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AN ABSTRACT OF THE THESIS of Devin M. Resko for the Master of Science in Biology presented, November 17th, 2017

Title: Assessing differences in food fish species between marine preserves and non-restricted waters on Guam

Approved: ______________________________________
Laurie J. Raymundo, Chair, Thesis Committee

Marine protected areas (MPAs) have become a popular conservational tool to combat overfishing and conserve fish populations. On the island of Guam, five marine preserves were established in 1997 to counteract the depletion of local fish stocks that had been observed over the last 50 years. This study investigates the effectiveness of four of these preserves in boosting fishery conservation in terms of abundance, biomass, and diversity. Standard protocols were used to census fish assemblages in four preserves and paired reference locations, where fishing is permitted. Only food fish important to Guam's fishery were considered in this study. Results showed that all preserves greater biomass and abundance of certain fish groups than nearby fished areas, but to varying degrees. Overall, biomass within the marine preserves was more than double that of the fished sites. Abundance was also greater within the preserves by an average of 45%. The Pati Point Marine Preserve and north side of Tumon Bay Marine Preserve showed the most

biomass and highest abundance, compared to their paired fished sites, whereas the Achang preserve showed less of both of these metrics. Beyond abundance, greater species diversity was only detected in the Tumon preserve. Overarching themes of MPA effectiveness derived from meta-data analyses regarding fish populations show that MPAs appear to provide benefits for targeted species. Results from this study showed that the species that experience the most local fishing pressure appear to be benefiting from the preserves. The preserves had, on average, 151% more biomass and 54% greater abundance of these species. Additionally, biomass and abundance were greater within four and three preserves, respectively, for the most desired species, compared to their respective fished sites. Observable benefits for high trophic level species tend to take decade to appear. Consistent with this patter, only two preserves in this study showed greater abundance and biomass for piscivores. Research has shown that a link between MPA age and positive fishery benefits exist. Therefore, it is suggested that additional positive trends will continue to increase for Guam’s marine preserves with time. While positive ecological effects are being realized, additional enforcement and improved compliance would likely boost conservation success. Suggestions to help achieve additional conservation support are provided.

TO THE OFFICE OF GRADUATE STUDIES

The members of the committee approve the thesis of Devin M. Resko presented November 17, 2017.

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Assessing differences in food fish species between marine preserves and non-restricted waters on Guam

BY

Devin M. Resko

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INTRODUCTION:

Over the last half of the past century, coral reef fish assemblages have been in decline on a global scale (Jackson et al. 2001, Hilborn et al. 2003, Newton et al. 2007, Pauly & Zeller 2016). While more broad-scale stressors such as climate change and marine pollution have contributed to the reduction of coral reef fishes, local stressors such as overfishing and destructive fishing practices are also to blame (McManus et al. 1997, Burke et al. 2011, Houk et al. 2015). One such destructive fishing practice that can have profound effects on a local ecosystem is known as “fishing down the food web,” which occurs when upper trophic level species are depleted, and lower trophic levels are then harvested in their place (Pauly et al. 1998, Mumby et al. 2012). Other destructive practices, seen in less developed regions, include the use of explosives, such as dynamite, and poisons (Petrossian 2015). More industrialized fisheries have difficulty scaling back operations due to investment burden; reducing a company’s yield due to conservation concerns is typically not seen as a smart business decision. This causes fishing to become unsustainable due to economic and possibly political pressure (Ludwig et al. 1993, Hilborn et al. 2003). All of these issues have profound effects on global reef fisheries.

The loss of a coral reef fish assemblage can leave the local coral reef ecosystem vulnerable to rapid and unfavorable changes (McManus et al. 1997, Jackson et al. 2001, Mora 2008). Herbivores and detritivores are important in maintaining coral reef substrates in calcifying states by removing turf algae and macroalagae, which compete with corals for substrate (Aronson & Precht 2006). Removal of these grazers can have profound effects on the local environment. Following a major coral mortality event, a loss of grazers can leave the environment susceptible to a phase shift to algal-dominated coral reefs (Hughes 1994, Fung et al. 2013, Huffmyer & Jadot 2014, Cramer et al. 2017).

Predators also help structure coral reef systems by stabilizing the local trophic levels (Rooney et al. 2006). Houk & Musburger (2013) found that reefs with an intact population of sharks also exhibited a high biomass of herbivores, as well as a high abundance of large-bodied fish species. The stability is achieved through the weak interactions present throughout the lower trophic levels (McCann et al. 1998). These weak interactions diminish oscillations between consumers and resources, which in turn lowers the probability of a population becoming locally extinct (McCann et al. 1998). Furthermore, predators increase ecosystem stability by consuming prey with both fast and slow biomass turnover rates (Rooney at al. 2006). This foraging practice prohibits populations of lower trophic levels from increasing to a point that they are detrimental to the local ecosystem. Predators also consume weak and dying individuals, which increases the overall fitness of the local reef fish assemblage (Dale Broder & Angeloni 2014, Hartman & Lawler 2014, Hall & Kingsford 2016). The removal of predatory fish species can destabilize the local ecosystem (Pauly et al. 1998, Pinnegar et al. 2000, Mumby et al. 2012, Britten et al. 2014). For instance, Mumby et al. (2012) observed a sharp decline in groupers and snappers in Belize, a result of unsustainable fishing practices. Consequently, mesopredator species increased in biomass of up to 880% over a 6-7 year period. This rapid increase of mesopredator species effectively predated upon lower trophic level species; populations of several study species dropped nearly 45% in the same time period.

In addition to the profound ecological importance, intact reef fish populations also are socio-economically important. The fishing industry plays a vital role in the livelihoods of millions of people worldwide. The number of people employed in the fishing industry is conservatively estimated at 43.5 million, while over 200 million are directly dependent on the industry (FAO 2005). Six million are labeled as individuals who fish coral reefs (Teh et al. 2013). The dependence is compounded in coastal and less developed areas. In these areas, fish are a vital component of a communities' dietary protein (Thorpe et al. 2006, Mohan Dey et al. 2007). Over a quarter of small-scale fishery operations take place on coral reef systems (Teh et al. 2013). Reduction of reef fish populations can affect the economies and health of millions of people, especially in developing countries. More industrialized countries have begun to increase their distant-water fishing, where fishing occurs within the exclusive economic zone of other countries, mostly developing countries (Le Manach et al. 2013, Pauly et al. 2013). While the developing countries do receive a payment for permitting the distant-water fishing, the country's small-scale fisheries are then forced to compete with the more efficient industrialized fishing fleets (Pauly & Zeller 2016).

Marine Protected Areas (MPAs) as a Management Tool

Marine protected areas are a popular management strategy to discourage overfishing and promote fisheries conservation (Roberts et al. 2005, Edgar et al. 2007). MPAs are defined areas of ocean where fishing, and possibly other human activities (e.g. boating, SCUBA diving) are limited or prohibited. MPAs can be found throughout the world, but most occur in coastal waters (Wood et al. 2008). According to the Marine Conservation Institute (2016), there are over 13,000 MPAs currently established, protecting approximately 3% of the world's oceans. Furthermore, only one-sixth of protected waters are designated as no-take areas, allowing for some degree of fishing to take place in all others. Over one quarter of coral reefs are afforded some type of protection (Burke et al. 2011). However, only 6% of coral reefs are believe to be managed effectively. MPA management and enforcement varies greatly (Halpern 2014, Edgar et al 2014). The Sinis MPA, located on the West Coast of Sardinia, Italy, is subdivided into three zones, each with varying degrees of protection: no entry, scientific research only, and a "partial protection zone," where commercial and recreational fishing are permitted, but the number of fishermen allowed is controlled. Marra et al. (2016) found no significant difference in abundances of commercially-important fish species between the three zones. The researchers hypothesized that illegal fishing, or poaching, due to inadequate enforcement may be a key reason as to why the MPA was not meeting its management goals. Other sites impacted by minimal enforcement and regulation may act as nothing but "paper parks": an area that, on paper, is a protected area but provides no real ecological benefits (Watson 1999). This leads to those MPAs failing to meet the ecological and social expectations set when they were established (Gallacher et al. 2016).

With proper regulation and enforcement, MPAs can produce positive ecological trends such as an increase in target species abundance, restored food webs and local ecosystem resilience (Pauly et al. 2002, Roberts et al. 2005, Mellin et al. 2016). However, these results may take years or even decades to be realized, depending on the management objectives. Abesamis and Russ (2005) examined the results of a 20-year-old no-take reserve at Apo Island, Philippines. Ecological trends such as increased biomass or abundance were not observed for nearly eight years. Since the MPA was established, two decades ago, however, the mean density of *Naso vlamingii*, a locally exploited fish, increased 300%. Also, average total length of *N. vlamingii* increased from 30 to 45 cm over the same period. A study also examined the effectiveness of the Mombasa MPA on the Kenyan coast after 16 years of protection (Munga et al. 2012). After several years, positive trends were observable. Results showed that the fully protected, no-take zone contained more fish biomass and higher fish diversity than in the partially protected zone. The difference in fish species between the two zones was linked to the removal of species important to the local fishing community. However, both zones of the MPA exhibited healthier fish stocks than outside the MPA after several years of no differences.

