TECHNICAL REPORT:

EVALUATING THE PERFORMANCE OF LMMAS IN THE DISTRICTS OF KOROLEVU-I-WAI, DAWASAMU, AND NAKOROTUBU

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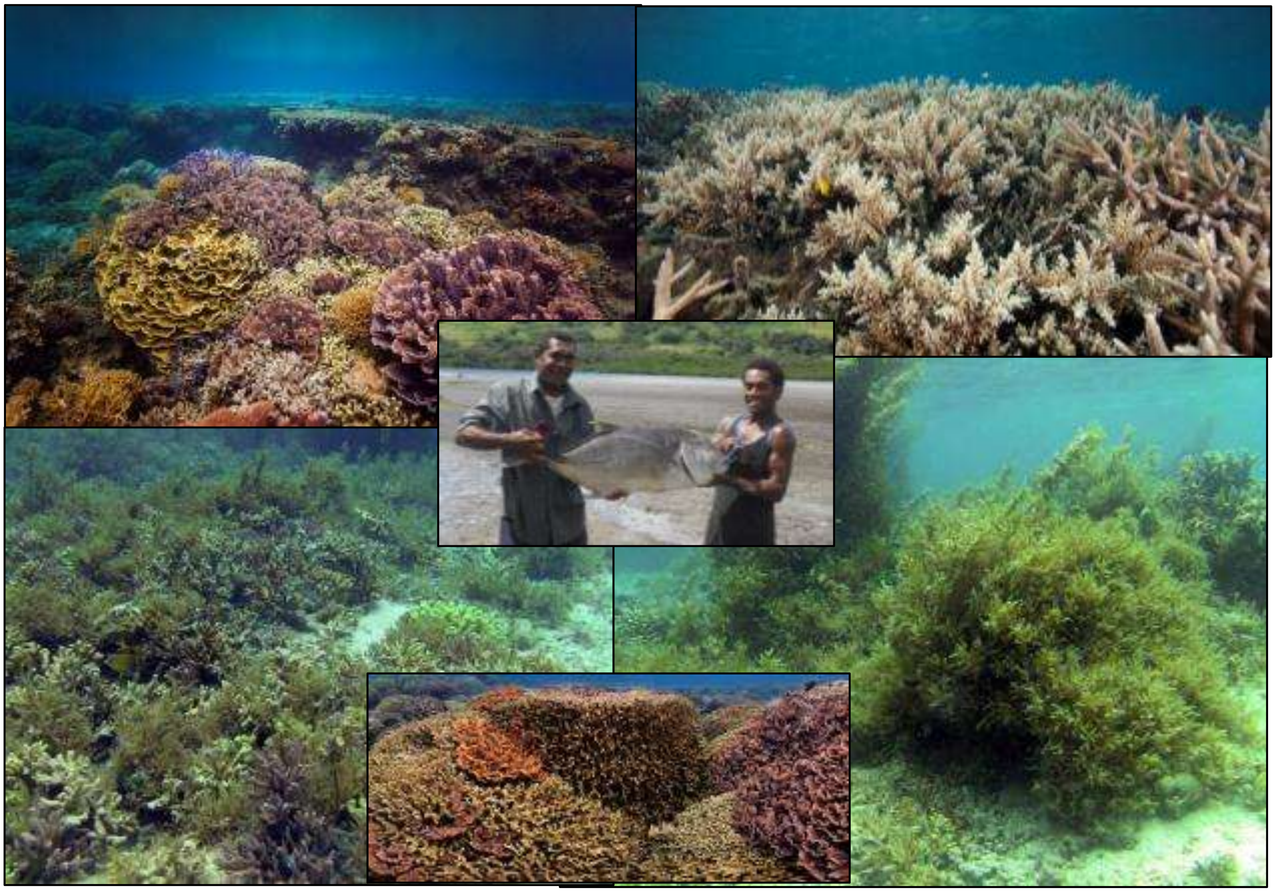

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1. INTRODUCTION

Unsustainable fisheries practices have contributed to worldwide declines in the coral reef ecosystems upon which coastal island populations depend for food security and livelihoods (Jackson et al. 2001). The dependence of coastal populations on these ecosystems makes fisheries management efforts especially challenging, particularly in tropical developing countries, such as the island nations of the South Pacific, where exploitation is often for subsistence purposes and limited resources are available for management. As the South Pacific is faced with overfishing and subsequent declines of marine resources due to population growth and climate change related issues, the ability of coral-reef fisheries to support future nutritional demands is uncertain (Kronen et al. 2010). With these fisheries likely to remain a primary source of subsistence protein in most Pacific island nations in the foreseeable future, effective approaches of protecting, maintaining, and restoring coral-reef ecosystems need to be implemented (Lubchenco et al. 2003).

Community-based adaptive co-management can be an effective approach to replenish depleted reef fish stocks and restore impacted marine ecosystems, particularly in South Pacific islands nations whose indigenous communities have significant control over their resources (Cinner et al. 2005, McClanahan et al 2006, Cinner and Aswani 2007, Bartlett et al. 2009; Govan 2009, Cinner et al 2012). The broad-scale acceptance of Locally-Managed Marine Areas (LMMAs) across the Pacific Islands is testimony to communities' perception of likely benefits which include recovery of natural resources, improved food security, improved security of tenure, and improved community organization and governance (Govan 2009). The establishment of LMMAs, with various levels of external partner participation and financing, is currently a primary fisheries and marine ecosystem management tool in Fiji where there are currently over 217 LMMAs located in 116 traditional Fijian fishing grounds covering approximately 10,800 km^2 of marine area (Govan 2009). In Fiji, LMMAs have been developed via participatory techniques with some level of external assistance and have management plans that generally address overfishing, destructive fishing and pollution threats, and alternative enterprise development.

Though no-take areas cover only approximately 600km^2 or 5.5% of Fijian LMMAs, their establishment is often an important part of Fijian LMMA strategy to improve fisheries resources (Govan 2009). Typically, no-take areas are established to serve two critical functions for coral reef ecosystems: (1) to preserve and protect the resources in the no-take area, and (2) to maintain a healthy reproductive stock of corals and other reef organisms in the no-take area that can enhance adjacent more impacted communities by providing adults and larvae. An abundance of case studies from around the world demonstrate how species abundance, biomass, size, species richness, reproductive potential, and community structure have benefited from protection (e.g. Halpern and Warner 2002, Gell and Roberts 2003, Halpern and Warner 2003, Claudet et al. 2008, Lester et al. 2009, Aburto-Oropeza et al 2011). Some studies now indicate that open-access fishing grounds can benefit from management restrictions placed on adjacent fishing grounds (McClanahan and Hicks 2011). There is also growing evidence that the resilience of coral reef ecosystems is strongly dependent on the presence of key functional groups, including large herbivorous and predatory fishes (Mora et al. 2006). Losses of critical functional groups can trigger negative indirect effects on coral reefs through trophic cascades (DeMartini et al. 2008, Sandin et al. 2010). Thus, for a no-take area to successfully protect and enhance resources the populations of functional groups that perform key ecosystem processes (e.g. herbivores, apex predators) must be maintained.

Since the establishment of marine regulations can only address the issues of over-extraction and direct damage to reef resources, the effectiveness of coral reef management efforts can often be improved when a holistic, integrated management approach is taken where coral reef ecosystems are protected from land based impacts thus building resilience. Many of the activities that cause environmental degradation are land-based, notably siltation from watershed activities (i.e. forestry, agriculture, mining) and coastal construction, and wastewater pollution. Thus, the effectiveness of LMMAs is largely dependent upon their being coupled with land management activities in adjacent watersheds as a means to control the impacts of sedimentation and pollution. Otherwise, the smothering effects of sediments and pollutants can cause disease and death to species, disrupt critical ecosystem functions, cause changes in the structure and dynamics of the food chain, and impede coral growth, reproduction and settlement of coral larvae.

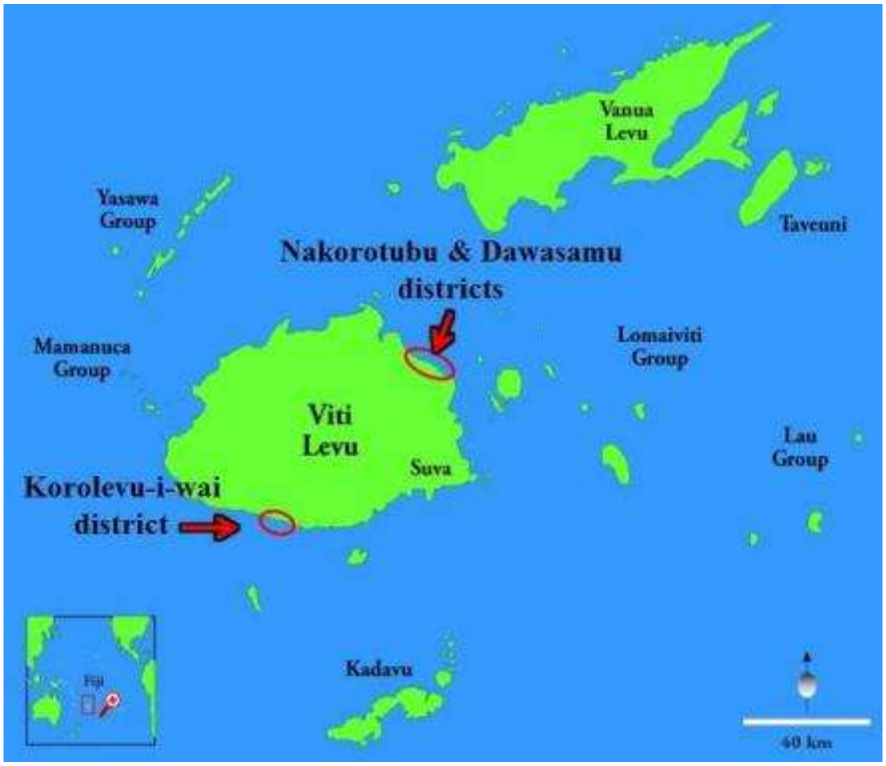
Globally and in Fiji, many coral reefs have undergone phase-shifts from coral to macro-algal dominated communities as reef communities have been impacted by over-extraction, destructive fishing practices, land-based pollutants, and bleaching events (Hughes et al. 2003, Bellwood et al. 2004, Diaz-Pulido et al. 2011). When populations of key herbivores are overfished or otherwise decline to a point where they are unable to graze back fleshy macro-algae, a phase-shift can occur as fleshy algae overgrow and cause damage to corals (Rasher and Hay 2010, Rasher et al. 2011), reduce coral fecundity, inhibit coral recruitment (Kuffner & Paul 2004), and spatially replace corals as they die. Scarids, Acanthurids (*Naso* spp.), Siganids, and Kyphosids are considered key herbivorous fishes that collectively remove the commonly dominant fleshy brown algae (*Padina*, *Turbinarea*, *Sargassium*, *Dictyota*) (Fox and Bellwood 2008, Hoey and Bellwood 2009, Hoey and Bellwood 2011) and calcified red and green algae (*Amphiroa*, *Halimeda*), thus their protection is critical to maintaining coral reef ecosystem integrity.

Most of the established no-take areas in Fijian LMMAs are relatively small (median size 1km^2, mean 2.6km^2) (Govan 2009). However, despite their generally small size, the establishment and enforcement of no-take areas are often considered critical components to LMMA success (Govan 2009) though few data have been collected regarding the efficacy of these small no-take areas in protecting stocks of exploited fishes (though see Clements et al. 2012) or conserving coral reef habitat. Additionally, there is some debate whether no-take areas with permanent or temporary closures are ultimately more successful in achieving the long-term fisheries benefits community-management schemes often aim for (Cinner et al. 2005, McClanahan et al. 2006). While the concept of banning harvesting from an area in order to improve target fish or invertebrate abundance and biomass within the area is generally well-understood and commonly practiced in traditional Fijian management regimes, the ban is usually just temporary and accrued benefits are often harvested after a certain period of closure; permanent closures to enhance adjacent fished area have not commonly been a part of traditional management practices. While periodic closures followed by harvesting can achieve some fisheries management objectives under certain management contexts (McClanahan et al 2006), carefully-regulated harvesting is not often practiced in Fiji and intense fishing pressure is generally experienced after no-take closures are lifted leaving the benefits accrued by the closure rapidly harvested (e.g. in Kubulau - Jupiter et al. 2012, in Navakavu - Semisi Meo personal communication, in Komave – Bonito personal communication); this intense harvesting can result in slipping baselines and continued overall decline of the fisheries depending on the overall context and management strategy of the fishing ground.

While community-based LMMAs have been widely established in Fiji and across the South Pacific (Govan 2009), relatively little has published regarding the long-term fisheries and conservation benefits they can offer under varying management regimes and levels of fishing pressure and development. Similarly, little is known about the long-term benefits that relatively-small no-take areas can offer in terms of fisheries enhancement and biodiversity conservation though they are being widely applied with such objectives as a part of LMMA strategies. Moreover, socioeconomic factors (e.g. access to customary fishing grounds, enforcement potential) often take precedence over ecological factors (size, habitat inclusion) when communities select locations for no-take protection (Aalbersberg et al. 2005). Apart from establishing no-take areas, generally few other fishing regulations beyond national fisheries laws are placed by communities in their LMMAs. Though national laws in Fiji that regulate fisheries as of June 2012 have size class, species, gear, and area restrictions (e.g. Fiji Islands Fisheries Act, Fiji Islands Endangered and Protected Species Act), rural areas often comply with customary tenure practices which don't always follow national regulations. Under more development pressure, compliance to customary tenure generally declines.

This study aimed to evaluate the performance of LMMAs established in customary Fijian fishing grounds of various sizes under a range of different management regimes, fishing pressures, and levels of development to determine whether any commonly-sought after fisheries and conservation benefits have been derived from these community-based co-management LMMA efforts. Study sites include LMMA projects established in two areas of Fiji's main island Viti Levu: 1) along the nearshore fringing reef of the south-west coast, affectionately known as Fiji's Coral Coast, in the Korolevu-i-wai district, and 2) on the fringing and offshore reefs of the north-east coast in the Nakorotubu and Dawasamu districts (Figure 1). All of the LMMAs examined during this study had established either small reef areas or entire patch reefs as temporary (tabu areas- either opened periodically or are expected to be after some time) or permanent (MPAs – reserves set for future generations) no-take areas.

Figure 1. Map of Fiji Islands showing Study Site Locations.



1.1 COMMUNITY-BASED MARINE MANAGEMENT IN KOROLEVU-I-WAI DISTRICT

Korolevu-i-wai (KiW) district is located on the southwest side of Viti Levu in Nadroga/Navosa Province and is in the heart of what is affectionately referred to as Fiji's Coral Coast. Fiji's tourism industry, which has grown to be the country's top economic earner, began with resort along the Coral Coast, the first of which was in the Korolevu-i-wai district. Korolevu-i-wai consists of four traditional coastal villages (Namada, Tagaqe, Vatuolali, and Votua), numerous settlements and residential areas, and coastal tourist developments ranging from 200+ room resorts to small, boutique resorts. The resident population of the four coastal villages is around 1200 people, while slightly more people than this reside in settlements and residential areas (Fong 2006, Fiji Bureau of Statistics 2007), both of which are largely employed in some aspect of the tourism industry. Apart from tourism, land owning clans (who are also the traditional fishing right owners) in the Korolevu-i-wai district also derive income from forestry activities conducted on their land, and much of the inland areas of watersheds in the district are planted with pine and mahogany, some of which is currently being harvested.

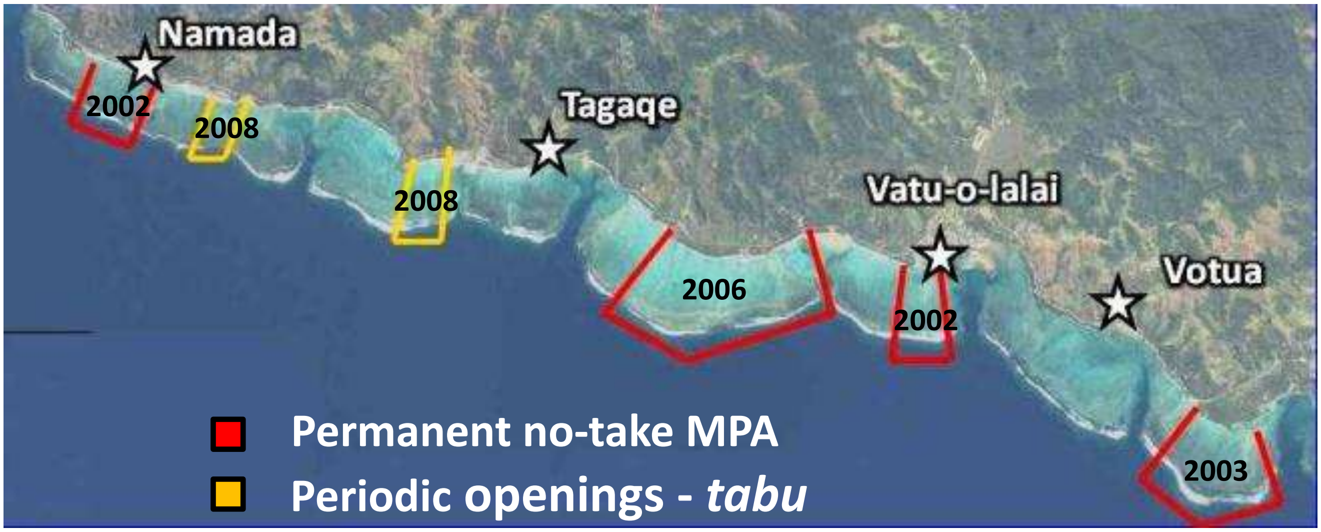
LMMA efforts in Korolevu-i-wai began when fishing right owners requested assistance from the University of the South Pacific's Institute of Applied Science with managing their fishing ground, of which the marine portion consists of $9km^2$ of fringing reef. Through a series of workshops held in 2002, representatives of the fishing right owners from each of the four traditional villages identified the marine management issues they face and devised a plan of action to follow so as to address the issues (Tawake et al. 2002, Tawake et al. 2003). Marine management plans included activities aimed to address overfishing and destructive fishing practices, pollution from piggeries and wastewater, and promote community-based ecotourism (e.g. homestay programs, village and cultural tours, snorkeling) and other community-operated income generating enterprises (e.g. cultured live-rock, ornamental flowers). With the intention of protecting reef areas for the future and ensuring sustainable harvests of marine resources, no-take areas were established on back reef areas and the use of poisons, nets with small (<3") mesh, and harvesting of coral or reef substrate were prohibited throughout the fishing ground. Small no-take areas (each $< 1km^2$) were established by fishing right owners from each of the four villages across the backreef of their village's section of the fishing ground for a preliminary five-year period (Figure 2).

In 2006, fishing right owners from the four coastal villages in Korolevu-i-wai and four inland villages from district of Koroinasau, who also share legal customary fishing rights to the same marine and freshwater areas as the coastal villages, formed the Korolevu-i-wai / Koroinasau Qoliqoli Trust (KKQT), a legal body established to represent the fishing right owners and their interest to preserve and protect their traditional fishing grounds. Along with their establishment of the KKQT, fishing right owners extended the boundaries of their current no-take zone to include the adjacent forereef area, declared all of the no-take areas as being established for future generations and thus not to be opened (permanent), and established a new no-take area (the largest in the district) that included a large, wide, deep section of reef containing large areas of sandy bottom and seagrass beds, and large coral colonies and coral covered bommies.

In 2007 and 2008, management plan review workshops were conducted for the first time in each village in the district individually, though representative from other villages attended each workshop. Progress on and challenges to addressing identified management issues were discussed, the results of research conducted on populations of key indicator species (e.g. corals, targeted food fishes) to assess management outcomes were discussed, and management plans were reviewed and revised (Simpson et al. 2008). Positive outcomes from and perceptions about no-take areas led two villages (Namada and Tagaqe) to establish temporary no-take areas (tabu) in their section of the fishing ground along with the permanent no-take areas; Tagaqe village later chose to open one of the two existing no-take areas in their fishing ground mainly because the adjacent 3-star resort refused to prioritize efforts to improve it's wastewater disposal methods though millions of dollars of renovations and upgrading occurred; the beachfront resort (like others) releases sewerage that has only primary treatment into the fragile coastal ecosystem. In 2006, Votua village began undertaking a pilot project to install a lowtech, easy to maintain wastewater treatment system for the 56-house village – it is the first of it's kind in Fiji and the South Pacific Islands. The success of the wastewater project in Votua led to Tagaqe villagers requesting assistance in installing a similar system for 44 houses in their village; this project is currently underway. Currently, the Korolevu-i-wai LMMA has four permanent no take areas (two established in 2002, one 2003, one 2006) and two temporary no-take areas (established in 2008) (Figure 3).

Figure 2. Korolevu-i-wai District Fishing Ground & LMMA – Original No-Take Area Configuration. The boundaries of the original four no-take areas established are shown with solid red lines while the total LMMA is outlined in yellow.

Figure 3. Korolevu-i-wai District Fishing Ground and LMMA – Current No-Take Area Configuration. The boundaries of current permanent no-take areas (MPAs) are shown with solid red lines and the boundaries of current temporary no-take areas (tabu) are shown with solid orange lines. Dates illustrate the years of establishment of each no-take area.



1.2 COMMUNITY-BASED MARINE MANAGEMENT IN DAWASAMU DISTRICT

Dawasamu district is located on the northeast side of Viti Levu in Tailevu Province. The district, which is largely undeveloped in terms of infrastructure (electricity, piped water, paved roads) and receives minimal tourism, consists of eleven traditional villages, five of which are coastal (Silana, Nasinu, Nataleira, Lolomalevu and Driti). The marine portion of the district's customary fishing ground covers ~150 km^2 and includes both nearshore fringing reef and offshore reefs (Figure 4). Coastal villages have between 20 and 34 households each and a total population of ~900 people that live largely subsistence livelihoods. Main sources of income include fisheries (particularly beche-de-mer), small-scale agriculture (mostly root crops and fruits), and some land-owning clans receive income from forestry activities on their land. Two small backpacker lodges, operated by the local community, have been built adjacent to coastal villages.

The five coastal villages began with community-based co-management efforts in 2006 with the primary goals of replenishing fish stocks and restoring fish grounds. Marine management efforts include the establishment of five no-take areas in the district's customary fishing area between 2006 and 2008 (four on the nearshore fringing reef and one on an offshore reef) (Figure 5) that were meant to be for a five-year duration before being assessed again, however the no-take area in Silana was opened after two years for a village function and was not subsequently closed and the no-take area in Lolomalevu was not well respected and is not currently recognized. An additional no-take area was established at an offshore reef (known as Moon Reef) in April 2011 to protect the reef, which is home to a resident pod of dolphins (Figure 6). Additionally, the communities have undertaken solid waste management efforts and mangrove restoration / rehabilitation activities.

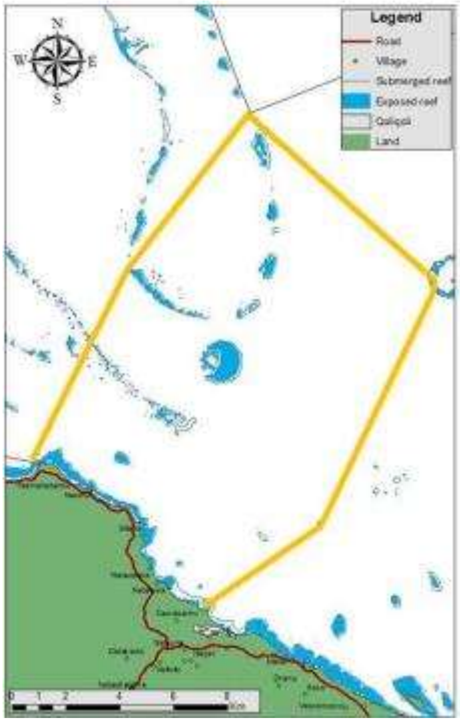


Figure 4. Map of Dawasamu District Customary Fishing Ground. Boundary of the fishing ground is shown in orange, reefs in blue, and the main island of Viti Levu in green.

Figure 5. Location and Year of Establishment of the Original Five No-Take Areas Established in Dawsamu District Fishing Ground.

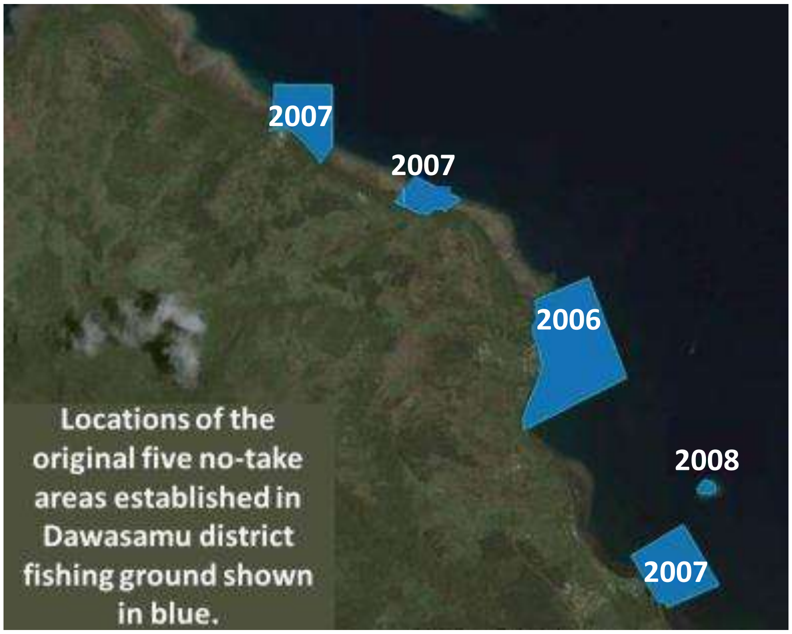
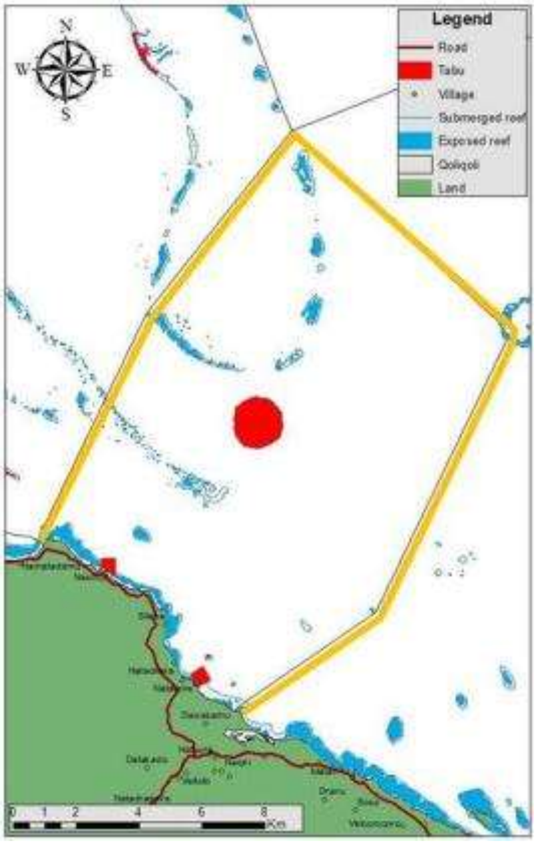


Figure 6. Location of Current No-Take Areas in Dawsamu District Fishing Ground. Qoliqoli boundary is shown in orange, reefs in blue, and no-take areas in red.



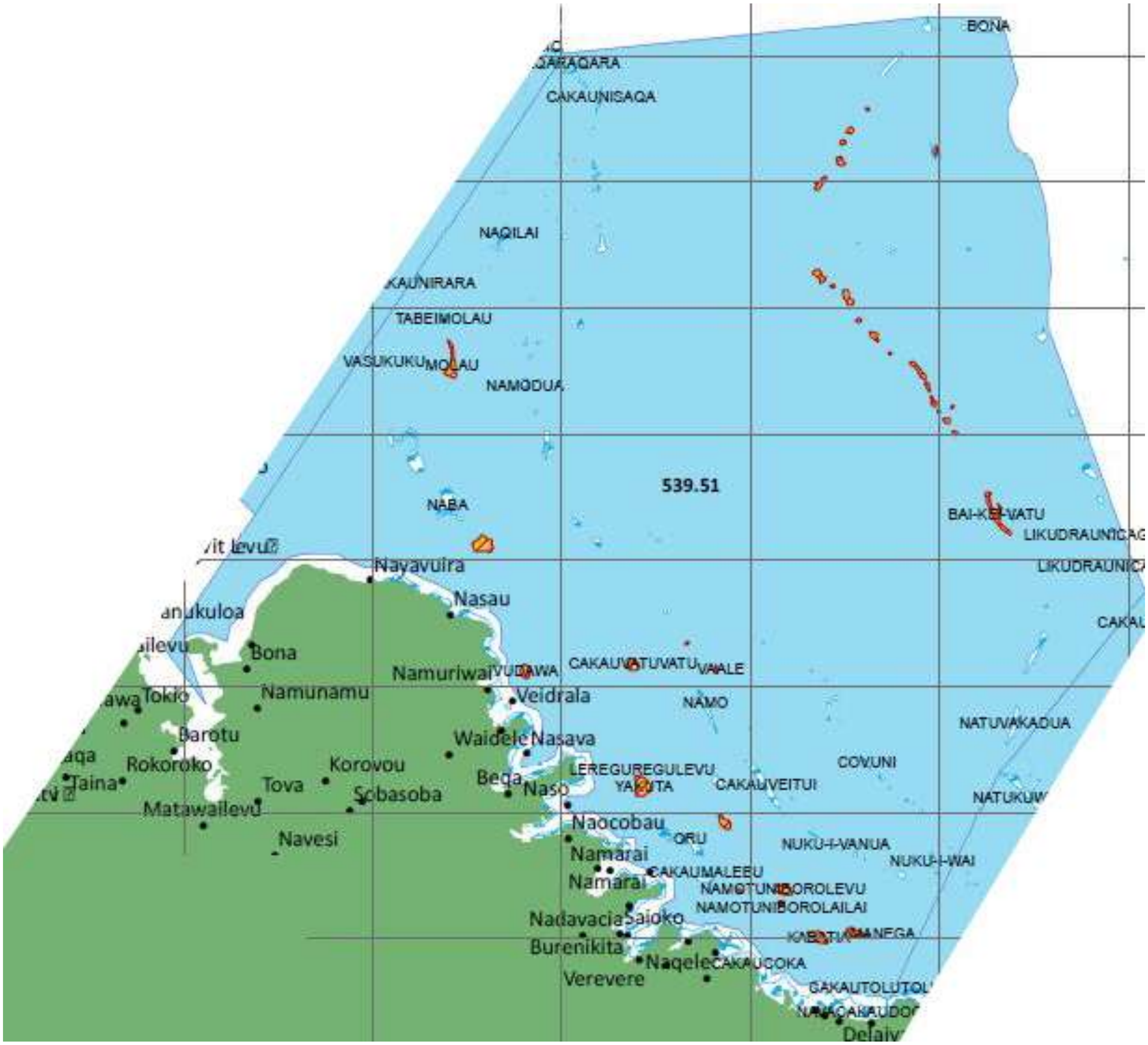
1.3 COMMUNITY-BASED MARINE MANAGEMENT IN NAKOROTUBU DISTRICT

Nakorotubu district is located on the northeast side of Viti Levu in Ra Province. The district consists of five traditional villages, four of which are coastal (Nacobau, Namarai, Verevere, Saioko). The marine portion of the district's customary fishing ground covers 540 km^2 and included both nearshore fringing reef and offshore reefs (Figure 6). In 2005, the Ra Provincial Council invited a representative from the University of the South Pacific to share the concept behind LMMA's with the district chiefs after they heard about the success communities in other areas of Fiji were having with their LMMAs. Following this discussion Nakorotubu district began with community-based co-management efforts in 2005 with the goal of replenishing and ensuring the sustainable use of fisheries stocks on the offshore reefs in their fishing ground. Marine management efforts include the establishment of twelve offshore patch reefs as no-take reserves across the nearshore reef system while additional reefs further offshore have also been declared no-take areas (Figure 7). Land management activities undertaken by the communities include participation in the COWRIE (Coastal and Watershed Restoration for the Integrity of Island Environments) and the 'Seed-Propagation' workshop, conducted by IAS, USP and the Forestry Dept. respectively. Coral and mangrove nurseries were begun with the support of OISCA in 2009 and new nurseries continue to be established in 2012.

The main source of livelihood in the Nakorotubu district comes from the sale of coconuts. This is a weekly activity and is a primary income earner for the district. While fishing is generally done for subsistence purposes, sometimes income generation is a motive for fishing. Only five individual fishermen have been issued commercial fishing licenses to fish in the district's fishing ground for commercial purposes. However, one of the management challenges the fishing right owners face is poaching by fisherman coming from surrounding market economies searching for fishing grounds to support the heavy demand for fresh fish and crustaceans and other marine resources like beche-de-mer.

Being one of the few coastal areas on Viti Levu to have not yet had any tourism development, the main economic activity on the district's land is logging of native timber. The most recent record of logging in Nakorotubu is in May, 2012 at the village of Saioko. The communities of the district understand the need for sustainable management of resources and the need for unity in working towards a common goal. Village governance and respect for the elderly authorities is one of the main challenges the community is facing.

Figure 7. Map of Nakorotubu Customary Fishing Ground. The 12 nearshore patch reef established as no-take areas in 2005 are shown in yellow with red outline and stripes along with the more recently protected offshore reefs; the boundary of the customary fishing ground is shown with the thin blue line.



2. METHODS

2.1 LMMA ASSESSMENT - KOROLEVU-I-WAI DISTRICT

The Korolevu-i-wai district LMMA covers ~9km^2 of fringing reef area that comprises the marine portion of the customary fishing grounds for the coastal district of Korolevu-i-wai as well as the inland district of Koroinasau. Roughly 35% (3.2km^2) of the LMMA has some sort of no-take status - ~31% (2.8 km^2) in permanent no-take areas (MPAs) and ~4% (0.4 km^2) in temporary no take areas. Forereef areas of the LMMA have a well-developed reef crest that extends down to ~5-8m depth and then drops steeply to 40m+ along most of the reef; only a few reef areas have terraces or moderate forereef slopes below the reef crest zone. Backreef areas consist of shallow (<4m depth) moat platforms ranging from ~450 to 750m in width and separated by a series of deep-water channels located at the discharge points of rivers. Fishing pressure in the LMMA is focused in the backreef moats and along the edge of channels due to easy access from shore and a lack of ownership of motorized boats by the local community. Only commercial fishing operations, some of which are based outside the district, fish regularly on forereef areas.

Due to reef type/structure, reef accessibility, and community fishing practices all assessments of the Korolevu-i-wai LMMA (including this study) have been done using research conducted on backreef areas. This LMMA assessment examined the middle and outer zone of the backreef moat and consisted of benthic and fish surveys as well as herbivory assays conducted in the six no-take areas (two tabu areas and four MPAs) and four fished locations in 2010 and 2011.

2.1.1 BENTHIC SURVEYS

The benthic community composition of the fringing reef comprising the Korolevu-i-wai district fishing ground was sampled in 2011 along a total of 96 transects. Transects were established in two back reef zones that are commonly fished (middle and outer moat) at each of ten sampling sites. Sampling sites included the four permanent no-take areas (MPA), two temporary no-take areas (tabu), and four areas zoned for fishing (fished). Transects were placed on reef areas that remain submerged at all times. In the outer reef zone, transect were placed along the seaward portion of the reef flat moat while transects in the middle zone were placed through the middle of the reef flat moat area. Replicate 50m-transects (N=5 MPA & fished, N=4 tabu) were established in each zone at each site (Figure 8) ensuring that the transects were at least 50m within the boundary of each MPA or tabu sites or in the case of fished sites, at least 100m away from any MPA or tabu. Transects were placed parallel to the reef crest and shoreline and the starting point of each transect was marked using a GPS. Transects were placed end to end at least 15m apart from each other, and in some cases were staggered across the zone.

