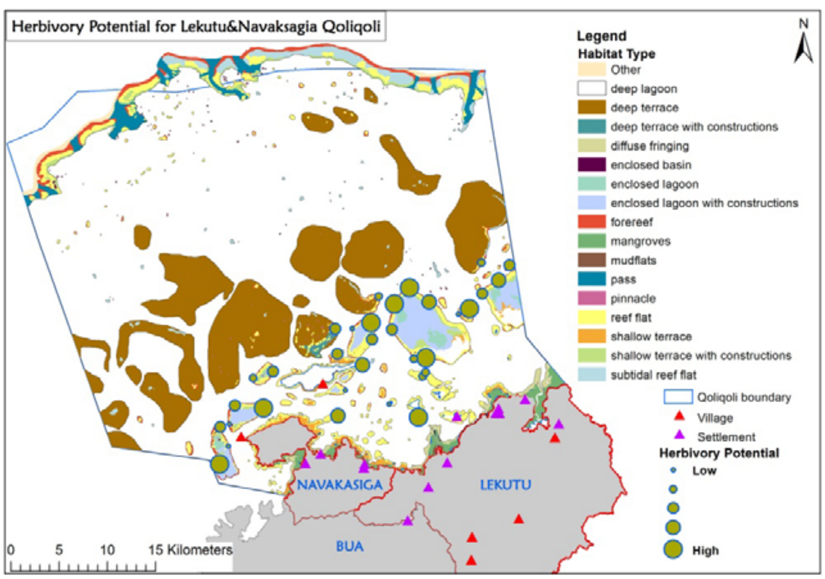

Figure 10: Map of herbivory potential for Lekutu/Navakasiga qoliqoli. The size of the green dots at the survey sites indicate the predicted relative amount of herbivory based on the abundance, size and types of herbivorous fish present.

Lekutu/Navakasiga Districts

The districts of Lekutu and Navakasiga share the same qoliqoli boundary with an area of 1821 km^2. This qoliqoli covers one of the most diverse reef ecosystems in western Bua Province, with approximately 17 different habitat types including mangroves and mudflats. We surveyed resilience factors and calculated resilience indices at 33 sites across different habitat types in the qoliqoli. Figure 10 shows the results for herbivory potential. Total average herbivore fish biomass varied from 54 – 1811 kg ha^{-1} across sites. Figure 11 indicates the relative present "health" of the reef as defined by the balance between live hard coral and macroalgae. Average live hard coral cover varied from 16-91%, while average macroalgal cover varied from 0-5%. Figure 12 shows the relative coral susceptibility to bleaching at each site. Most sites within 5 km from land are composed of relatively thermally tolerant coral genera, likely because silty conditions have prevented dominance of fast growing, thermally sensitive genera like *Acropora* and *Pocillopora*. Figure 13 shows the spatial distribution of relative potential for coral recruitment across Lekutu and Navakasiga qoliqoli.

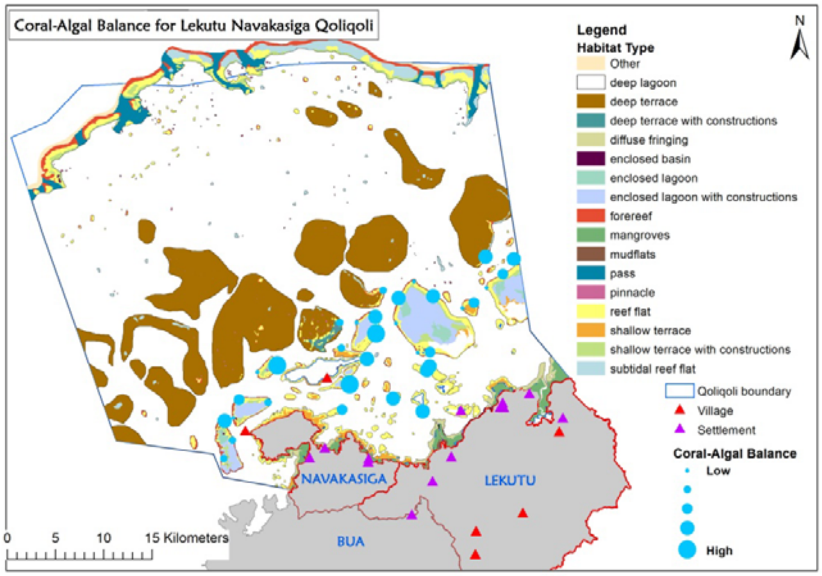

Figure 11: Map of coral-algal balance for Lekutu/Navakasiga qoliqoli. The size of the blue dots at the survey sites indicate the relative amount of live coral minus macroalgal cover.

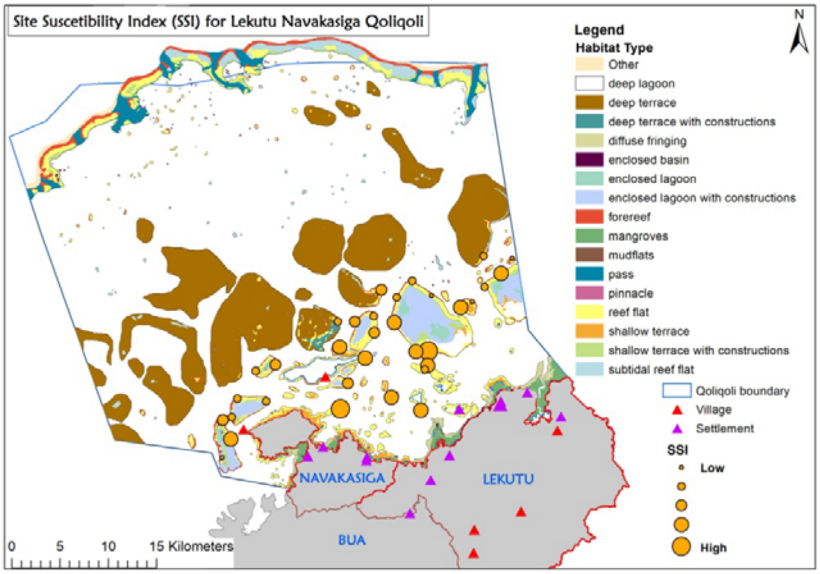

Figure 12: Map of relative site susceptibility to coral bleaching in Lekutu/Navakasiga qoliqoli. Larger orange dots indicate more tolerant coral communities.