The designation of an MPA also has important socio-economic factors. Coastal communities, especially in more remote areas of the world, rely heavily on the local marine environment for their well-being (Thorpe et al. 2006, Gallacher et al. 2016, Rasheed et al. 2016). The increased restrictions on fishing associated with the creation of an MPA can incite negative feelings from local fishermen (Di Lorenzo et al. 2016). Meeting catch quotas after a reduction of fishing grounds can impact local fisheries in the short term (McClanahan 1999, Guidetti & Claudet 2010). Rasheed et al. (2016) examined how the largest MPA in the Maldives, the South Ari Atoll MPA, affected commercial, subsistence, and recreational fishers four years after being implemented. Commercial and subsistence fishers were severely impacted, with commercial fishers being slightly more affected since their profession and main source of income was at risk. Subsistence fishers' dietary needs were diminished. Lastly, recreational fishers were affected, but to a much lesser degree. The MPA, while affecting their leisure activity, posed little threat to the recreational fishers' health or main source of income. Overall, all groups which interacted with the now-restricted waters were negatively affected.

However, if a community can overcome the short-term effects of restricted fishing, an MPA can yield positive results for local fishermen in the long run (Roberts et al. 2001, Rees et al. 2013). By increasing species biomass within the MPA, positive results can be realized through spillover. Spillover is achieved by movement of juveniles and/or adults found within the boundaries of the MPA, or by passive transport of eggs and larvae, emigrating out of the protected waters (Russ et al. 2005, Grüss et al. 2011). Alcala et al. (2005) examined the effects an MPA had on nearby fished areas in the Philippines. Sumilon Island was redesignated a no-take MPA from 1987 to 1991 and from 1995 to 2001. By 2001, fish biomass had increased within the reserve by over 27%. At the same time, fishery yields outside of the MPA increased by 26% - evidence of spillover. Gallacher et al. (2016) examined the local community's perception after the introduction of an MPA in southern England. The primary purpose of this MPA was to protect the declining local benthic fish species. Shortly after the MPA restriction took effect, local fishermen expressed difficulty in meeting catch quotas due to the reduction of fishing grounds. However, three years after the MPA declaration, local species assemblages increased both within and outside the MPA boundaries, indicating spillover was occurring (Sheehan et al. 2013, Gallacher et al. 2016). There was also a noticeable decline in the number of fishermen who held negative perceptions towards the MPA, since they were able to increase their fishing yields due to spillover (Gallacher et al. 2016).

Methods to Evaluate MPAs

Due to the ecological and socio-economic consequences involved with the introduction of an MPA, it is important to evaluate its success (Maypa et al. 2012, Gallacher et al. 2016). Underwater visual census (UVC) approaches have become the preferred method of surveying marine fish species and communities (Thresher & Gunn 1986). Much of the appeal of utilizing UVCs is due to the minimal disturbance associated with these methods, as well as their cost effectiveness and ease of use (Watson and Quinn 1997). UVCs allow for rapid data collection of coral reef fish communities, including data on relative abundance and size distributions, allowing for biomass estimates during data analysis (Samoilys & Carlos 2000).

There are several types of UVCs frequently employed, each having their benefits and drawbacks (Edgar et al. 2004). Some of these popular techniques are: (1) *timed swims*- where a diver records the number of species sighted during a fixed time period, (2) *stationary point counts*- where a diver scans 360^{o} through a visually-estimated cylinder and records species that are in, or pass through, the cylinder, and (3) *strip transects*- where a diver records species while swimming along a strip of fixed length and width (Edgar et al. 2004). The species of concern should be considered when determining which UVC to employ.

Strip transects are typically used to assess reef fish populations (Kingsford & Battershill 1998, Caldwell et al. 2016). Transect UVC methods can be used for a multitude of fish groups, ranging from small cryptic species (Correia et al. 2015) to large mobile fishes (Friedlander & DeMartini 2002). Colvocoresses & Acosta (2007) showed few statistically distinguishable differences between stationary point counts and strip transects for observed species. However, the authors noted that larger, more mobile species rarely entered the count cylinder and were possibly underrepresented as compared to those surveyed using transect methods. One species that exhibited this behavior was the black grouper (*Mycteroperca bonaci*). Researchers proposed this difference was due to the fish's shy nature towards divers, since it is a targeted species. For any method, predetermining appropriate transect dimensions (i.e., length and width of transect) is necessary for optimum data collection. Dimensions are dictated by the species of concern in the study (Mapstone & Ayling 1993, Samoilys & Carlos 2000).

Fishing and Marine Preserves in Guam

Guam, the largest and southernmost of the Mariana Islands, has approximately 110 km^2 of nearshore reef and lagoonal habitat (Burdick et al. 2008). It also has the largest population in Micronesia, approximately 160,000 (U.S. Census Bureau 2010). Centuries ago, before the first contact with Europeans, the natives of Guam, the Chamoru, relied on the island's nearshore waters for subsistence fishing (Hensely & Sherwood 1993). These practices are still important to the local culture (Burdick et al. 2008, Weijerman et al. 2016); van Beukering et al. (2007) reported that up to 40% of households on Guam engage in fishing activities. Guam's local fishery is estimated at nearly $4 million per year and is, therefore, a notable component of the island's economy. Total yearly reef fish harvest is estimated at 114, 262 kg (DAWR unpubl. data). The rapid population increase Guam experienced during the previous century, along with advancements in fishing gear, has stressed Guam's local fish populations. Concerns about unsustainable overfishing occurring on Guam's coral reefs began as early as the 1970s (Hensely & Sherwood 1993). Guam is the only island in Micronesia where

SCUBA can be used while spearfishing (Houk et al. 2012), which has raised concern about the sustainability of the island's targeted reef fish populations (Flores 2006, Bejarano et al. 2013).

Zeller et al. (2007) discovered gross underreporting of both commercial and recreational catches in Guam's local fishery throughout the second half of the last century. Using re-estimated data to account for the underreporting, Zeller determined that Guam experienced an 86% decline in catches of nonpelagic species from 1950 to 2002. This decline resulted in an annual per capita catch rate reduction from 16.0 kg to 0.8 kg and a decline in catch rates on coral reefs from 4.7 t/km^2/year to 0.6 t/km^2/year. Weijerman et al. (2016) examined Guam's fishery data spanning back several decades and found similar results. Parrotfish species, as well as other herbivores, have declined to concerning levels on Guam's coral reefs. Bejarano et al. (2013) examined possible risks to reef fishes in Guam through catch data and interviews with local fishermen, and suggested three species are locally at high risk due to heavy fishing pressure: *Hipposcarus longiceps*, *Siganus punctatus*, and *Scarus rubroviolaceus*.

To address concerns about sustainability of fishing practices, five marine preserves were established on Guam via Public Law 24-21. These sites were declared marine preserves in 1997 by the Guam Department of Aquatic and Wildlife Resources (DAWR). These five preserves are: Achang Reef Flat, Pati Point, Piti Bomb Holes, Sasa Bay, and Tumon Bay, referred to hereafter as Achang, Pati, Piti, Sasa Bay, and Tumon, respectively. Boundaries of the preserve extend 10 m inland, and out to sea to the 100 fathom depth contour. These preserves restrict fishing in 16.4% of the island's nearshore reefs and lagoons (Burdick et al. 2008). Enforcement did not begin until 1999 in the form of warnings; penalties were not issued until 2001 (Burdick et al. 2008). With the exception of Sasa Bay, which is strictly no-take, limited fishing is allowed, such as shore fishing for select species and trolling for pelagic species (Burdick et al. 2008). Additionally, permits are issued periodically for traditional harvesting practices for seasonal runs of *Ptercaesio tile*, *Selar crumenophthalmus,* and *Siganus argenteus* in the Achang and Piti preserves (Burdick et al. 2008).

Studies of MP Effectiveness on Guam

A study in 2006 examined four of Guam's marine preserves to investigate their ability to protect reef fish species (Pioppi, unpubl. data). Target species were chosen from the following families: Acanthuridae, Scaridae (now subfamily Scarinae), and Siganidae. Results suggested that larger individuals were observed in the preserves; this effect was largest for scarids more than any other family. A study in 2011 that examined the entirety of Tumon, with paired fish sites at both Tanguisson and East Agana Bay, found no difference in reef fish abundances, with the exception of increased *Caranx melampygus* abundance in the preserve (Hickey, unpubl. data). Tupper & Donaldson (2005) compared the Piti preserve with an area without fishing restrictions, Asan Bay. Biomass was significantly greater in Piti for all but one of nine target species surveyed. Taylor & McIlwain (2010) investigated populations of *Lethrinus harak*, a heavily exploited emperorfish, between two of Guam's marine preserves, Achang and Piti, and two fished sites, in a paired design. By examining otoliths from captured individuals, the authors concluded that the preserves had greater mean ages and lower total mortality. Another study found spawner biomass (the collective weight of reproductively mature individuals) was sixteen times higher inside Achang and Piti compared to reference fished sites

(Taylor et al. 2012). These findings suggested greater reproductive viability inside the preserves. A greater proportion of the population is reproductively viable when there are older individuals present. This is disproportionately true for females, which experience exponential increases in ovary weight with length and age (Taylor & McIlwain 2010). Taylor & Mills (2013) examined movement patterns of *L. harak* and *L. obsoletus* throughout the Piti preserve. Through the use of acoustic telemetry, the researchers suggested that despite the relatively small size of the Piti preserve, benefits can be achieved for heavily targeted fish species. Furthermore, the study suggested that spawning events for *L. harak* occurred within the preserve, which can have major ecological benefits in regards to reproductive output.