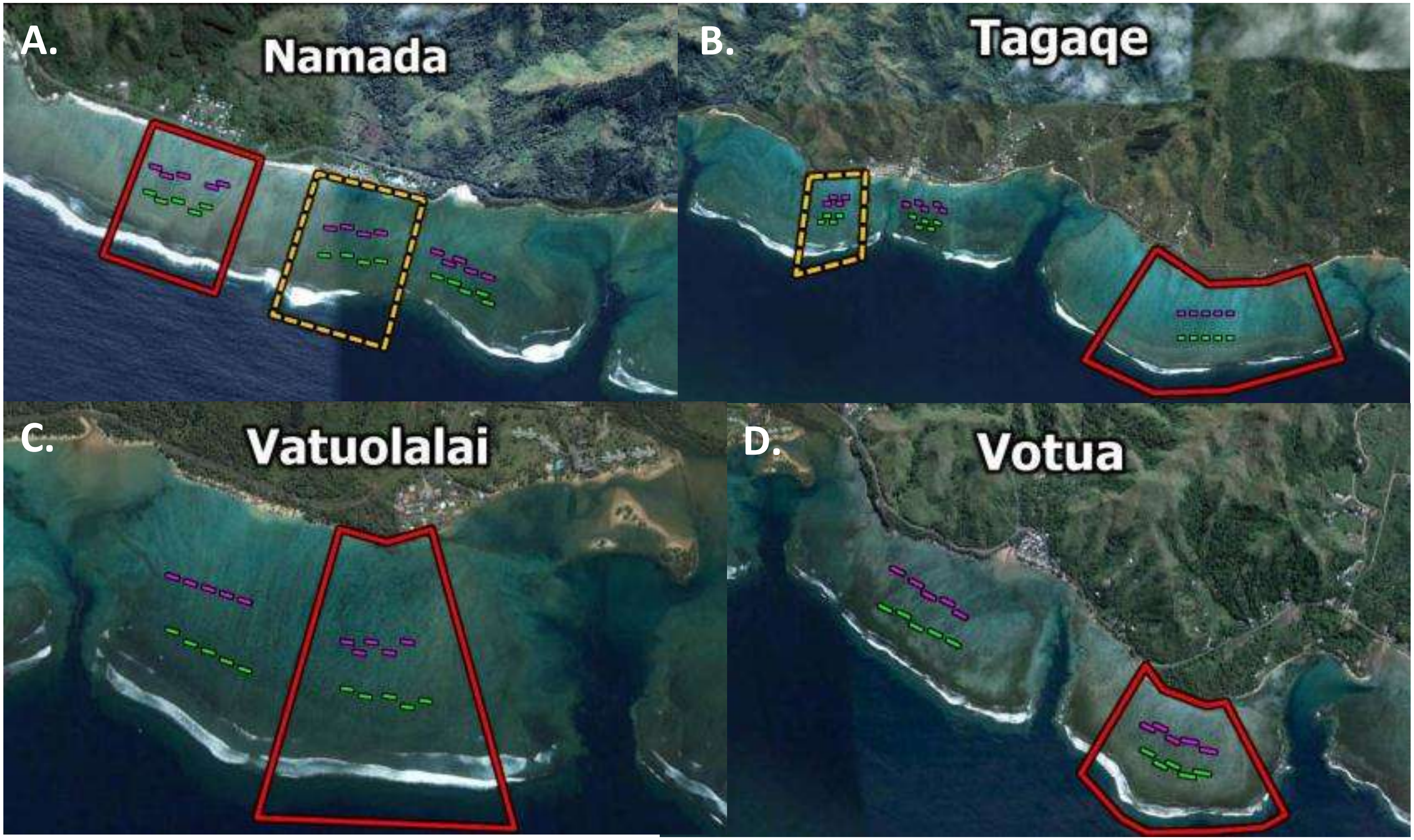
Benthic composition was sampled using the point-intercept method along each transect. The benthic life form under the transect tape was recorded to the lowest taxonomic level possible (generally species) every 50cm along each transect for a total of 100 sample points along each 50m transect.

Coral species richness was sampled in a 1m belt along each 50m benthic transect. All the coral species present within 1m of either side of the transect tape were recorded providing a sample of coral species richness per 100m^2.

Data were first analyzed by site (Namada, Tagaqe, Vatuolalai, Votua), protection status (MPA, Tabu, Fished), and zone (middle, outer) in order to examine the benthic community at individual sites. Summary statistics were calculated by benthic category (sand, rubble, sponge, gorgonian, soft coral, cyanobacteria, crustose coralline algae, turf, macro-algae, hard coral) to examine overall mean benthic composition for each of the 10 sites surveyed by zone. As the amount of unconsolidated substrate (sand and rubble) was highly variable among the sites, summary statistics were calculated to examine the mean benthic composition of hard bottom area by benthic category for each site by zone. To examine the similarity of the hard bottom benthic composition of the 10 sampling sites, the mean relative abundances of each hard bottom benthic category type at each site were used to create similarity indices and MDS plots in PRIMER 5.0 for each zone. To examine coral community composition at sites, the relative abundance of each coral family present along benthic transects were calculated by protection status and zone. To examine macro-algal community composition at sites, the relative abundance of each genus of macro-algae present along benthic transects were calculated by protection status and zone. To examine coral species richness at the sites, the mean number of coral species present along the 50m^2 belt transects was calculated by site, protection status and zone and compared using one-way ANOVAs and Tukey Kramer HSD post hoc tests.

The benthic communities at sites with different protection statuses were examined to determine the potential influence of protection status on the benthic community. Summary statistics were calculated for the mean hard bottom composition of each benthic category by protection status and zone. To elucidate the relationship between crustose coralline algae (CCA) and hard coral along the benthic transects, linear regressions were calculated using the mean percent CCA cover and hard coral cover for each of the 10 sampling sites. To compare hard coral cover of hard bottom area between the different protection statuses, data were appropriately transformed as necessary and one-way ANOVAs and Tukey Kramer HSD post hoc tests performed using individual transects as samples. To compare coral species richness between areas with differing protection status, data from individual 50m^2 belt transects were appropriately transformed as necessary and one-way ANOVAs and Tukey Kramer HSD post hoc tests performed. To compare coral community composition between areas with varying protection status, the relative abundance of each coral family present along benthic transects were calculated by zone for each protection status using individual transects as samples. To compare macro-algal community composition between areas with varying protection status, the relative abundance of each genus of macro-algae present along benthic transects were calculated by zone for each protection status using individual transects as samples.

Figure 8. Location of Benthic Transects at Korolevu-i-wai LMMA Sampling Sites (A - Namada, B - Tagaqe, C - Vatuolalai, D - Votua). Green bars represent outer reef zone transects and purple bars represent middle reef zone transects. Red boxes delineate the boundaries of permanent no-take marine protected areas (MPAs) while orange boxes delineate the boundaries of temporary no-take areas (Tabu).



2.1.2 TARGET FISH SURVEYS

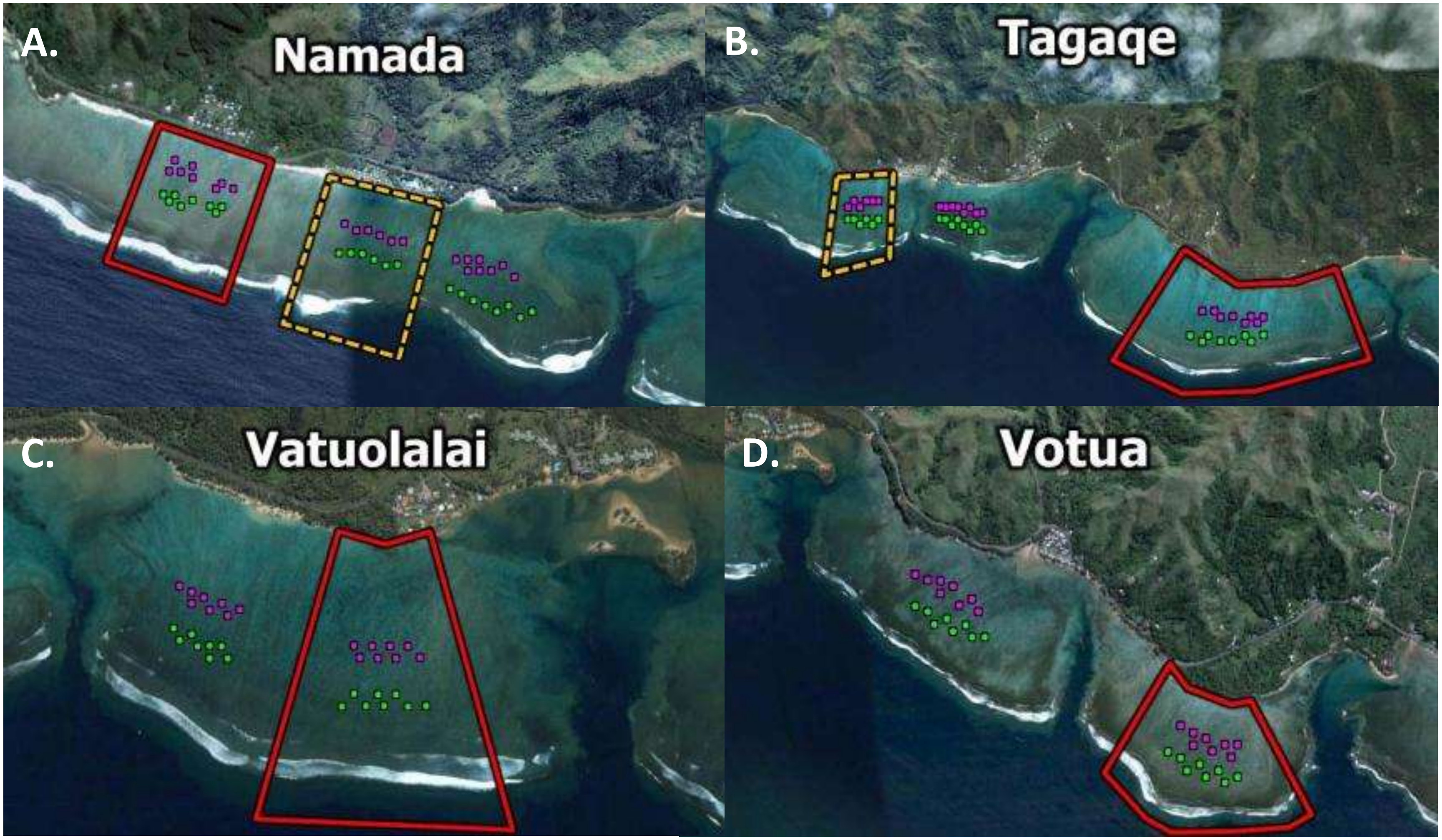
Target fish populations on the fringing reef comprising the Korolevu-i-wai district fishing ground were sampled in 2011 by conducting 152 point counts in the same two reef zones and ten sampling sites as benthic surveys. Target fish families include those fishes most targeted by local fisherpersons and most likely to be important for removal of fleshy algae: Acanthuridae, Kyphosidae, Scaridae, Siganidae, Haemullidae, Lethrinidae, Lutjanidae, Serranidae, Mullidae. Replicate 15m-diameter point counts (N=8 MPA & fished, N=6 tabu) were conducted in each zone at each site (Figure 9) ensuring that the point counts stations were at least 50m within the boundary of each MPA or tabu sampling location or in the case of fished locations, at least 100m away from any MPA or tabu boundary. Point counts were conducted within two hours of high tide on days when high tide was between 8:30am and 11:30am.

At each point count station, a 15m transect tape was laid out across the reef to demarcate the cylinder diameter. After laying the transect tape, the observer placed himself in the center of the cylinder and waited for three minutes for fish to acclimate to observer presence before beginning the sampling period. The sampling period lasted for seven minutes during which the observer recorded the target fish species present in the cylinder and the estimated size of each fish (to the nearest cm). The center point of each point count cylinder was marked using a GPS. Point counts were conducted at least 30m apart from each other (cylinder center to cylinder center), and in some cases were staggered across the zone.

Data were first analyzed by site (Namada, Tagaqe, Vatuolalai, Votua), protection status (MPA, tabu, fished), and zone (middle, outer) in order to examine target fish assemblage trends between individual sites. Overall target fish abundance were compared across the 10 sampling sites by zone using one-way ANOVAs and Tukey Kramer HSD post-hoc tests. Similarly, the mean abundances of each target fish families were calculated for each of the 10 sampling sites by zone. To examine size class distribution of fishes at each site, fishes were placed in 10cm size classes (<10cm, 10-20cm, 20-30cm, 30-40cm, >40cm) and the mean relative abundance of each size class calculated for each target fish family by site and zone. Overall species richness of target fishes was compared between the 10 sampling sites by zone using one-way ANOVAs and Tukey Kramer HSD post-hoc tests. The estimated biomass of each fish recorded during point counts was calculated using published length-weight metrics (Fish Base 2012). Overall total target fish biomass was compared between the 10 sampling sites by zone using one-way ANOVAs and Tukey Kramer HSD post-hoc tests.

Target fish assemblages from the 10 sampling sites were compared to examine the potential influence of protection status on fishes. To compare the target fish assemblages between sites with different protection statuses, the mean relative abundances of target fish species at each site were used to create similarity indices and MDS plots in PRIMER 5.0 for each zone individually and combined. A SIMPER analysis was conducted on the fish assemblage structure using PRIMER 5.0 to elucidate differences between assemblages in areas with different protection status. Overall target fish abundance, species richness, and biomass were compared between the different protection statuses using one-way ANOVAs and Tukey Kramer post-hoc tests. To compare size class composition of target fishes between areas with different protection statuses, the relative abundance of fishes in each size class was calculated by fish family and zone. To elucidate differences between abundance, size, and biomass of target fish genera between areas with different protection status (both zones combines), one-way ANOVAs and Tukey Kramer post-hoc tests were performed on appropriately-transformed data.

Figure 9. Location of Target Fish Point Counts Stations at Korolevu-i-wai LMMA Sampling Sites (A - Namada, B - Tagaqe, C - Vatuolalai, D - Votua). Green spots represent outer reef zone point counts and purple spots represent middle reef zone point counts. Red boxes delineate the boundaries of permanent no-take marine protected areas (MPAs) while orange boxes delineate the boundaries of temporary no-take areas (Tabu).



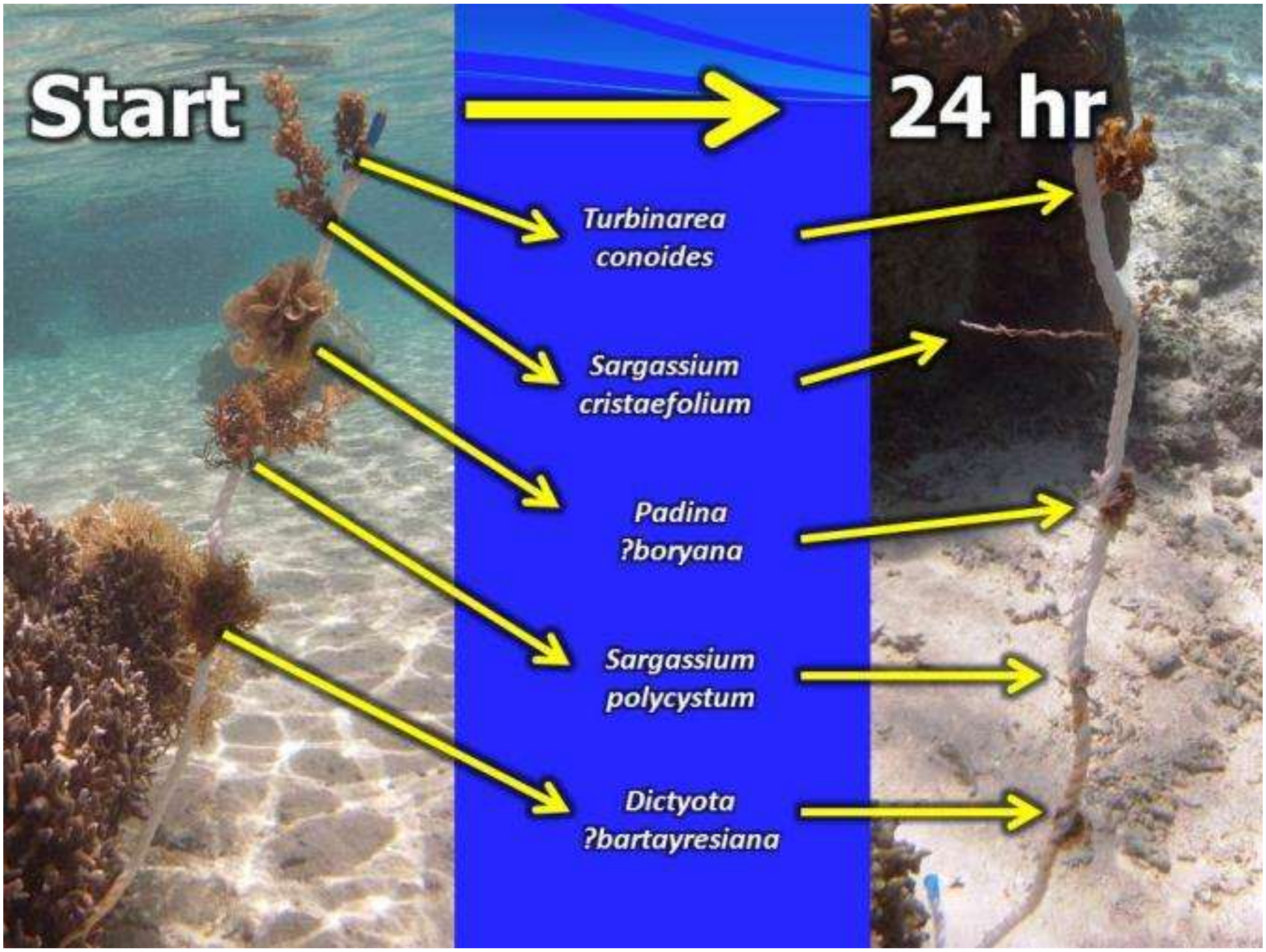
2.1.3 HERBIVORY ASSAYS

Paired herbivory assays were conducted using five of the most abundant species of macro-algae (*Turbinarea conoides, Sargassum cristaefolium, Padina ?boryana, Sargassum polycystum, and Dictyota ?bartayresiana*) found on Coral Coast reefs to assess if differences in levels of fish herbivory on these algae could contribute to their visually-obvious extreme differences in abundance between areas with different protection status (MPA, Fished, Tabu). Assays were conducted at the same ten sampling locations where fish and benthic sampling occurred as well as an additional fished site adjacent to the western border of the permanent no-take area (MPA) in Tagaqe. Assays were conducted both in 2010 (April/May) and 2011 (July/August) to ensure consistency of results.

Assays were conducted at 11 sites paired into five temporally-coinciding setups: 1) Namada MPA, tabu, and fished sites, 2) Tagaqe tabu and adjacent fished site, 3) Tagaqe MPA and adjacent fished site (not sampled during benthic or fish sampling), 4) Vatuolalai MPA and fished site, and 5) Votua MPA and fished site (see Figure 33). All algae were collected from the fished area in Votua, except on four occasions when *Dictyota* was collected from the fished site in Vatuolalai. Algae were cut into standard replicate pieces that were visually similar (length and mass) for each species, though not necessarily between species. One piece of each species was attached in a random order to one end of a 1m length braided polypropylene rope at intervals of about 10cm apart by untwisting the rope and inserting the algal holdfast (see Figure 10). Ropes with algal pieces attached (N=10) were deployed at each sampling site by untwisting the rope at the end without algae attached and sliding it over a piece of dead substrate; five replicate ropes were deployed in the middle reef zone and five replicate ropes in the outer reef zone with each replicate rope being at least 10m apart from any other replicate. After ropes had been deployed on the reef for 24 hours, a common observer returned to score the assays (see Figure 10). Assays were scored by visually estimating the amount of each algae eaten from each rope using the categories: 0% eaten (untouched - no visible bite marks), >0 - 25% eaten, >25 - 50% eaten, >50 - 75% eaten, >75 - <100% eaten, and 100% eaten (eaten right down to the braided rope). During initial trial algal assays, caged replicates (ropes with algae placed inside of ¼” mesh cages) were included at all sites to determine if currents were able to remove algae from the ropes. Since algae were not torn from the ropes by currents, these cages replicates were left out of the sampling design for all future assays, which were conducted during similar tides / ocean conditions.

To determine whether there were differences in the amount of each algae eaten between paired locations, each of the five herbivory assays conducted in 2010 and 2011 were scored independently; the amount of each individual species of algae eaten between paired sites were compared using nonparametric Wilcoxon signed rank tests. To elucidate overall herbivory trends between areas with different protection status, data from the five paired assays were combined by year and the amount of algae consumed on each replicate compared by protection status and year using nonparametric Wilcoxon signed rank tests.

Figure 10. Photograph of One Replicate Rope Deployed as Part of the Herbivory Assays. The replicate rope is shown at the start and 24 hours later when being scored.



2.2 LMMA ASSESSMENT – NASINU VILLAGE, DAWASAMU DISTRICT

The LMMA at Nasinu Village, located at the northern end of Dawasamu district close to the border with Ra Province, was established in 2007 on the fringing reef area comprising the marine portion of the village's customary fishing area. This LMMA include a small no-take area (~0.3 km^2) that was initially closed for one year, however due to the lack of support and management by community members, the no-take area was occasionally opened and in general compliance was poor.

Dense mangroves line the coastal areas adjacent to Nasinu village and a small creek runs to the north of the village and drain into a narrow channel that cuts back through the reef flat. The fringing reef is comprised of a narrow (~150-200m) reef flat platform that extend from the mangroves and is largely intertidal except at the seaward margin where a narrow section at the reef crest remains submerged at all times and has living coral cover. The inner portion of the reef flat platform is mostly rock and rubble covered with mud while the mid-section is largely dominated by silt and macro-algae. The reef flat platform drops off moderately to steeply on the reef slope to a soft bottom area around 12-18m deep. The reef slope has a healthy assemblage of corals dominated by *Acropora* and *Porites* spp. Fishing pressure is concentrated on along the fringing reef dropoff as it is close to the village and accessible from shore without a boat.

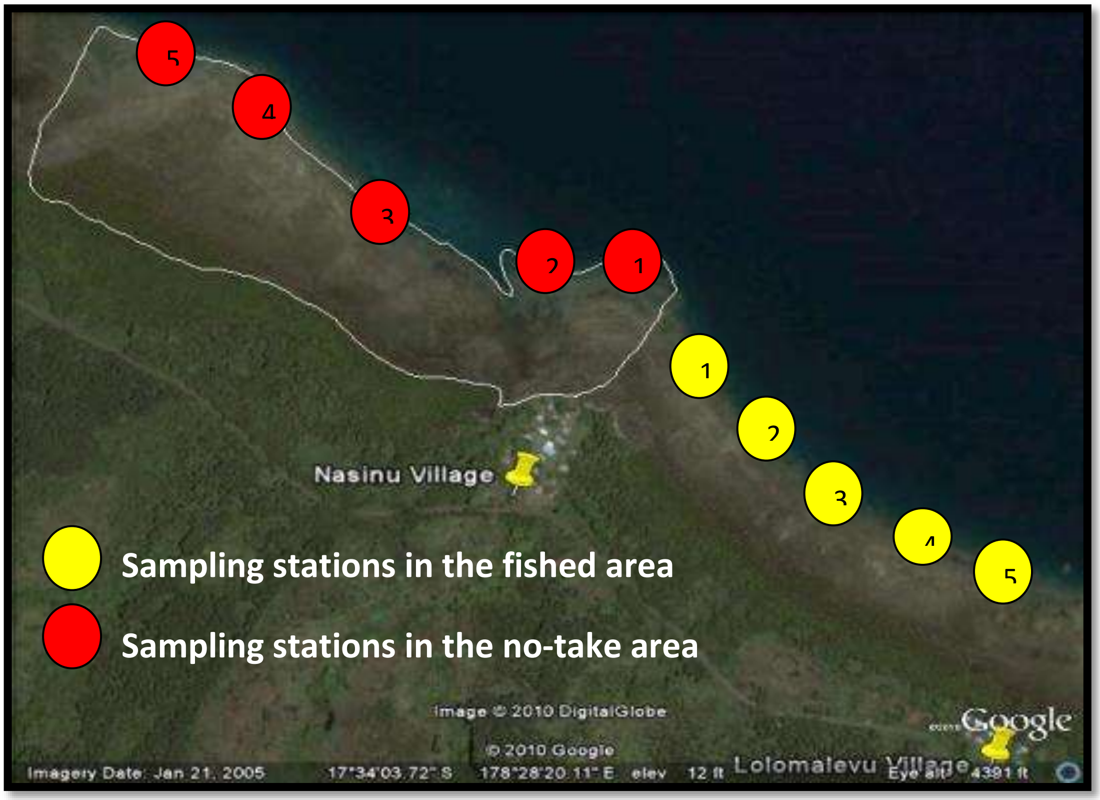
Due to reef type/structure, reef accessibility, and community fishing practices this assessment of the Nasinu LMMA has been done using research conducted along the fringing reef dropoff. This LMMA assessment consisted of fish surveys, algal biomass surveys, as well as paired herbivory assays conducted at stations in the no-take and fished areas of the LMMA in September 2010.

2.2.1 TARGET FISH SURVEYS

Target fishes (Acanthurids, Scarids, Siganids, Lethrinids, Lutjanids, and Serranids) were sampled using underwater point counts. Point counts, in a 10m radius cylinder, were conducted at five sampling stations in both the no-take and fished areas of the LMMA (Figure 11). Sampling stations were located at the dropoff so that ~1/2 of the sampling cylinder was over the dropoff, while the other half was over the reef crest. At each sampling station, the observer laid a 20m transect across the reef crest and positioned himself in the center. For ten minutes, the observer recorded the species and size of all target fishes seen within a 10-m radius. All sampling station locations were recorded with a GPS.

Summary statistics were calculated for the fish assemblages recorded. Mean abundance of target fishes (total and by family) were compared between the no-take and fished area using paired nonparametric Wilcoxon signed rank tests. Mean size of target fishes (by family) were compared between the no-take and fished area using paired one-way ANOVAs. Summary statistics on size distribution of target fishes were calculated. The estimated biomass of each fish was calculated using published length/weight relationships (FishBase 2012). The mean biomass of target fishes (total and by family) were compared between the no-take and fished area using paired one-way ANOVAs.

Figure 11. Sampling Stations at the Nasinu LMMA. Red dots show the locations of sampling stations in the no-take area, while yellow dots represent sampling stations in the fished area.



2.2.2 ALGAL BIOMASS SURVEYS

Macro-algal biomass was surveyed at each of the five sampling locations in the no-take and fished areas (Figure 11). At each sampling location, four 20m randomly-placed transects were laid across the reef flat near the dropoff and a 25cm by 25cm quadrat was place at the 6, 12, and 18m mark along the transect. At each quadrat, the observer removed all of the macro-algae present and placed it in labeled plastic bags. Following field sampling activities each day, each quadrat sample of algae was spun dry using a mesh bag and the wet weight of each species recorded.

The mean biomass of each macro-algae per 625cm2 quadrat was calculated overall and by genus for the fished and no-take areas, and compared using paired nonparametric Wilcoxon signed rank tests.

2.2.3 HERBIVORY ASSAYS

Paired herbivory assays were conducted using three species of algae (*Sargassum* sp. *Padina* sp., and *Turbinarea* sp.) collected from the fished area of the reef by breaking algae off at the holdfast. Algae were cut into standard replicate pieces that were visually similar (length and mass) for each species, though not necessarily between species. One piece of each species was attached in a random order to one end of a 1m length braided polypropylene rope at intervals of about 10cm apart by untwisting the rope and inserting the algal holdfast (see Figure 10). Ropes with algal pieces attached (N=10) were deployed at each sampling station (stations 1, 3, and 5 in both the no-take and fished area – see Figure 11) by untwisting the rope at the end without algae attached and sliding it over a piece of dead substrate; replicates were deployed at least 10m apart from each other. After ropes had been deployed on the reef for 24 and 48 hours, a common observer returned to score the assays. Assays were scored by visually estimating the amount of each algae eaten from each rope using the categories: 0% eaten (untouched - no visible bite marks), >0 - 25% eaten, >25 - 50% eaten, >50 - 75% eaten, >75 - <100% eaten, and 100% eaten (eaten right down to the braided rope).

To determine whether there were differences in the amount of each alga eaten in the no-take and fished areas, the mean amount of each individual species of algae eaten in each area were compared using nonparametric Wilcoxon signed rank tests.

2.3 LMMA ASSESSMENT – NAMARAI VILLAGE, NAKOROTUBU DISTRICT

The LMMA assessed at Namarai Village, located in the district of Nakorotubu, was established in 2005 on the nearshore fringing reef and offshore reefs comprising the marine portion of the village's customary fishing area. As there were not any no-take areas established on fringing reef area (only a mangrove area), the LMMA assessment focused on four adjacent offshore reefs - two no-take reefs (Vatale and Nuku) and two reefs where fishing is allowed (Oru and Votuvotu) (Figure 12). Sampling was conducted at stations on the leeward and windward sides of Vatale and Oru and the leeward sides of Nuku and Votuvotu on both the reef top (along the reef crest) and at the base of the reef slope where the bottom flattens out (~12m depth).

The patch reefs sampled have shallow tops, the center areas of which are exposed during low tide while the reef crest remains submerged at all times and has living coral cover. The reef slope drops off moderately to steeply from the crest to a soft bottom area around 10-15m deep. Fishing pressure is concentrated on along the fringing reef dropoffs as this reef area is accessible by boat during all tides.

Due to reef type/structure, reef accessibility, and community fishing practices this assessment of the Namarai LMMA has been done using research conducted on the edge of the reef top and just at the base of the reef slope/dropoff where the bottom flattens out. This LMMA assessment consisted of fish surveys, benthic community surveys, as well as paired herbivory assays conducted at stations in both zones of the no-take and fished areas of the LMMA in March 2011.

Figure 12. Sampling locations in the Namarai LMMA

2.3.1 BENTHIC SURVEYS

The benthic community composition off the four offshore reefs was sampled in 2011 along a total of 60 transects. Transects were established on the reef top near the reef crest (n=30) and on the reef slope, at the base of the slope where it levels out (N=30) at each of the six sampling sites. Replicate 20m-transects (N=5) were established in each zone at each site (Figure 12) ensuring that transects were at least 10m apart from each other end to end. Transects were placed parallel to the reef crest and the starting point of each transect was marked using a GPS.

Benthic composition was sampled using the point-intercept method along each transect. The benthic life form under the transect tape was recorded to the lowest taxonomic level possible (generally genus) every 20cm along each transect for a total of 100 sample points along each 20m transect.

The amount of hard bottom area covered with coral and macro-algae was determined by zone for each of the six sampling sites. Coral and macro-algal covers were compared by zone between sites using one way ANOVAs and Tukey Kramer HSD post-hoc tests. Summary statistics were calculated to determine the coral community composition (by family) at each sampling site by zone. Coral cover was compared between fished and no-take areas by zone using a one-way ANOVA and Tukey Kramer HSD post hoc test. Coral and macro-algal community composition (by family and genus respectively) were determined by zone for fished and no-take areas.

2.3.2 TARGET FISH SURVEYS

Target fishes (Acanthurids, Scarids, Siganids, Lethrinids, Mullids, Lutjanids, and Serranids) were surveyed at the same six sites and two zones where benthic surveys were done. Target fishes were sampled using five 20m x 5m belt transects (same 20m transects as benthic surveys were conducted on) at each site and zone. The family and size (to nearest cm) of each target fish seen along belt transects were recorded.

The mean abundance and size of target fish was calculated by family for each sampling site by zone. A Wilcoxon signed rank test and one way ANOVA were used to compare the overall mean abundance and size of fish (respectively) by zone. Mean fish abundance and size by family were compared between no-take and fished areas using paired Wilcoxon signed rank tests.

2.3.3 HERBIVORY ASSAYS

Paired herbivory assays were conducted using six species of algae (*Sargassum* sp. *Padina* sp., *Turbinarea* sp., *Halimeda* sp., *Galaxura* sp., and *Dictyosphaeria* sp.) collected from the fished area of the reef by breaking algae off at the holdfast. Algae were cut into standard replicate pieces that were visually similar (length and mass) for each species, though not necessarily between species. One piece of each species was attached in a random order to one end of a 1m length braided polypropylene rope at intervals of about 10cm apart by untwisting the rope and inserting the algal holdfast (see Figure 10). Ropes with algal pieces attached (N=10) were deployed at each sampling station (Reef Top: wondwards sites at Oru, Vatale, and Bikini; Reef Slope all sites on Oru, Vatale, and Votuvotu – see Figure 12) by untwisting the rope at the end without algae attached and sliding it over a piece of dead substrate; replicates were deployed at least 10m apart from each other. After ropes had been deployed on the reef for 24 hours, a common observer returned to score the assays. Assays were scored by visually estimating the amount of each algae eaten from each rope using the categories: 0% eaten (untouched - no visible bite marks), >0 - 25% eaten, >25 - 50% eaten, >50 - 75% eaten, >75 - <100% eaten, and 100% eaten (eaten right down to the braided rope).

Summary statistics were calculated for the herbivory assays by zone for each algae. To determine whether there were differences in the amount of each algae eaten in the no-take and fished areas, the mean amount of each individual species of algae eaten in each area were compared by zone using nonparametric Wilcoxon signed rank tests.

3. RESULTS

3.1 KOROLEVU-I-WAI DISTRICT

3.1.1 BENTHIC SURVEYS

The benthic composition at each sampling site consisted of both hard bottom and unconsolidated loose rubble/soft bottom areas. Loose rubble and sand comprised 5-60% of the benthos in both zones, though the outer reef zone generally had less of this unconsolidated substrate than the middle reef zone (Figure 13). Though the benthos in MPAs general consisted of more unconsolidated substrate than the paired fished sites, MPAs still had 4-8 times the amount of hard coral cover than fished sites with hard coral covering 20-40% of the benthos in MPAs compared to 4-14% at fished and tabu sites (Figure 13).

Hard bottom areas across the sample sites consisted mainly of hard coral, fleshy macro-algae, turf algae, and crustose coralline algae (CCA) cover with other life forms (i.e. soft coral, gorgonians, sponges, ascidians, and cyanobacteria) covering less than 15% (in most cases less than 10%) of the hard bottom benthos (Figure 14). MPAs generally harbored hard bottom communities that were distinct from the fished and tabu sampling location (Figure 15). Mean coral cover on hard bottom areas in MPAs ranged from 36-75% and 39-55% in the middle and outer reef zones respectively while at other sampling sites only exceeded 20% in the tabu area at Tagaqe (Figure 14). MPAs had little to no macro-algae, while macro-algae dominated fished and tabu areas covering up to 87% of the hard bottom in some locations (Figure 14). Similarly, CCA cover on hard bottom was generally greatest in MPAs, particularly in the outer reef zone where it ranged from 5-21% compared to 0-5% in fished areas (Figure 14). The composition of hard bottom communities in the outer reef zone of the four MPA sites surveyed were very similar while in the middle reef zone was distinct, yet more variable in hard bottom composition (Figure 15). Of the four MPA sites, Vatuolalai recorded the highest hard coral (63%) and CCA (14.5) cover on hard bottom though both Votua and Tagaqe also had more than 50% coral and in Tagaqe up to 10% CCA cover in the MPAs. The more recently established tabu area at Tagaqe (2008) had 27% hard coral and 7% CCA cover while in Namada the tabu area was no different from fished areas having only 5% hard coral and 1% CCA cover.

Macro-algal community composition was dominated by *Sargassum* and *Turbinarea* in fished and tabu sampling locations; in the MPAs, only *Turbinarea* was recorded in the middle reef zone and *Turbinarea* and *Chlorodesmis* recorded in the outer reef zone (Figure 16). Overall, *Sargassium, Turbinarea, Padina, Dictyota*, and *Hormophysa* were the most abundant genera of macro-algae across all survey sites (Figure 16).