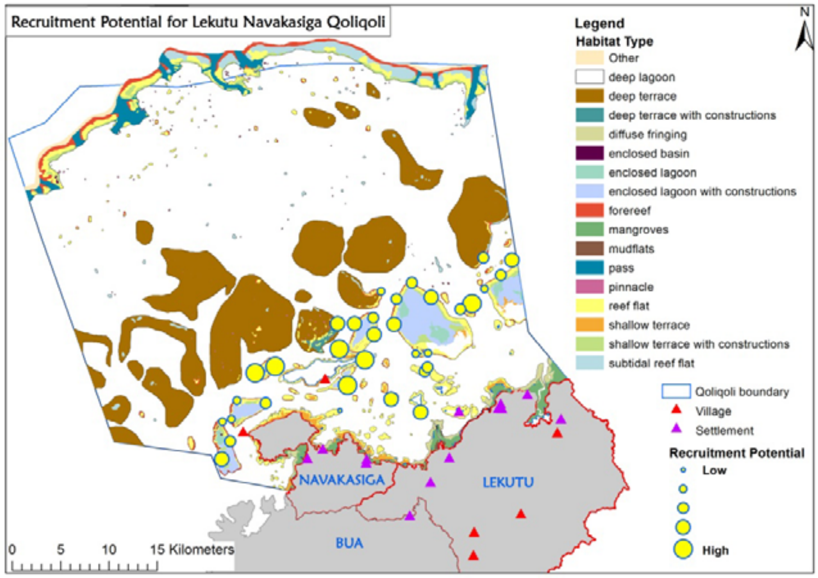

Figure 13: Map of relative coral recruitment potential for Lekutu/Navakasiga qoliqoli. Larger yellow dots indicate higher potential for recruit settlement and survivorship.

Vuya District

Vuya District consists of two qoliqoli that covers an area of 761 km^2. There are 13 different types of habitats and 3 existing tabu areas within the two qoliqoli. Vuya district has 4 villages and 8 settlements. Our survey was restricted only to 4 sites because of adverse weather conditions and cyclone warnings, thus, the results below are only a snapshot and should not be interpreted as being broadly representative of the entire reef system within the two qoliqoli.

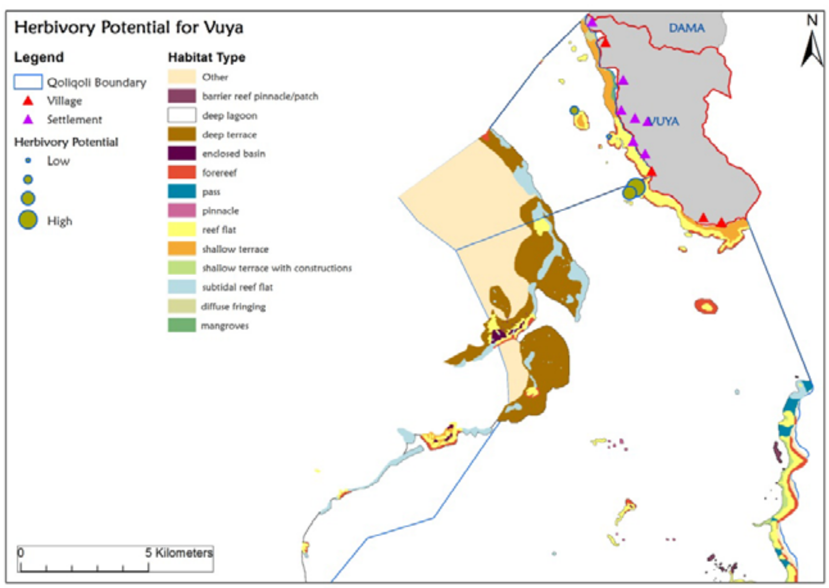

Figure 14: Map of herbivory potential at 4 inshore sites in Vuya qoliqoli. The size of the green dots at the survey sites indicate the predicted relative amount of herbivory based on the abundance, size and types of herbivorous fish present. The southern portion of Vuya qoliqoli is cut off as weather prohibited reef surveys more than 2 km offshore.

Figure 14 shows the results for herbivory potential. Total average herbivore fish biomass varied from 8 – 940 kg ha^{-1} across sites. Figure 15 indicates the relative present “health” of the reef as defined by the balance between live hard coral and macroalgae. Average live hard coral cover was high, ranging from 47-63%, while average macroalgal cover varied from 1-13%. Figure 16 shows the relative coral susceptibility to bleaching at each site, while Figure 17 shows the spatial distribution of relative potential for coral recruitment across the four sits surveyed.