A NOAA study examined fish populations at 113 locations around Guam using stationary point counts (SPCs) (Williams et al. 2012). Surveys were done at depths ranging from 2-29 m, and all fish species encountered were recorded. Results showed total reef fish biomass within Guam's marine preserves was 2.4 times that in fished sites. Survey sites in Achang and Pati showed the most fish biomass. Researchers also noted that Pati had more encounters of uncommon species, such as sharks, jacks, and *Cheilinus undulatus*.

Despite the encouraging results from these studies, all noted that these ecological gains may be hindered by poaching. Most poaching is done by spearfishing, performed at night to minimize detection (Taylor & McIlwain 2010). Enforcement of Guam's fishing laws within marine preserves is carried out by the Guam Department of Agriculture, hereafter referred to as the enforcement agency. Since full enforcement of the marine preserves began in 2001, there have been over 300 arrests for poaching in the preserves.

However, personal accounts from conservation officers describe limited resources and personnel, creating a challenge for effective enforcement. The understaffed enforcement agency is not only tasked with patrolling the marine preserves for illegal fishing, but is also in charge of responding to illegal hunting of deer and pigs and assisting with forest fires. Additionally, officers mentioned logistical difficulties with some of the preserves; it can take up to 45 minutes to reach Achang from the enforcement agency's headquarters. The hurdles present for the enforcement agency only bolster the need for scientific research on Guam's marine preserves.

STUDY GOALS

This study used strip transects to survey populations of select coral reef fish species inside and outside of Guam's preserves in a paired design. The fish species of concern in this study were those regularly targeted in Guam's local fishery. Having a paired, non-restricted site for each marine preserve site allowed comparisons between sites that were structurally similar, with fishing pressure being the main difference. Using multiple metrics (biomass and abundance) and multiple groups (parrotfishes, levels of fishing intensity, etc.) results aimed to shed light on the current status of Guam's marine preserves. It is hoped that these results will aid policymakers and resource managers in developing better management practices and strategies for Guam's preserves.

RESEARCH QUESTIONS

Q1: Will reef fish biomass differ between the preserves and fished areas?

$H1_0$: There will be no observed difference in biomass between the preserves and fished areas.

$H1_a$: Reef fish biomass will differ between marine preserves and fished areas.

Q2: Will reef fish abundance differ between the preserves and fished areas?

$H2_0$: There will be no observed difference in abundance between marine preserves and fished areas.

$H2_a$: Reef fish abundance will differ between the marine preserves and fished areas.

Q3: Will reef fish diversity differ between marine preserves and fished areas?

$H3_0$: There will be no observed difference in diversity between marine preserves and fished areas.

$H3_a$: Reef fish diversity will differ between marine preserves and fished areas.

Q4: Will size class distributions of fish species differ between the preserves and fished areas?

$H4_0$: There will be no difference in the size class distribution of fish between marine preserves and fished areas.

$H4_a$: Size class distributions will differ between marine preserves and fished areas.

METHODS

Study Sites

Five pairs of marine preserve and non-protected sites were surveyed in this study: Achang /Rios Bay and Cocos, Pati /Ritidian, Piti /Breakwater, North Tumon /Tanguisson, and South Tumon /East Agana Bay (Fig. 1).

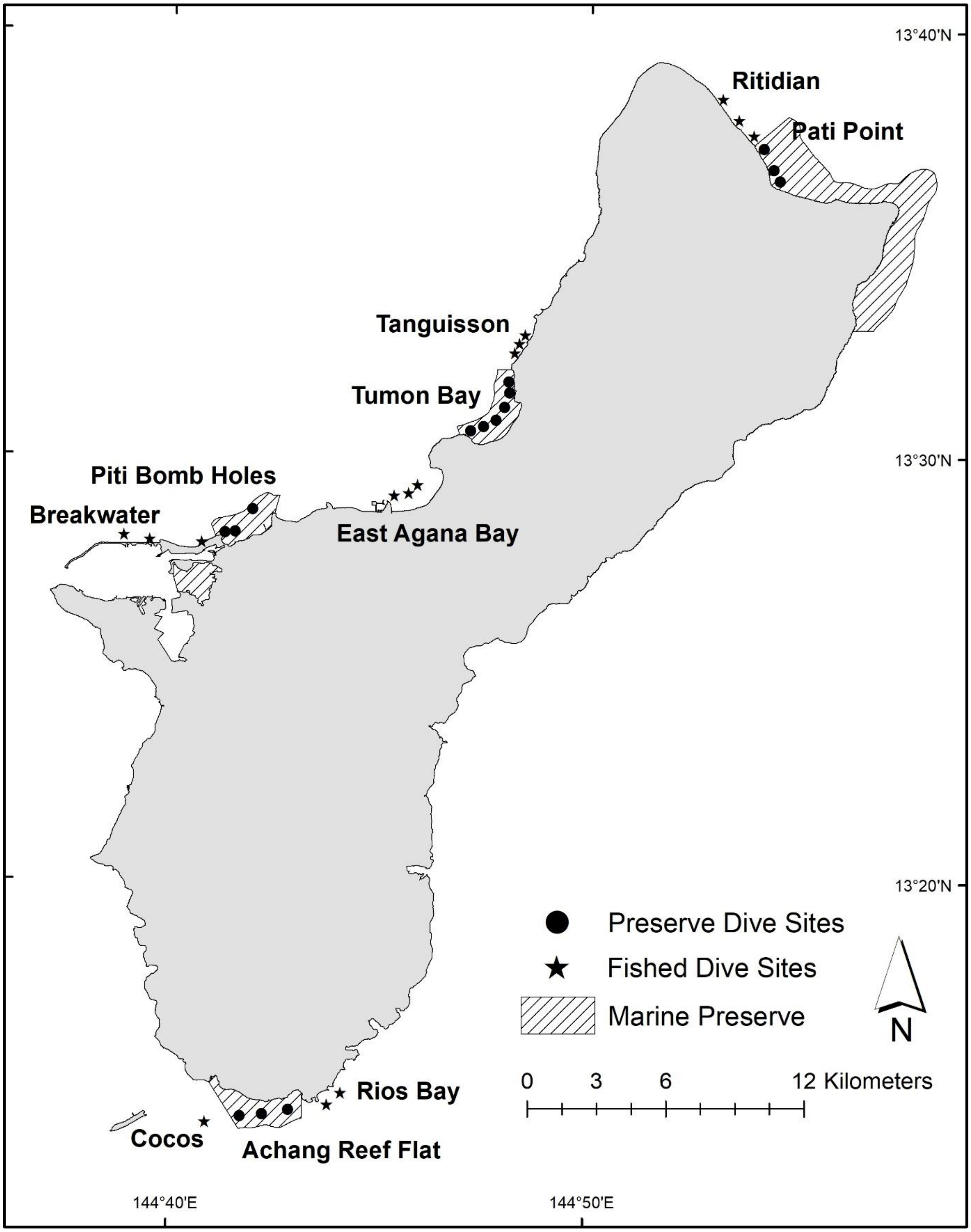

Figure 1: Map of Guam showing the island's marine preserves of concern in this study, as well as all survey sites.

Sasa Bay was excluded due to the site being naturally different than the other sites; the site is dominated by sand, pavement, and mangroves, with little coral cover present (Burdick 2006).

The Achang preserve, located in the southernmost village of Merizo, is the second largest marine preserve on Guam (Table 1). Mangrove patches line much of the western shore, and extensive seagrass beds and coral reefs are present throughout much of the preserve. There are three river channels which bisect the reef. The fished sites selected as paired sites are located on either side of the preserve: to the east is Rios Bay, and to the west is Cocos Lagoon. Rios Bay was originally chosen to be the sole location for the paired fish sites. However, it lacked a sufficient amount of habitat similar to the preserve for all three stations for data collection. Therefore, Cocos was selected as a second fished site to compare to Achang.

The Tumon preserve is located in the centrally located village of Tamuning, the heart of Guam's tourism (Denton & Sian-Denton 2007, Burdick et al. 2008). Reef habitat is found throughout the preserve, with an extensive reef flat interrupted by the headlands on either side of its boundaries. A change in benthic composition lies near the middle of the preserve. The seaward slope in the northern half of Tumon is dominated by hard coral, whereas the southern half shows more heterogeneity of hard coral, sand, and pavement. The Tumon site was split into two categories (North and South Tumon) based on this benthic change. Each half of the Tumon preserve site had a separate paired fished site.

Table 1: Marine preserve features. Size data from NOAA (2008). Population data from 2010 U.S. Census

Marine Preserve	Size (km^2)	Village	Population	Fished Site
Achang Reef Flat	4.5	Merizo	1,850	Cocos Lagoon, Rios Bay
Pati Point	19.6	Yigo	20,539	Ritidian
Piti Bomb Holes	3.6	Piti	1,454	Breakwater
Tumon Bay	4.1	Tamuning	19,685	E. Agana, Tanguisson

The fished sites were chosen because of their proximity to their respective MP, as well as having similar benthic profiles. Tanguisson, North Tumon's paired site, lies just north of the preserve's boundary near Puntan Dos Amantes (Two Lovers Point). Tanguisson is a nearby popular fishing site and was thus selected as a fished paired site for North Tumon. The paired fished site for South Tumon, East Agana Bay, is located to the southwest of the preserve, separated by Hospital Point. East Agana Bay has been used in previous studies as a paired site to the preserve (Hickey unpubl. data, Lindfield et al. 2014). Areas surveyed in both South Tumon and East Agana Bay were similar in benthic composition.