A total of 101 hard coral species (29 genera in 12 families) were detected on the point intercept transects. Corals from four families (Acroporaidae, Faviidae, Pocilloporidae, and Poritidae) were most abundant across survey locations. Corals in the genus *Acropora* were the most species-rich genus of hard coral found during benthic surveys with the outer reef zone generally having less Acroporidae and more coral families present than the middle zone (Figure 17).

A total of 148 hard coral species (38 genera in 14 families) were detected along the $50m^2$ belt transects sampled for coral species richness (Table 1). MPA locations generally had higher mean coral species richness (30-45 species middle zone; 44-52 species outer zone) than fished and tabu locations (14-31 species middle zone; 15-35 species outer zone), and mean coral species richness was generally greater in the outer reef zone than in the middle reef zone, particularly in MPAs (Figure 18). The Vatuolalai MPA recorded the highest species richness in both zones (mean 45 inner, 52 outer).

Overall, hard bottom in MPAs consists of relatively high hard coral (>50%) and little to no macro-algal (<0.5%) cover compared to fished and tabu areas, which have little hard coral (<13%) and high macro-algal cover (>67%) (Figure 19). Similarly, MPAs also have 300% more crustose coralline algae (CCA) cover (9%) than the fished and tabu areas (Figure 19). Though they were not independently sampled, CCA cover was significantly correlated with hard coral cover ($r^2=0.74$ $p=0.0059$ middle zone; $r^2=0.65$ $p=0.0124$ outer zone) indicating that CCA and corals were found most abundantly in the same locations (Figure 20). Overall, the mean coral cover on hard bottom in MPAs was significantly greater than in fished or tabu locations in both zones sampled ($p<0.0001$) with coral cover up to five times greater in the MPAs (Figure 21). Though mean coral cover was higher in tabu than in fished locations, particularly in the outer reef zone, these differences were not significant (Figure 21).

Coral species richness as sampled along the $50m^2$ belt transects was significantly greater in MPAs than in fished or tabu areas for both reef zones sampled ($p<0.0001$) (Figure 22); in the inner zone species richness was approximately double that found in either the fished or tabu areas while in the outer zone species richness in the MPA was approximately double that of fished areas and 50% greater than that recorded in tabu areas (Figure 22).

Overall, coral communities in both reef zones were largely dominated by Poritids in fished and MPA zones (~25-60%), though MPAs had more Acroporid cover than fished or tabu areas with the middle zone comprised of nearly 50% Acroporid cover (Figure 23a). The outer reef zone harbored more mixed coral assemblages that were largely dominated by Poritids (>40%) in all location types sampled; Acroporids were less than 25% of the coral cover in outer zone (Figure 23a).

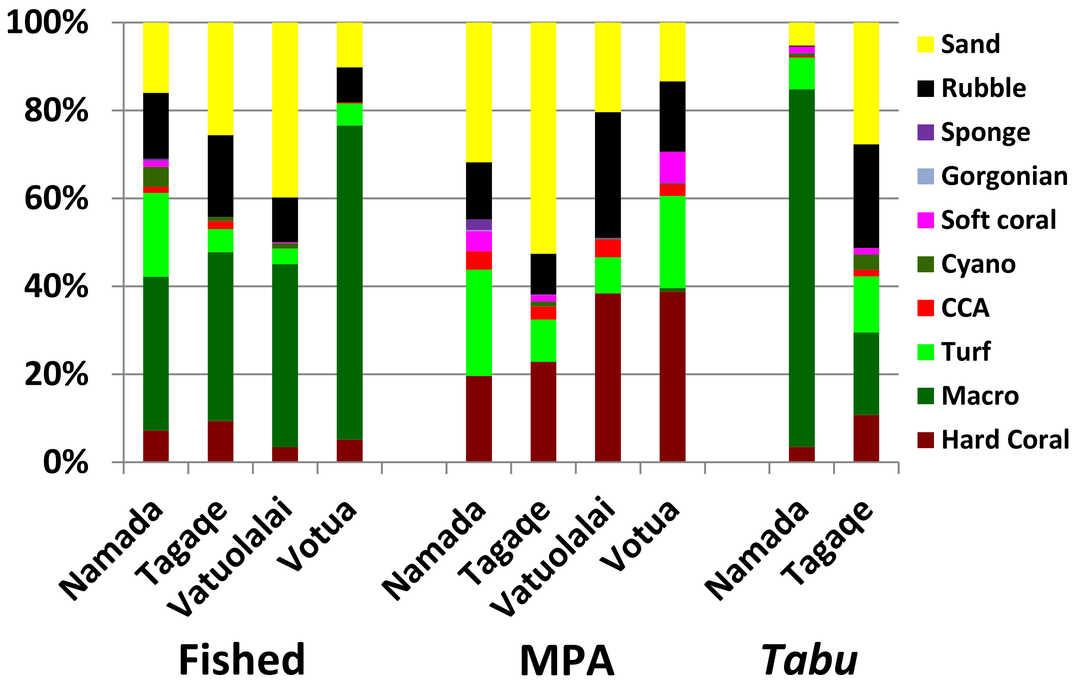
Macro-algal communities mainly consisting of brown algae were dominated by *Sargassum* in the fished and tabu areas (>70%). In MPAs, where little to no macro-algae was found, *Turbinarea* was the most common, and in the inner zone the only, macro-algae found (Figure 23b).

Table 1. Coral Families and Species Present in Species Richness Transects

Acroporidae	**Agariciidae**	**Fungiidae**
Acropora acuminata	*Coeloseris mayeri*	*Fungia fungites*
Acropora aff. nasuta	*Gardineroseris planulata*	*Fungia paumotensis*
Acropora aspera	*Pavona* af. *danai*	*Fungia scutaria*
Acropora austera	*Pavona cactus*	*Fungia* sp. 1 (high blade septa)
Acropora cerealis	*Pavona chirquensis*	*Herpolitha limax*
Acropora cf. papilarae	*Pavona decussata*	**Merulinidae**
Acropora cf. selago	*Pavona divaricata*	*Hydnophora grandis*
Acropora cf. subulata	*Pavona explanulata*	*Hydnophora microconos*
Acropora cuneata	*Pavona frondifera*	*Hydnophora rigida*
Acropora cytherea	*Pavona varians*	*Merulina ampliata*
Acropora digitifera	*Pavona* sp. 1 (granulated)	*Merulina scabricula*
Acropora divaricata	*Pavona* sp. 2 (high ridge)	**Milleporidae**
Acropora echinata	*Pavona venosa*	*Millepora dichotoma*
Acropora exquisita	**Astrocoeniidae**	*Millepora platyphylla*
Acropora florida	*Stylocoeniella armata*	*Millepora tuberosa*
Acropora formosa	**Dendrophylliidae**	**Mussidae**
Acropora gemmifera	*Turbinarea mesenterina*	*Acanthastrea echinata*
Acropora humilis	*Turbinarea reniformis*	*Lobophyllia corymbosa*
Acropora hyacinthus	*Turbinarea stellulata*	*Lobophyllia hemprichii*
Acropora latistella	**Euphyllidae**	*Symphyllia recta*
Acropora longicyanthus	*Euphyllia cristata*	**Oculinidae**
Acropora loripes	**Faviidae**	*Galaxea fascicularis*
Acropora microphthalma	*Caulastrea furcata*	*Galaxea horrescens*
Acropora millepora	*Cyphastrea agassizi*	**Pocilloporidae**
Acropora nasuta	*Cyphastrea chalcidicum*	*Pocillopora damicornis*
Acropora prostrata	*Cyphastrea decadia*	*Pocillopora danae*
Acropora robusta	*Cyphastrea serailia*	*Pocillopora elegans*
Acropora samoensis	*Cyphastrea* sp. 1	*Pocillopora meandrina*
Acropora sp. 1 ("fine blue tip")	*Diploastrea heliopora*	*Pocillopora verrucosa*
Acropora sp. 2 (naraform-staghorn)	*Echinopora horrida*	*Seriatopora aculeata*
Acropora tenuis	*Echinopora lamellosa*	*Seriatopora hystrix*
Acropora vaughani	*Favia favus*	*Stylophora pistillata*
Acropora wardii	*Favia matthaii*	**Poritidae**
Anacropora forbesi	*Favia pallida*	*Alveopora* sp. 1
Astreopora listeri	*Favia rotundata*	*Goniopora minor*
Astreopora myriophthalma	*Favia* sp. 1 (mottled)	*Porites annae*
Astreopora randalli	*Favia speciosa*	*Porites attenuata*
Montipora aequitubuculata	*Favia stelligera*	*Porites australiensis*
Montipora capitata	*Favites abdita*	*Porites* cf. *stephesoni*
Montipora cf. *monastriata*	*Favites complanata*	*Porites cylindrica*
Montipora danae	*Favites pentagona*	*Porites distortia*
Montipora digitata	*Goniastrea aspera*	*Porites latistella*
Montipora efflorescens	*Goniastrea edwardsi*	*Porites lutea*
Montipora grisea	*Goniastrea pectinata*	*Porites murrayensis*
Montipora hispida	*Goniastrea retiformis*	*Porites rus*
Montipora incrassata	*Leptastrea pruinosa*	*Porites solida*
Montipora informis	*Leptastrea purpurea*	*Porites* sp. 1 (encrusting-aff. superfusa)
Montipora nodosa	*Leptastrea transversa*	***Siderastreidae***
Montipora peltiformis	*Leptoria phrygia*	*Coscinerea columna*
Montipora sp. 1 (dash & dot papillae)	*Montastrea curta*	*Psammocora contigua*
Montipora tuberculosa	*Platygyra daedalea*	*Psammocora haimeana*
Montipora verrucosa	*Platygyra lamellina*	*Psammocora obtusangula*
	Platygyra pini	*Psammocora stellata*
	Platygyra sinensis	

Figure 13. Mean Benthic Composition by Protection Status, Site and Zone (A – Middle, B – Outer).

A.



B.

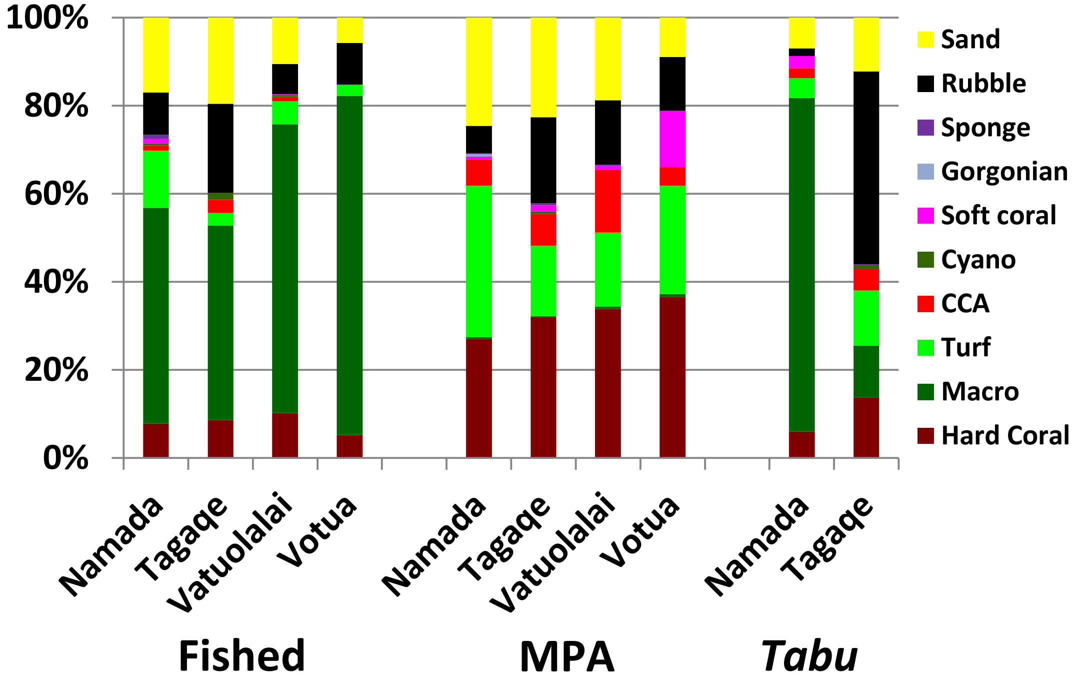


Figure 14. Mean Hard Bottom Composition by Protection Status, Site and Zone (A – Middle, B – Outer).

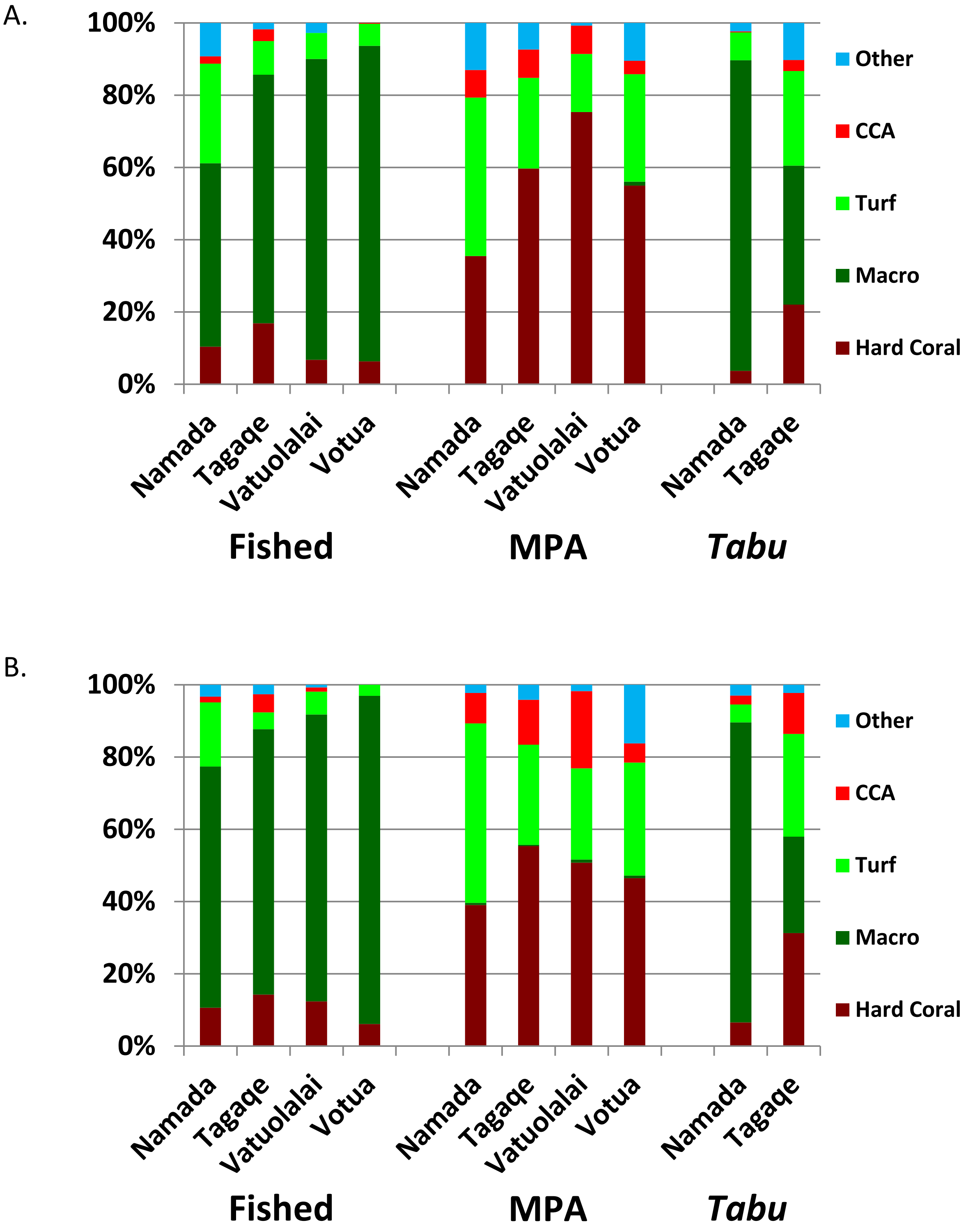
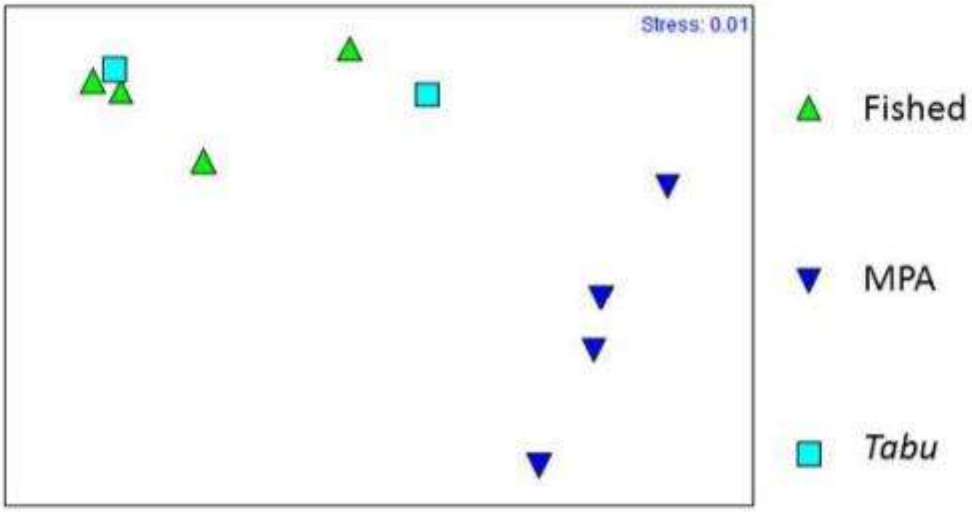


Figure 15. MDS Plot of Hard Bottom Composition by Status, Site and Zone (A – Middle, B – Outer).

A.



B.

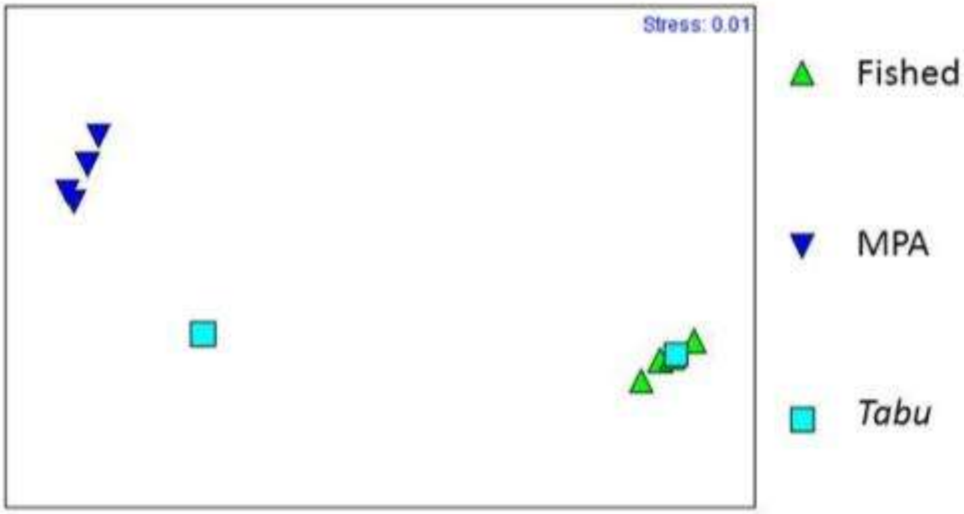
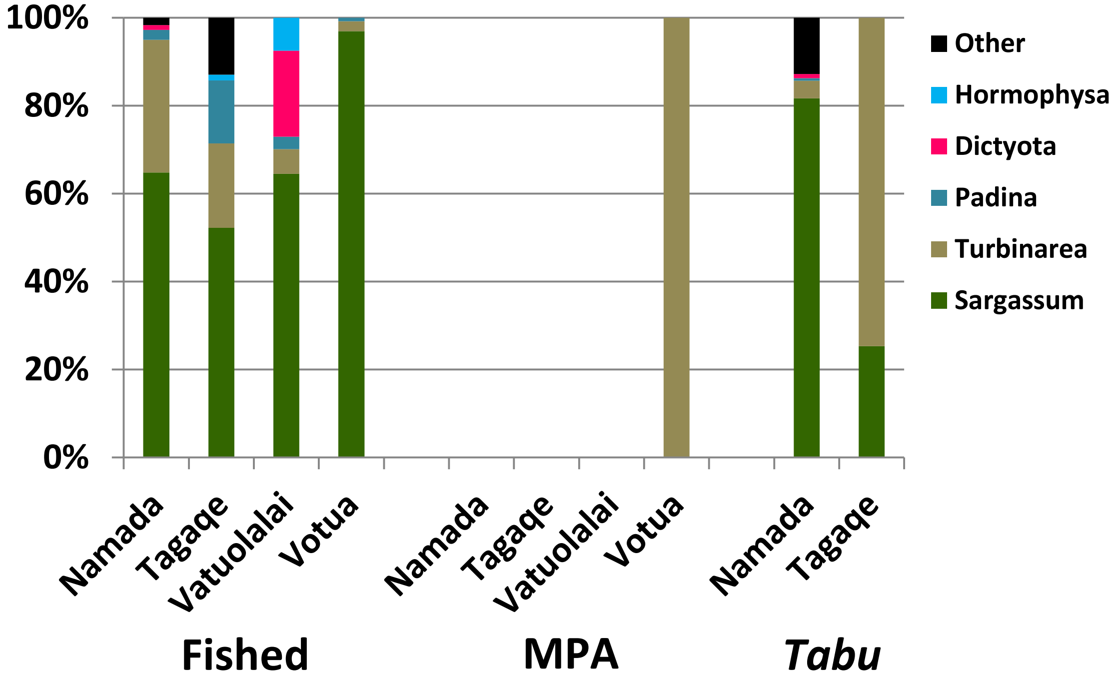


Figure 16. Macro-algal Composition (Genus) by Protection Status, Site and Zone (A – Middle, B – Outer).

A.



B.

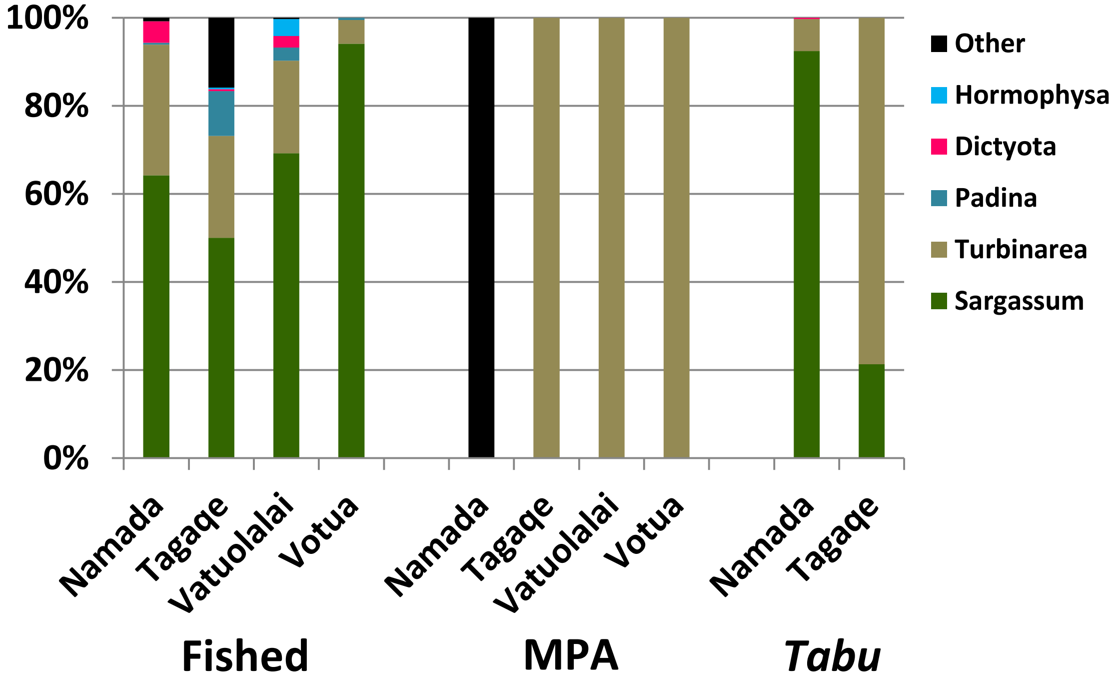
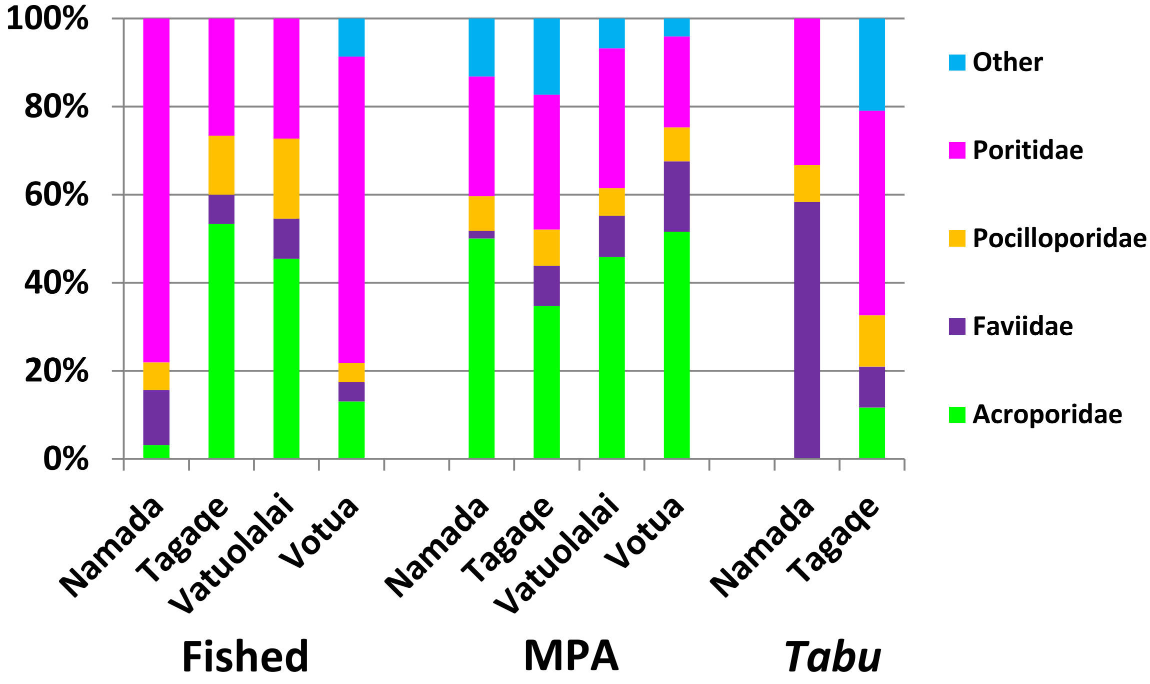


Figure 17. Coral Composition (Family) by Protection Status, Site, and Zone (A – Middle, B – Outer).

A.



B.

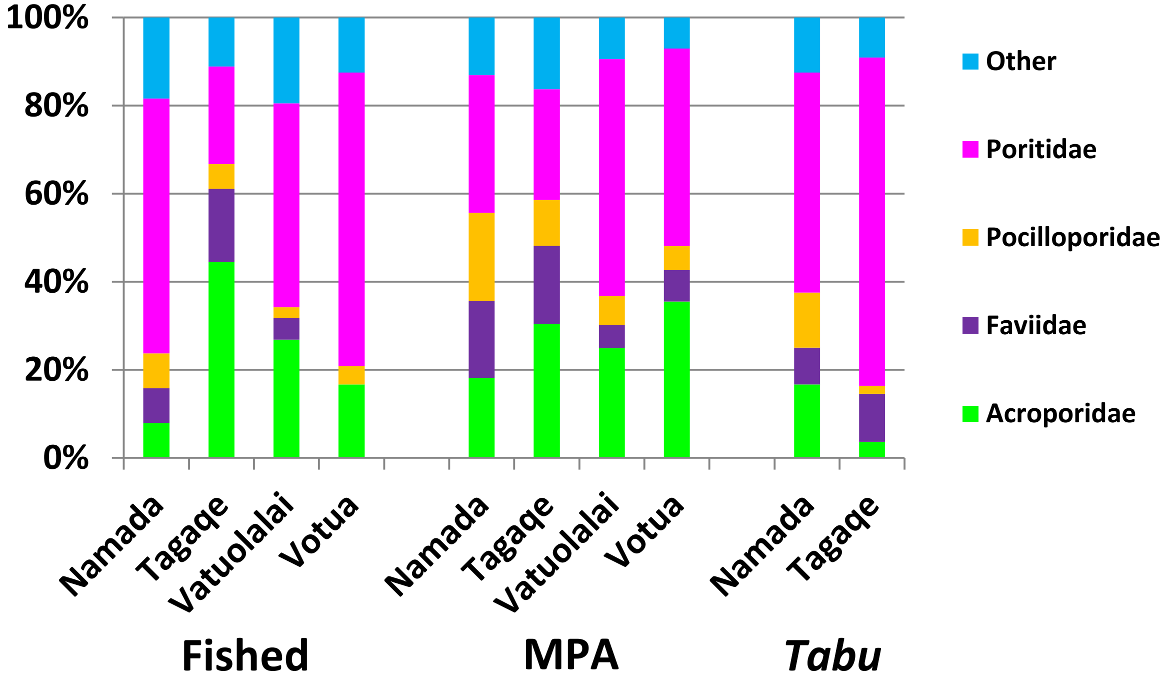


Figure 18. Mean Coral Species Richness per $100m^2$ by Protection Status, Site and Zone (A – Middle, B – Outer). In each zone, N=5 for each Fished and MPA location and N=4 for each Tabu location. P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letter show differences detected by Tukey Kramer HSD post-hoc tests.

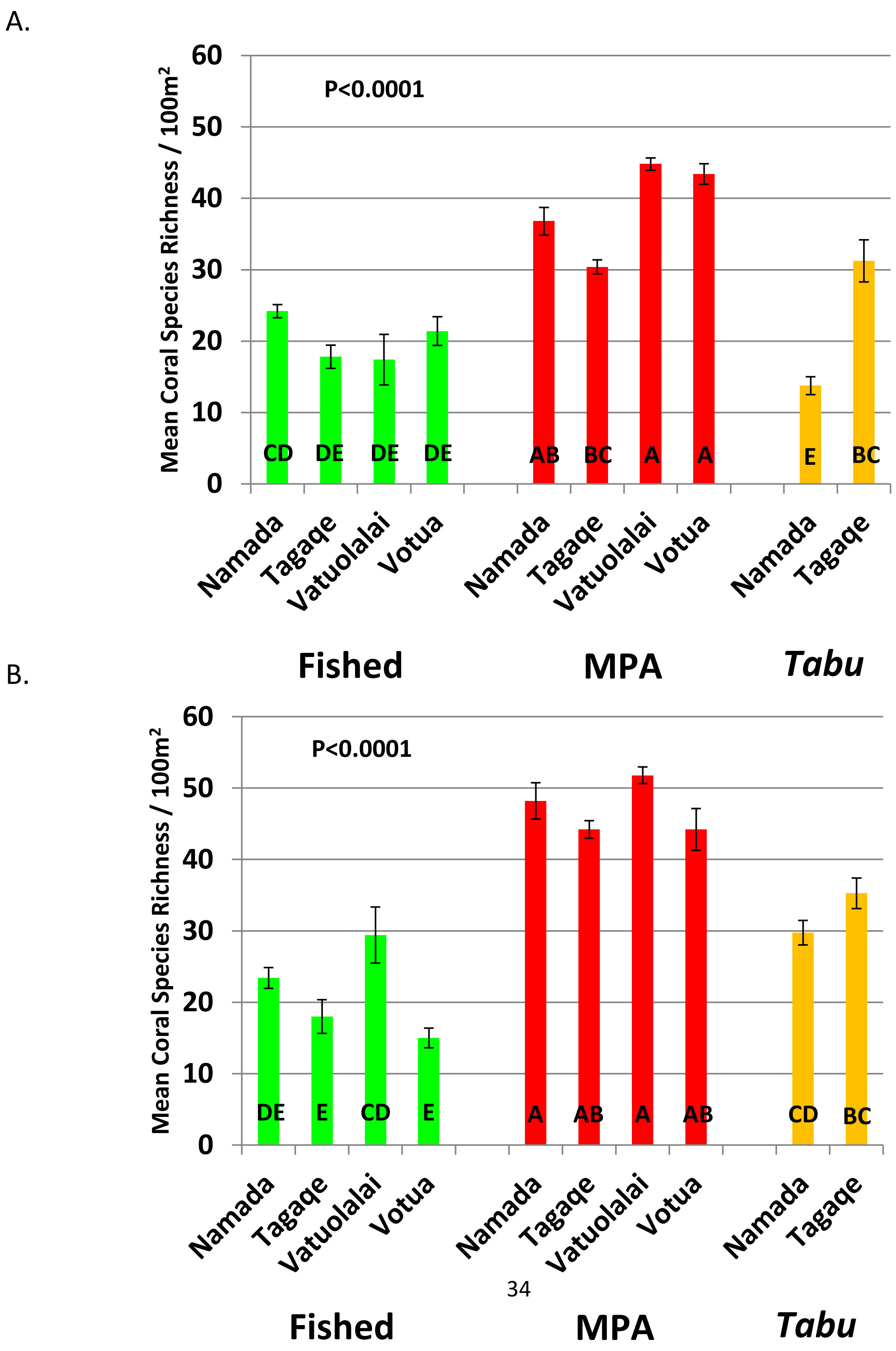


Figure 19. Mean Hard Bottom Composition by Protection Status and Zone.

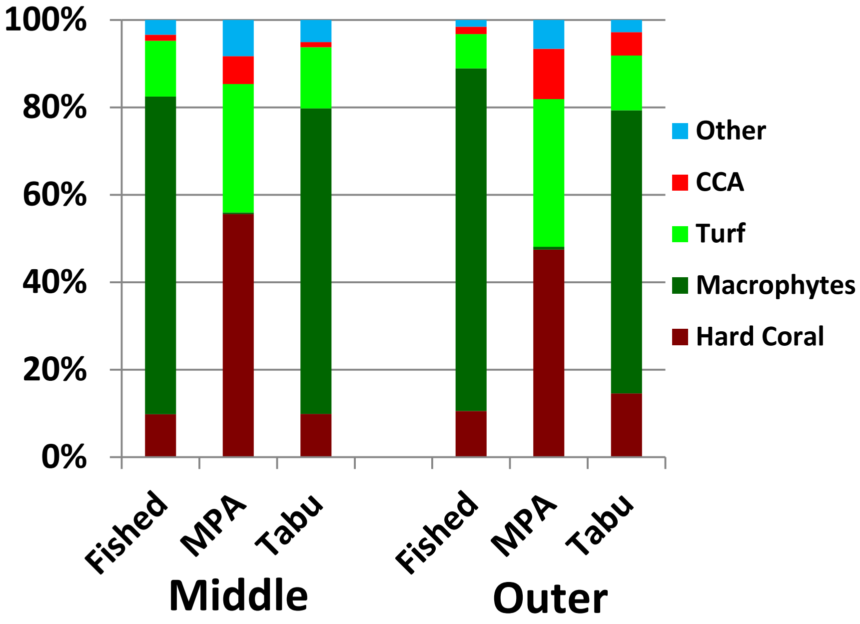


Figure 20. Linear Regression of the Relationship Between Hard Coral and Crustose Coralline Algae (CCA) Cover on Hard Bottom Areas by Zone (A – Middle, B- Outer).