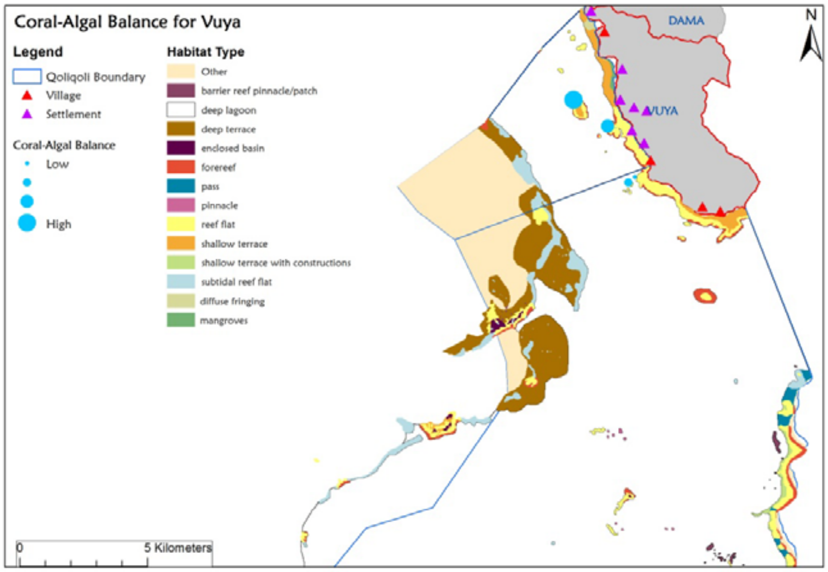

Figure 15: Map of coral-algal balance for Vuya qoliqoli. The size of the blue dots at the survey sites indicate the relative amount of live coral minus macroalgal cover.

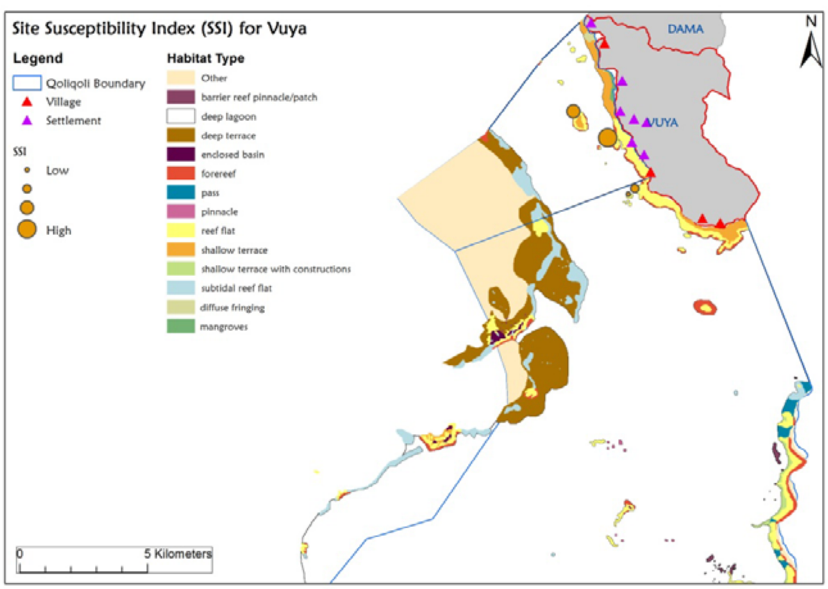

Figure 16: Map of relative site susceptibility to coral bleaching in Vuya qoliqoli. Larger orange dots indicate more tolerant coral communities.

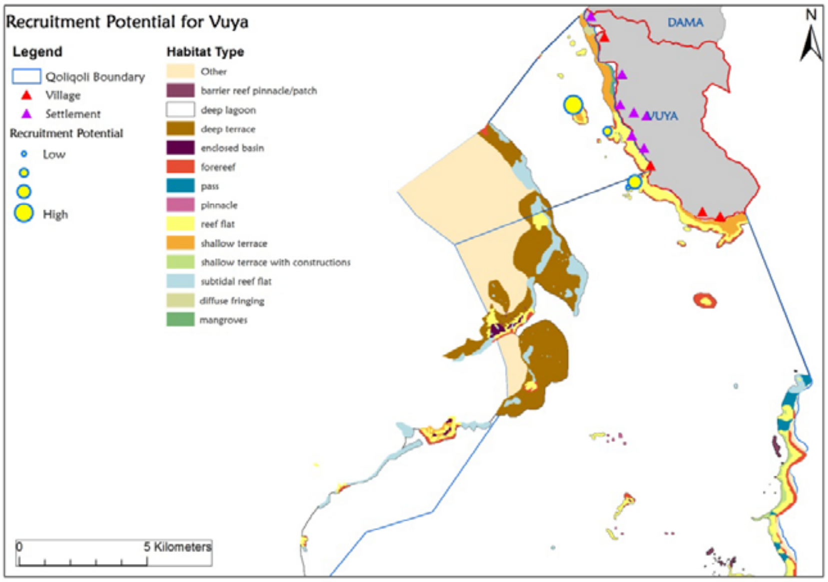

Figure 17: Map of relative coral recruitment potential for Vuya qoliqoli. Larger yellow dots indicate higher potential for recruit settlement and survivorship.

Yadua

The qoliqoli in which Yadua Island sits is formally registered to the Buli Raviravi. It covers only a small portion of land area that includes Yadua Island and Yadua Taba. The qoliqoli area is 1981 km^2 containing 15 types of reef geomorphic habitat. High swells and winds prevented our team from surveying reefs and pinnacles more than 10 km away from Yadua Island, and thus sites tended to be concentrated within sheltered bays. We surveyed a total of 16 sites surveyed, 4 sites inside tabu areas and 12 sites in open fished areas.