The Pati preserve is on the northeastern corner of the island, located in the Yigo village. Pati is the largest preserve, with a size exceeding all other preserves combined (Table 1). Strong currents, coupled with being on the windward side of the island, make access difficult during much of the year. Spur-and-groove reef is found in the shallows on the preserve, as are underwater caverns. The cliff line near Pati is primarily rocky and difficult to traverse. All land near Pati is controlled by the United States Air Force. This study focused on the western boundary of the preserve, as logistical constraints and weather conditions ruled out examining the southern boundary of the preserve (see Fig. 1 for dives sites within Pati). The paired fish site, Ritidian, is located northwest of Pati's boundaries.

The Piti preserve is in the south-central Piti village, and encompasses the entirety of Tepungan (Piti) Bay. The preserve is bounded by Asan Point to the east and the Cabras Power Plant water intake channel to the west. Hard and soft coral communities are present. The reef is intersected by a channel in the western portion of the preserve and is interrupted in the eastern portion by karst sinkholes called “bomb holes.” These depressions are scattered through the preserve and can be as deep as 10 m. The largest depression has an underwater observatory which is a popular tourist destination (Burdick 2008). Recreational SCUBA divers, snorkelers, and fish feeding are common near the observatory (Taylor & Mills 2013). To limit bias due to fish feeding, survey sites were not located near the observatory; the closest surveys were approximately 800 m from feeding sites. Past studies that have investigated the Piti preserve have paired it with Asan Bay, which lies just to the east of the preserve (Tupper & Donaldson 2005). However Asan Bay’s benthic profile did not match that of Piti’s, a requirement in this study. Therefore, the fished site selected to compare to Piti was the northern part of Apra Harbor’s breakwater.

Data Collection

Data collection was undertaken between 8 June and 29 July 2017. In total, 30 stations were surveyed, totaling 150 transects (Fig. 1). No station was within 400 m of the preserve’s border. Five replicate transects, 50 m long by 10 m wide, were deployed for fish surveying at three stations within each site, resulting in 15 transects for each site (1500 m^2 of reef). The chosen dimensions and level of replication are commonly used for assessing coral reef fishes (evaluated in Samoilys & Carlos 2000). Transect locations were chosen haphazardly along the seaward slope at a depth of approximately 10 m. Divers swam a set number of fin strokes along the reef before the start of data collection in order to minimize possible disturbance from the presence of the boat (Samoilys & Carlos 2000). Observer One recorded fish while Observer Two deployed the transect (based on methods from Mapstone & Ayling 1998). Observer One recorded species that are present within the transect boundaries, as well as the length of individuals. Observer One looked ahead, along the transect, to count more mobile species, before counting closer species that were less likely to flee. Since Observer One swam ahead of the transect, Observer Two alerted the other when the 50 m transect had been completed using an underwater noisemaker. Start and stop signals between the two observers were established before field work began. After the completion of one transect, the observers swam approximately 10-15 m before starting the next transect, based on methods from Lindfield et al. (2014).

At the conclusion of fish surveying (the end of the fifth transect) benthic data were collected, primarily using methods from Ayotte et al. (2011). Both observers turned around and collected data on the five transects previously laid out for fish surveying. Observer One collected benthic data while Observer Two gathered transects. Benthic cover was assessed using a point intercept transect (PIT) method at intervals of 2.5 m. The PIT method can provide similar benthic composition information at the line intercept transect (LIT) method, and can be performed more quickly (Facon et al. 2016). Data were collected using the following categories: hard coral, soft coral, dead coral, macroalgae, crustose coralline algae, turf algae, sand, and pavement. These data were used to ensure the paired protected/fished sites had similar benthic compositions.

Fish Species of Concern

All fish species that regularly contribute to Guam's local fishery were considered in this study, collectively grouped as "overall" (refer to Table 2 for in-depth descriptions of categories used in this study). Species were also placed into consumer groups: primary consumer, secondary consumer, and piscivores. Houk et al. (2012) listed the fifteen

Table 2: Descriptions of all categories fishes were placed in for this study.

Species Group	Description	Number of Species
-- Miscellaneous		
Overall	All fish species that regularly contribute to Guam's local fishery.	71
Parrotfish	Species from subfamily *Scarinae*.	16
Acanthurids	Species from family *Acanthuridae*, consisting of surgeonfishes, tangs, and unicornfishes.	15
-- Consumer Group		
Primary Consumer	Herbivores and detritivores, consisting primarily of surgeonfishes and parrotfishes.	33
Secondary Consumer	Species that are primarily omnivorous or feed on invertebrates.	19
Piscivore	Higher tropic level fishes that consume other fishes.	15
-- Fishing Intensity		
Fished	Herbivores that received a desirability score < 1 (Bejarano et al. 2013). Non-herbivorous fishes that are not targeted by spearfishing on Guam (Lindfield et al. 2014).	13
Target	Herbivores that received a desirability score 1-3 (Bejarano et al. 2013). Non-herbivorous fishes that are commonly targeted by spearfishing on Guam (Lindfield et al. 2014).	22
High Value	Herbivores that received a desirability score > 3 (Bejarano et al. 2013). Regularly targeted species from families *Epinephelidae, Lethrinidae*, and *Lutjanidae* (Lindfield et al. 2014). Food fishes that are uncommonly observed (e.g., *C. undulatus*).	36
Most Wanted	Species that make account for 70% of total landings in Guam (Houk et al. 2012).	13

species or species groups that account for up to 70% of total landings in Guam. Thirteen were observed in this study; these species make up the “most wanted” group (species are marked in bold in the Supplemental Table S1).

Additional grouping of fish species targeted in this study is based on methodology from Bejarano et al. (2013) and Lindfield et al. (2014). Bejarano et al. (2013) interviewed 19 fishers on Guam to determine the desirability of commonly fished herbivorous reef fishes (Table 3). Fish species of concern in this study are placed into three groups: fished, target, and high value. *Fished* species are ones that received a desirability score >1. *Target* species include fish species that received a 1-3 desirability score. Finally, *high value* include species that received a desirability score >3. Lindfield et al. (2014) applied similar values to non-herbivorous fishes. Species encountered that were not given a value from either study were placed as high value due to their uncommon occurrence.

Some individuals were excluded in statistical analyses regarding biomass, abundance, and size class distributions (all fishes observed were included in species diversity). These exclusions included large individuals and large schools that were rarely encountered throughout surveying. Large individuals and large schools can attribute large amounts of biomass to a site. If these individuals, or schools, are rarely observed, the large influx of biomass may be misleading. The two species removed from these statistical tests are *C. undulatus* (n=5) and *Lutjanus bohar* (n=3). Schools of two species were excluded: *Carangoides ferdau* (n=19) and *Chlorurus spilurus* (n=8).

Table 3: Desirability score categories associated with answers from interviewing fishermen on Guam (Bejarano et al. 2013).

Desirability Score	**Feelings toward fish species of concern**
4	‘I target this species’
3	‘I would catch it if I see it’
2	‘I would catch it if I see it and it is big’
1	‘I would not catch this species’

Statistical Analyses

Fish survey data are commonly nonparametric. Fish survey data were tested for normality using Shapiro-Wilk tests and all nonparametric data were transformed. Biomass data were typically log-transformed. If log-transformed data were non-normal or heteroscedastic, other transformations were applied (e.g., square root, Box-Cox). Abundance data were log(x+k) transformed, where x and k represent the abundance and a constant, 1, respectively. The constant was added to avoid log-transformations of zeros, which would result in undefined results. Data from paired sites were transformed identically. Biomass was estimated using length-weight regressions for each species from FishBase (Froese & Pauly 2013). When available, only Guam-based values were used.

Species richness values were determined by first calculating the Shannon Index $H'=\sum_{i=1}^{R} n_i \ln n_i$, where n_i represents the number of species i in the total number of species R (Shannon & Weaver 1963). H' alone, however, does not reflect community diversity well due its highly nonlinear nature (Jost 2007). Therefore, the preliminary Shannon values, *effective number of species* (ENS) values were calculated. ENS values represent the number of equally-common species necessary to attain a particular value of a diversity index (Jost 2007). These values allow for easier comparisons and interpretations. Rarefaction curves were plotted to estimate the total number of species in the given survey site. Size class data were tested with Kolmogorov-Smirnov (K-S) tests.

Statistical power analyses were performed on all data before hypothesis tests were performed. Statistical power is the probability that the null hypothesis can be rejected when it is false (Peterman 1990). Power was calculated with the 'pwr' package (Champely 2017) in R (R Core Team 2016). Achieved power of at least 0.8 was considered sufficient in this study. Low power is a result of high standard deviation. When sufficient power was unable to be reached for a particular group, the theoretical sample size (e.g., number of strip transects) to achieve 0.8 power was calculated.

Mixed-effects two-way nested ANOVA was performed for species richness and for all fish groups (see Table 2) for both biomass, abundance, and species diversity, between the two protection types (preserve and fished). A mixed-effects model was used to account for any inherent variation between the three dive stations within each site. All metrics used in this study are commonly tested in research settings investigating differences in fish populations. ANOVAs were performed with the 'lme4' package (Bates et al. 2015) and all results were plotted with the 'ggplot2' package (Wickham 2009) in R. Benthic community compositions were converted into percent contributions and compared with a principal coordinate analysis and analysis of similarity (ANOSIM) using PRIMER 6.0 (Anderson et al. 2008).