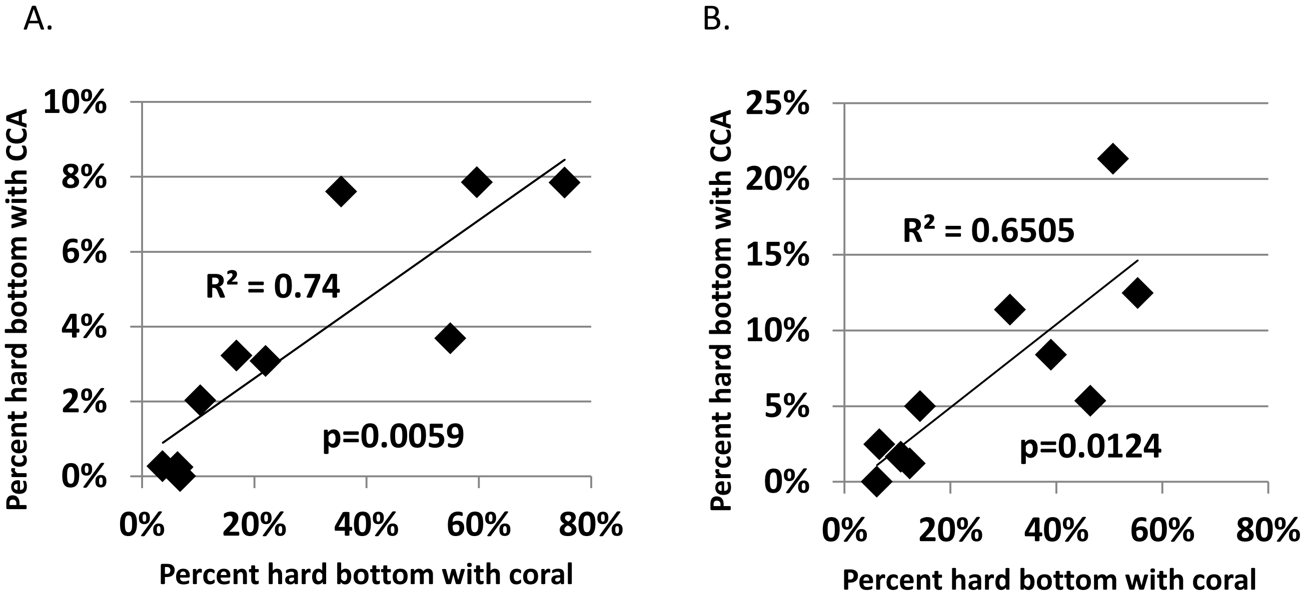


Figure 21. Percent Coral Cover on Hard Bottom Area by Protection Status and Zone. P-values reflect the results of a one-way ANOVA; Error bars illustrate standard error; Letter show differences detected by Tukey Kramer HSD post-hoc tests; N=20 for MPA and Fished and N=12 for Tabu in each zone.

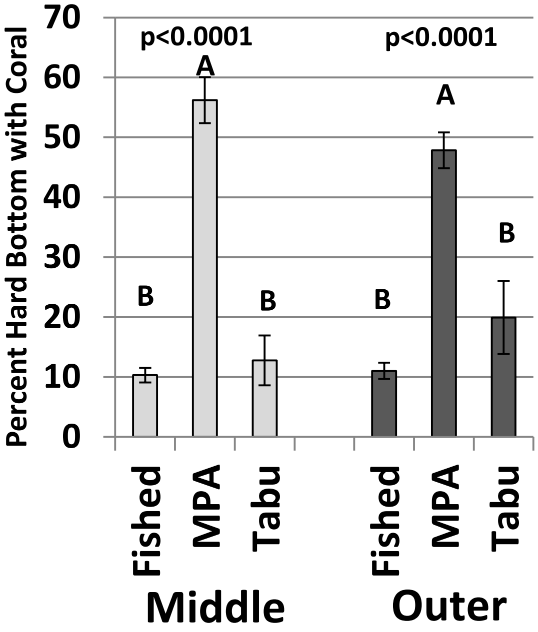


Figure 22. Coral Species Richness per 100m^2 by Protection Status and Zone. P-values reflect the results of a one-way ANOVA; Error bars illustrate standard error; Letter show differences detected by Tukey Kramer HSD post-hoc tests; N=20 for MPA and Fished and N=12 for Tabu in each zone.

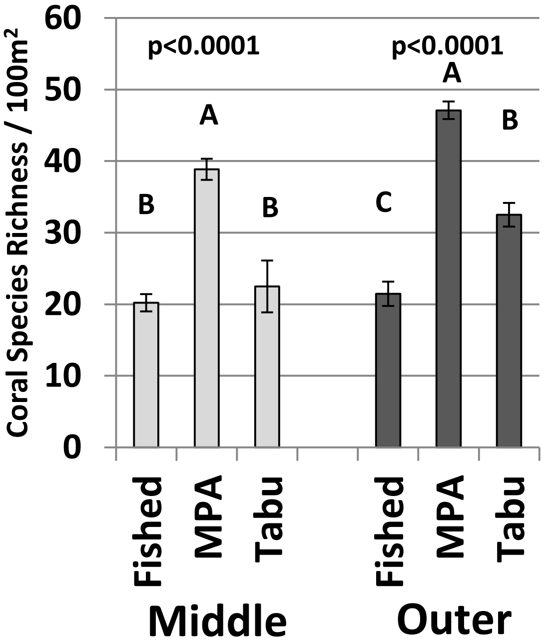
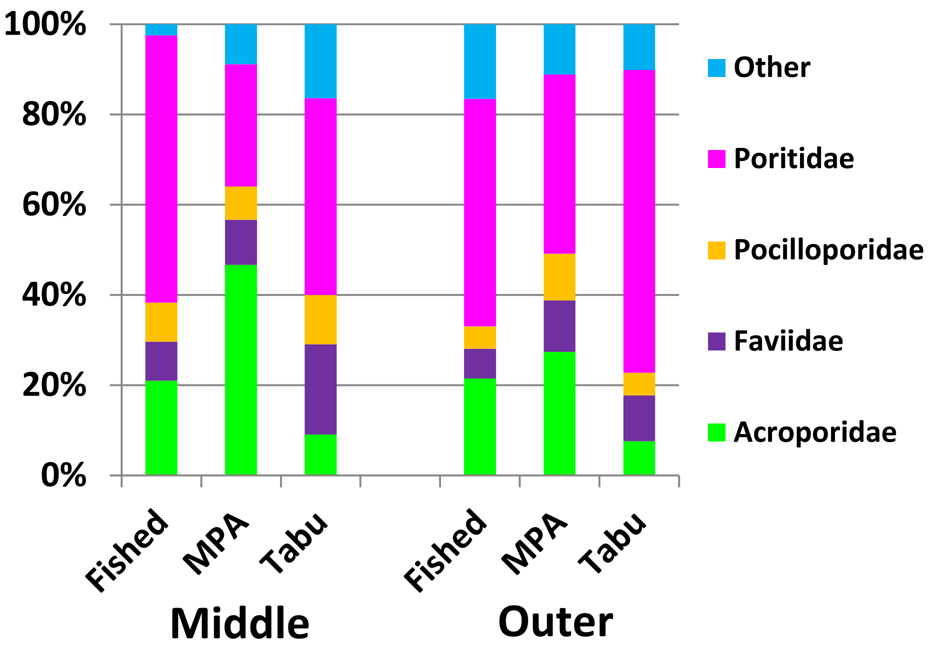
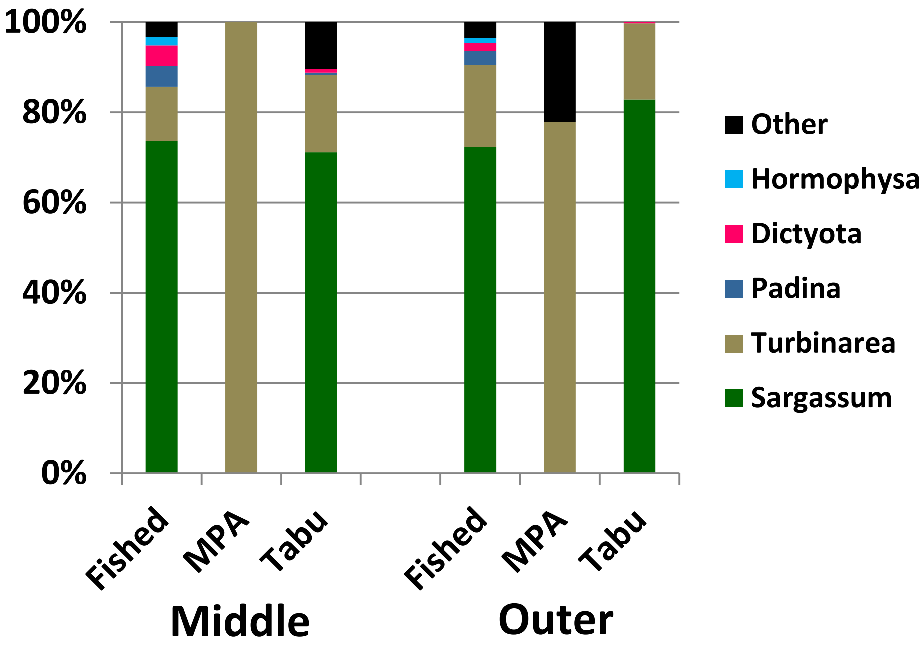


Figure 23. Coral (A) and Macro-algal (B) Composition by Protection Status and Zone.

A.



B.



3.1.2 TARGET FISH SURVEYS

A total of 11,573 fish representing 56 species and 19 genera in the target 9 families were recorded during the point-count surveys. Scarids (5507), Acanthurids (3276), and Siganids (1076) were the most abundant fish recorded overall during the surveys. Scarids and Acanthurids combined accounted for 70% of the total fish biomass recorded.

Overall, there were significant differences found in the total abundance of target fishes in each zone between sampling sites (Figure 24). In both the middle and outer zones, the highest abundances of target fishes were recorded in MPAs (particularly Namada and Vatuolalai MPAs), though some fished and tabu sites recorded total abundances that were not significantly different from MPA sites. This trend held true among all families of target fishes except Siganids which were found most abundantly in the fished sites (Figure 25).

All families of fish showed very clear trends of having larger-sized individuals in the MPAs, with fish above 30cm in length being found exclusively in the MPAs (Figure 26). MPAs also harbored greater species richness of fishes recorded during the surveys in the outer zone at the ten sampling locations; differences were less profound in the middle zone (Figure 27). Total target fish biomass reflected the generally larger size and greater abundance of target fishes in the MPAs with total fish biomass recorded in the outer zone being significantly greater in the MPAs than fished or tabu areas; differences were again less profound in the middle zone (Figure 28).

The MDS plots based on fish assemblage composition (by species) show that overall the MPA sites in both zones are all similar to each other, while assemblages at fished and tabu sites are more variable and often have a distinct assemblage structure from the MPAs (Figure 29). Fish assemblages found in the outer zone are more distinct between MPA and other (fish and tabu) sites while in the middle zone, fish assemblages in the MPAs are very similar to each other as well as a fished and a tabu site (Figure 29). Overall, MPAs showed a 68% similarity in the fish assemblage structure with one another, while fished and tabu sites showed only a 49% and 58% similarity respectively. Between areas with different protection statuses, MPAs and fished sites showed the least similarity in assemblage structure (47%) while MPAs and tabu sites shared 54% similarity, and fish and tabu sites shared 54% similarity. Difference in the relative abundance and presence of species of scarids, acanthurids, and siganids were responsible for most of the differences between sites.

Overall, MPAs had significantly higher total abundance, species richness, and biomass of target fishes recorded in the surveys than fished areas, while tabu areas showed intermediate levels of abundance and species richness (only in the outer zone) (Figure 30). MPAs had 300-500% more fish biomass as was recorded in fished and tabu areas (Figure 30). While this is partly due to fact that there were more fish recorded in the MPAs (20-30% more), it is mainly a reflection of the fact that fish in the MPAs (in all target families) were generally larger than in fished and tabu areas (Figure 31). When the overall abundance, size, and biomass of individual genera of fish are examined by sites (both zones combined), the trend of MPAs having more and larger fish than fished areas is clearly shown for most genera with tabu areas being intermediate, but more similar to fished area; only siganids were significantly less abundant in MPAs though they were much larger than in fished and tabu areas (Figure 32).

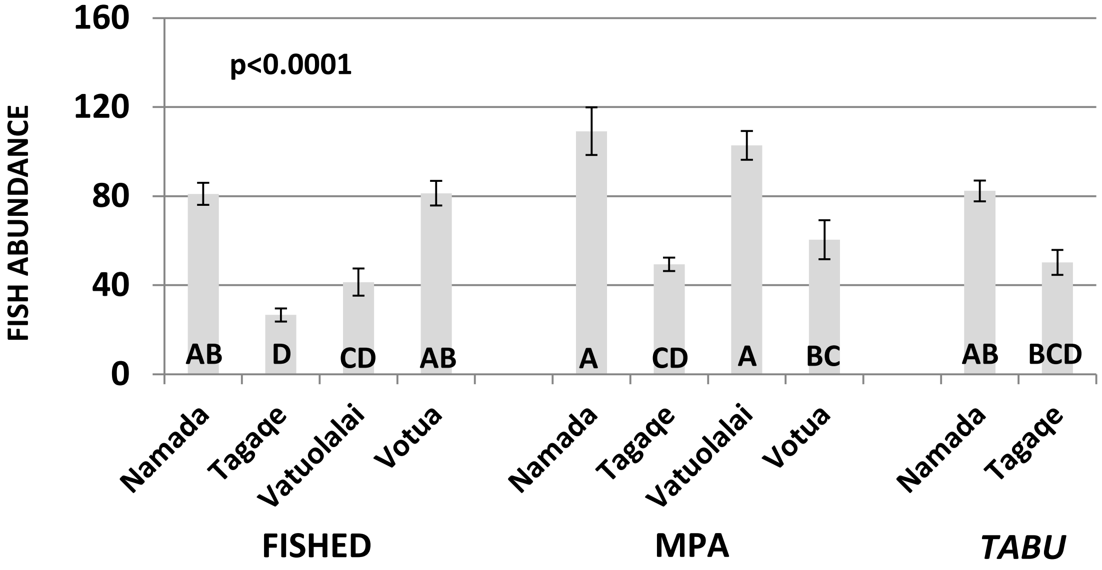
Table 2. Target Fish Species Recorded During Point Counts.

Acanthuridae
Acanthurus blochii
Acanthurus nigricauda
Acanthurus pyroferus
Acanthurus triostegus
Acanthurus xanthopterus
Ctenochaetus striatus
Ctenochaetus strigosus
Naso lituratus
Naso unicornis
Zebrasoma scopas
Haemullidae
Plectorhinchus gibbosus
Kyphosidae
Kyphosus vaigiensis
Lethrinidae
Lethrinus atkinsoni
Lethrinus harak
Lethrinus miniatus
Lethrinus obsoletus
Lethrinus xanthochilus
Monotaxis grandoculis
Lutjanidae
Lutjanus argentimaculatus
Lutjanus bohar
Lutjanus ehrenbergii
Lutjanus fulvus
Lutjanus gibbus
Lutjanus monostigma
Lutjanus semicinctus
Mullidae
Mulloidichthys flavolineatus
Mulloidichthys vanicolensis
Parupeneus barberinus
Parupeneus crassilabris
Parupeneus cyclostomus
Parupeneus indicus
Parupeneus multifasciatus
Parupeneus pleurostigma
Upeneus vittatus

Scaridae
Calotomus carolinus
Cetoscarus ocellatus
Chlorurus sordidus
Scarus altipinnis
Scarus chameleon
Scarus dimidiatus
Scarus frenatus
Scarus globiceps
Scarus oviceps
Scarus psitticus
Scarus rivulatus
Scarus rubroviolacea
Scarus schlegeli
Serranidae
Cephalopholis argus
Epinephelus fuscoguttatus
Epinephelus hexagonatus
Epinephelus merra
Epinephelus splitoceps
Siganidae
Siganus argenteus
Siganus doliatus
Siganus punctatus
Siganus spinus

Figure 24. Mean Total Fish Abundance by Site, Protection Status and Zone (A – Middle Zone, B – Outer Zone). P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letters show differences detected by Tukey Kramer HSD post-hoc tests; N=8 for MPA and Fished sites and N=6 for Tabu sites in each zone.

A.



B.

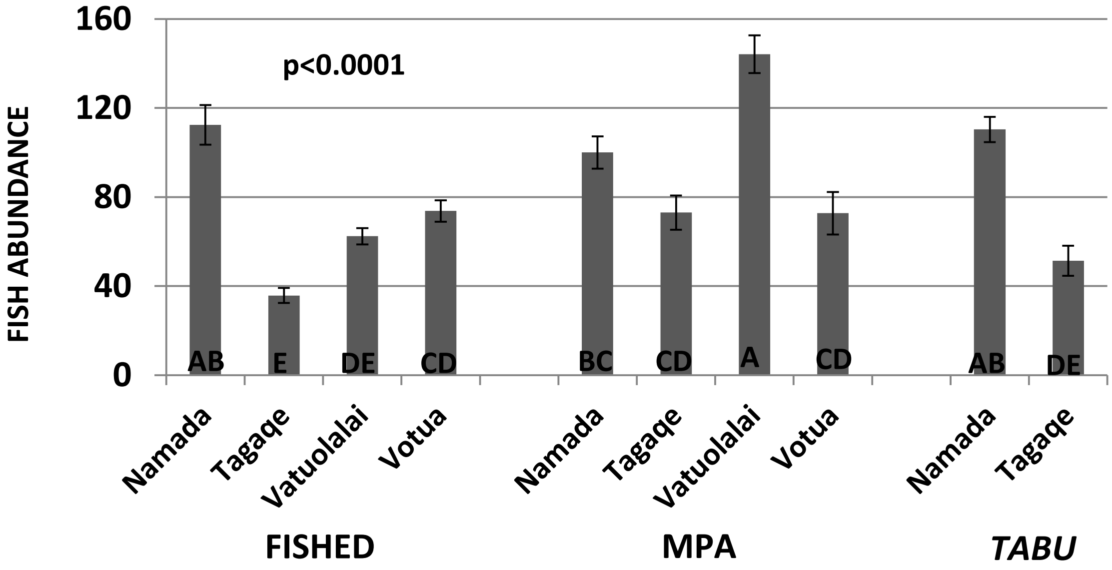
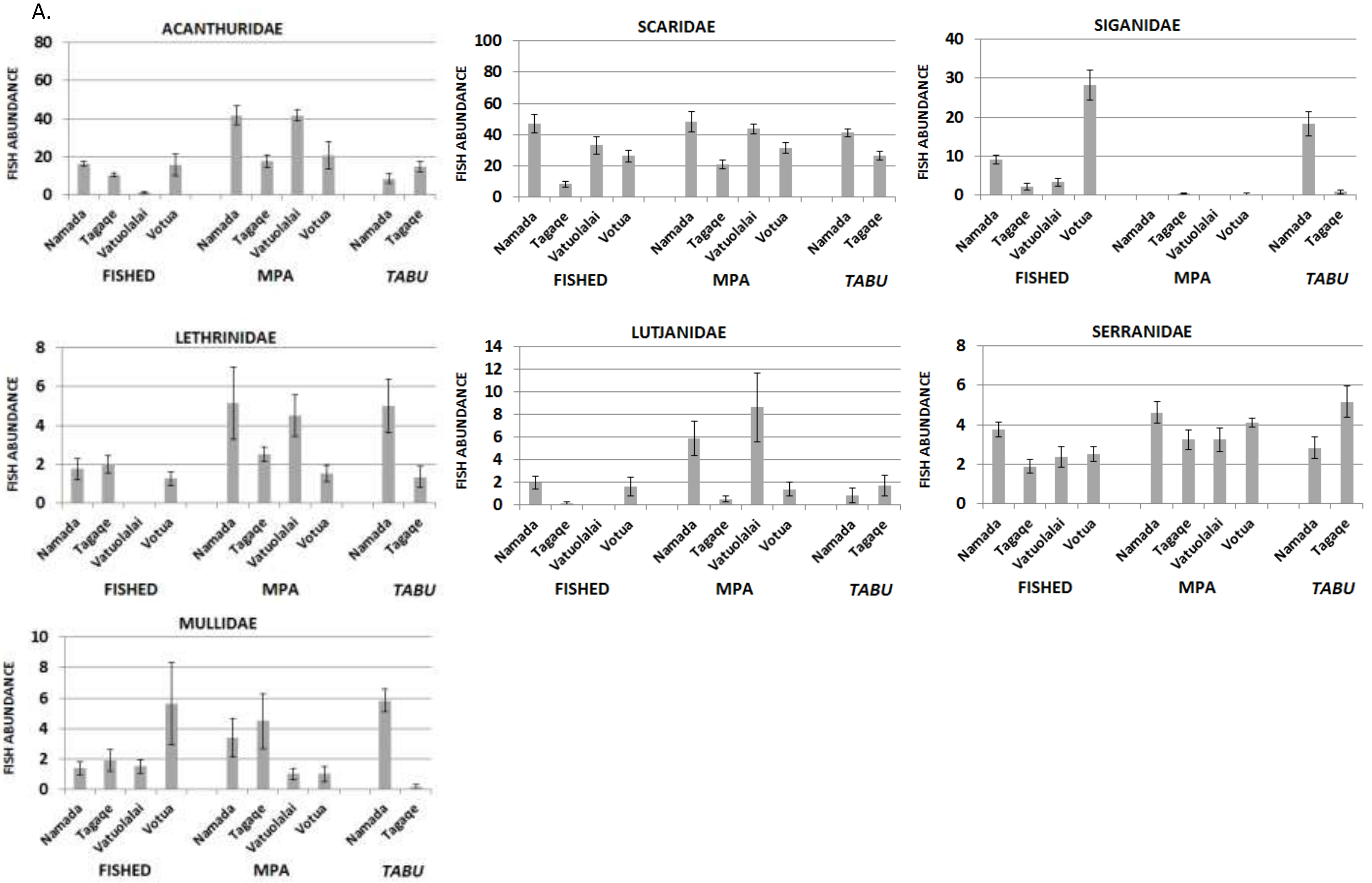


Figure 25. Mean Abundance of Target Fish Families by Site, Protection Status and Zone (A – Middle Zone, B – Outer Zone). N=8 for MPA and Fished sites and N=6 for Tabu sites in each zone.



B.

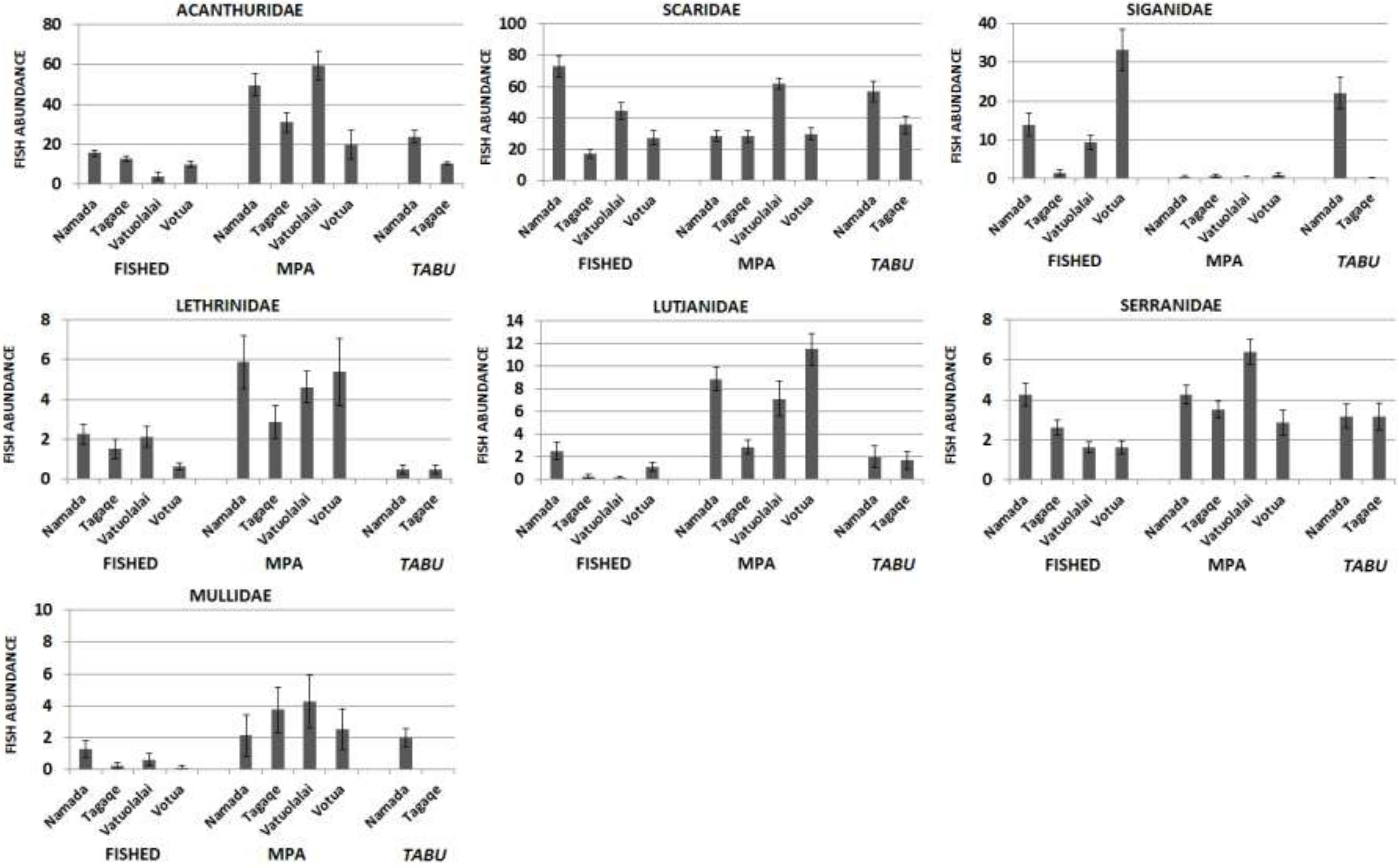

ACANTHURIDAE
SCARIDAE
SIGANIDAE
LETHRINIDAE
LUTJANIDAE
SERRANIDAE
MULLIDAE
FISH ABUNDANCE
0
20
40
60
80
100
Namada
Tagaqe
Vatuolalai
Votua
FISHED
MPA
TABU

Figure 26. Size Class Composition of Target Fish Families by Site, Protection Status and Zone (A – Middle Zone, B – Outer Zone).

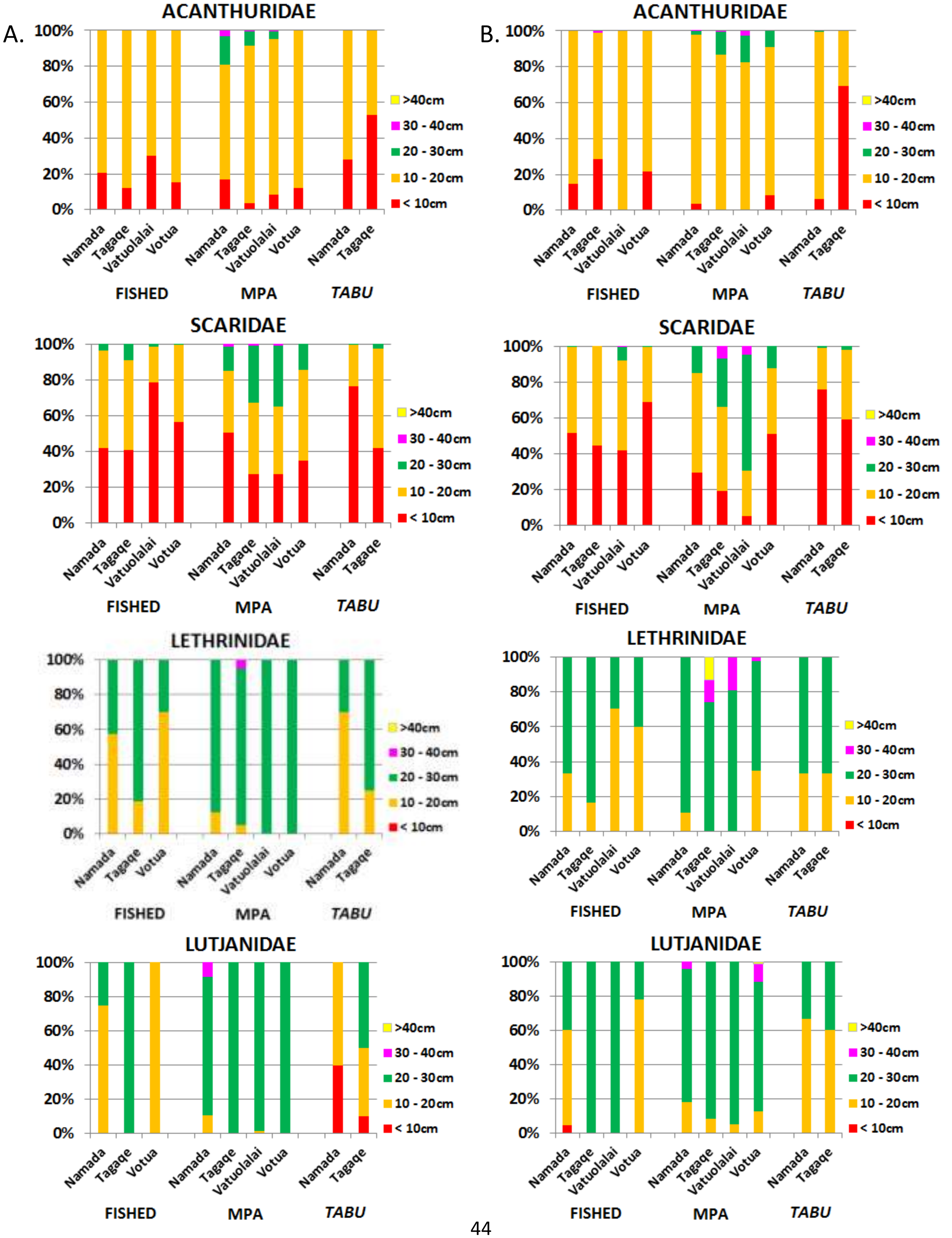
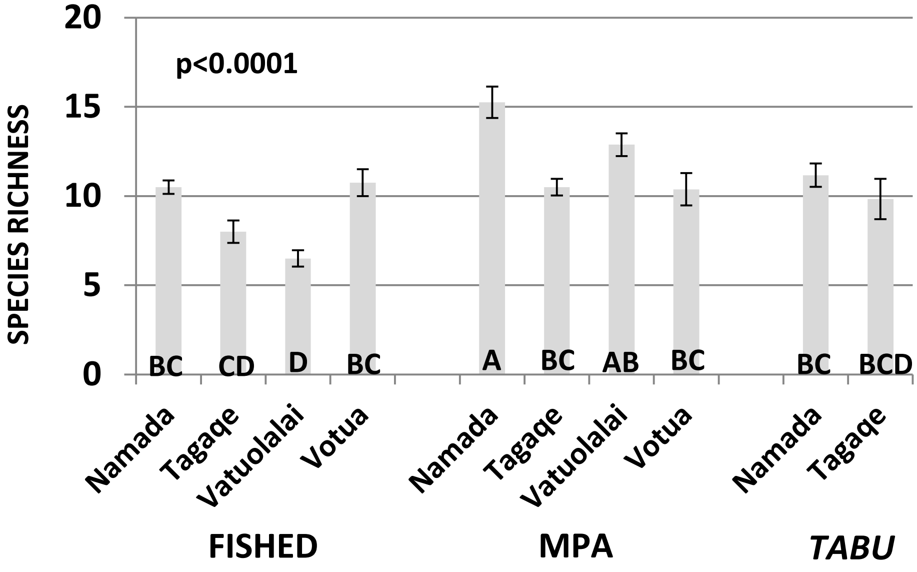


Figure 27. Mean Species Richness of Target Fishes by Site, Protection Status and Zone (A – Middle Zone, B – Outer Zone). P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letters show differences detected by Tukey Kramer HSD post-hoc tests; N=8 for MPA and Fished sites and N=6 for Tabu sites in each zone.

A.



B.

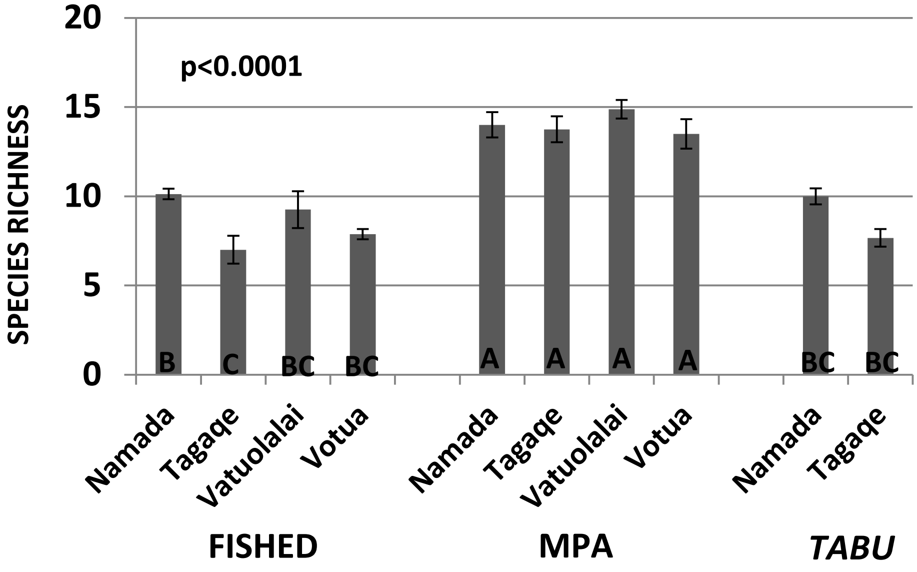
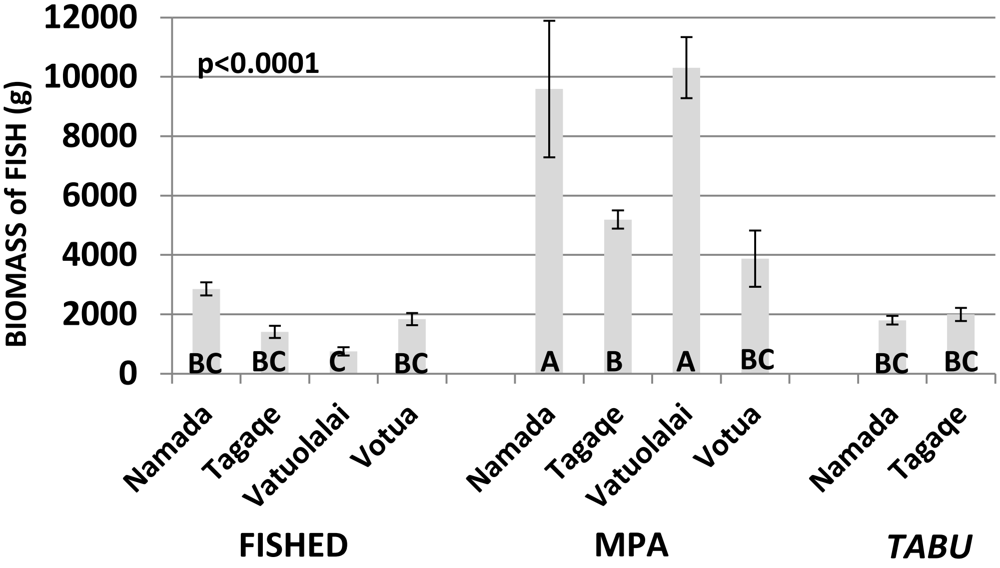


Figure 28. Mean Biomass of Target Fishes by Site, Protection Status and Zone (A – Middle Zone, B – Outer Zone). P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letters show differences detected by Tukey Kramer HSD post-hoc tests; N=8 for MPA and Fished sites and N=6 for Tabu sites in each zone.

A.



B.