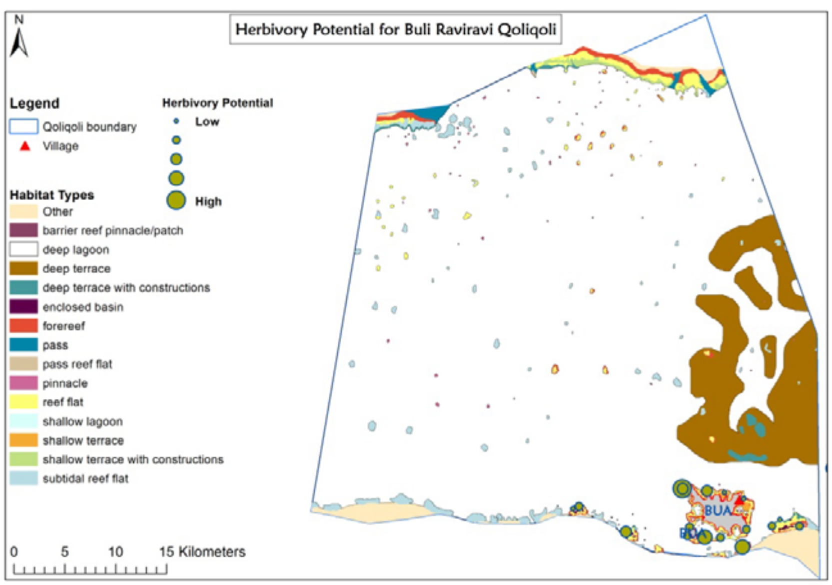

Figure 18: Map of herbivory potential at sites around Yadua Island. The size of the green dots at the survey sites indicate the predicted relative amount of herbivory.

Figure 18 shows the results for herbivory potential. Total average herbivore fish biomass varied from 95 – 1430 kg ha^{-1} across sites. Figure 19 indicates the relative present “health” of the reef as defined by the balance between live hard coral and macroalgae. Average live hard coral cover was high, ranging from 17-79%, while average macroalgal cover varied from 0-33%. Figure 20 shows the relative coral susceptibility to bleaching at each site, while Figure 21 shows the spatial distribution of relative potential for coral recruitment across the four sits surveyed.

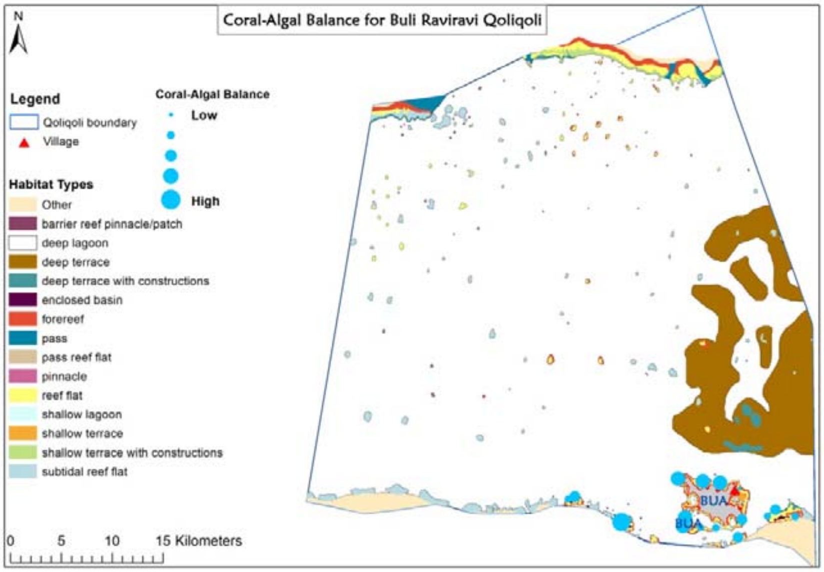

Figure 18: Map of coral-algal balance for sites around Yadua. The size of the blue dots at the survey sites indicate the relative amount of live coral minus macroalgal cover.

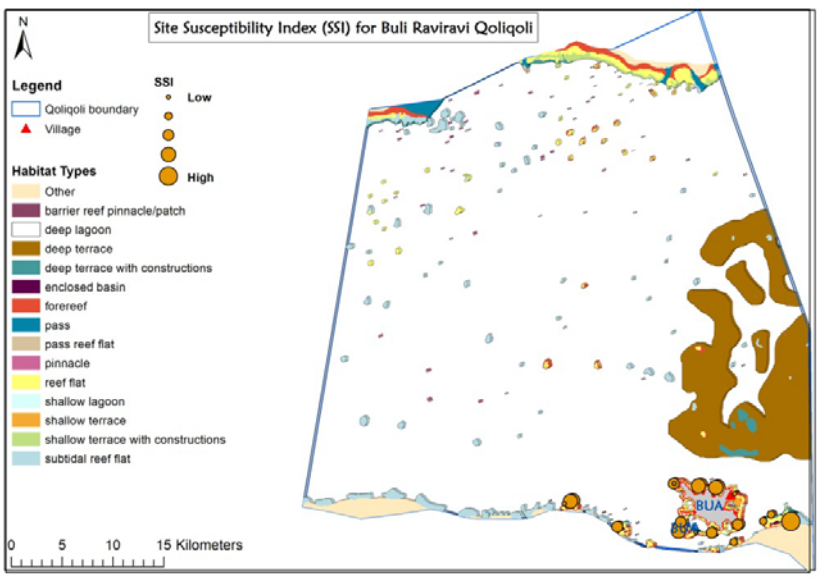

Figure 20: Map of relative site susceptibility to coral bleaching around Yadua Island. Larger orange dots indicate more tolerant coral communities.

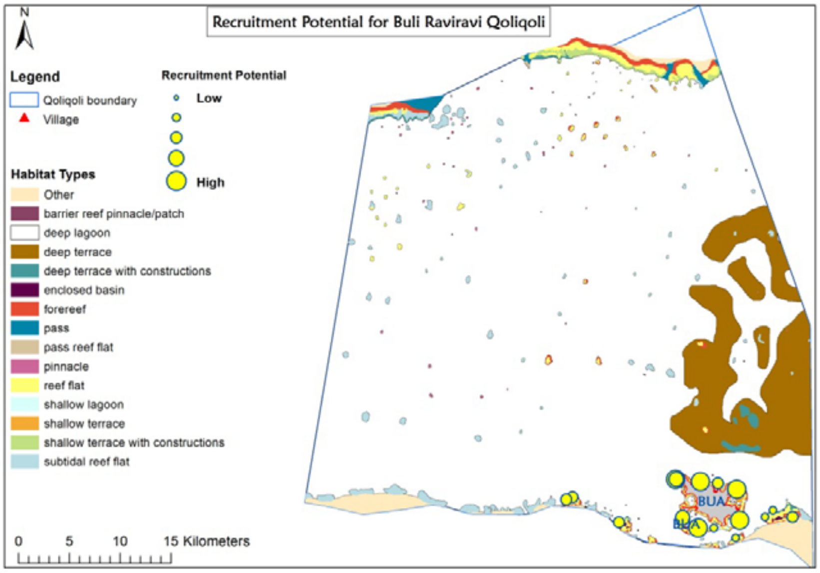

Figure 21: Map of relative coral recruitment potential around Yadua Island. Larger yellow dots indicate higher potential for recruit settlement and survivorship.