RESULTS

Overall Results

The similarity of the selected site pairings were confirmed, as benthic profiles did not differ significantly ($p>0.05$) between any paired preserves and fished sites (Supplemental Figs. S1-5 for Achang, Pati, Piti, North and South Tumon, respectively). In total, 11,550 fishes were recorded during the study, representing 71 species from 11 families (Supplemental Table S1). For all site pairings and tests, there were no instances where significantly more biomass or abundance was present outside the preserve compared to inside. Variation in the data between dive stations was uncommon; only three instances occurred: overall biomass for Rios/Cocos, and secondary consumer biomass for Achang and Rios/Cocos. With regards to the number of species recorded in this study, the sampling effort was sufficient to represent the areas sampled (Supplemental Fig. S6). The rarefaction curves plotted show that sampling effort was approaching an asymptotic boundary for all ten sites surveyed. Therefore, it can be suggested that additional strip transect sampling effort would not have resulted in additions of new species.

Overall biomass was significantly greater within the preserve for all sites except Achang (Fig. 2A). Biomass for parrotfishes was greater within the preserve for Pati, Piti, and North Tumon (Fig. 2B). Achang, Piti, and North Tumon had greater biomass of acanthurids (Fig. 2C). Primary consumer biomass was greater within the preserve for all sites but South Tumon (Fig. 3A). No preserve had greater biomass for secondary consumers (Fig. 3B). North Tumon was the only site that saw greater biomass for piscivores (Fig. 3C). Fished species had greater biomass within Achang, Piti and North Tumon, compare to their reference fished sites (Fig. 4A). For target species, North Tumon was the sole preserve that had greater biomass compared to its paired fished site (Fig. 4B). Biomass for high value species was greater within Pati and North and South Tumon (Fig. 4C). The species that composed the most wanted group had greater biomass within all sites except Achang (Fig. 4D).

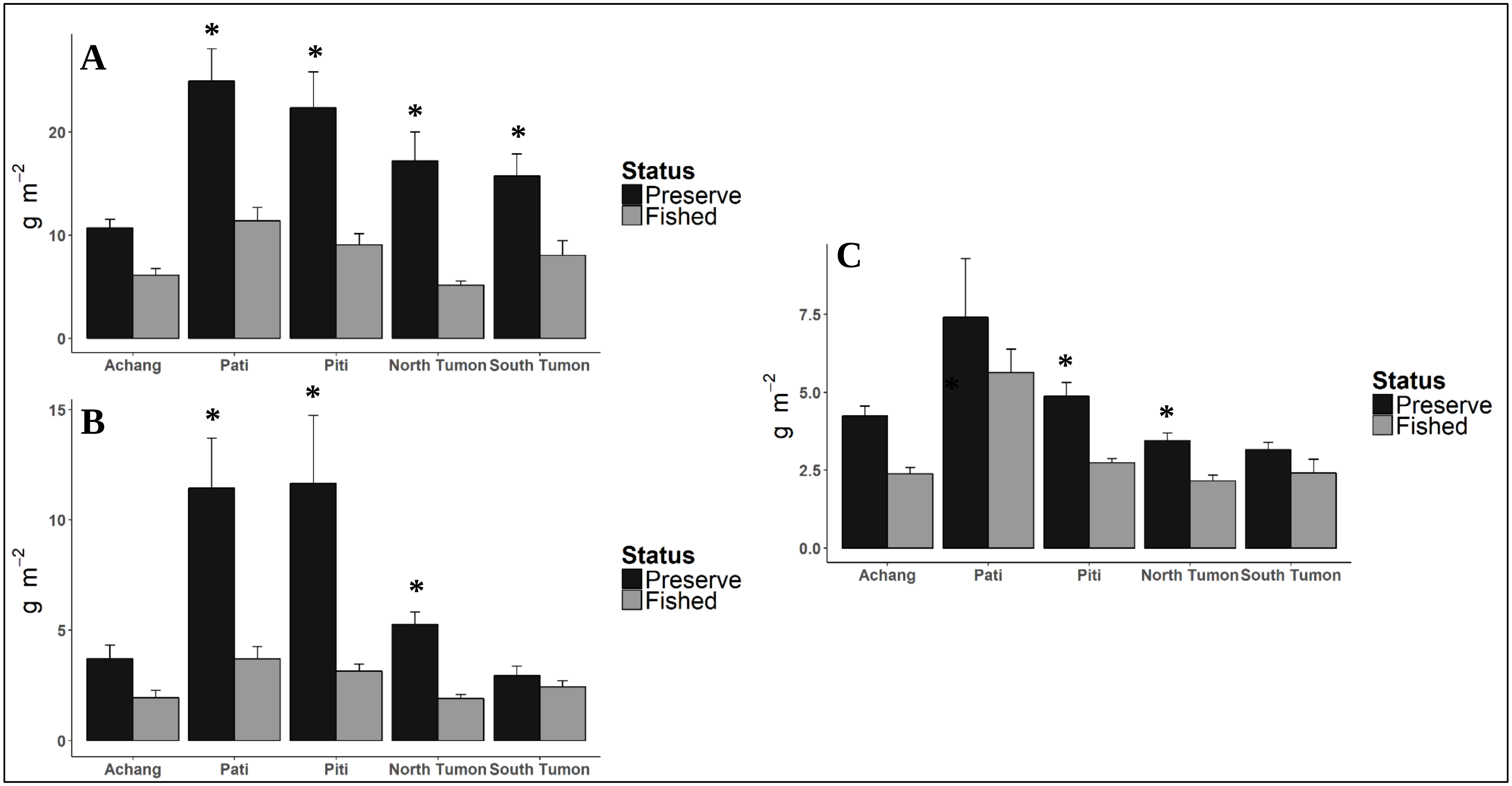

Figure 2: Biomass comparisons of overall (A), parrotfish (B), and acanthurids (C) between marine preserves and fished areas. Test results of $p<0.05$ are noted by *. Note: plots are means and one standard error of untransformed data.

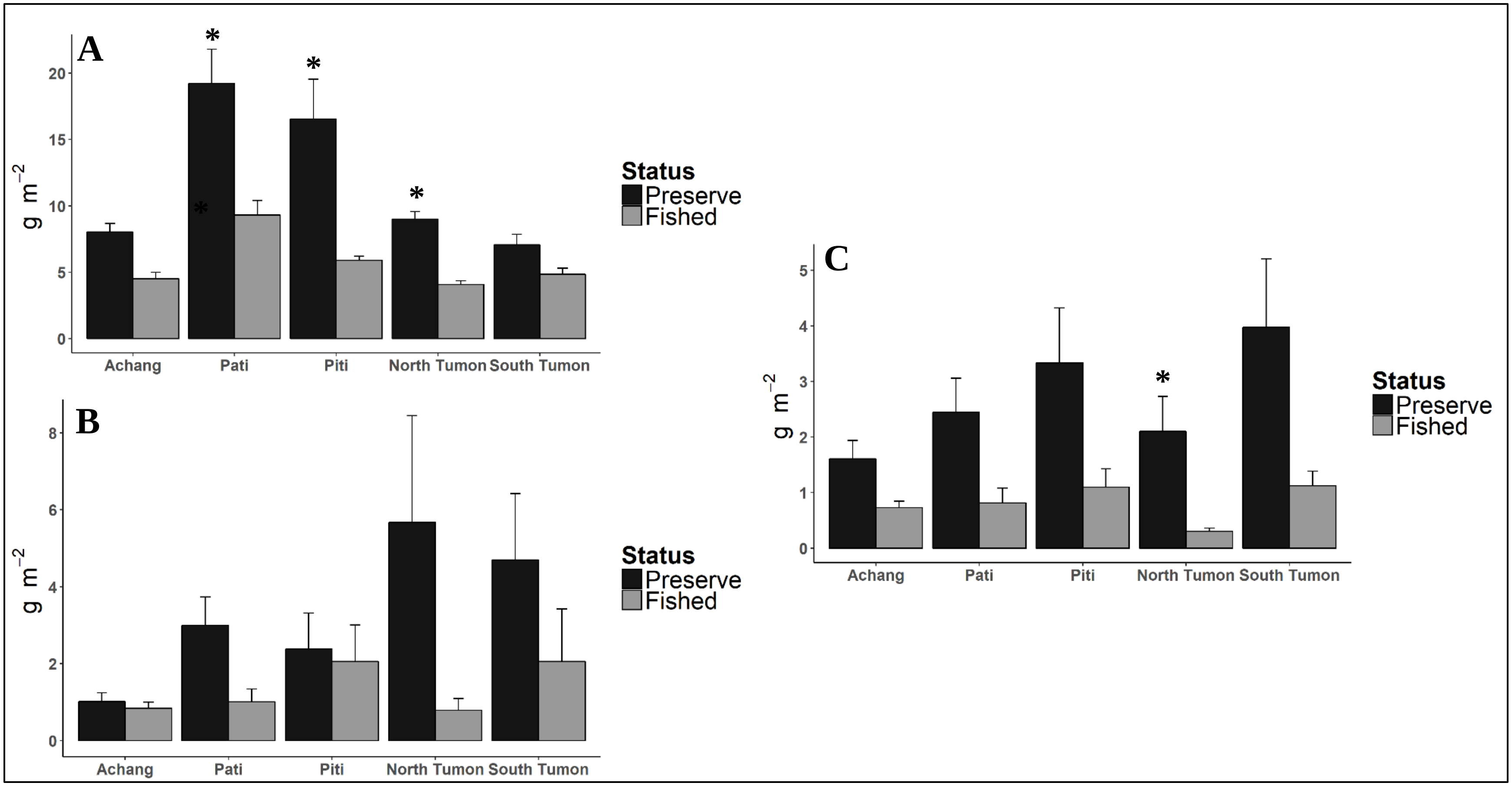

Figure 3: Biomass comparisons of primary consumers (A), secondary consumers (B), and piscivores (C) between marine preserves and fished areas. Test results of p<0.05 are noted by *. Note: plots are means and one standard error of untransformed data.