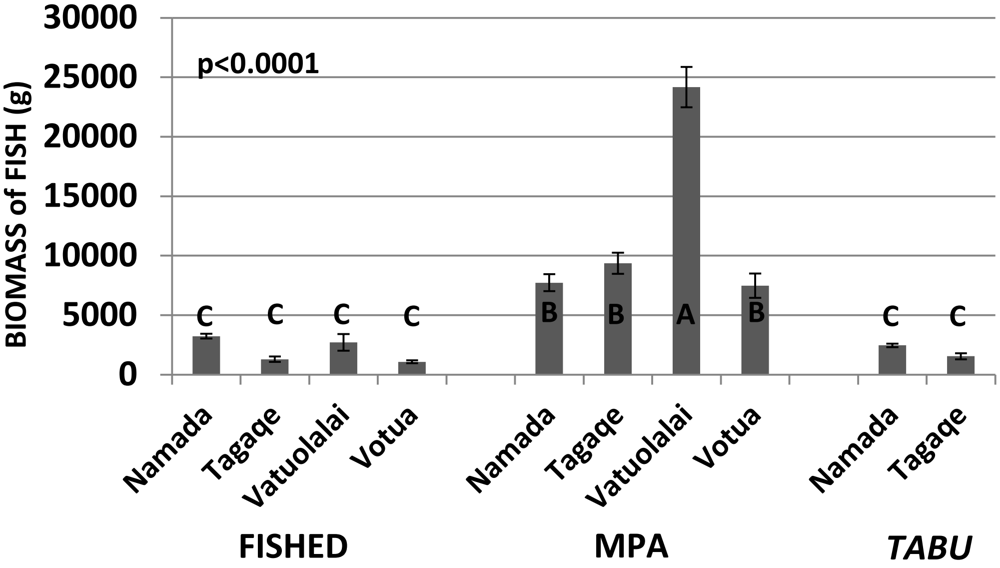


Figure 29. MDS Plot of Target Fish Community Composition by Status, Site and Zone (A – Overall, B - Middle, C – Outer).

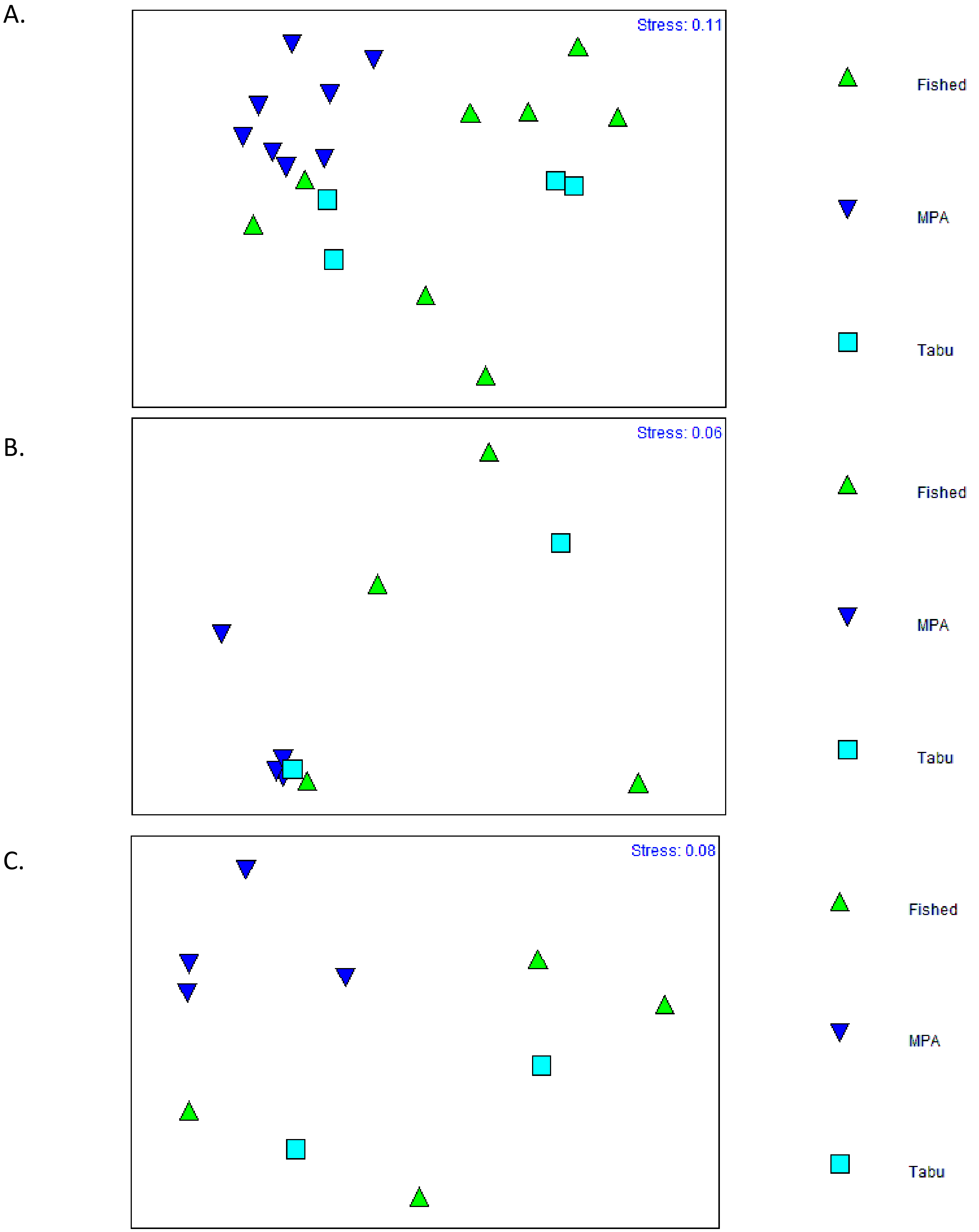


Figure 30. Mean Target Fish A) Abundance, B) Species Richness, C) Biomass by Protection Status and Zone. P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letters show differences detected by Tukey Kramer HSD post-hoc tests; N=32 for MPA and Fished sites and N=12 for Tabu sites in each zone.

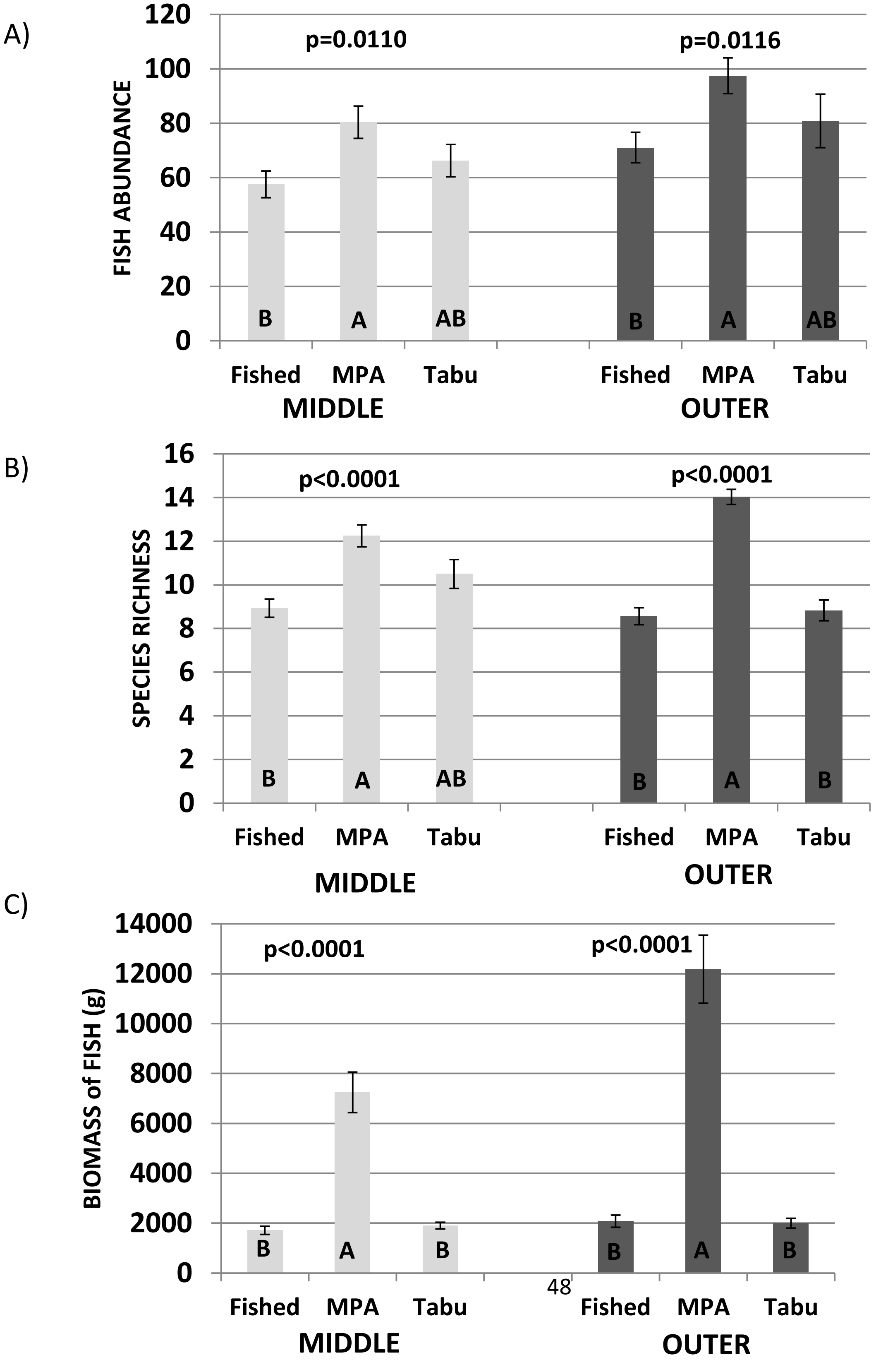


Figure 31. Size Class Composition of Target Fish Families by Protection Status and Zone.

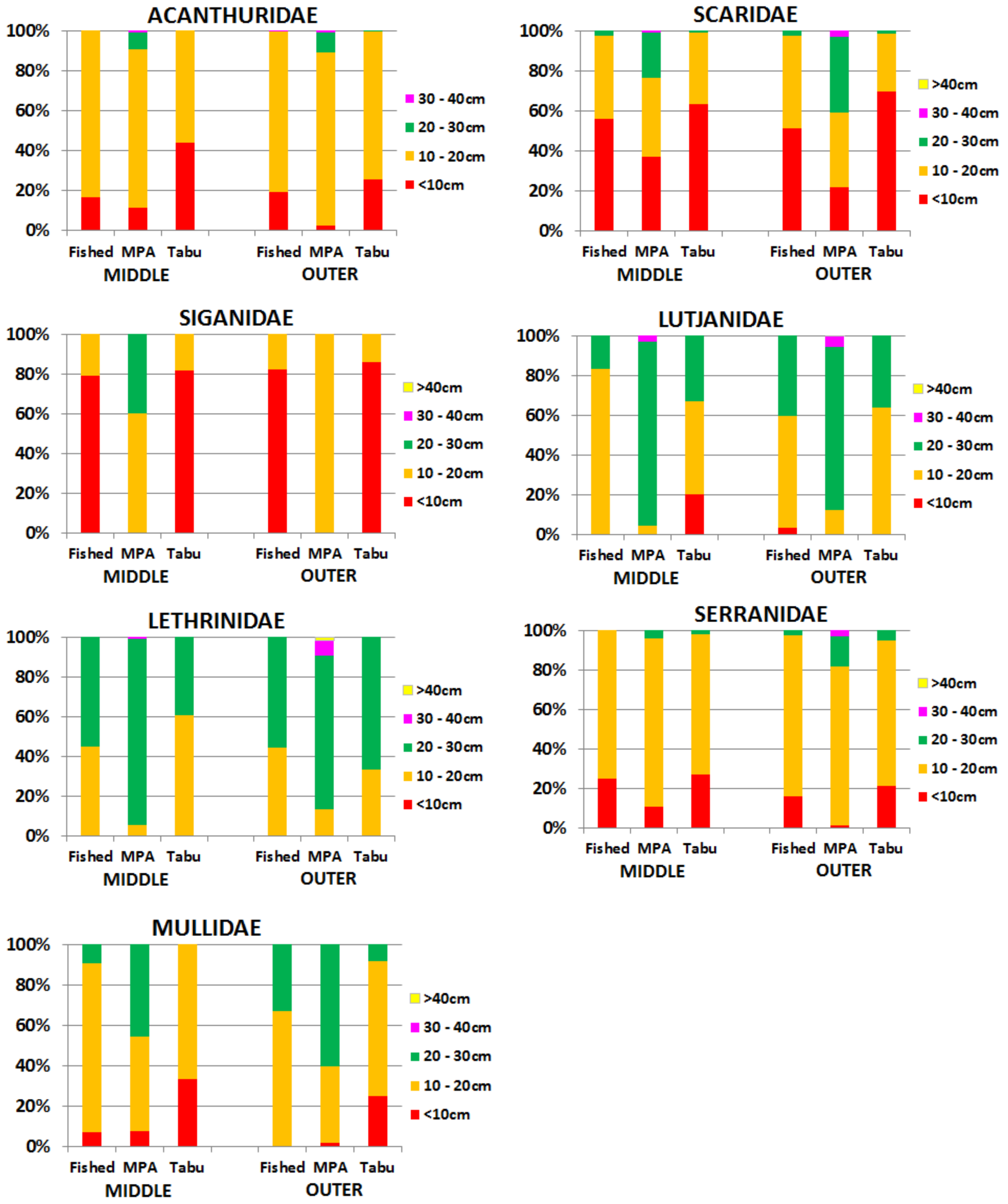
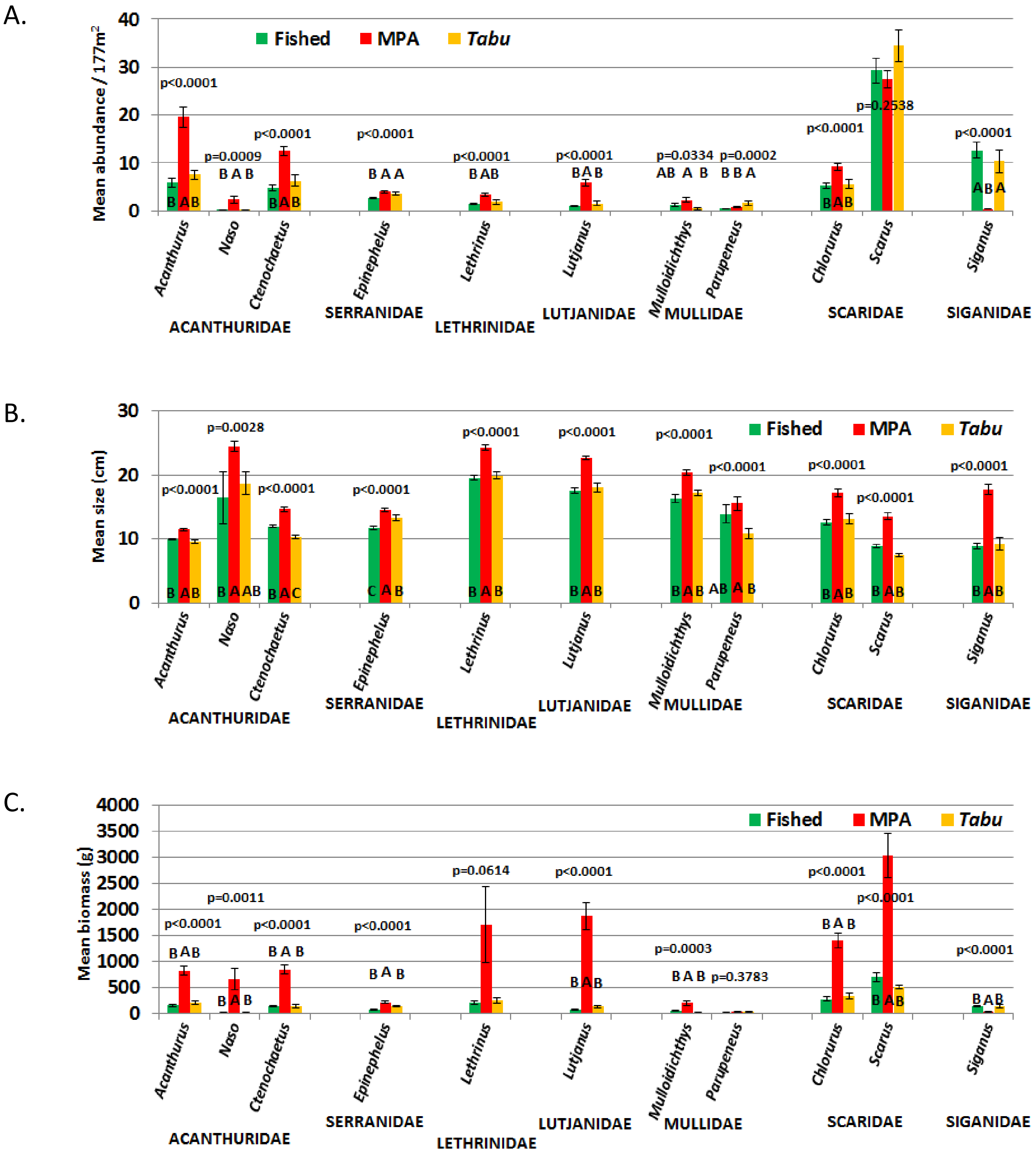


Figure 32. Mean Target Fish A) Abundance, B) Size, C) Biomass by Protection Status. P-values reflect the results of one-way ANOVAs; Error bars illustrate standard error; Letters show differences detected by Tukey Kramer HSD post-hoc tests; N=64 for MPA and Fished sites and N=24 for Tabu sites.



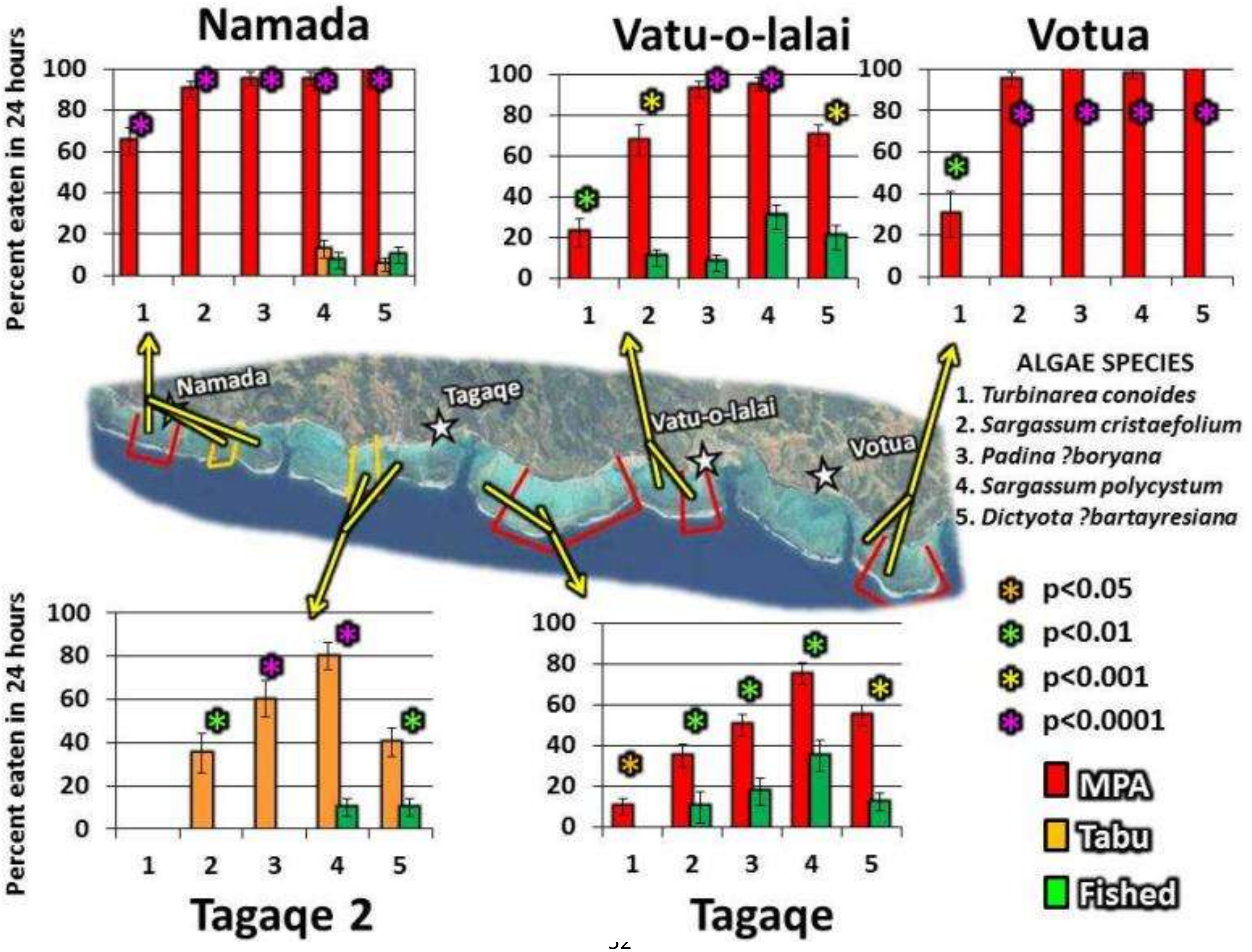
3.1.3 HERBIVORY ASSAYS

Herbivory assays conducted in 2010 and 2011 clearly show that herbivory on the five common species of brown algae used in the assays was significantly greater in the MPAs than in the paired fished areas (Figure 33) with more than 80% of the algae being consumed at some MPA sites while little to no algae were consumed at the fished sites. The MPA at Tagaqe was the only MPA with lower levels of herbivory that were not significantly greater that the adjacent fished area; ironically, herbivory levels recorded in this fished area, however, were the highest of any of the fished sites examined. While relatively no herbivory was recorded in Namada's tabu area, Tagaqe's tabu area recorded relatively high levels of herbivory on four of the five algae used in the assays with these results being consistent between the two sampling periods (Figure 33).

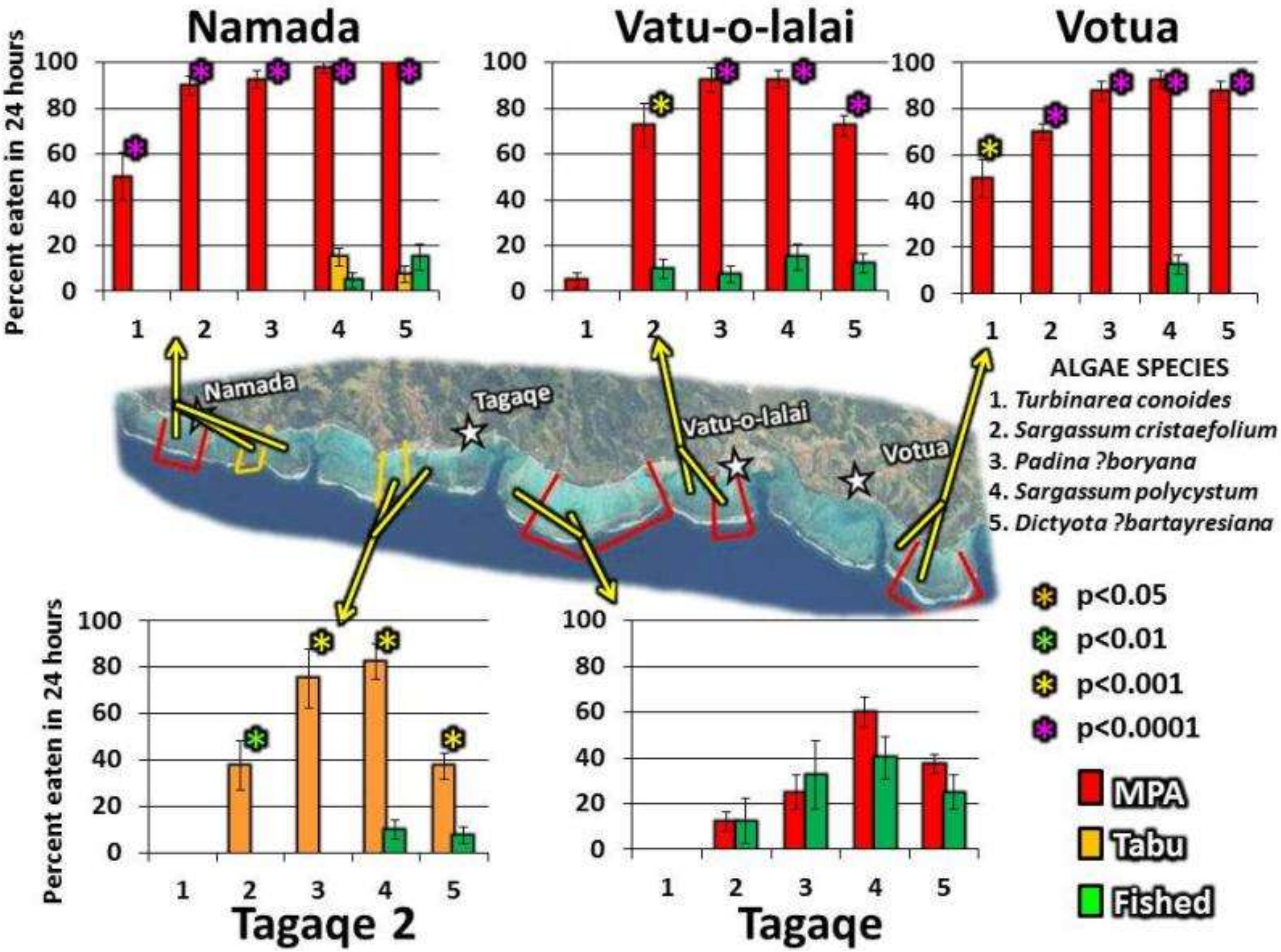
Overall, herbivory levels recorded in the MPAs was significantly greater (5-18 times more) than what was recorded in fished areas for all five of the algae used in the assays (Figure 34). *Turbinarea* was the least consumed of all the algae, while the other four algae were largely consumed in the MPAs (Figure 34). *Padina* was the most consumed algae regardless of the protection status of sites. Tabu areas showed levels of herbivory intermediate to fished and MPA sites, however this relationship was driven exclusively by the relatively-high levels recorded in the Tagaqe tabu area (Figure 34).

Figure 33. Mean Percent of Algae Eaten in 24 hours During Herbivory Assays in A) 2010 and B) 2011 by Site and Protection Status. P-values reflect the results of paired Wilcoxon comparisons; Error bars illustrate standard error; N=10 for each sampling site.

A.



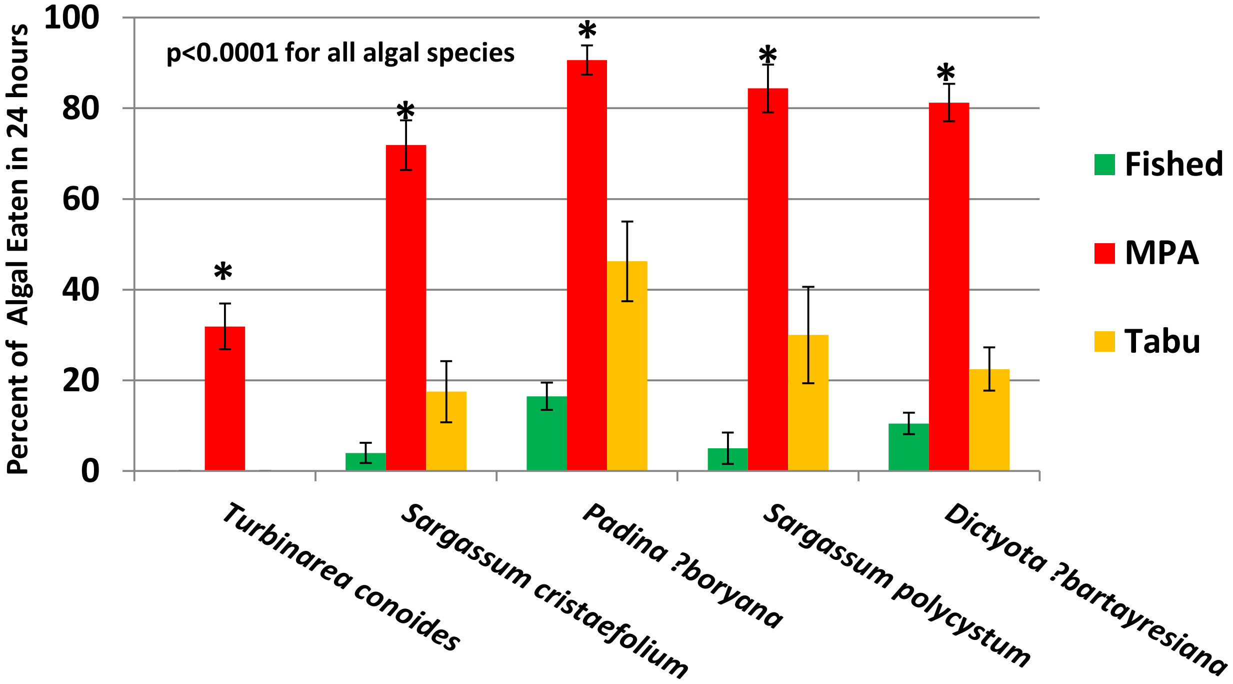
B.



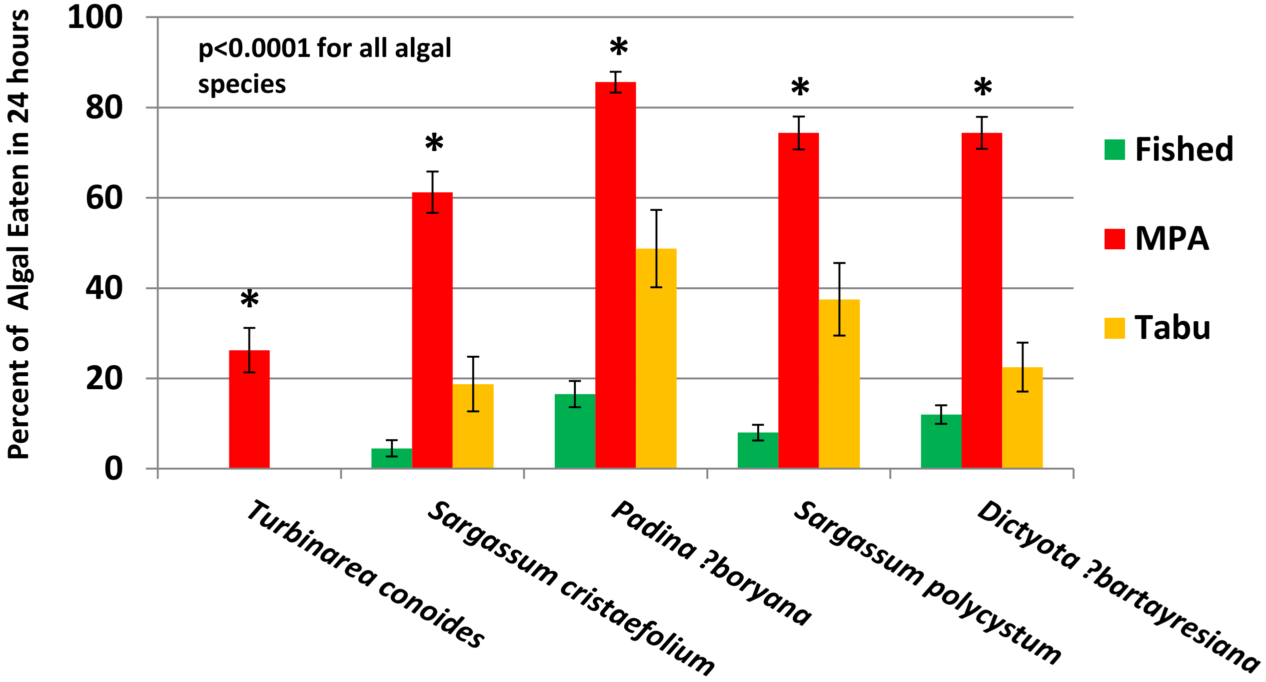
Namada
Vatu-o-lalai
Votua
Percent eaten in 24 hours
100
80
60
40
20
0
1
2
3
4
5
Namada
Tagaqe
Vatu-o-lalai
Votua
ALGAE SPECIES
1. Turbinarea conoides
2. Sargassum cristaefolium
3. Padina ?boryana
4. Sargassum polycystum
5. Dictyota ?bartayresiana
p<0.05
p<0.01
p<0.001
p<0.0001
MPA
Tabu
Fished
Tagaqe 2
Tagaqe

Figure 34. Mean Percent of Algae Eaten in 24 hours During Herbivory Assays in A) 2010 and B) 2011 by Protection Status. P-values reflect the results of paired Wilcoxon comparisons; Error bars illustrate standard error; N=50 Fished, N=40 MPA, N=20 Tabu for all paired comparisons.

A.



B.



3.2 NASINU VILLAGE, DAWASAMU DISTRICT

3.2.1 TARGET FISH SURVEYS

A total of 304 fish (12 species) from the six target families were recorded during fish surveys. Fish abundance was overall very low in both the no-take and fished areas (~20% of total abundance in MPAs in the Korolevu-i-wai district). Acanthurids, Scarids, and Siganids were the most abundant target fishes in the LMMA. Though the mean abundances of Scarids, Siganids, Lethrinids, and Lutjanids were greater in the no-take area than in the fished area, these differences were not significant (Figure 35). The fished area, however, did have significantly more Acanthurids than the no-take area (Figure 35); this was due to small schools of *Acanthurus triostegus* at some of the sampling stations - *A. triostegus* was the only fish species with significantly different abundances between the fished and no-take areas (p=0.0119). Serranids were rarely seen during the surveys (Figure 35).

The mean size of fishes was relatively small for all target families (Figure 36). Only Lethrinids differed in size significantly between the fished and no-take area (Figure 36); this difference was due to a few large *Lethrinus harak* that were the only Lethrinids recorded in the fished area. While there were no significant differences in the mean sizes of fishes in the no-take and fished areas apart from Lethrinids, relatively more larger-sized Scarids, Siganids, and Lutjanids were found in the fished area along with the only fishes >30cm in length (Figure 37).

Mean fish biomass per survey (314m^2) was relatively low in both the fished and no-take areas and reflected the low abundance and small size of fishes (Figure 38); Korolevu-i-wai recorded similar levels of biomass at fished sites, however biomass in the Korolevu-i-wai MPAs was up to 14 times greater than the no-take area at Nasinu. Only the biomass of Acanthurids differed significantly between the no-take and fished areas (Figure 38) with this difference again being driven by the presence of schools of *A. triostegus* in the fished area; *A. triostegus* was the only fish with significant differences in biomass between the no-take and fished areas (P=0.0061).

Figure 35. Mean Abundance of Fishes by Protection Status P-values reflect the results of paired Wilcoxon rank sign tests; Error bars illustrate standard error; N=5 No-Take and N=5 Fished for all paired comparisons.

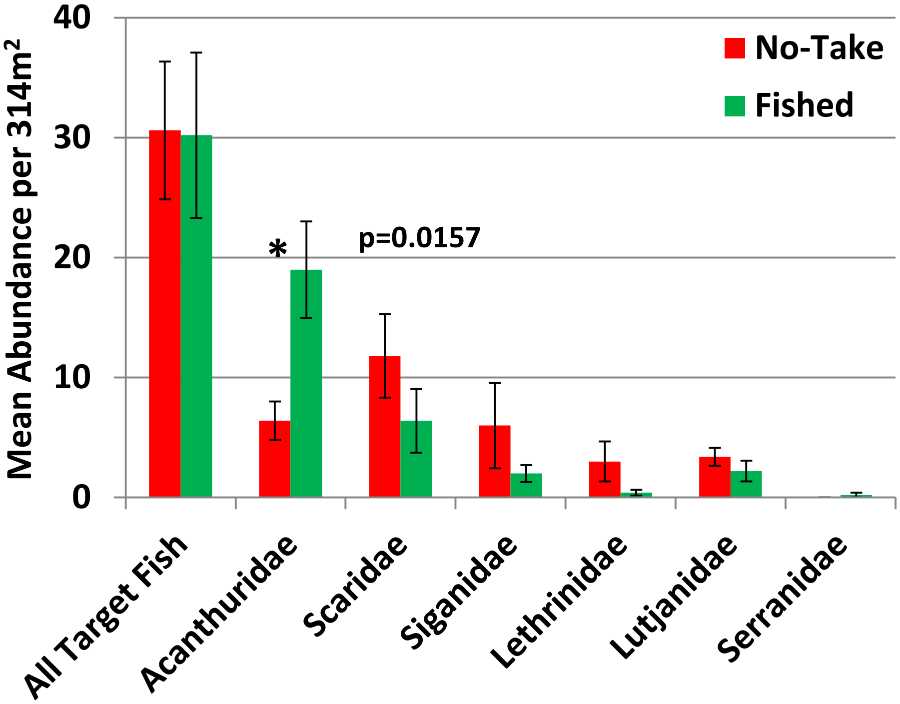


Figure 36. Mean Size of Fishes by Protection Status. P-values reflect the results of paired one-way ANOVAs; Error bars illustrate standard error; N for each mean is shown in the respective bar.