Recommendations for MPA network design

Table 2 outlines general principles for resilient MPA network design and the measures that WCS has taken to apply these across western Bua Province. Below, we provide further details on how recommendations were formulated for representation of habitat types.

A principal objective of MPA network design is to ensure that all habitat types present within the region are adequately represented (Roberts et al. 2003). Protecting the full range of habitat types maximizes the likelihood of capturing the full range of biodiversity within them (McLeod et al. 2009), and connections between them (McCook et al. 2009). Managers should endeavour to protect multiple examples of each habitat type (replication), and spread these across the region to reduce the chance that they are all impacted by a major disturbance event (McLeod et al 2009).

Acquisition of high-resolution habitat maps in 2011 from the Millennium Coral Reef Mapping Project (Andrefouet et al. 2006) has greatly improved our ability to assess and plan for habitat representation for MPA network design across western Bua Province. Following the Fiji Government commitment to protect and effectively managed 30% of its inshore and offshore marine habitat (Jupiter et al. 2010), we proposed a representation targets such that the total amount of coral reef habitat selected would equal approximately 30% of the qoliqoli area within the six qoliqoli (Vuya, Raviravi, Dama, Bua, Lekutu & Navakasiga, Raviravi/Yadua) across the western Bua planning region (Figure 1). We set targets for individual coral reef habitats ranging from 10-40%, with habitats more important for fisheries production (e.g. forereefs) having higher targets.

We used the conservation-planning software Marxan (Ball and Possingham 2000) to explore how the MPA networks might be developed to improve habitat representation across western Bua Province. Marxan is a decision-support tool that assists users to identify MPA networks that achieve specified biodiversity objectives while minimizing socioeconomic impacts. When provided information on the amount of each biodiversity feature (in this case reef habitat types) in each “planning unit”, Marxan identifies sets of planning units that achieve biodiversity targets in an efficient manner. In this case, our measure of efficiency took into account management costs that would be associated with establishment of MPAs far offshore with respect to the amount of fuel that would need to be purchased for surveillance and enforcement. We calculated fuel cost from coastal villages to reefs within a distance of 5 km, 10 km, and 100 km and assigned costs that increased exponentially with the amount of fuel that would need to be purchased for a return trip to each location. Reefs within 5 km from villages had the lowest fuel cost, hence the cost of setting up and managing protected areas within this distance was low. Reefs further away from coastal villages had a high fuel cost, therefore high management costs, such that it would be less likely for Marxan to select these areas in choosing areas to add to suggested MPA networks. Existing MPAs were "locked in" to the Marxan solutions, so that new sites were prioritised on the basis the conservation value that they contributed to the existing system.

Table 2. Application of recommendations for resilient MPA network design to the Kubulau qoliqoli

Resilience principle[1]	Strategy for Western Bua
Size: "Bigger is better" – MPAs should be large enough to protect the full range of marine habitat types and the ecological processes on which they depend	Encourage communities to increase the size of existing small tabu areas, which may be smaller than the home range of targeted fish species.
Shape: Simple shapes should be used to minimize edge effects while maximizing interior protected area	Recommend that MPA boundaries follow the reef edge, especially where confusion over boundaries has led to reduced management effectiveness.
Risk spreading: Protect at least 20–30% of each habitat type overall, with replicates spread out to reduce the chances they will all be affected by the same disturbance event	Establish reasonable targets to achieve 30% protection of critical reef areas for fisheries production; Marxan outputs provide priority maps for achieving this goal. Highlight underrepresented habitats and where they might be protected to communities.
Critical areas: Protect critical areas that are most likely to survive the threat of climate change	Sites with high natural resilience to climate change-induced bleaching events identified through analysis of WCS survey data and prioritised for inclusion in MPA reconfigurations.
Connectivity: MPAs should be spaced a maximum distance of 15–20 km apart to allow for replenishment via larval dispersal	Because individual villages have traditional fishing grounds (*i kanakana*) that are generally within this distance, this principle is generally easy to apply when each village establishes their own tabu area.
Maintain ecosystem function: Maintain healthy populations of key functional groups, particularly herbivorous fishes	Communicate the importance of herbivores to reef resilience to communities through workshop presentations; Distribute "Fish Rulers" to communities include recommended size limits for parrotfishes.
Ecosystem-based management: Embed MPAs in broader management frameworks that address other threats external to their boundaries	Embed MPA networks within broader EBM Plans for districts of western Bua Province, revising management rules where necessary.

[1] Adapted from McLeod et al. (2009)

When run multiple times, Marxan produces a "selection frequency" output: the number of times that each planning unit was selected for inclusion in an MPA network that achieved the representation target. Sites that have a high selection frequency are likely to be important to achieve the conservation objective, and should be prioritised for protection. Selection frequency maps offer a clear way to communicate priorities to local stakeholders, and do not have the appearance of a "decision already made." A map of the selection frequency outputs for Marxan run across all of western Bua appears is presented in Figure 22. Areas in red were selected the most number of times and mean that they would be most important to include in MPA network designs to ensure adequate habitat representation across the 6 qoliqoli.