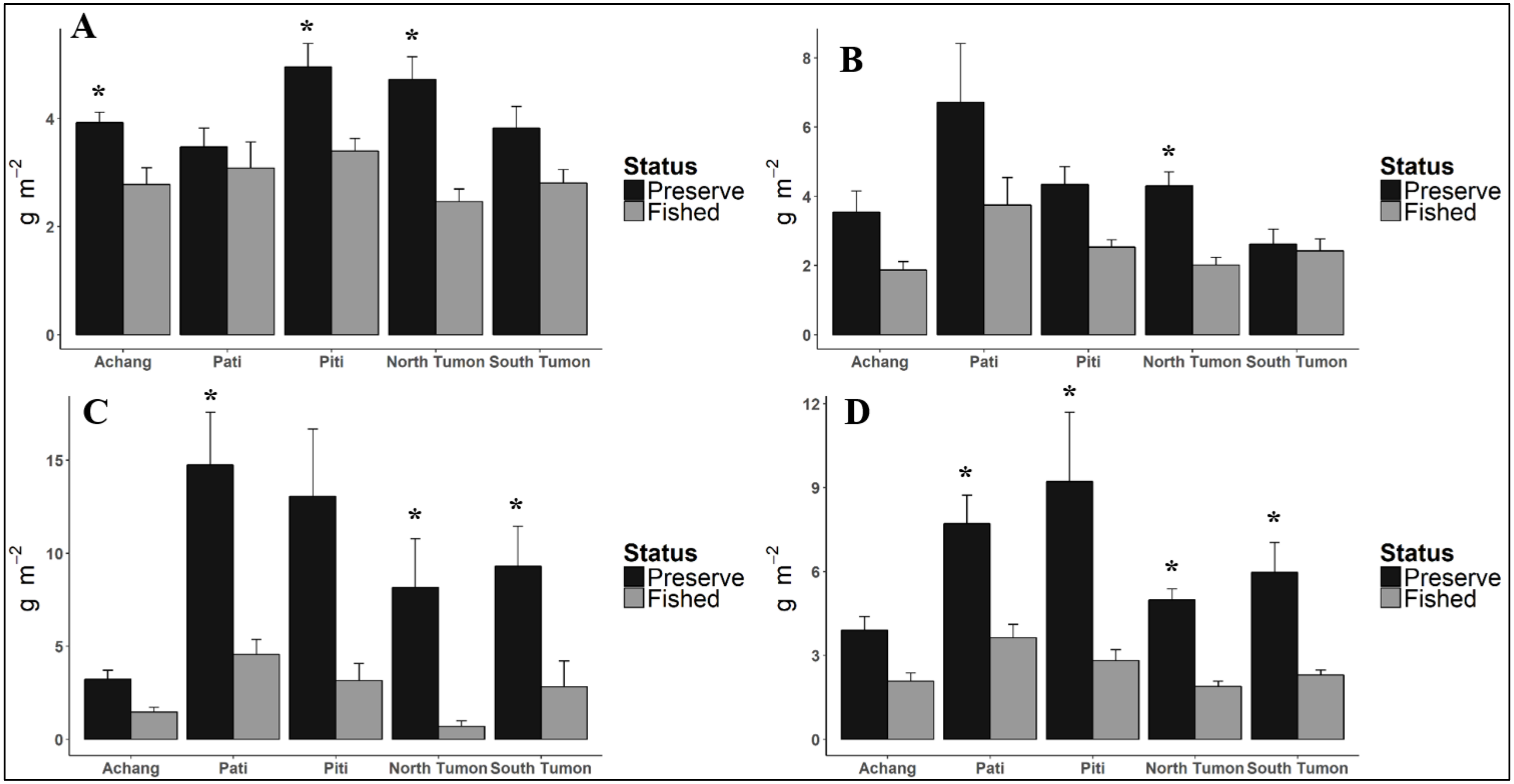

Figure 4: Biomass comparisons of fished (A), target (B), high value (C), and most wanted (D) species between marine preserves and fished areas. Test results of p<0.05 are noted by *. Note: plots are means and one standard error of untransformed data.

Compared to their respective fished sites, overall abundance was significantly greater within the Piti and North Tumon preserves (Fig. 5A). Parrotfish abundance was greater inside the preserve for Pati, Piti, and North Tumon (Fig. 5B). Achang, Piti, and North Tumon had greater abundances of acanthurids (Fig. 5C). Primary consumer abundances were greater within Achang, Piti, and North Tumon (Fig. 6A). There were no difference in abundances of secondary consumers for all sites (Fig. 6B). Piscivore abundances were greater within Pati and North Tumon (Fig. 6C). Abundances of fished species were greater within Piti and North Tumon (Fig. 7A). North Tumon also showed greater numbers of target species, the only site to do so (Fig. 7B). High value species were in greater abundance in both North and South Tumon (Fig. 7C). Additionally, the most wanted species were in greater numbers within Piti and North and South Tumon (Fig. 7D).

Results per Site

Achang

Overall biomass did not differ significantly between the preserve and the fished areas. Furthermore, nearly all tested biomass groups showed similar trends of no difference between the two sites ($p > 0.05$), including all consumer groups, all levels of catch desirability, and parrotfishes (Table 4). The lone group that showed greater biomass within the preserve was acanthurids ($p=0.032$).

Abundances of tested groups showed similar results (Table 4). Only acanthurids ($p=0.03$) and primary consumers ($p=0.035$) were more abundant within the Achang preserve. All other metrics tests showed no differences between Achang and its paired fished site.

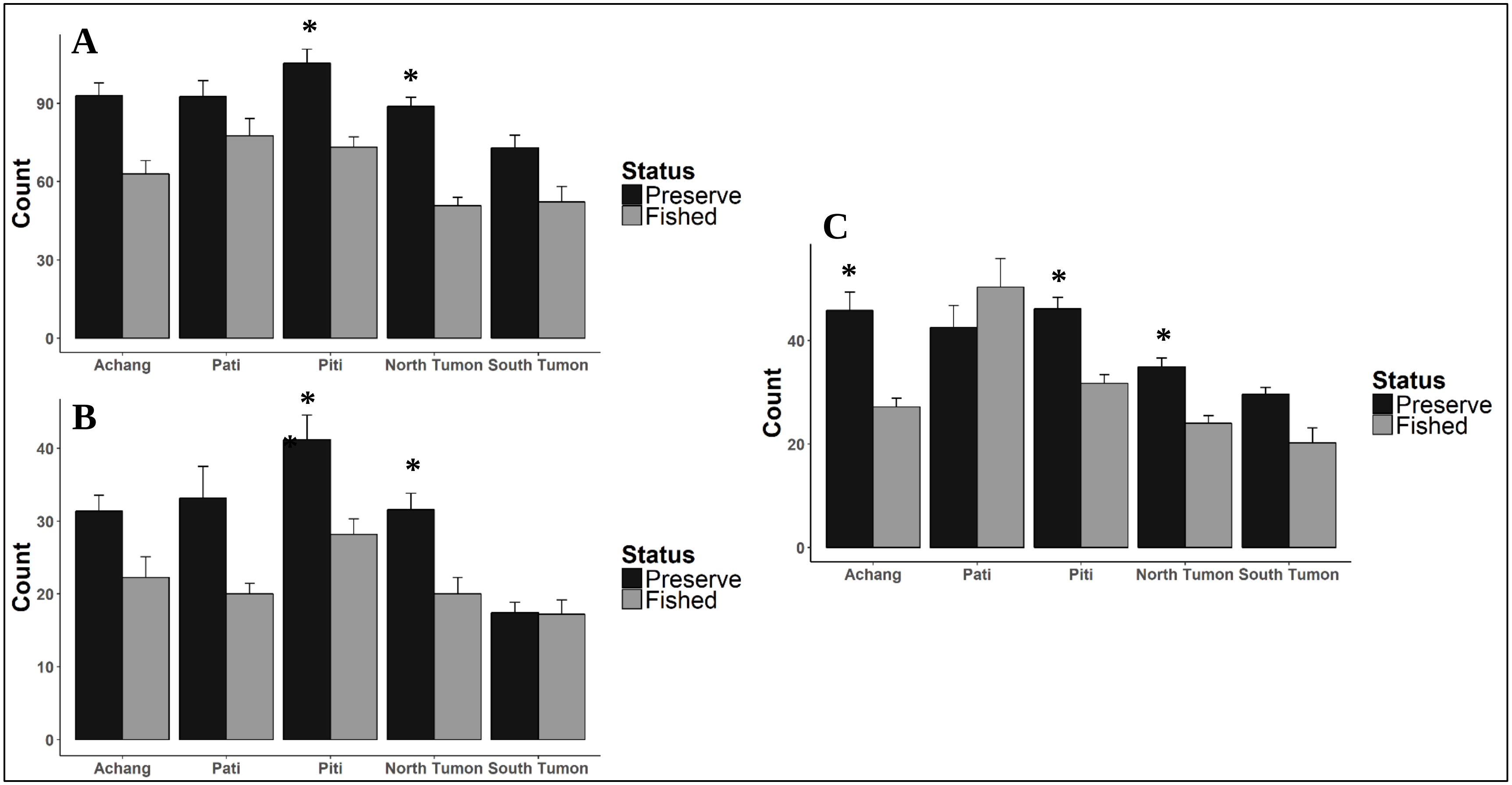

Figure 5: Abundance comparisons of overall (A), parrotfish (B), and acanthurids (C) between marine preserves and fished areas. Test results of $p<0.05$ are noted by *. Note: plots are means and one standard error of untransformed data.