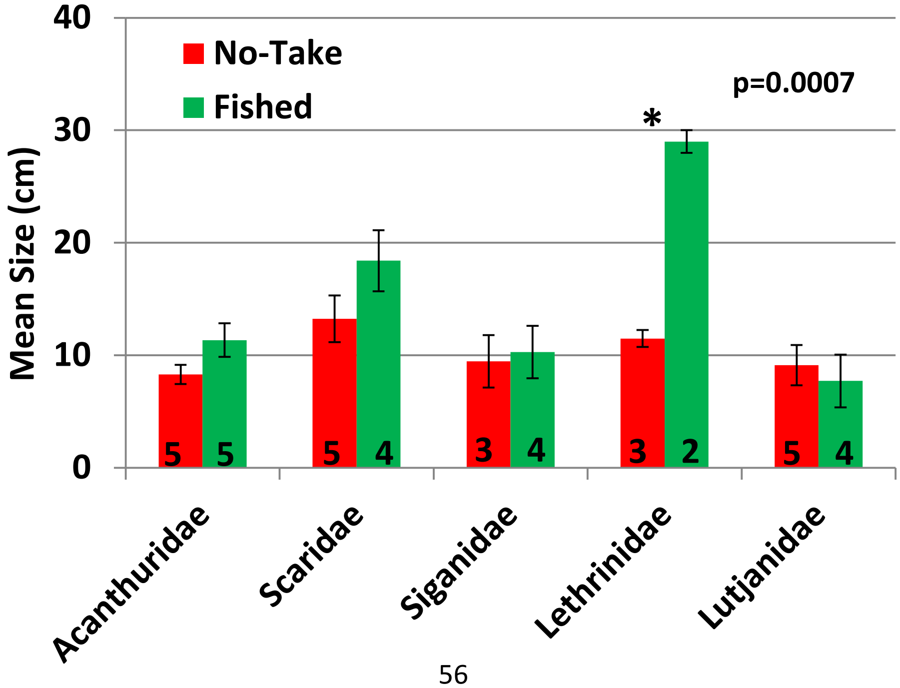


Figure 37. Size Class Composition of Target Fish Families by Protection Status.

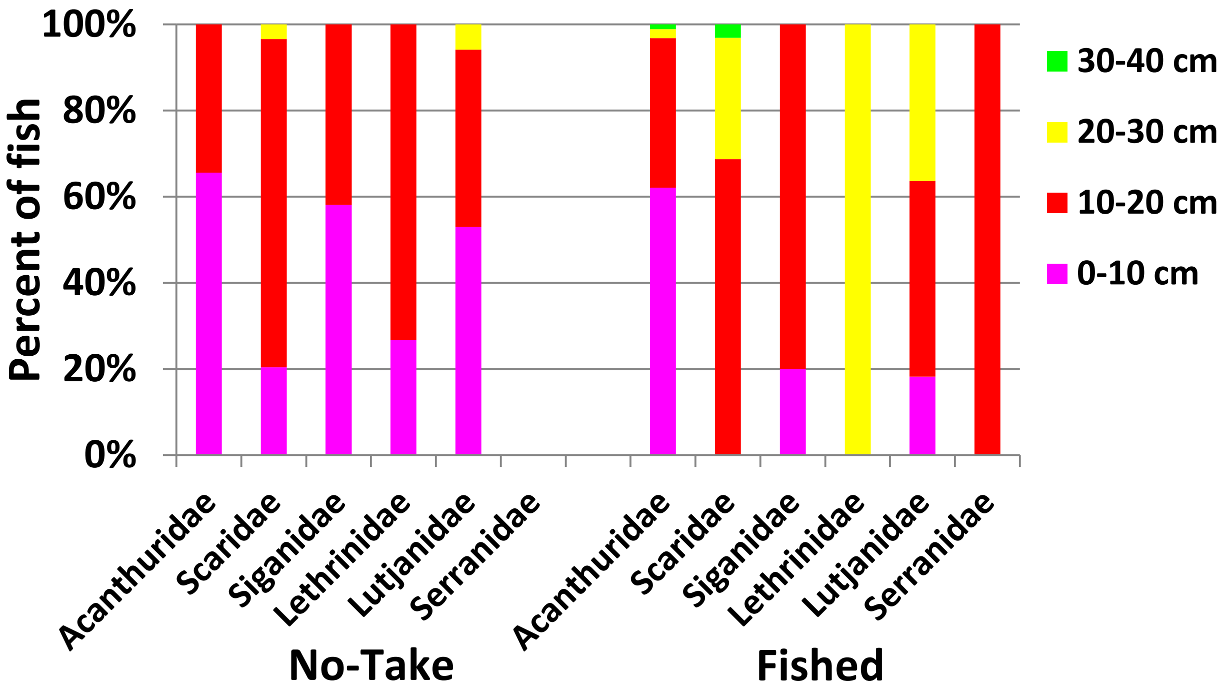
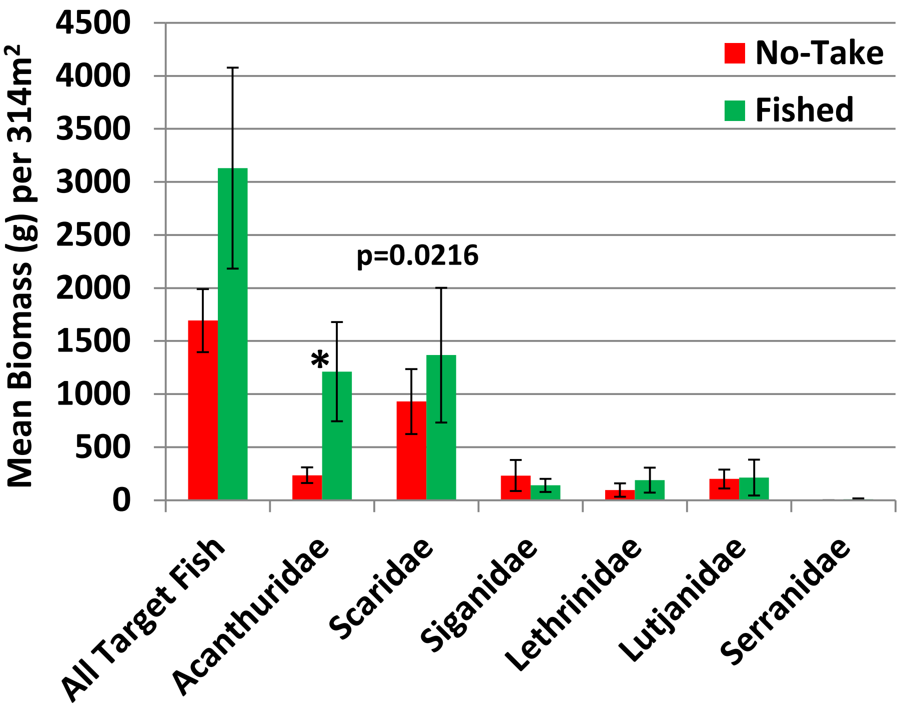


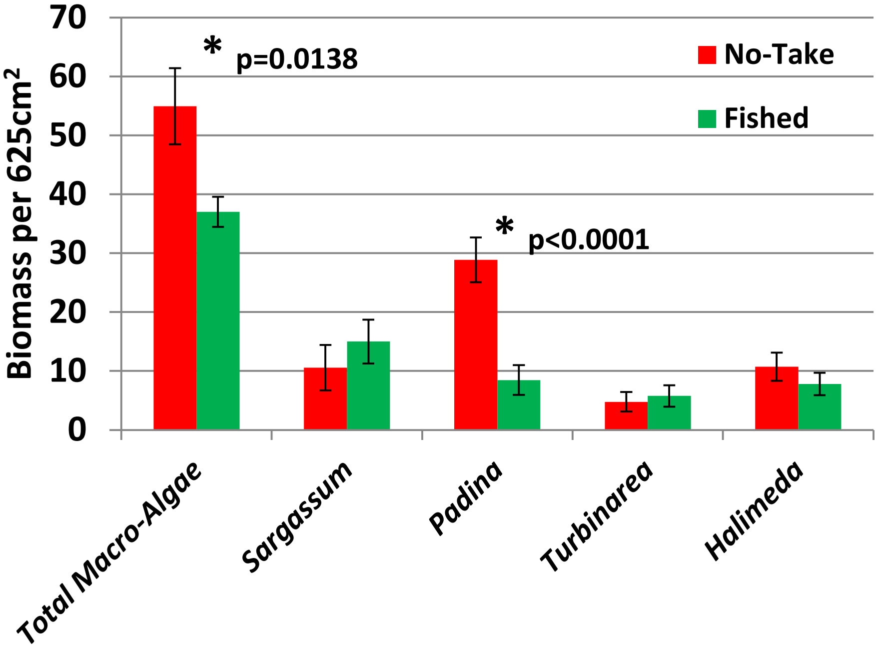
Figure 38. Mean Biomass of Target Fishes by Protection Status. P-values reflect the results of paired one-way ANOVAs; Error bars illustrate standard error; N=5 No-Take and N=5 Fished for all paired comparisons.



3.2.2 ALGAL BIOMASS SURVEYS

Sargassum, *Padina*, *Turbinarea*, and *Halimeda* were the only genera of macro-algae found in the quadrats with *Padina* being overall the most abundant (Figure 39). Overall, the no-take area had about 60% more biomass of macro-algae than the fished area; this difference was significant and largely driven by *Padina*, which constituted roughly half of the algal biomass present and was the only algae who biomass differed significantly between the fished and no-take areas (Figure 39).

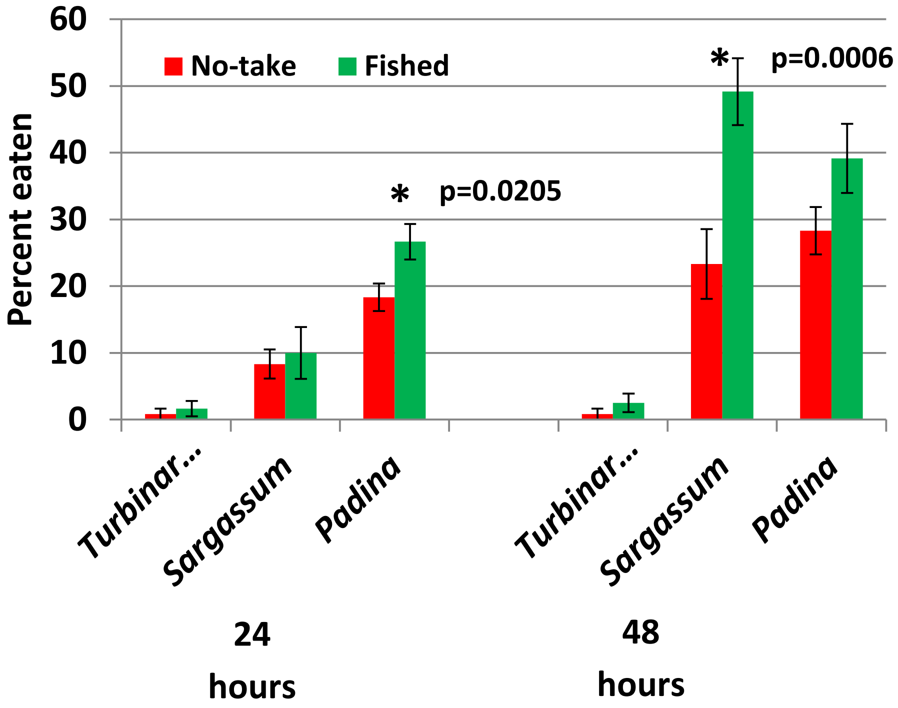
Figure 39. Biomass (g) of Macro-algae per 625cm^2 in the Nasinu LMMA. Mean biomass of each algal genera are shown by red bars (no-take area) and green bars (fished area); Error bars show standard error; N=20 at each location; * and p-values show significant differences in biomass found between the two areas by Wilcoxon paired comparisons.



3.2.3 HERBIVORY ASSAYS

Overall, levels of herbivory on the three species of algae used were relatively similar those recorded at fished sites in the Korolevu-i-wai LMMA; compared to those recorded in MPAs in the Korolevu-i-wai LMMA though, herbivory levels were low with more than 50% of the mass of the most-consumed algae (*Sargassum*) remaining after 48 hours (Figure 40). Significantly more *Sargassum* and *Padina* were eaten after 48 hours than 24 hours indicating a low but steady rate of herbivory (Figure 40). While herbivory was generally greater in the fished areas, the only significant differences recorded in herbivory between the two areas was with *Padina* after 24 hours, and *Sargassum* after 48 hours (Figure 40).

Figure 40. Mean Percent of Algae Eaten in 24 and 48 hours During Herbivory Assays by Protection Status. P-values reflect the results of paired Wilcoxon comparisons; Error bars illustrate standard error; N=30 for each sampling site.



3.3 NAMARAI VILLAGE, NAKOROTUBU DISTRICT

3.3.1 BENTHIC SURVEYS

Sampling stations in the reef top zone contained significantly more ($p<0.0001$) hard bottom area than those on the reef slope. In the reef top zone, hard bottom covered a mean of 53% (minimum 11%, maximum 94%) of the benthos in no-take areas and 70% (minimum 40%, maximum 90%) of the benthos in fished areas, while in the reef slope zone hard bottom area covered only a mean of 42% (minimum 14%, maximum 79%) of the benthos in no-take areas and 38% (minimum 5%, maximum 57%) of the benthos in fished areas.

While coral cover varied significantly among sampling sites in the reef top zone, no significant differences were found between the sites in the reef slope zone (Figure 41). Coral communities were largely dominate by the coral families Acroporaidae, Faviidae, Pocilloporidae, and Poritidae, with more Acroporidae generally being found in the shallower reef top zone and Poritidae generally dominating the reef slope coral community (Figure 42). The coral communities at sampling stations on Oru reef were largely dominated by Poritidae on both the windward and leeward exposures in both zones sampled (Figure 42).

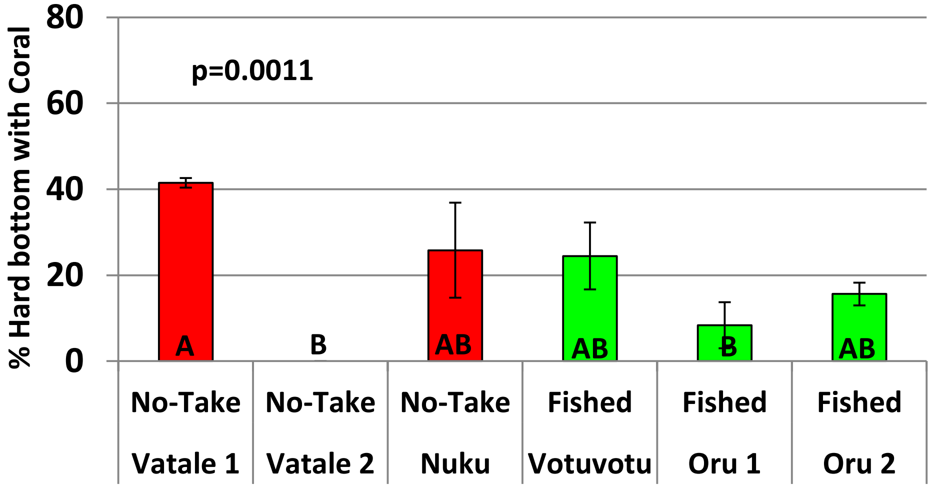
Macro-algal cover on hard bottom areas was not significantly different between reef zones, and at all but three out of twelve sampling sites was generally low - less than 20% (Figure 43). Macro-algal cover did vary significantly among sites within zones however, with the windward side of Vatale and the leeward side of Oru having significantly more macro-algal cover on hard bottom area than other reef top sites, and the reef slope site at Votuvotu having significantly more macro-algal cover than other reef slope sites (Figure 43).

Overall, hard coral covered more than double the amount of hard bottom area in the reef slope zone than in the reef top zone and this difference was significant ($p<0.0001$). Though there were no significant difference in coral cover between no-take and fished area in each zone, both no-take and fished areas had significantly more coral cover on the reef slope (Figure 44).

Overall, coral communities in the no-take areas had more Acroporidae cover than those in fished areas, though more than half of the coral cover in all but the no-take reef top zone consisted of Poritidae species (Figure 45a). Sargassum was the most common macro-algae recorded in the reef top zone, comprising > 70% of macro-algal cover, while Halimeda and Lobophora were the most abundant macro-algae recorded in the reef slope zone (Figure 45b).

Figure 41. Mean Percent Hard Bottom with Coral Cover by Reef and Protection Status. A) Reef Top, B) Reef Slope. Mean coral cover on hard bottom areas is shown by red bars (no-take area) and green bars (fished area); Error bars show standard error; N=5 at each location; p-values show significant differences in coral cover found between sites by a one way ANOVA; Letters show differences detected by Tukey Kramer HSD post-hoc tests.

A)



B)

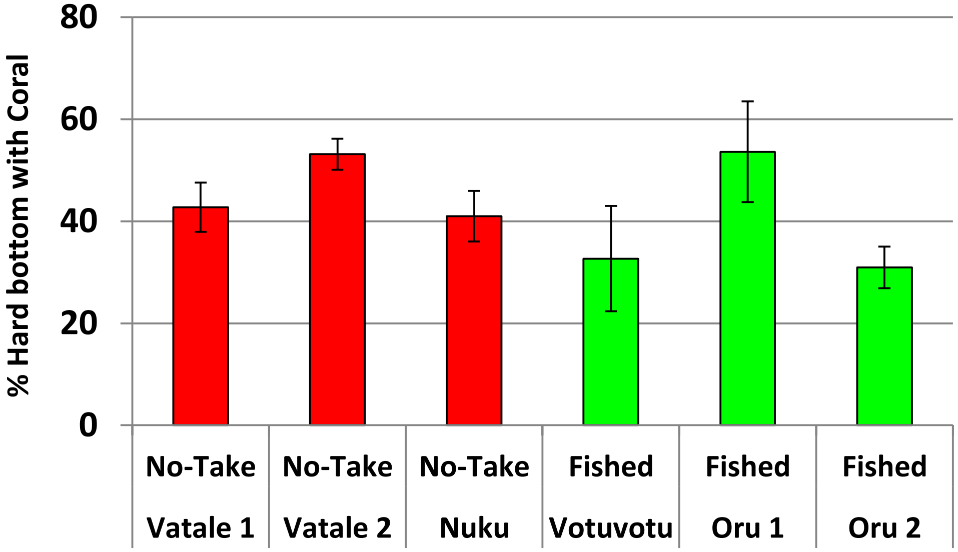
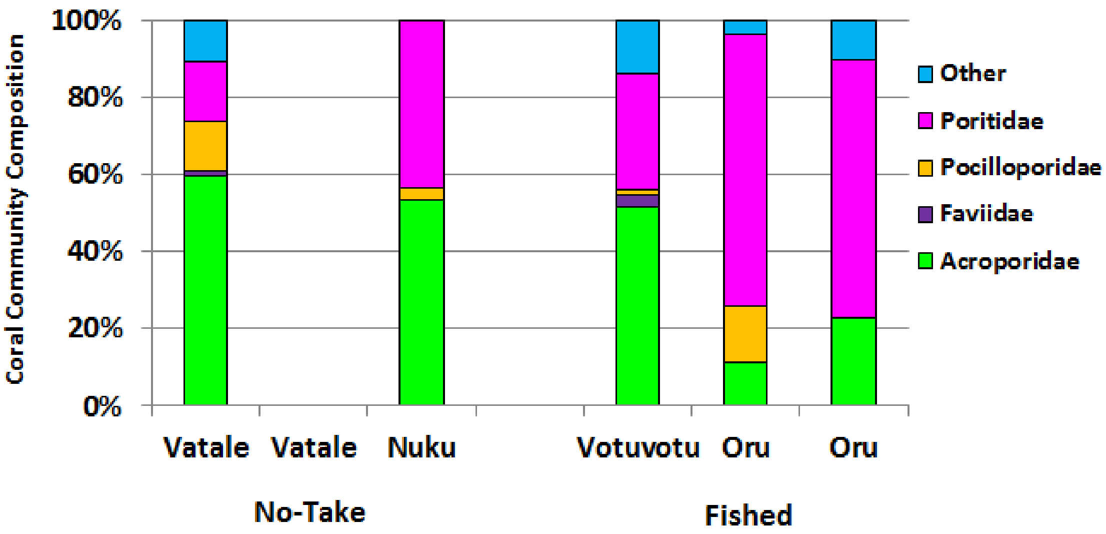


Figure 42. Mean Coral Community Composition by Reef and Zone. A) Reef Top, B) Reef Slope. N=5 at each location.

A)



B)

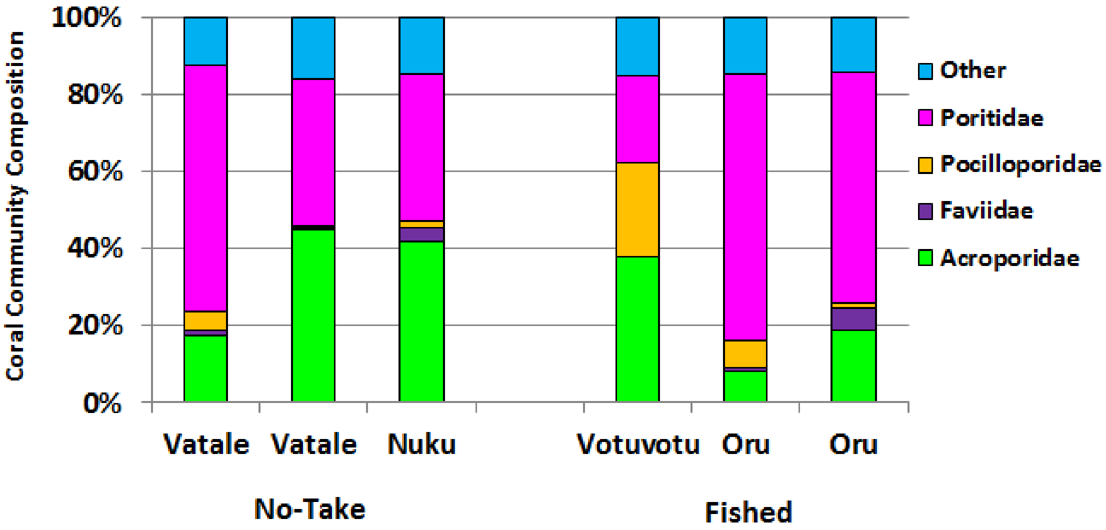
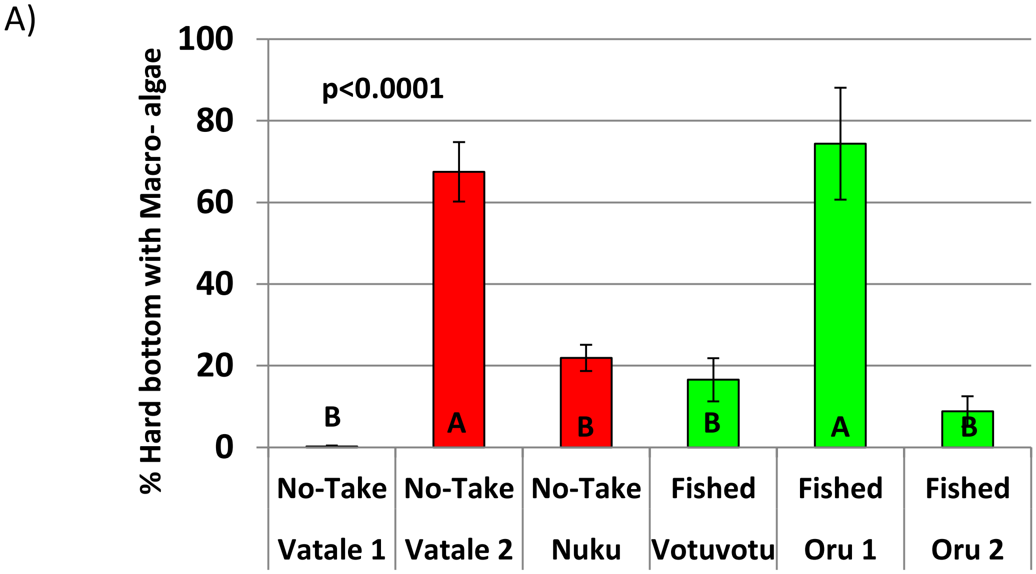


Figure 43. Mean Percent Hard Bottom with Macro-algal Cover by Reef and Protection Status. A) Reef Top, B) Reef Slope. Mean macro-algal cover on hard bottom areas is shown by red bars (no-take area) and green bars (fished area); Error bars show standard error; N=5 at each location; p-values show significant differences in macro-algal cover found between sites by a one way ANOVA; Letters show differences detected by Tukey Kramer HSD post-hoc tests.



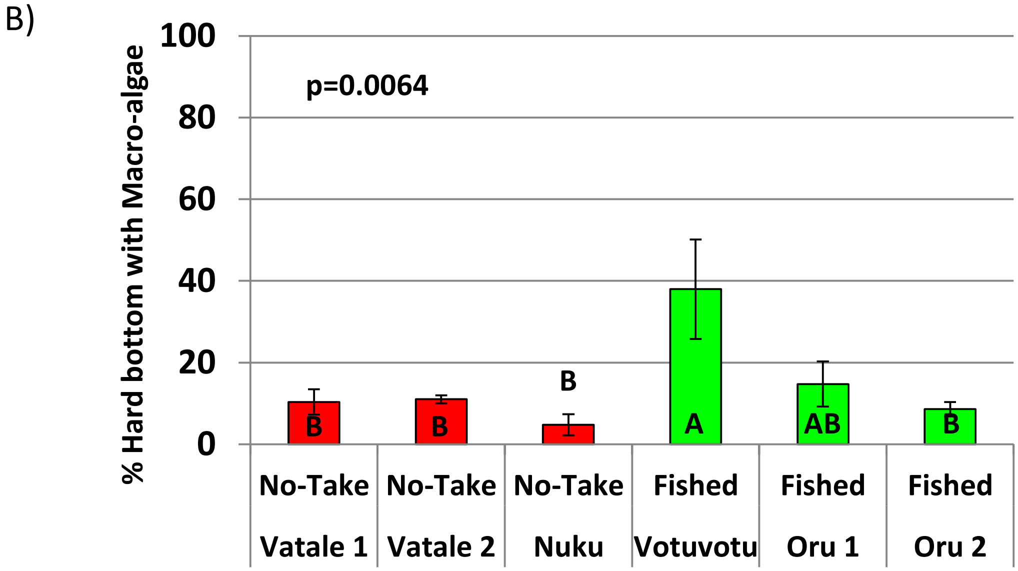


Figure 44. Mean Percent Hard Bottom with Coral Cover by Zone and Protection Status. Mean coral cover on hard bottom areas is shown by red bars (no-take) and green bars (fished); Error bars show standard error; N=15 at each location; P value is from a one-way ANOVA; letter indicate differences found using Tukey Kramer HSD post hoc test.

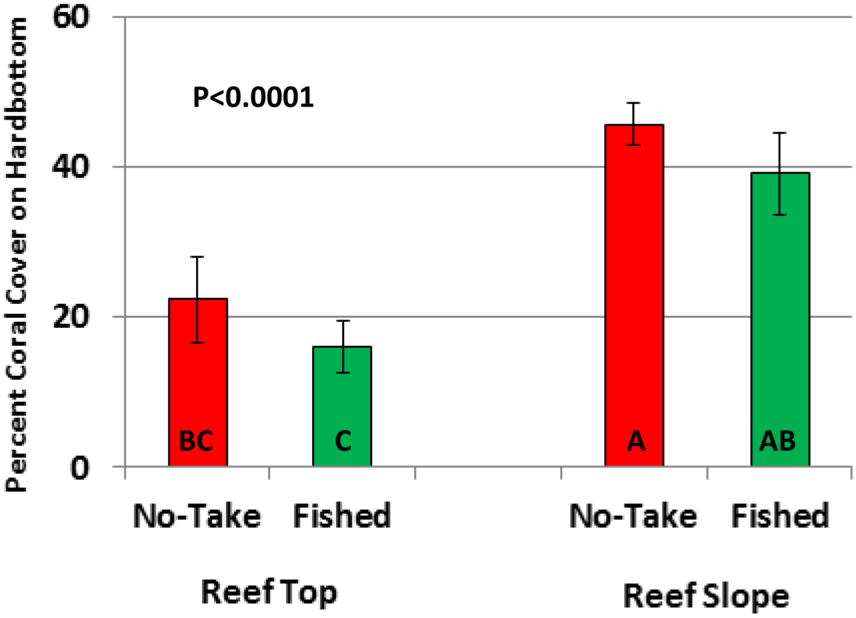
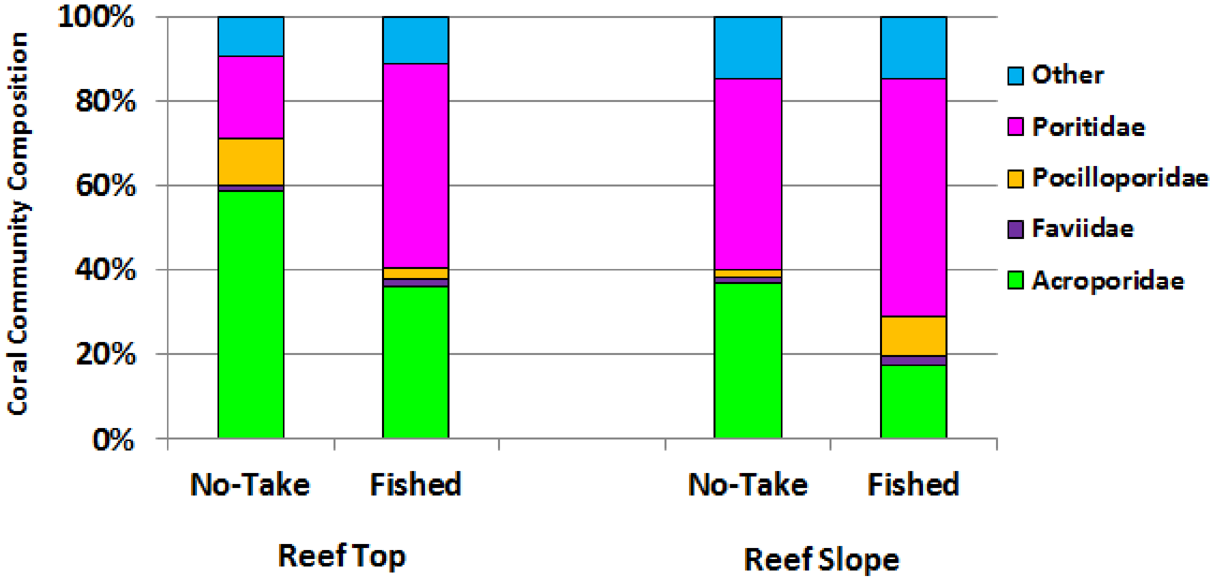
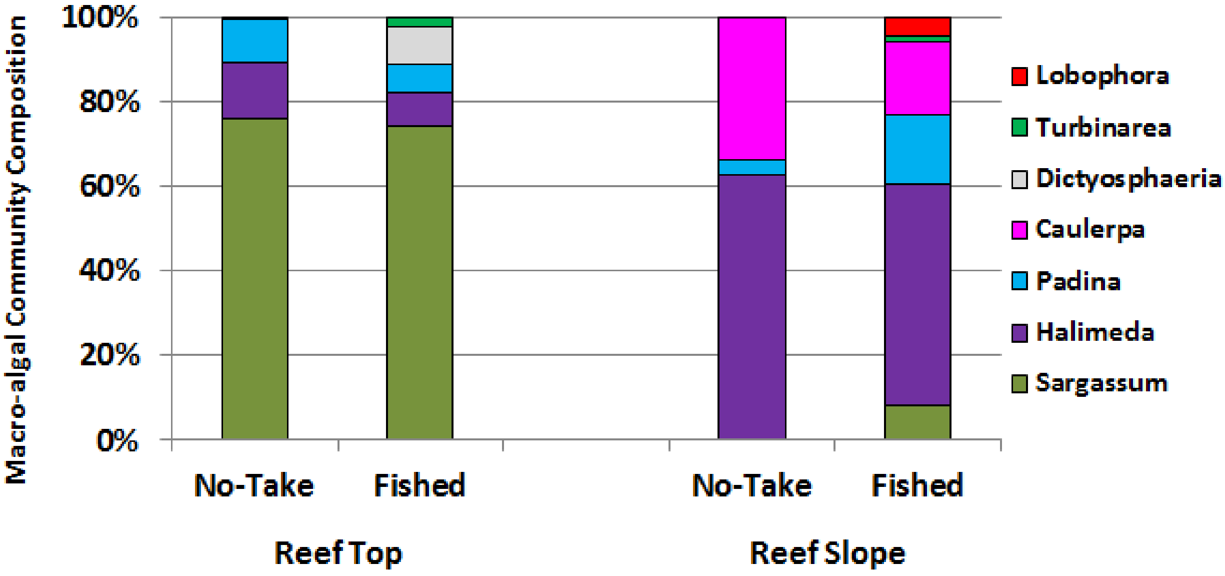


Figure 45. Mean A) Coral and B) Macro-algal Community Composition by Zone and Protection Status. N=15 for each category.

A)



B)



3.3.2 TARGET FISH SURVEYS

A total of 928 fishes in the seven target families were recorded during the surveys with Scarids, Siganids, and Acanthurids being most abundant and together accounting for over 85% of the fish recorded. In general, fish were not very abundant at any site, and some fish families (in particular the non-herbivorous fishes) were not recorded during surveys at some sampling sites (Figure 46). The average size of fishes in each family was generally larger in the reef slope zone than in the reef top zone (Figure 47).

Though the results varied by reef (Figure 46), overall Acanthurids, Siganids, Lethrinids, Mullids, and Serranids were overall significantly more abundant in no-take areas than in fished areas (Figure 48). However, by the same comparison only Siganids were significantly larger in the no-take areas (Figure 49). Mean fish size for most families were similar to what was recorded in the Korolevu-i-wai LMMA, though they were generally smaller than what was recorded in the Nasinu LMMA.

Figure 46. Mean Abundance of Fishes by Site and Zone. Red bars represent No-Take Areas and Green bars represent Fished Areas; Error bars illustrate standard error; N=5 for each sampling location.