The maps of the relative resilience indicator values can be combined with maps that show important areas to improve habitat representation to use as a starting point for discussions of where to add to the existing MPA network for a stronger design (Weeks and Jupiter in press).

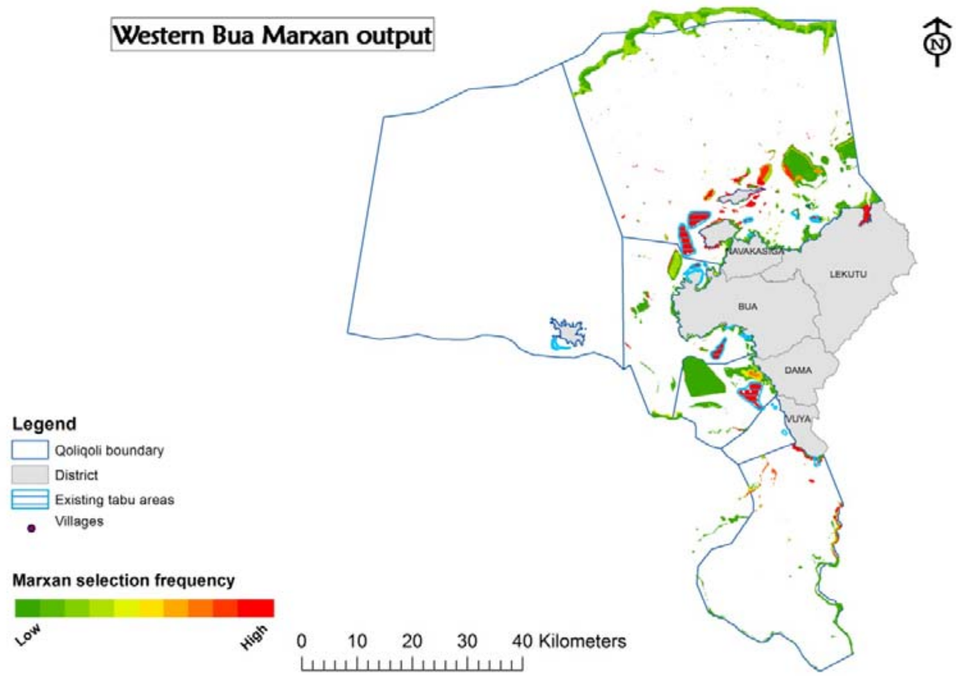

Figure 22: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs across western Bua Province. Areas in red were selected the most number of times and are most important for representing coral reef habitats that support fisheries production at the least cost for enforcement.

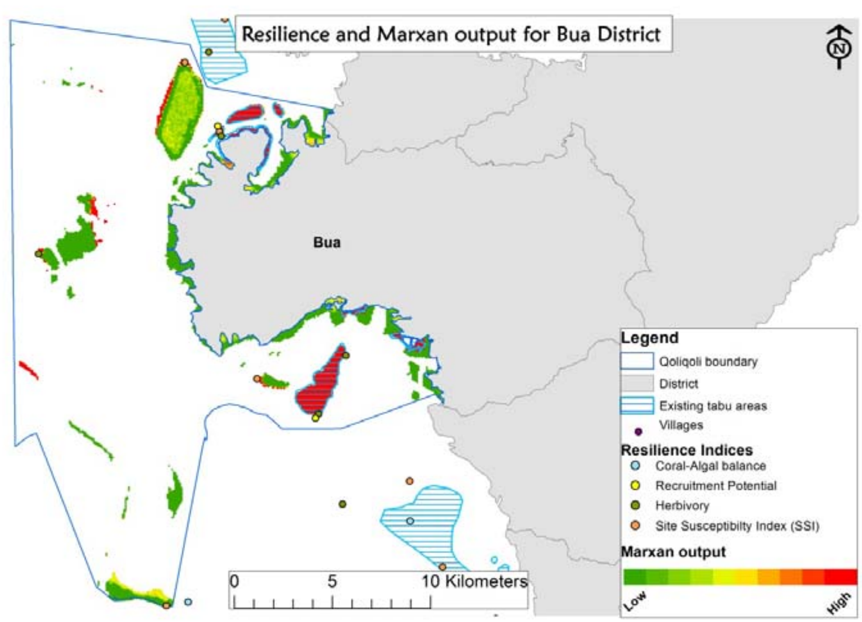

Figure 23: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs specifically within Bua District. Areas in red were selected the most number of times and are most important for representing coral reef habitats that support fisheries production at the least cost for enforcement. Sites that are most important for resilience indicators are shown in blue (for coral-algal balance), yellow (for recruitment potential), green (for herbivory potential), and orange (for the least site susceptibility to bleaching.

Additional maps by qoliqoli in Figures 23-27 show priority areas in red for habitat representation, and inclusion of sites that are most important for present coral reef health (coral-algal balance), herbivory potential, recruitment potential, and sites with the least potential susceptibility to coral bleaching. We recommend that a range of these sites be considered as priorities for placement in MPAs as the will theoretically help create a stronger MPA network that might be better able to resist and recover from climate disturbance.