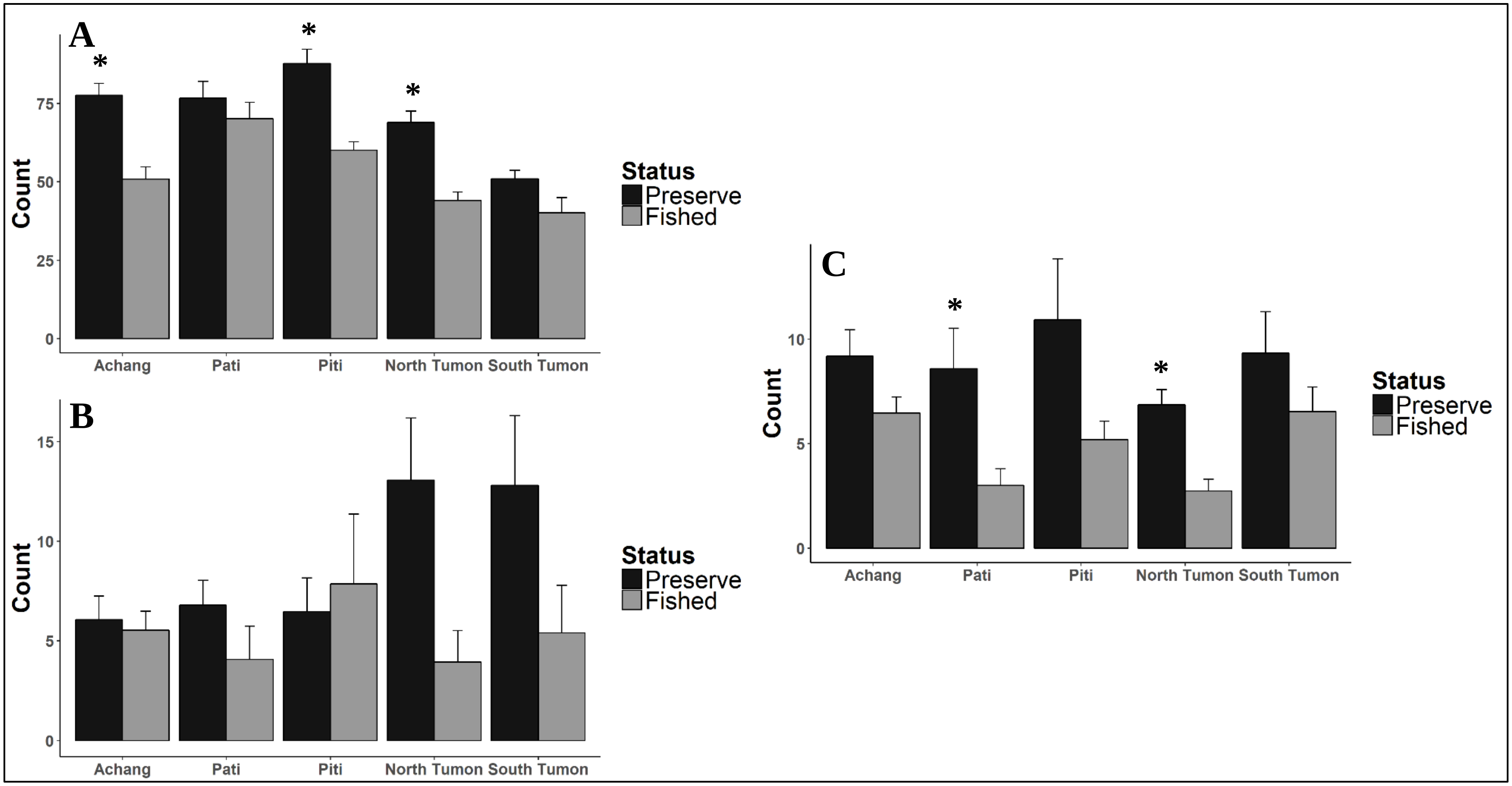

Figure 6: Abundance comparisons of primary consumers (A), secondary consumers (B), and piscivores (C) between marine preserves and fished areas. Test results of $p<0.05$ are noted by *. Note: plots are means and one standard error of untransformed data.

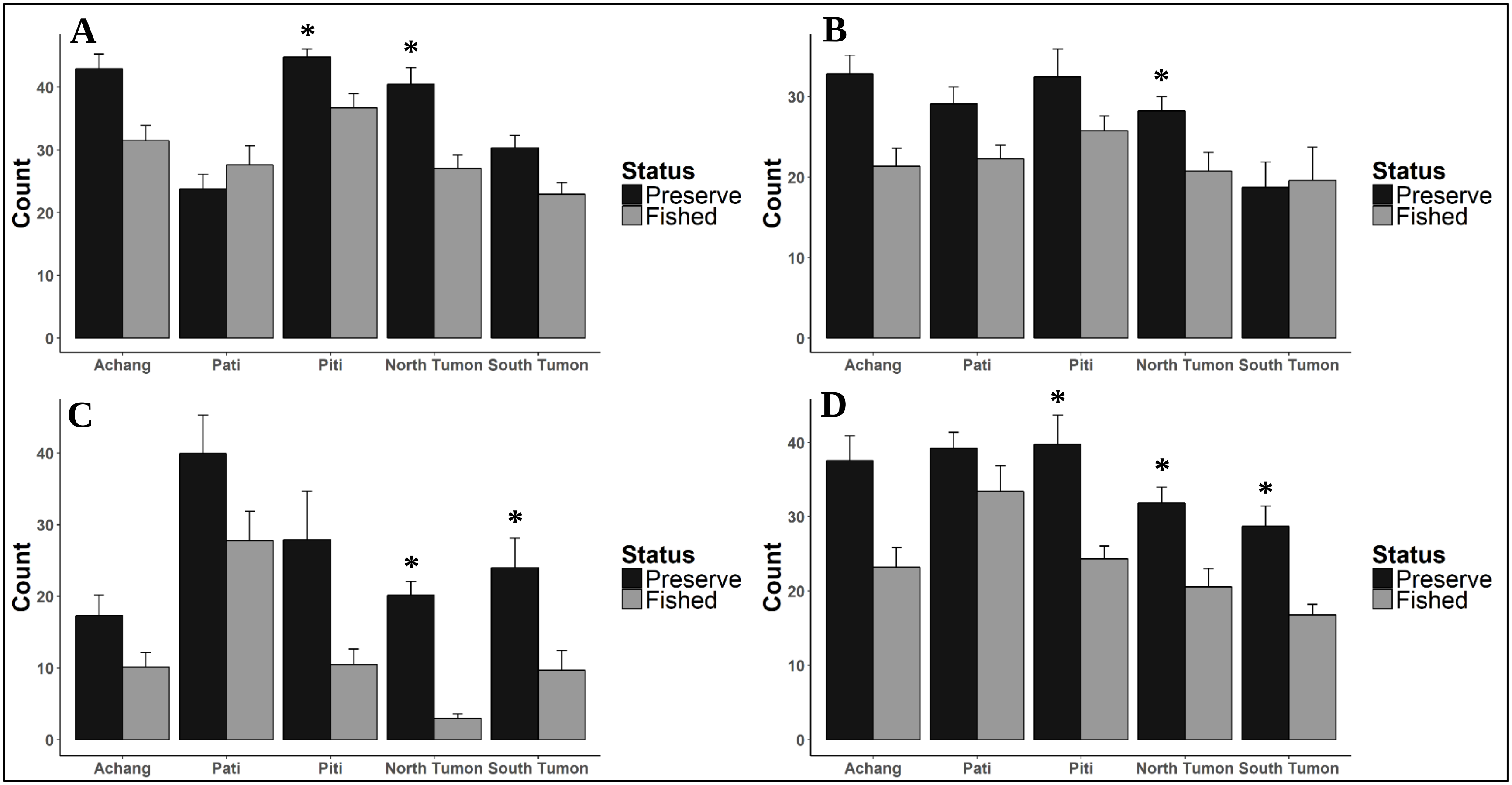

Figure 7: Abundance comparisons of fished (A), target (B), high value (C), and most wanted (D) species between marine preserves and fished areas. Test results of $p<0.05$ are noted by *. Note: plots are means and one standard error of untransformed data.

Table 4: Statistical results from all biomass and abundance tests performed between Achang and its paired fish sites, Rios and Cocos Bays. The theoretical number of transects needed to achieve sufficient statistical power (0.8) is listed for tests that did not achieve sufficient power. The last column is the percent difference between the marine preserve and its paired fish site.