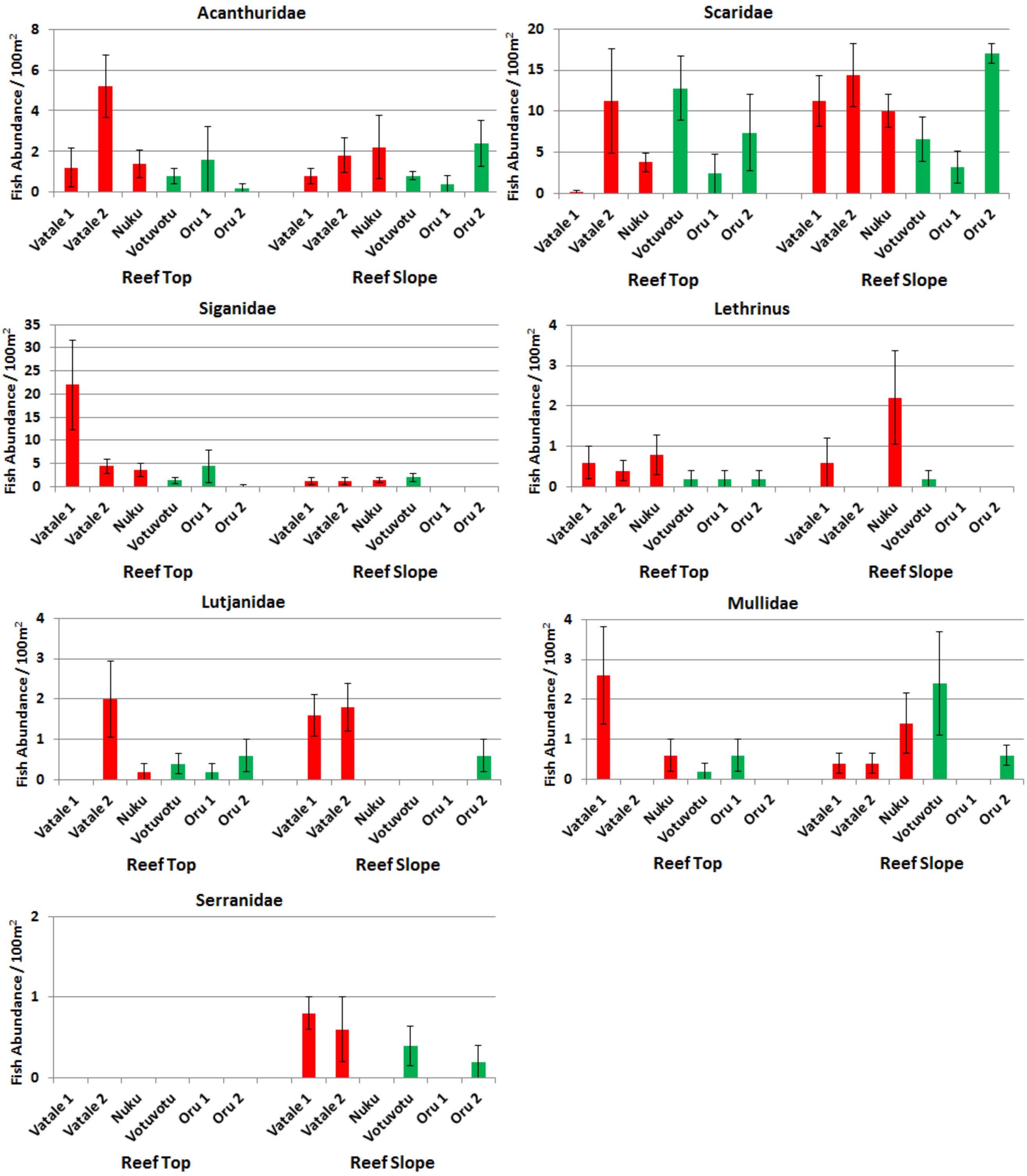
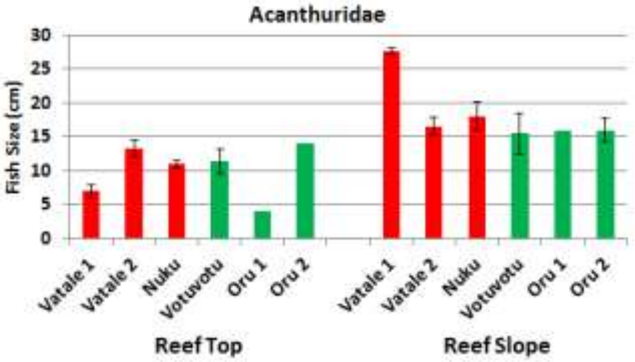
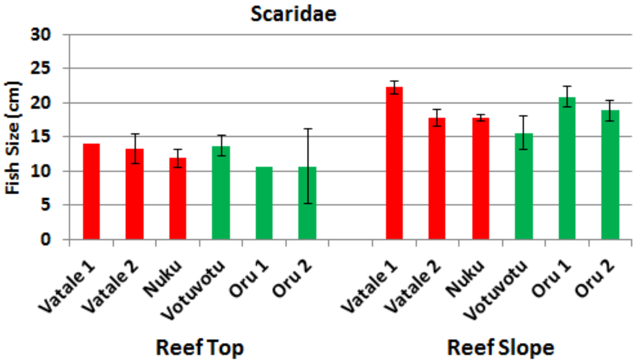
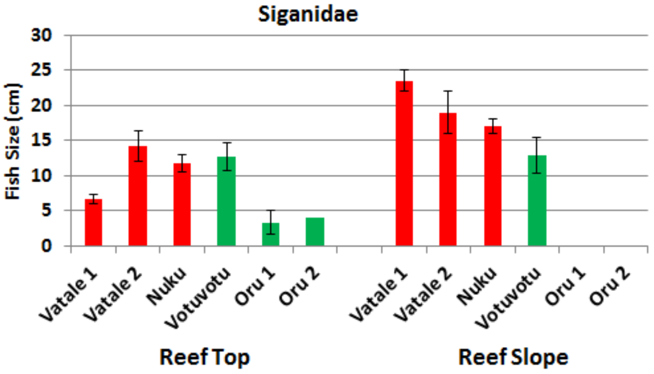
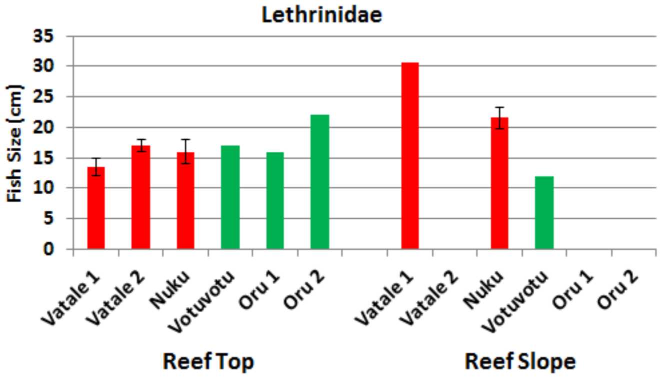


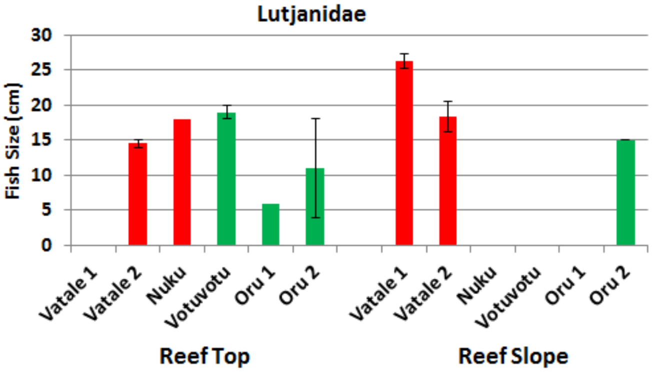
Figure 47. Mean Size of Fishes by Site and Zone. Red bars represent No-Take Areas and Green bars represent Fished Areas; Error bars illustrate standard error.

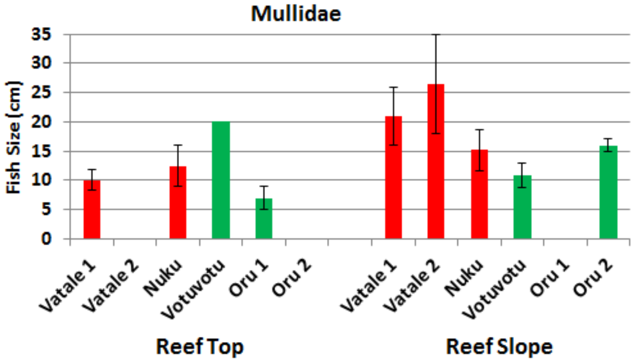












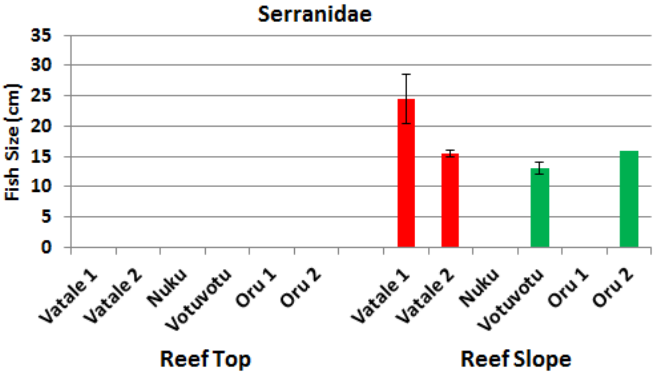


Figure ??.

Figure 48. Mean Abundance of Fishes by Protection Status. P-values reflect the results of paired Wilcoxon comparisons; Error bars illustrate standard error; N=30 for each Protection Status.

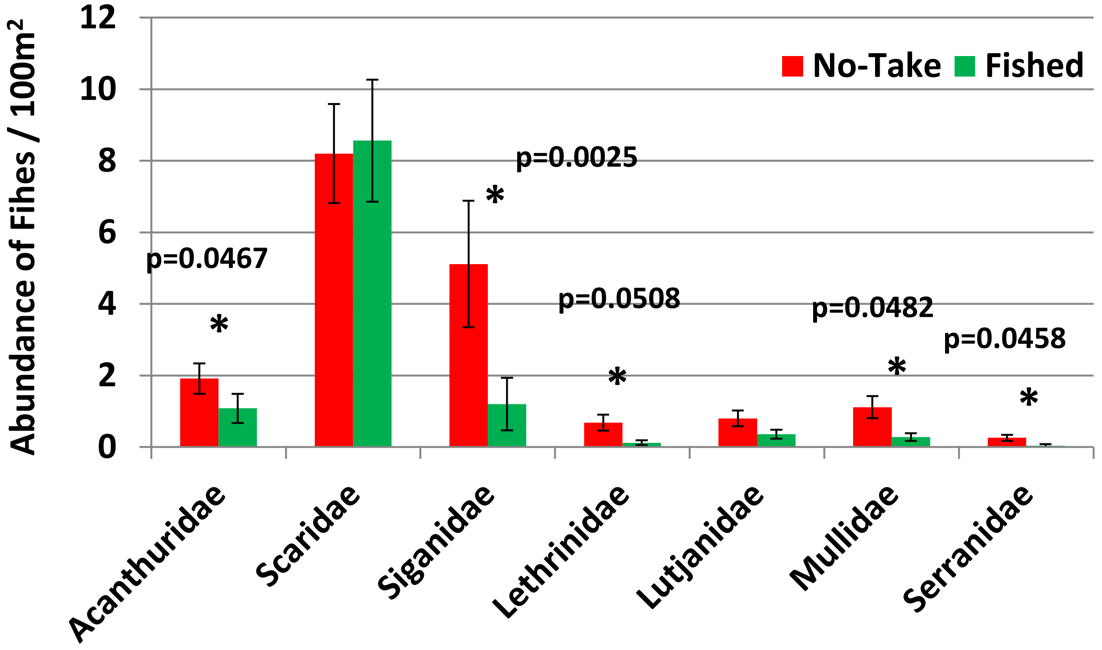
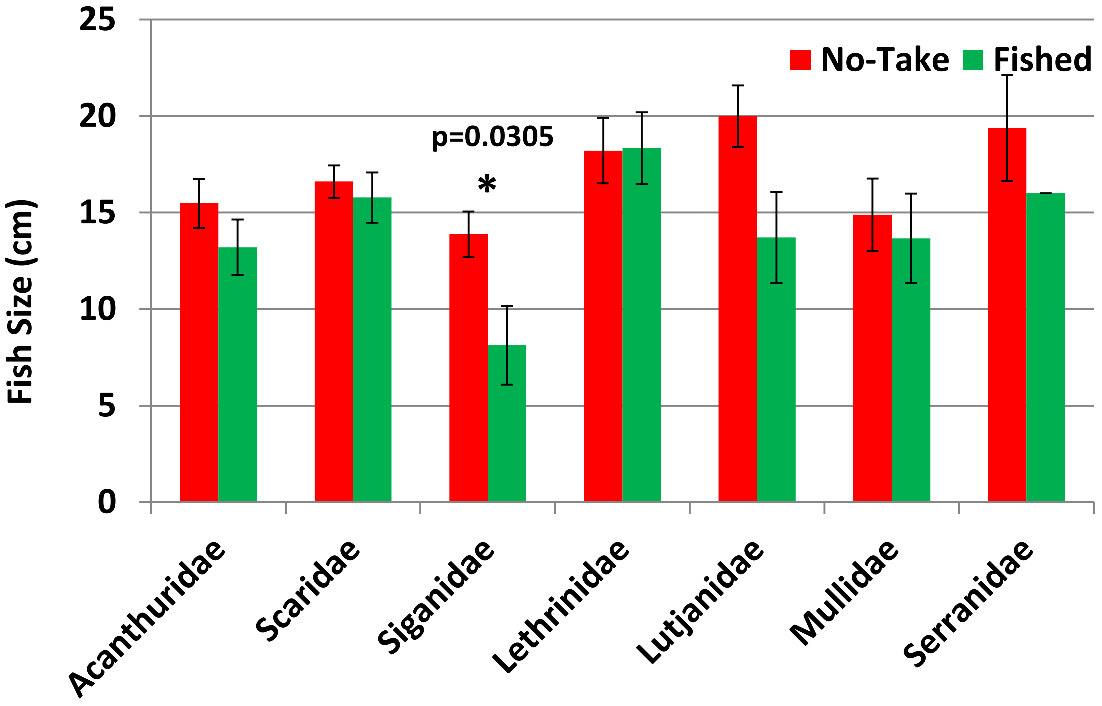


Figure 49. Mean Size of Fishes by Protection Status. P-values reflect the results of paired Wilcoxon comparisons; Error bars illustrate standard error; N=30 for each Protection Status.



3.3.3 HERBIVORY ASSAYS

Overall, herbivory levels varied widely amongst sites and zones. In general, herbivory levels on *Sargassum* and *Padina* were greater than on other algae, with some algae not grazed at all during herbivory assays (Figure 50). On average, ~40% of the *Sargassum* and ~20% of the *Padina* were eaten during the assays (Figure 51). On the reef top, *Sargassum* and *Padina* were grazed on significantly more in the no-take areas than in the fish areas (Figure 51); however, on the reef slope there were no significant differences in herbivory levels between the no-take and fished areas.

Figure 50. Mean Percent of Algae Eaten in 24 hours During Herbivory Assays by Reef Area. Error bars show standard errors. N=10 for each sampling site.

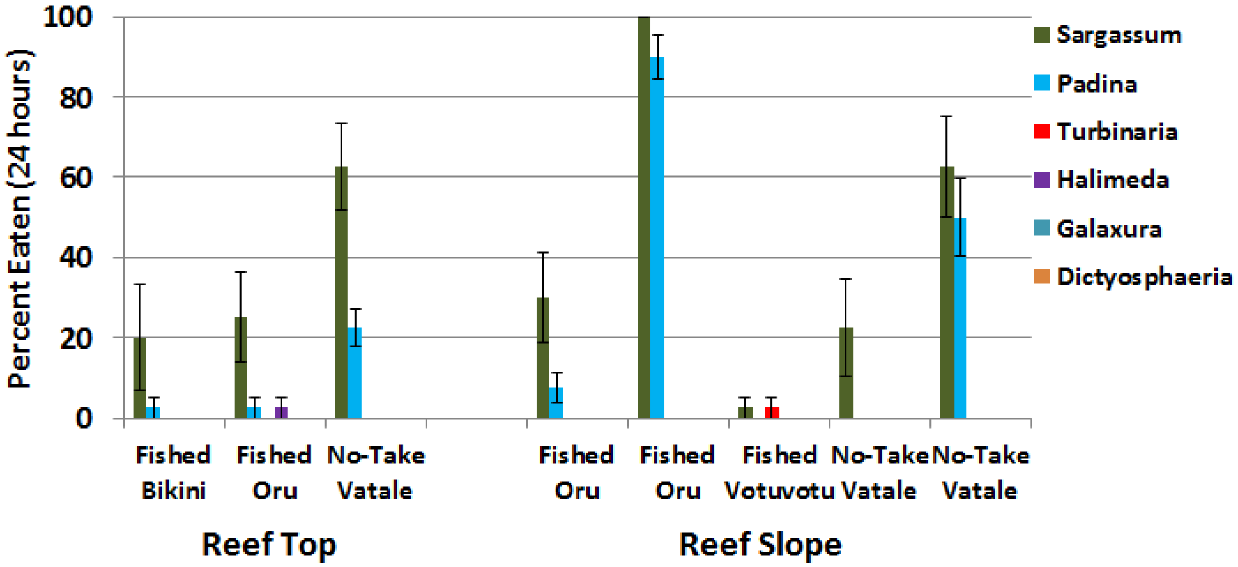
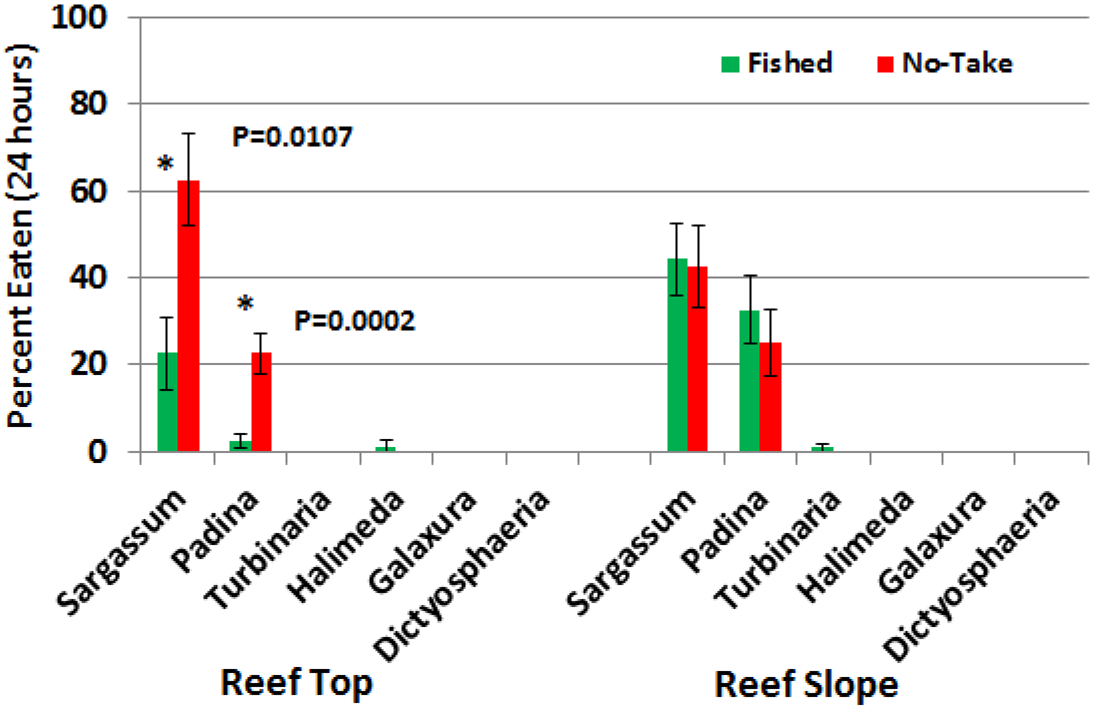


Figure 51. Mean Percent of Algae Eaten in 24 hours During Herbivory Assays by Protection Status. N=20 Fished Reef Top, N= 10 No-Take Reef Top, N=30 Fished Reef Slope, N=20 No-Take Reef Slope. P-values reflect the results of paired Wilcoxon comparisons



4. DISCUSSION

Locally-managed marine areas (LMMAs) in Fiji have generally been established to address overfishing, destructive fishing practices, and pollution threats with the aim to enhance and ensure the sustainability of local fishing grounds. Apart from activities aimed at reducing land-based threats to coastal resources, the management plans developed by communities for their LMMAs generally use gear restrictions and the establishment of no-take areas as their primary fisheries management tools. Gear restrictions generally include banning the use of poisons and undersized nets (<2" mesh), and rarely exceed the standards set by Fiji Fisheries regulations; thus there are legal mechanisms to support their enforcement if they are congruent with fisheries laws. The establishment of no-take areas, however, can be a challenge to communities as without them being gazetted by Government, there is no legal mechanism for their enforcement except in the case of licensed commercial fisherpersons. Communities are often reluctant to gazette their no-take areas as the boundaries and restrictions become permanent and most community-established no-take areas are not set for permanent, long-term durations. The fact that only a few (less than six) of the over 200 no-take areas established in Fiji are gazetted is testament to the reluctance of communities to commit to their establishment on a permanent basis in exchange for the ability to legally enforce them. This leaves compliance to what communities and co-management partners perceive as a primary fisheries management tool legally unenforceable and thus a major threat to the success of community-based management efforts.

Apart from land-based impacts (i.e. pollution, sedimentation), overfishing is the primary threat that communities in Fiji aim to address with the establishment of LMMAs. Overfishing leads to the depletion of reproductive stocks, and can have indirect effects on coral reefs through tropic cascades. Fisheries catch records recorded by communities participating in the Fiji Locally-Managed Marine Areas network (FLMMA) suggest that a large majority of coral reef fishes being caught in Fiji have not yet reached reproductive size (FLMMA unpublished data) and thus indicate that overfishing is indeed a major concern. One of the primary indirect effects of this overfishing is that reef areas which were once coral dominated are now becoming increasingly dominated by macro-algae as populations of key herbivores have dwindled; such is the case along Fiji's Coral Coast where macro-algae (mainly Phaeophytes) now dominate much of the backreef area (Bonito et al. 2011, Bonito in prep). There is much debate about the influence and importance of bottom-up or top-down processes in driving coral / algal phase-shifts. However, studies from the Coral Coast suggest that while nutrient levels in coastal waters far exceed ideal oligotrophic condition for coral reefs (Mosley and Aalbersberg 2002), the lack of herbivory seems to be the primary factor driving the macro-algal phase-shift happening locally and if populations of key herbivores are protected this phase-shift is reversible (Bonito et al. 2011, Rasher et al. 2012). As macro-algal dominance is reduced coral communities can improve in terms of both cover and species richness of the assemblage (Bonito et al. 2011, Bonito unpublished data), though this process requires temporal durations that generally exceed the protection provided to fish populations in no-take areas.

Given the increasing coastal development and populations in Fiji, reliance on coastal fisheries for subsistence and commercial harvests is likely to remain high and the problem of overfishing unlikely to end in the foreseeable future. No-take areas are a primary management tool applied in most Fijian LMMAs to address the threat of overfishing though overall no-take areas are generally a minor portion of the LMMA and are often relatively small ($<1km^2$) (Govan 2009). While their establishment is generally expected to provide fisheries and conservation benefits through the protection of fish populations and habitat area, most no-take closures are only established on a temporary basis (generally for five years or less and often for only a year or two) following more traditional management approaches; only a very few currently existing no-take areas have been established for a more permanent duration and been relatively well-respected and complied with for more than five years. While some increase in the biomass, abundance, and perhaps catchability (Januchowski et al. 2011) of targeted fishes can be expected from shorter closures (<5 years), significant levels of larval and adult spillover from protected to fished areas - beyond the daily movement patterns of fishes which may exceed the no-take boundaries – are unlikely to be acquired from these closures due to the life history characteristic of targeted food fishes. Moreover, as the home range size of many targeted fishes may exceed the boundaries of protection due to the relatively-small ($<1km^2$) size of most no-take areas, the ability of these small no-take areas to provide adequate protection to target fishes thus contributing to the sustainability of local fisheries and coral reef ecosystems is largely assumed and perhaps wrongly so.

This study aimed to evaluate the ability of relatively-small no-take areas established in several LMMAs to provide fisheries and conservation benefits and in general improve the sustainability of the entire LMMA. If these no-take areas were protecting stocks of targeted food fishes, we expected to find a greater abundance and biomass of these fishes in the no-take areas than in the fished areas and we expected to find more fish of larger size in the no-take areas as well. If the no-take areas were protecting coral habitat, we expected to find 1) higher levels of herbivory in the no-take than in the fished areas; 2) less macro-algal cover in the no-take than in the fished areas, particularly in the Coral Coast LMMA since this reef area was dominated by macro-algae when the LMMA was established in 2002; 3) relatively high levels of coral cover in the no-take areas since it had been over a decade since the last mass bleaching event in Fiji; and 4) higher coral species richness and coral communities with more Acroporid species in the no-take than fished areas since Acroporids are the most specious coral family in Fiji and they are generally less hardy and more susceptible to impacts than Poritids and Faviids. We also examined the fished areas in terms of their benthic composition and assemblages of targeted food fishes to determine whether the current management practices are likely to create a sustainable fishery and reef environment.

4.1 KOROLEVU-I-WAI DISTRICT

4.1.1 LMMA ASSESSMENT

Overall, the benthic structure and fish assemblages found in the fished and permanent-no-take areas (MPAs) in the Korolevu-i-wai LMMA are distinctly different. These differences, when viewed in context with historical data, indicate that though the MPAs are relatively small, they are likely providing substantial fisheries and conservation benefits. Moreover, some key ecological processes (i.e. herbivory, recruitment) appear to be maintained in the MPAs but not the fished areas, resulting in two very different reef communities. While compliance to the MPAs may not be 100%, these data suggest that overall there has been enough compliance to result in a recovery trajectory of coral and fish communities within the MPAs since their establishment. However, the establishment of MPAs and other current management regulations begun nearly a decade ago now are clearly unable to sufficiently protect important coral habitat in fished areas, and thus in the long run may not alone be sufficient to sustain local fisheries and coral reef communities.

Historical data from 81 transects located in the MPAs and fished areas show that in 2004, just a couple of years after the MPAs were established, coral cover was comparably low between the MPAs and fished areas (<10%) while macro-algal cover was more than five times greater than coral cover and significantly greater in the MPAs compared to fished areas (Figures 52 and 53). Community members indicated that the low coral cover recorded across the LMMA in 2004 was in part due to a major bleaching event in 2000 that killed many of the corals. Sampling of the same 81 transects in 2007 found that coral cover had increased significantly in both the MPAs and fished areas, though it was greater in the MPAs, and macro-algal cover decreased significantly in the MPAs while no significant change was recorded in the fished areas. This study found that in 2011, MPAs had benthic communities with relatively high coral cover (>40%) with little to no macro-algal cover, while fished areas still had low coral cover (<10%) and were dominated by macro-algae (mostly Phaeophyta - brown algae); coral cover again increased significantly in the MPAs (more than doubling since 2007), while there was no significant increase in the fished areas. Similarly, macro-algal cover decreased significantly since 2007 in the MPAs while increasing significantly in the fished areas. Though the 2011 benthic sampling was not conducted along the same transects as 2004/2007 sampling, it was done across the same reef areas and using the same sampling methodology (point-intercept).

Coral communities in the MPAs and fished area are also markedly different with MPAs having greater coral species richness per area than fished areas in 2011 as was the case as well in 2007 (Figure 54). Historical coral species richness data are limited to sampling conducted in 2007 using a slightly different sampling method (circular sampling plots rather than linear transects), but these data indicate that coral species richness has increased significantly in the MPAs between 2007 and 2011, while no significant change occurred in the fished areas; coral species richness per area in the MPAs is

Figure 52. Mean percent coral cover on hard bottom in no-take MPAs and fished areas in the Korolevu-i-wai fishing ground. P value is from a one-way ANOVA; letter indicate differences found using Tukey Kramer HSD post hoc test.

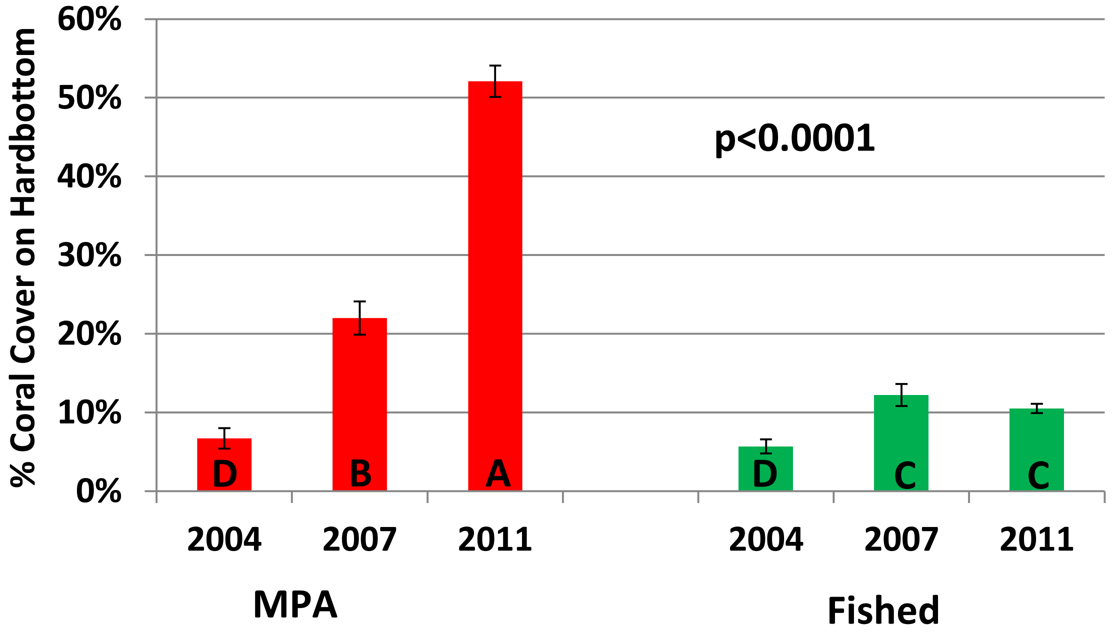


Figure 53. Mean percent macro-algal cover on hard bottom in no-take MPAs and fished areas in the Korolevu-i-wai fishing ground. P value is from a one-way ANOVA; letter indicate differences found using Tukey Kramer HSD post hoc test.

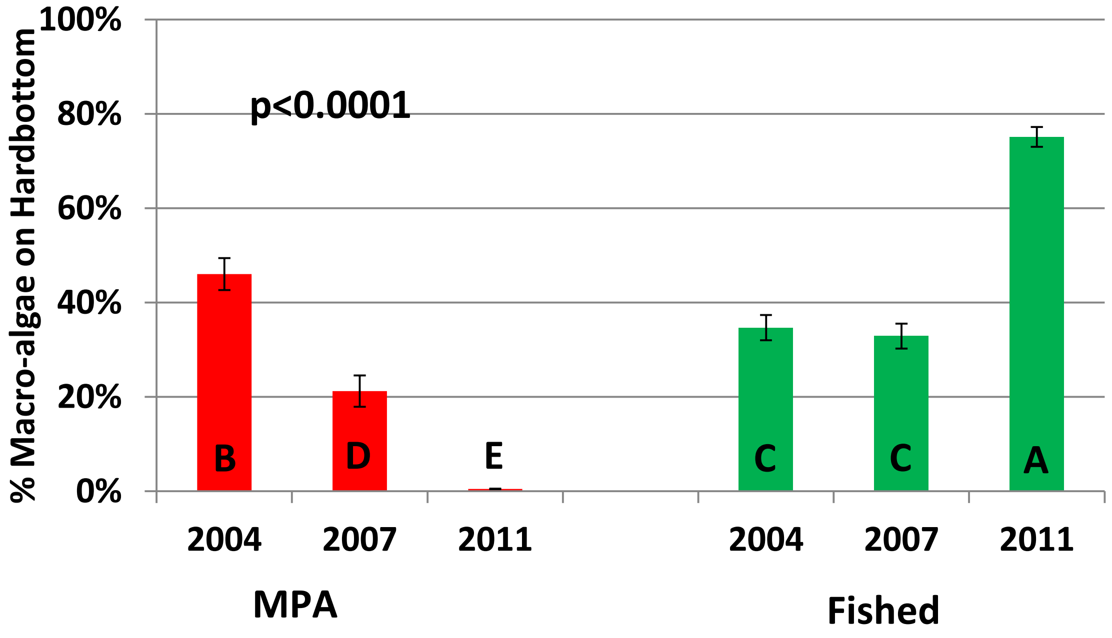
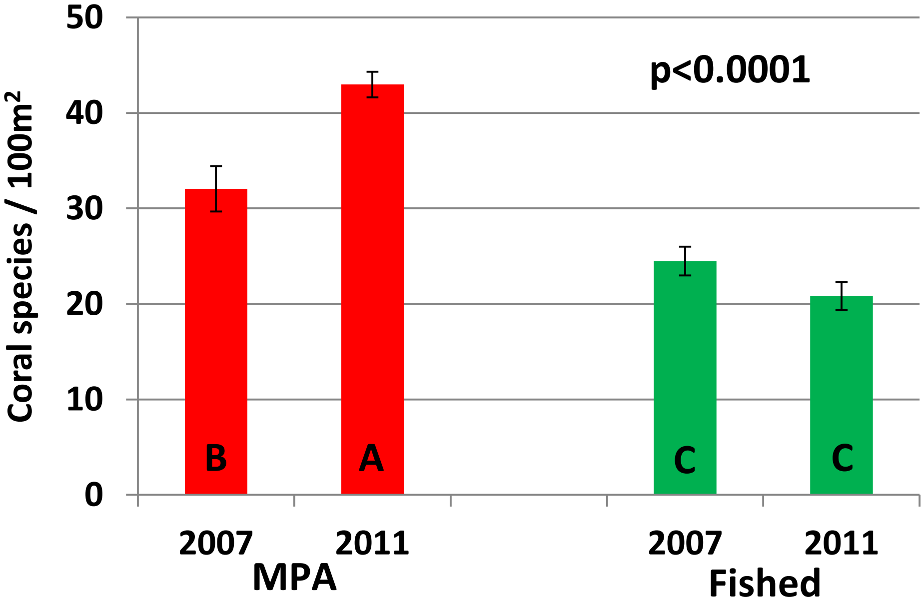


Figure 54. Mean coral species richness per 100m^2 in no-take MPAs and fished areas in the Korolevu-i-wai fishing ground. P value is from a one-way ANOVA; letter indicate differences found using Tukey Kramer HSD post hoc test.



now double that recorded in the fished areas while in 2007 it was only 30% greater. The higher coral species richness per area found in the MPA relative to fished sites indicates that not only has coral cover continued to increase, but that the increase in cover is likely due to the recruitment of new corals as well as the growth of existing corals. Moreover, as macro-algal cover has decreased in the MPAs, coral species richness and cover have continued to increase with many of the more disturbance-prone species (i.e. Acroporids) recruiting into the coral communities. Coral communities in the MPAs currently consist of more Acroporid species than in fished areas, while the fished areas generally were dominated by Poritids (>50%). Acroporids were by far the most diverse family of corals found during 2011 surveys, and their recruitment since 2007 was largely responsible for the increase in coral species richness in the MPAs in 2011.

Overall, MPAs harbored greater abundance (~35% more), species richness (~50-75% more), and biomass (~350-600% more) of target fishes than the fished areas; all genera of target fishes had a greater mean abundance (except for *Scarus* spp.), size, and biomass (except for *Parupeneus* and *Siganus* spp.) in the MPAs with larger fishes of all target taxa found only in the MPAs. This indicates that despite their small size and perhaps lack of inclusion of the entire home range of these fishes, the MPAs are able to provide sufficient protection to populations of key herbivorous fishes and other targeted food fishes and that at least some fishes are able to survive until reaching sexual maturity and obtain larger sizes that may exponentially increase their reproductive output. The absence of large fishes and lower abundance of fishes in the fished areas indicates that fishing pressure is indeed high and target populations are likely being overfished; this reiterates the importance of the MPAs to protecting reproductive stock as without them the local reproductive potential of target fish populations, as assessed by this study, are minimal.

The decrease in macro-algal cover in the MPAs over time but not in fished areas indicates that herbivory on these algae in the MPAs is likely greater than in the fished areas. The herbivory assays conducted in 2010 and 2011 across the LMMA indicate that this is indeed the case, and that herbivorous fishes alone can remove these macro-algae when present. *Turbinarea* was the least consumed of the five species of algae used in the herbivory assays, perhaps because of it's tougher more rigid texture. Video assays conducted during the study indicate that Phaeophyte grazers prefer to consume the softer, less rigid algae first (*Padina*, *Dictyota*, *Sargassum polycystum*) and the more rigid species (*Hormophysa*, *Turbinarea*) once softer ones are less abundant (Bonito, in prep).