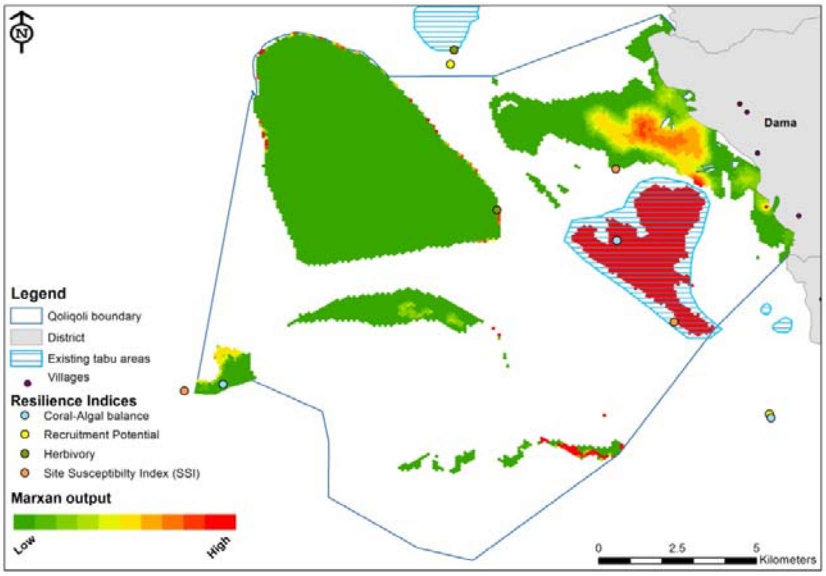

Figure 24: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs specifically within Dama District qoliqoli.

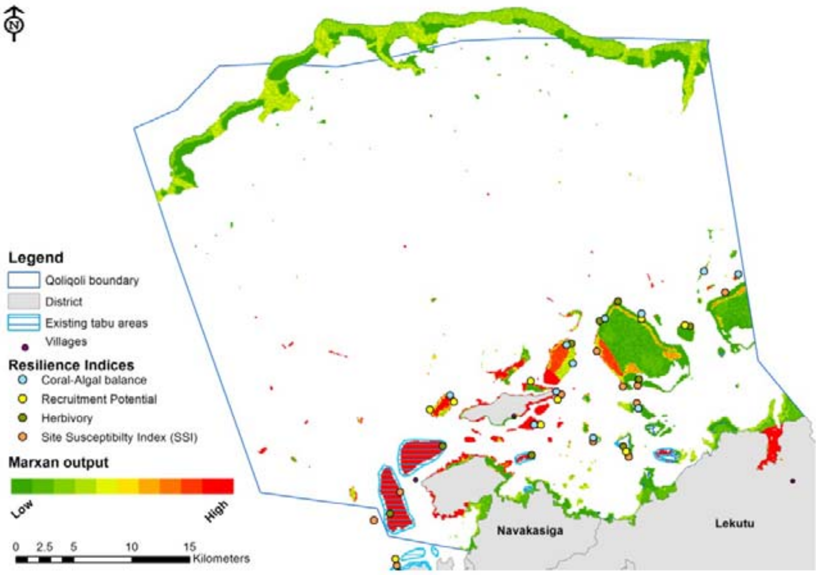

Figure 25: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs specifically within Lekutu and Navakasiga district qoliqoli.

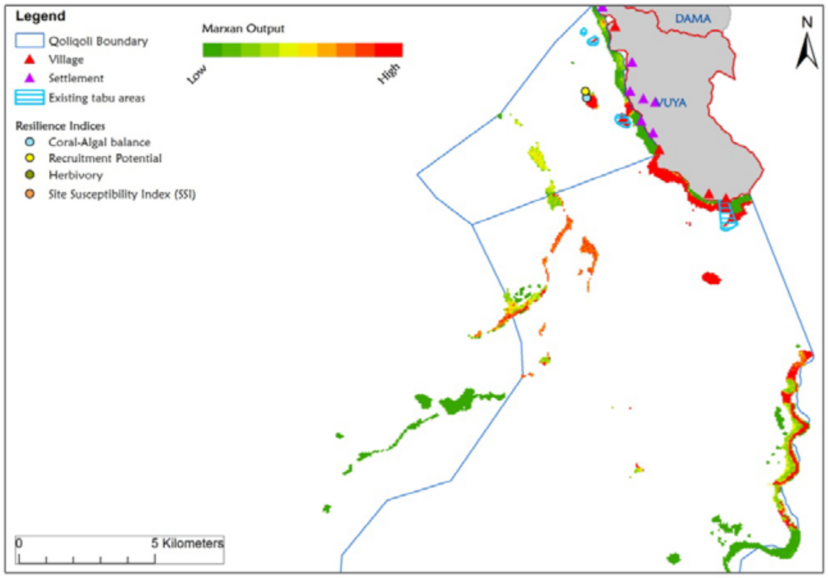

Figure 26: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs specifically within Vuya district two qoliqoli.

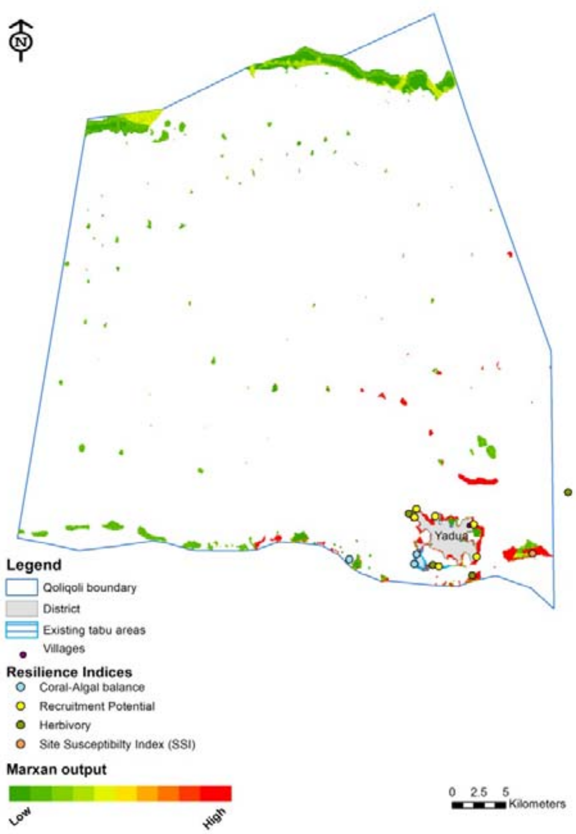

Figure 27: Map of selection frequency outputs for areas to prioritise for inclusion within MPAs specifically within the qoliqoli surrounding Yadua Island and reefs.