The video algal assays conducted in three MPAs during this study using the most abundant macro-algae in the LMMA (including the five species used in herbivory assays) found that two species of herbivorous fishes (*Naso unicornis* and *N. lituratus*) were responsible for 99% of all the bites taken on these most abundant Phaeophytes, despite the presence of over a dozen other herbivorous fishes in the assays (Bonito, in prep). These *Naso* spp., though more abundant in the MPAs than fished areas, were not abundant in any of the target fish assessments, which were conducted during high tide; however, they were documented feeding on the experiment plots of Phaeophytes in much larger numbers (over 20 fish at a time on occasion) in the MPAs during low tide. While acoustic tagging of these *Naso* spp. resulted in minimal detections, the tagged fish were only detected on the forereef during high tide, and more frequently on the backreef area (where the fish and herbivory assessment were made) during low tide. This suggests that the diurnal movement of these fishes, which can be very site specific (Hardman et al. 2010, Marshall et al. 2011), may have resulted in the low detection of their presence in MPAs as sampling was conducted during high tides when these fish may move to the forereef. Underwater visual censuses (UVC) of fish such as these *Naso* spp. may not be as reliable to detect their presence or perhaps more importantly ecological functioning as other assessments, such as the herbivory assays, which are conducted without an in-situ observer and over a longer time period (in this case 24 hours). Though afforded some protection in the MPAs, population of these *Naso* spp. appear unable to control macro-algal overgrowth in the fished areas.

The two temporary no-take areas (tabu), established in 2008 by Namada and Tagaqe villages in their area of jurisdiction in the Korolevu-i-wai LMMA, have been afforded some two to six years less protection than the current MPAs and have been opened for fishing on occasions since their establishment. In 2011, the tabu areas were most similar to the fished areas (coral and macro-algal cover, coral species richness) and remain largely dominated by macro-algae, though the macro-algal community in Tagaqe's tabu area had less *Sargassum* than other fished/tabu sites and more of the less-palatable *Turbinarea*; coral cover was not significantly different from the fished areas, however coral species richness was intermediate between fished areas and MPAs in the outer sampling zone. Overall, target fish assemblages were not significantly different from fished areas; however, this is not surprising given the more recent establishment of tabu areas and only limited protection from fishing pressure. Due to their more recent establishment, continued monitoring of the LMMA and the MPAs, tabu areas, and fished areas in it is required to better understand the long-term benefits that can be acquired from temporary closures such as these.

4.1.2 KOROLEVU-I-WAI MPAs

The MPA established by Tagaqe village is the largest in the Korolevu-i-wai LMMA (~1km^2), as well as the newest (established in 2006). This site was chosen for protection primarily because it was a wide, deep section of the reef that historically had been a productive fishing area, and because reef areas near the village were preferred for fishing due to ease of access. The backreef area of this MPA has extensive soft bottom area extending from the shoreline to the middle of the reef flat moat that contains some with patches of seagrass, and more hard bottom coral habitat toward the front of the reef flat moat. Of the four MPAs, Tagaqe's had the highest coral cover in the outer zone, but lower species richness per area than other MPAs most likely because it had less hard bottom area to support corals along the transects. Since poaching has been reported in the Tagaqe MPA more frequently than at other KiW MPAs, and because it was established more recently, it is not surprising that the abundances of target fishes recorded during this study was less than in other MPAs. However, large fish of all target taxa were still recorded in the MPA, and this MPA was the only one harboring lethrinids that were >30cm in length in the middle zone and >40cm in the outer zone. This MPA is currently being impacted by sedimentation issues due to poor land-use practices in the adjacent watershed – a >300 lot residential development that is occurring on a steep hillside.

The MPAs established by Vatuolalai and Namada villages are the smallest (~0.5km^2 each) and oldest MPAs in the LMMA. These MPAs were established on reef areas in front of the villages to encourage compliance through improved visibility of the site. Both sites have comparable amounts of soft bottom and rubble area – less than in Tagaqe's MPA, but more than in Votua's MPA. Despite it's relatively-small size, Vatuolalai's MPA has the highest coral and CCA cover on hard bottom area, and highest overall abundance and biomass of target fishes of all the MPAs. Similarly, while Namada's MPA had the lowest coral cover on hard bottom areas of the four MPAs, overall target fish abundance, species richness, and biomass were only exceeded by the MPA in Vatuolalai. This suggests that the higher-level of compliance reported from these MPAs due to increased visibility by the village has benefitted populations of target fishes.

The MPA established by Votua village in 2003 is the second largest in the KiW LMMA (~0.8 km^2) and has the least amount of soft bottom and rubble area of the four MPAs. In 2002, a site in front of the village was selected for protection to encourage compliance through improved visibility of the site. However in 2003, the MPA was moved to it's current location, which is out of sight of the village, because the current site has no creeks or streams draining into it and the communities felt that the tradeoff between water quality and enforcement potential was worthwhile. After the Tagaqe MPA, Votua's MPA has the second highest reported level of poaching (Bonito, personal communication). Coral cover and species richness was relatively-high in Votua's MPA, and the coral community was largely comprised of Acroporids – more so than in other MPAs. However, overall target fish abundance and biomass were the lowest of the four KiW MPAs, perhaps due to the impact of poaching.

4.1.3 KOROLEVU-I-WAI TABU AREAS

After seeing the accrued fisheries benefits in the KiW MPAs after 5 years of closure, the villages of Namada and Tagaqe decided to establish temporary closures (tabu) on reef areas for the short-term fisheries benefits they likely could offer; however these tabu areas are smaller than all the KiW MPAs (~0.2km^2 each). Since their establishment in 2008, the Tagaqe tabu area has had one or two fish drives conducted in it yearly and the Namada tabu area has received considerably more (but an unknown amount) of fishing pressure than the Tagaqe tabu.

The Tagaqe tabu area, which received less fishing pressure than the Namada tabu, showed more promise of offering long-term benefits from the fishing restriction, likely because fishing pressure and extraction was more limited in this area. Tagaqe villagers have been pleased with the harvests during the fish drives in the tabu area (Bonito, personal communication), thus some apparent short-term fisheries benefits have been obtained by the temporary closure. Benthic sampling of the tabu areas found that the Tagaqe tabu area has coral and macro-algal covers and coral species richness that are intermediate to MPA and fished locations in the KiW LMMA. While little of the key grazers of the most abundant macro-algae were recorded during fish surveys, the difference in benthic community is likely due to higher levels of herbivory as the results of herbivory assays indicate. If fishing in the tabu areas can be minimized as done in Tagaqe, tabu restrictions may offer more long-term habitat benefits as well as the perceived short-term fisheries benefits.

4.1.4 KOROLEVU-I-WAI FISHED AREAS

The Korolevu-i-wai LMMA receives relatively high fishing pressure due to rapidly-growing coastal populations from largely due to the immigration of non-landowners/fishing right owners who come seeking employment in the expanding tourism industry. The removal of key herbivorous fish and other impacts from fishing and development activities have left the fished areas in the KiW LMMA dominated by macro-algae (predominately Phaeophytes); a return to a coral-dominated reef appears unlikely under the current management regime as macro-algal cover has increased since the last sampling of these areas in 2007. Fish counts and herbivory assays indicate that macro-algal overgrowth is likely due to dwindling populations of key herbivorous fishes. Though coral communities are impacted by algal overgrowth and little coral cover remains in any of the fished areas, the fished areas sampled in Tagaqe and Vatuolalai have managed to maintain more Acroporid species while other areas are predominately comprised of Poritids. While overall abundance of targeted fishes in some fished areas were equivalent, or in some cases significantly greater than MPA sites, these fish were small; all fish recorded in fished areas were less than 30 cm in length except for a few Scarids at the Vatuolalai site and one *Naso unicornis* at the Tagaqe site.

4.1.5 MANAGEMENT RECOMMENDATION

Overall, the management actions taken over the last decade in the Korolevu-i-wai LMMA appear to have made significant improvements in both habitat quality and fish assemblages compared to pre-management conditions; however, these improvements are currently limited to the MPAs. Populations of key herbivores in fished and tabu areas are unable to maintain adequate levels of herbivory to prevent macro-algal overgrowth, thus these areas remain largely overgrown with macro-algae. The abundance of macro-algae across the fished and tabu areas of the LMMA is likely to not only continue to hinder coral recruitment and survivorship, but also might reduce recruitment levels of larval fish (Danielle Dixon, unpublished data / in prep) thus leading to further declines in the fisheries. Additionally, enforcement of current Fiji fisheries regulations is weak across the LMMA, and compliance to national laws as well as community-established no-take areas remain a challenge for fishing right owners. With ~35% of the LMMA currently under some sort of no-take status, the establishment of further MPAs is unlikely to be accepted nor complied with by either fishing right owners or non-fishing right owners, both of which rely heavily on the fishery for daily subsistence needs.

In order to improve the current LMMA management regime, the following actions are recommended:

- Place a traditional ban on the harvesting of *Naso unicornis* and *N. lituratus* across the entire LMMA as these fish are the primary herbivores responsible for removing the macro-algae that are most abundant across the LMMA.

- Establish additional tabu areas (one each for Votua and Vatuolalai villages), and more closely limit the harvesting of fish from tabu areas so as to accrue more long-term benefits from their establishment.

- Limit the use of nets, and set a minimum 3” mesh size for nets (current Fiji fisheries regulations have a minimum 2” mesh size).

- Place a traditional ban on night fishing with lights and spears; limit night fishing to hook and line.

- Improve compliance to both Fiji Fisheries regulations and additional community actions being taken to address the decline in ecosystem health and productivity. An improved understanding of not only the laws and additional rules to the fishing ground, but also why they are important for the management and long-term sustainability of the fishing ground is needed in communities, particularly settlements outside of the traditional villages where non-fishing right owners reside. While the no-take areas cannot be legally enforced, completing all traditional ceremonies and presentations to formalize them under traditional governance can likely improve compliance.

- Improve enforcement capability of Fiji fisheries regulations by working with the Department of Fisheries to train community Fish Wardens who are empowered to work with Police to monitor fishing activities and arrest fisherpersons who are breaching Fiji fisheries regulations.

- Relocate village piggeries away from the creeks to reduce nutrient pollution in the fishing ground.

- Closely monitor all developments (new and existing) in the district that are likely to have an impact on the fishing ground. Of greatest concern is nutrient pollution from wastewater and sedimentation from poor land-use practices. All new developments should go through the Environmental Impact Assessment (EIA) process, and fishing right owners need to take a more active role to ensure that a high standard of EIA are conducted and subsequently compliance to development / operational guidelines is enforced.

- Lobby Government for the legal recognition of community established no-take areas and for further control in regulating fishing activities by non-fishing right owners using the results from the KiW LMMA monitoring that show the benefits of community-based management.

4.2 NASINU VILLAGE, DAWASAMU DISTRICT

4.2.1 LMMA ASSESSMENT

The LMMA established in Nasinu village does not appear to be adequately addressing the impact of overfishing as reflected by the relatively low abundance and size of target food fishes across the LMMA despite it having been established some four years before this assessment. Additionally, the abundance of macro-algae found at the site indicate that populations of key herbivores are unable keep these Phaeophytes under control. These data indicate that the LMMA area continues to be overfished and is likely to continue to decline unless management practices improve.

Though it was established some four years before this study took place, the no-take area shows little sign of providing protection to targeted food fishes. Underwater visual censuses of targeted fishes found no difference in total fish abundance between the no-take and fished areas. Acanthurids were the only fishes whose abundance was significantly different between no-take and fished areas with the fished areas harboring approximately triple the abundance of these fishes than was found in the no-take area. While the abundances of Scarids, Siganids, Lethrinids, and Lutjanids were higher in the no-take area than in the fished area, these differences were not significant and varied widely between samples. Overall, the mean size of target fishes was relatively small, and no differences were found between no-take and fished areas except for Lethrinids, which were larger (nearly triple the mean size) in the fished area; this difference is likely not important as there was only a couple of larger Lethrinids found in the fished area while more fish were seen in the no-take area. Very few fish greater than 25cm in length were recorded in the no-take area, while fish assemblages in the fished area consisted of greater percentages of fishes in the larger size classes. While overall and individual-family fish biomasses were generally greater in the fished area due to the presence of larger fish, this relationship was only significant for Acanthurids.

Phaeophytes (brown algae) were the dominant macro-algae found along the reef edge in the LMMA. The biomass of these macro-algae was significantly greater in the no-take area than the fished area suggesting that herbivory on these algae is likely less in the no-take than fished area, though this relationship was largely driven by the abundance of *Padina* found in the no-take area. The herbivory assays confirmed this is likely the case as herbivory on the three most abundant Phaeophytes was greater in the fished than no-take area.

4.2.2 MANAGEMENT RECOMMENDATION

Though the Nasinu LMMA had been established for four years when this study took place, it appears to still be heavily impacted by overfishing with no significant benefits acquired from the establishment of the no-take area. Villagers confirmed that there is still regular fishing taking place in the no-take area, as we suspected was likely the case; as the LMMA is adjacent to the village and there is little development around the village, addressing the poaching can likely be done through traditional governance forums.

In order to improve the current LMMA management regime, the following actions are recommended:

- Improve compliance to both Fiji Fisheries regulations and additional community actions being taken to address the decline in ecosystem health and productivity. An improved understanding is needed in the community of not only the laws and additional rules to the fishing ground, but also why they are important for the management and long-term sustainability of the fishing ground. Traditional ceremonies and presentations to formalize the no-take area through the traditional governance system are likely to improve compliance with the no-take areas and other LMMA regulations.

- Extend the no-take boundary offshore past the reef slope over the soft bottom area beyond the reef. This will extend the coverage of no-take protection across a broader range of habitats likely used by targeted food fishes.

- Place a traditional ban on the harvesting of *Naso unicornis* and *N. lituratus* across the entire LMMA as these fish are the primary herbivores responsible for removing the macro-algae that present and most abundant across the LMMA.

- Establish an additional no-take area so that both a long-term closure and a more temporary closure exist. This is likely to allow the community to benefit from the short term closure of an area on occasions while allowing an area to remain protected from all fishing pressure so more long-term benefits may accrue. Having a closure of each kind can also likely be a valuable learning experience to the community in terms of understanding the differences between temporary and permanent no-take areas and the benefits that each can offer.

- Limit the use of nets, and set a minimum 3” mesh size for nets (current Fiji fisheries regulations have a minimum 2” mesh size).

- Place a traditional ban on night fishing with lights and spears; limit night fishing to hook and line.

- Improve enforcement capability of Fiji fisheries regulations by working with the Department of Fisheries to train community Fish Wardens who are empowered to work with Police to monitor fishing activities and arrest fisherpersons who are breaching Fiji fisheries regulations.
- Improve land use practices in the inland watershed areas to reduce sedimentation in the LMMA, and continue with mangrove planting / restoration efforts.

4.3 NAMARAI VILLAGE, NAKOROTUBU DISTRICT

4.3.1 LMMA ASSESSMENT

The four patch reefs sampled in the Namarai LMMA are showing signs of overfishing, but have not deteriorated to the state that the nearshore reefs sampled in Korolevu-i-wai and Nasinu have. A lack of historical data from these sites makes it difficult to know the trajectory of these reefs. Observations made by the community suggest that poaching of the reefs by commercial fishing operations coming from the Suva area and Vanua Levu (neighboring big island) is a common occurrence at night; no commercial fishing licenses have been issued at present for the fishing ground. Overall, hard bottom coral cover on the edge of the reef tops was less than what was found on the reef slopes (roughly half). Macro-algal cover was greater on the reef top, though this varied by sampling site, and the community composition also varied between the reef tops and slopes with *Sargassum* being the dominant macro-algae and on the reef top and *Halimeda* being most common on the reef slope.

Only marginal differences were found between the no-take (Vatale and Nuku) and fished (Votuvotu and Oru) reefs though the no-take statuses were declared five years before this sampling occurred. While coral cover on no-take and fished reefs were not significantly different, no-take reefs overall had higher coral cover and coral communities with more Acroporids and less Poritids than fished reefs indicating that the no-take areas are likely providing some habitat protection despite the regular poaching that occurs in them. Macro-algal cover was generally low (<20%) at all sampling sites, however hard bottom areas on the windward side of Vatale (no-take) and leeward side of Oru (fished) were largely covered with macro-algae on the reef top (>60%) indicating that herbivory is low in these areas. Acanthurids, Siganids, Lethrinids, Mullids, and Serranids were all more abundant in the no-take area, though in most cases only marginally so, however only Siganids differed in size between the two areas. This suggests that the no-take areas likely could afford some protection to reef fish stocks if compliance to their status improves. Overall, herbivores mainly consumed *Sargassum* and *Padina* during the herbivory assays with significantly more of these algae being eaten on protected than fished reef tops while on the slope, grazing was moderate and did not differ between fished and no-take areas. The highest levels of herbivory were surprisingly recorded in Oru (fished site) where almost all of the *Padina* and all of the *Sargassum* were consumed.

4.3.2 MANAGEMENT RECOMMENDATION

While the no-take reefs did show some signs of promising results, poaching on these reefs remains a major threat to the success of these no-take areas. The protection of offshore reefs, however, poses a great deal of enforcement challenges including, but not limited to, the cost for boat/s and fuel for patrolling, lack of visibility from the village, as well as the lack of a legal mechanism to halt subsistence fishing pressure.

In order to improve the current LMMA management regime, the following actions are recommended:

- Improve enforcement capability of Fiji fisheries regulations by working with the Department of Fisheries to train community Fish Wardens who are empowered to work with Police to monitor fishing activities and arrest fisherpersons who are breaching Fiji fisheries regulations. Fish Wardens also need to patrol the LMMA, particularly at night, as it appears as if there is a lot of unlicensed commercial fishing going on and these poachers do not comply with the community's no-take areas.

- Improve compliance to both Fiji Fisheries regulations and additional community actions being taken to address the decline in ecosystem health and productivity. Apart from patrolling the fishing grounds, raising community awareness of the Fiji fisheries regulation is likely to assist with compliance.

- Place a traditional ban on the harvesting of *Naso unicornis* and *N. lituratus* across the entire LMMA as these fish are the primary herbivores responsible for removing the macro-algae that present and most abundant across the LMMA. If Halimeda continues to expand it's coverage on the reef, then perhaps the parrotfish that feed on it would also require some similar protection.

- Establish additional no-take areas on the nearshore fringing reef. Currently, no-take areas have only been established on offshore reefs where enforcement is challenging. A nearshore MPA, if properly placed, will likely complement the protection being afforded to the mangrove areas at present; it will also be easier to enforce and therefore more likely to succeed in provide fisheries benefits to adjacent nearshore reef areas.

- Limit the use of nets, and set a minimum 3" mesh size for nets (current Fiji fisheries regulations have a minimum 2" mesh size).

- Place a traditional ban on night fishing with lights and spears; limit night fishing to hook and line.

- Improve land use practices in the inland watershed areas to reduce sedimentation in the LMMA, and continue with mangrove planting / restoration efforts.

- Closely monitor all developments in the district that are likely to have an impact on the fishing ground. Of greatest concern is nutrient pollution from wastewater and sedimentation from poor land-use practices. All new developments should go through the Environmental Impact Assessment (EIA) process, and fishing right owners need to take a more active role to ensure that a high standard of EIA are conducted and subsequently compliance to development / operational guidelines is enforced.

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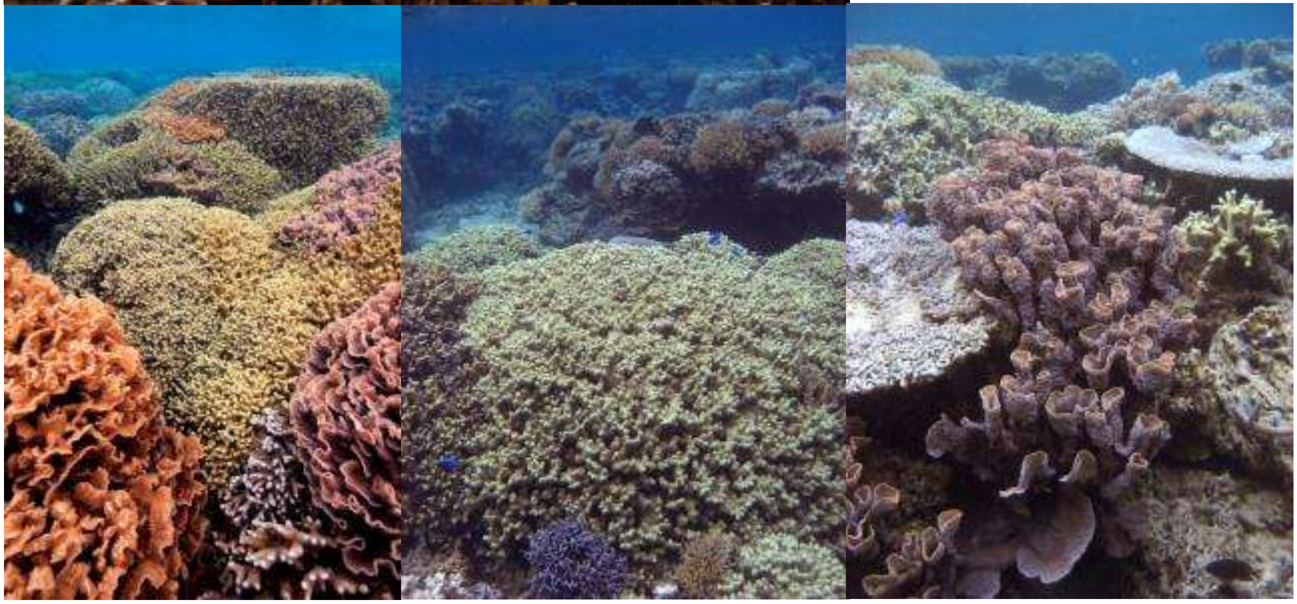
7.0 LMMA PHOTOS – KOROLEVU-I-WAI

Votua’s MPA

Well-developed coral communities in the outer sampling zone of Votua’s MPA. Note the lack of macro-algae.



Vatuolalai’s MPA

Well-developed coral communities in the outer sampling zone of Vatuolalai’s MPA (top row, left).

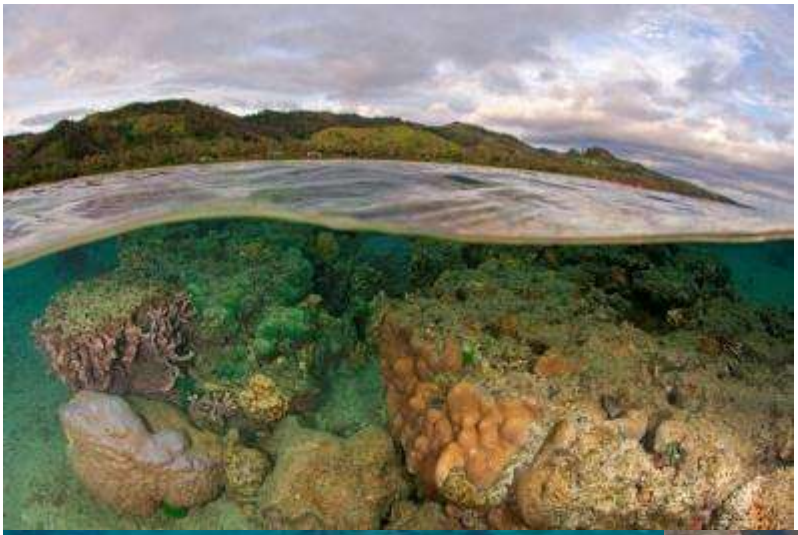
Naso unicornis and *N. lituratus* feed on Phaeophytes during video algal assays in the middle sampling zone of Vatuolalai’s MPA (below and bottom).

Coral community in the middle zone of Vatuolalai’s MPA – looking back at the village shoreline (above).

Tagaqe’s MPA

Well-developed coral community in Tagaqe’s MPA: Outer (top row) and middle (left and bottom) sampling zones. Note the lack of macro-algae.

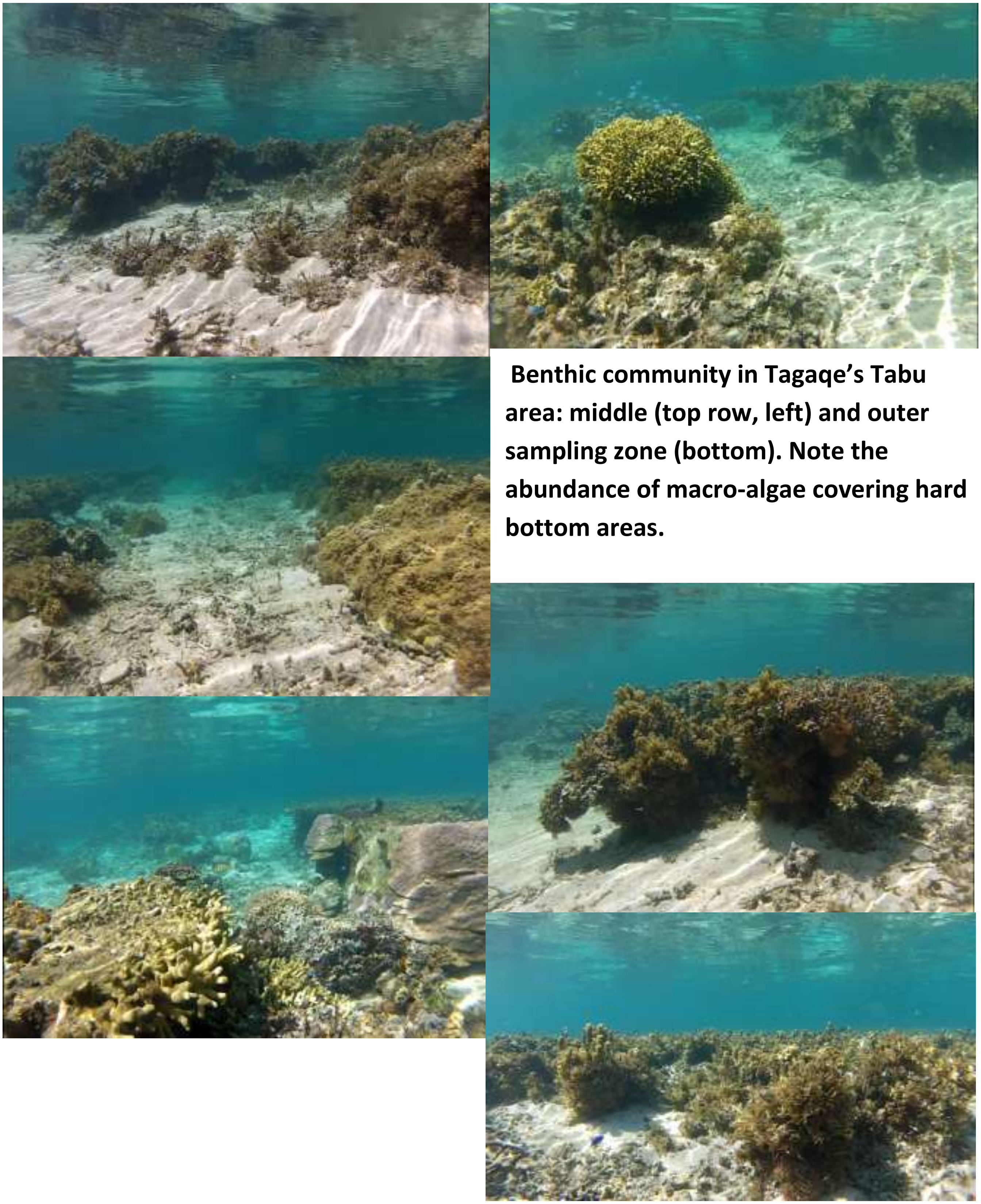
Namada’s MPA



Well-developed coral community in Namada’s MPA : Middle sampling zone looking back at the village (left) and outer sampling zone (middle row). Note the lack of macro-algae.

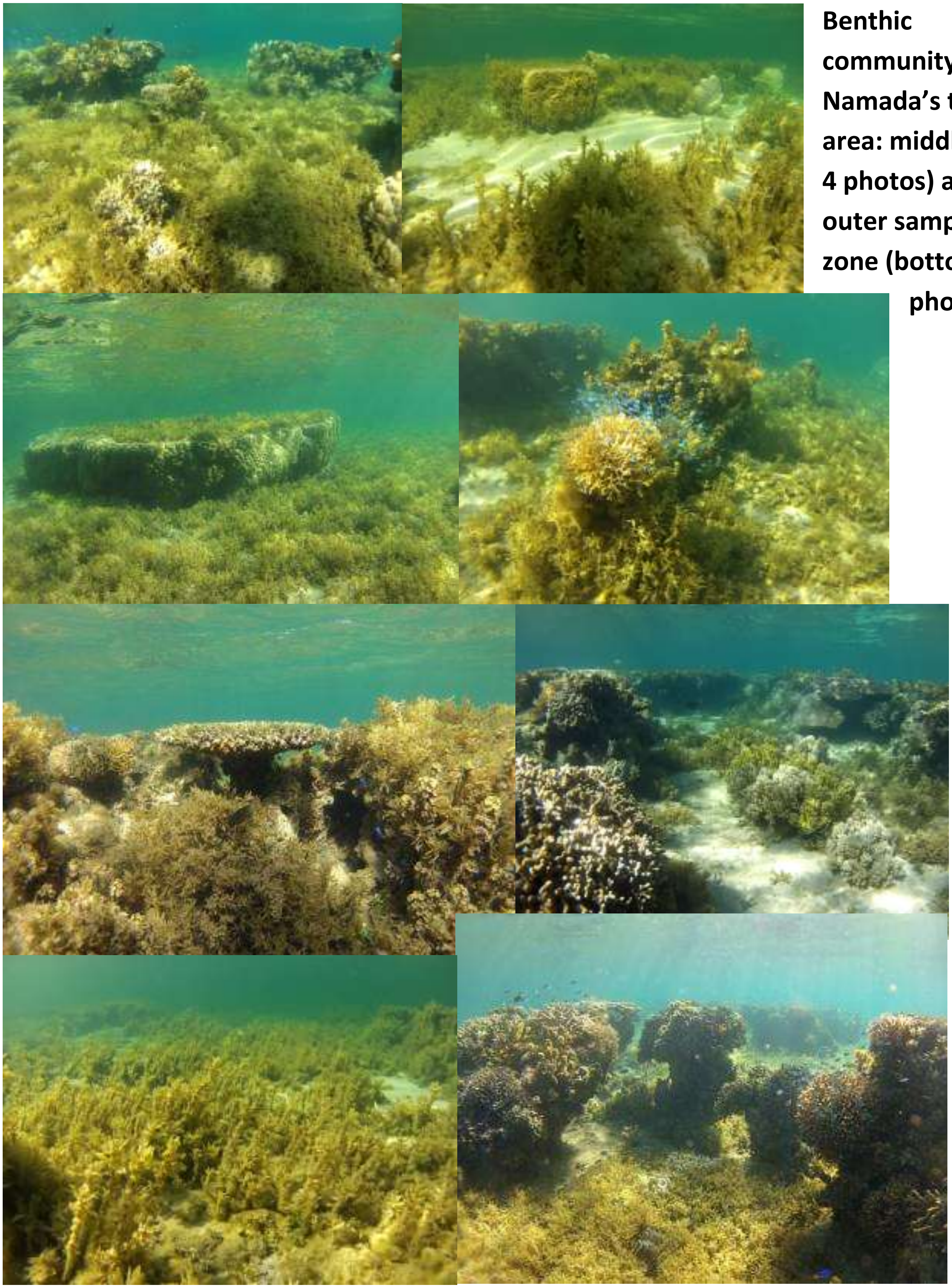
***Naso unicornis* in the middle zone of Namada’s MPA.**

Tagaqe’s Tabu Area



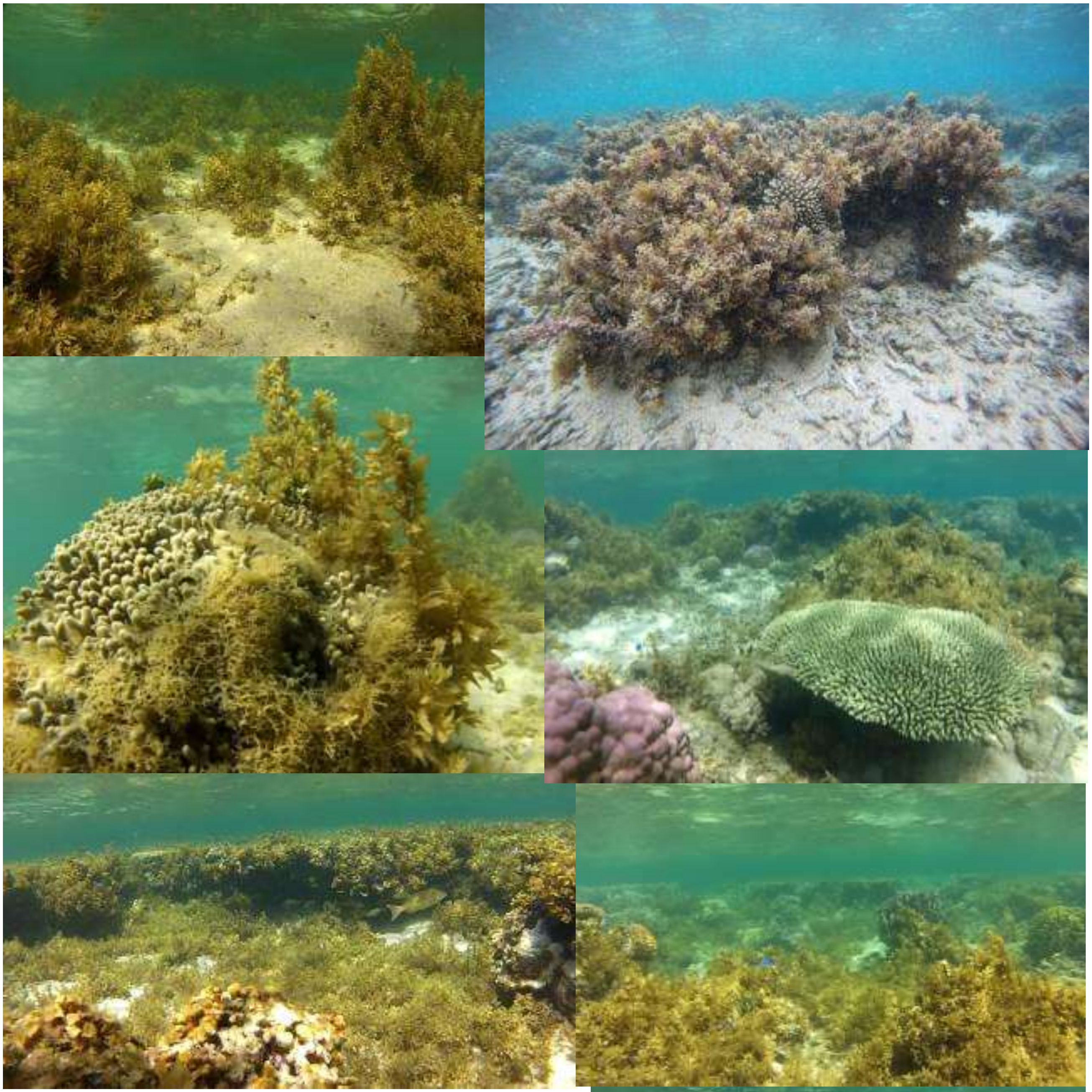
Benthic community in Tagaqe’s Tabu area: middle (top row, left) and outer sampling zone (bottom). Note the abundance of macro-algae covering hard bottom areas.

Namada's Tabu Area



Benthic community in Namada's tabu area: middle (top 4 photos) and outer sampling zone (bottom 4 photos).

Fished Areas



Benthic communities in the fished areas of Votua (top row), Vatuolalai (middle row), Tagaqe (3rd row) and Namada (bottom right). Note the macro-algal overgrowth of the reef.