Conclusion and Recommendations

Our surveys of western Bua Province indicated that the reefs were generally in good condition, with some sites that appear to potentially be highly resilient to climate impacts.

Based on the findings of this research, we recommend that:

1. The results of these surveys should be used to form the basis for initial discussions with community members to identify priority sites for expansion of existing MPA networks
2. Existing tabu areas that were found to be resilient, such as Bavu Bua tabu, should be maintained with proper monitoring and enforcement of rules
3. Consultations should be as participatory as possible, recognizing the interests of all resource users in each district.

References

Andrefouet S, Muller-Karger FE, Robinson JA, Kranenburg CJ, Torres-Pulliza D, Spraggins SA, Murch B (2006) Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. 10th International Coral Reef Symposium:1732-1745

Ball IR, Possingham HP (2000) MARXAN (V1.8.2): Marine reserve design using spatially explicit annealing, a manual. University of Queensland, Brisbane

Clarke P, Jupiter SD (2010) Law, custom and community-based natural resource management in Kubulau District (Fiji). Environmental Conservation 37:98-106

Colgan MW (1987) Coral reef recovery on Guam (Micronesia) after catastrophicpredation by *Acanthaster planci*. Ecology 68: 1592-1605

Green AL, Bellwood DR (2009) *Monitoring Functional Groups of Herbivorous Reef Fishes as Indicators ofCoral Reef Resilience: A practical guide for coral reef managers in the Asia Pacific Region.* IUCN, Gland, Switzerland: IUCN working group on Climate

Harrington L, Fabricius K, De'ath G, Negri A (2004) Recognition and selection of settlement substrata determine post-settlement survival in corals. Ecology 85:3428-3437

Jupiter SD, Egli DP (2011) Ecosystem-based management in Fiji: successes and challenges after five years of implementation. Journal of Marine Biology 2011 doi:10.1155/2011/940765

Jupiter S, Mills M, Comley J, Batibasaga A, Jenkins A (2010) Fiji marine ecological gap assessment: interim progress report. Wildlife Conservation Society, Suva, Fiji 26 pp

Kuffner IB, Walters LJ, Beccero MA, Paul VJ, Ritson-Williams R, Beach KS (2006) Inhibition of coral recruitment by macroalgae and cyanobacteria. Marine Ecology Progress Series 323:107-117

Laurans Y, Pascal N, Binet T, Brander L, Clua E, David G, Rojat D, Seidl A (2013) Economic valuation of ecosystem services from coral reefs in the South Pacific: Taking stock of recent experience. Journal of Environmental Management 116:135-144

Loya Y, Sakai K, Yamazato K, Nakano Y, Sambali H, van Woesik R (2001) Coral bleaching: the winners and the losers. Ecology Letters 4:122-131

McClanahan TR, Donner SD, Maynard JA, MacNeil MA, Graham NAJ, Maina J, Baker AC, Alemu JB, Beger M, Campbell SJ, Darling ES, Eakin CM, Heron SF, Jupiter SD, Lundquist CJ, McLeod E, Mumby PJ, Paddack MJ, Selig ER, van Woesik R (2012) Prioritizing key resilience indicators to support coral reef management in a changing climate. PLoS ONE 7:e42884. doi:42810.41371/journal.pone.0042884

McCook LJ, Almany GR, Berumen ML, Day JC, Green AL, Jones GP, Leis JM, Planes S, Russ GR, Sale PF, Thorrold SR (2009) Management under uncertainty: guide-lines for incorporating connectivity into the protection of coral reefs. Coral Reefs 28:353-366

McLeod E, Salm R, Green A, Almany J (2009) Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7:362-370

Mumby PJ, Harbourne AR (2010) Marine reserves enhance the recovery of corals on Caribbean reefs. PLoS ONE 5:e8657

Mumby PJ, Harborne AR, Williams J, Kappel CV, Brumbaugh DR, et al. (2007) Trophic cascade facilitates coral recruitment in a marine reserve. Proceedings of the National Academy of Sciences of the United States of America 104: 8362-8367

Obura DA (2004) Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean. Estuarine Coastal and Self Science 63:353–372.

Obura D, Grimsditch G (2009) *Resilience Resilience Assessment of coral reefs– Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress. IUCN working group on Climate Change and Coral Reefs.* Gland, Switzerland: IUCN

Rasher DB, Hay ME (2010) Chemically rich seaweeds poison corals when not controlled by herbivores. Proceedings of the National Academy of Sciences 107:9683-9688

Roberts CM, Branch G, Bustamante RH, Castilla JC, Dugan J, Halpern BS, Lafferty KD, Leslie H, Lubchenco J, McArdle D, Ruckelshaus M, Warner RR (2003) Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecological Applications 13:S215-S228

Smith J, Shaw M, Edwards R, Obura D, Pantos O, Sala E et al. (2009). Indiret effects of alage on coral: alage-mediated, microbe-induced coral mortality. Ecology Letters 9*:* doi:10.1111/j. 1461-0248.2006.00937.x

WCS (2010) *WCS-Fiji marine biological handbook. Version 3.0.* Suva, Fiji: Wildlife Conservation Society.

WCS (2012) *Ecosystem-Based Management Plan: Kubulau District, Vanua Levu, Fiji.* Suva, Fiji: Wildlife Conservation Society.

Weeks R, Jupiter SD (2013) Adaptive co-management of a marine protected area network in Fiji. Conservation Biology doi: 10.1111/cobi.12153

West JM, Salm RV (2003) Resistance and resilience to coral bleaching: implications for coral reef conservation and management. Conservation Biology 17:956-967

Appendix 1

Map of reef geomorphic habitats across Western Bua, with locations of WCS survey sites from November – December 2012.