Achang Biomass						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	10.7 (3.2)	6.1 (2.6)	75	0.102	0.997	N/A
Parrotfish	3.7 (2.4)	1.9 (1.3)	91	0.139	0.916	N/A
Acanthurids	4.2 (1.2)	2.4 (0.8)	78	0.032	0.999	N/A
Primary Consumer	8.0 (2.4)	4.5 (1.8)	78	0.083	0.995	N/A
Secondary Consumer	1.0 (0.9)	0.8 (0.6)	21	0.949	0.050	758253
Piscivore	1.6 (1.3)	0.7 (0.4)	120	0.142	0.439	36
Fished	3.9 (0.7)	2.8 (1.2)	41	0.115	0.914	N/A
Target	3.5 (2.4)	1.9 (0.9)	89	0.129	0.916	N/A
High Value	3.2 (1.8)	1.5 (1.0)	121	0.098	0.800	N/A
Most Wanted	3.9 (1.9)	2.1 (1.2)	88	0.115	0.920	N/A

Achang Abundance						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	93.1 (18.6)	62.9 (20.1)	48	0.058	0.989	N/A
Parrotfish	31.4 (8.3)	22.3 (10.9)	41	0.200	0.729	18
Acanthurids	45.8 (13.7)	27.1 (6.5)	69	0.030	0.997	N/A
Primary Consumer	77.6 (14.9)	50.9 (15.2)	53	0.035	0.998	N/A
Secondary Consumer	6.1 (4.6)	5.5 (3.7)	10	0.864	0.064	959
Piscivore	9.2 (4.8)	6.5 (2.9)	42	0.184	0.46	35
Fished	42.9 (9.2)	31.5 (9.3)	36	0.053	0.925	N/A
Target	32.8 (9.0)	21.3 (8.7)	54	0.088	0.942	N/A
High Value	17.3 (11.1)	10.1 (7.8)	71	0.177	0.540	28
Most Wanted	37.5 (12.9)	23.2 (10.2)	62	0.062	0.919	N/A

Pati

Biomass for nearly all groups for which there was sufficient power resulted in significantly positive results (Table 5). Overall biomass was greater in Pati than its comparable fished site (p=0.012). Parrotfish biomass was also greater within the preserve (p=0.009). The preserve also had greater biomass for both primary consumers (p=0.016) and piscivores (p=0.038). Biomass of high value (p=0.012) and most wanted species (p=0.013) were greater within the preserve. Secondary consumers and targeted species showed no difference between the two sites.

Greater abundances were found within the Pati preserve for only parrotfishes (p=0.044) and piscivores (p=0.047). All other tests metrics showed no difference between the two sites (Table 5).

Piti

Piti showed highly significant results consistently across groups (Table 6). Overall, biomass was greater within the preserve (p=0.022), and for both parrotfishes (p=0.009) and acanthurids (p=0.012). However, by consumer group, only primary consumers showed greater biomass within the preserve (p=0.004). Both secondary consumers and piscivores showed no differences. Fished species had greater biomass within the preserve (p=0.041), while target and high value species showed no differences. Most wanted species showed greater biomass within the preserve (p=0.046).

Abundances in Piti showed similar patterns as biomass (Table 6). Overall abundance was greater within the preserve (p=0.009), as were parrotfishes and acanthurids (p=0.031 and p=0.007, respectively). Primary consumers were in greater abundance within the preserve (p=0.006), while secondary consumers and piscivores

Table 5: Statistical results from all biomass and abundance tests performed between Pati and its paired fish site, Ritidian. The theoretical number of transects needed to achieve sufficient statistical power (0.8) is listed for tests that did not achieve sufficient power. The last column is the percent difference between the marine preserve and its paired fish site.

Pati Biomass						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	24.9 (12.1)	11.4 (5.1)	119	0.012	0.999	N/A
Parrotfish	11.4 (8.8)	3.7 (2.1)	209	0.009	0.997	N/A
Acanthurids	7.4 (7.3)	5.6 (2.9)	31	0.679	0.082	N/A
Primary Consumer	19.9 (10.3)	10.3 (4.9)	107	0.016	0.978	N/A
Secondary Consumer	3.0 (2.9)	1.0 (1.3)	198	0.058	0.938	N/A
Piscivore	2.4 (2.3)	0.8 (1.0)	201	0.038	0.871	N/A
Fished	3.5 (1.3)	3.1 (1.8)	13	0.645	0.083	N/A
Target	6.7 (6.5)	3.7 (3.1)	79	0.109	0.398	29
High Value	14.8 (10.9)	4.6 (3.1)	224	0.012	0.991	N/A
Most Wanted	7.7 (3.9)	3.6 (1.8)	112	0.013	0.988	N/A

Pati Abundance						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	92.7 (23.5)	77.7 (25.4)	19	0.167	0.392	42
Parrotfish	33.2 (16.7)	20.0 (5.7)	66	0.044	0.928	N/A
Acanthurids	42.5 (16.3)	50.3 (21.4)	-15	0.403	0.203	94
Primary Consumer	76.8 (20.4)	70.2 (20.2)	9	0.423	0.162	127
Secondary Consumer	6.8 (4.8)	3.9 (6.6)	67	0.112	0.776	16
Piscivore	8.6 (7.4)	3.0 (3.1)	187	0.047	0.982	N/A
Fished	23.7 (9.3)	27.6 (11.9)	-14	0.543	0.167	121
Target	29.1 (8.1)	22.3 (6.6)	31	0.089	0.709	19
High Value	39.9 (20.8)	27.8 (15.8)	44	0.146	0.438	37
Most Wanted	39.2 (8.4)	33.4 (13.5)	17	0.309	0.292	60

Table 6: Statistical results from all biomass and abundance tests performed between Piti and its paired fish site, Breakwater The theoretical number of transects needed to achieve sufficient statistical power (0.8) is listed for tests that did not achieve sufficient power. The last column is the percent difference between the marine preserve and its paired fish site.

Piti Biomass						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	22.3 (13.5)	9.1 (4.2)	146	0.022	0.999	N/A
Parrotfish	11.7 (11.9)	3.1 (1.2)	272	0.009	0.999	N/A
Acanthurids	4.9 (1.7)	2.7 (0.5)	78	0.012	0.999	N/A
Primary Consumer	16.5 (11.7)	5.9 (1.2)	181	0.004	0.999	N/A
Secondary Consumer	2.4 (3.6)	2.1 (3.7)	13	0.939	0.053	4035
Piscivore	3.3 (3.8)	1.1 (1.3)	205	0.063	0.784	16
Fished	5.0 (1.7)	3.4 (0.9)	46	0.041	0.849	N/A
Target	4.3 (2.0)	2.5 (0.9)	72	0.166	0.819	N/A
High Value	13.1 (13.9)	3.4 (3.6)	315	0.148	0.906	N/A
Most Wanted	9.2 (9.6)	2.8 (1.5)	228	0.046	0.954	N/A

Piti Abundance						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	105.5 (20.9)	73.2 (15.4)	44	0.009	0.998	N/A
Parrotfish	41.2 (13.0)	28.2 (8.2)	46	0.031	0.904	N/A
Acanthurids	46.1 (8.6)	31.7 (6.5)	45	0.007	0.999	N/A
Primary Consumer	87.8 (17.7)	60.1 (10.5)	46	0.006	0.999	N/A
Secondary Consumer	6.1 (6.5)	7.9 (13.5)	-18	0.854	0.061	1208
Piscivore	10.9 (11.3)	5.2 (3.4)	110	0.194	0.590	25
Fished	44.8 (4.9)	36.7 (8.7)	22	0.036	0.875	N/A
Target	32.5 (13.3)	25.7 (7.2)	26	0.346	0.407	40
High Value	27.9 (26.1)	10.5 (8.4)	167	0.224	0.787	16
Most Wanted	39.7 (15.2)	24.3 (6.6)	63	0.037	0.950	N/A

showed no differences. Fished species had greater numbers within the preserve (p=0.036). Abundances of target and high value species did not differ between the preserve and fished sites. Most wanted species, however, did have greater numbers within the preserve (p=0.037).

North Tumon

Many groups differed between North Tumon's preserve and the fished site (Table 7). Overall biomass was quite greater within the preserve (p=0.006). Biomass was greater inside the preserve for both parrotfishes (p=0.006) and acanthurids (p=0.037). Both primary consumers and piscivores had greater biomass within the preserve (p=0.002 and p=0.012, respectively). Secondary consumers did not show significant differences between sites.

All three levels of fishing intensity groups showed greater biomass within the preserve (p=0.032, p=0.006, and p=0.009 for fished, target, and high value, respectively). Most wanted species also had greater biomass within the preserve (p=0.002).

Similar significant differences between the paired sites were observed for patterns of abundance (Table 7). Overall abundance was greater within North Tumon (p=0.003). Abundances were greater for both parrotfishes (p=0.039) and acanthurids (p=0.033). Both primary consumers and piscivores had greater numbers within the preserve (p=0.045 and p=0.011, respectively). Secondary consumers did not show differences in numbers between the two paired sites. As was the case with biomass, abundances of all fishing intensity levels were greater within the preserve (p=0.036, p=0.044, and p=0.001 for fished, target, and high value, respectively). Most wanted species also had greater numbers inside the preserve (p=0.018).

Table 7: Statistical results from all biomass and abundance tests performed between North Tumon and its paired fish site, Tanguisson. The theoretical number of transects needed to achieve sufficient statistical power (0.8) is listed for tests that did not achieve sufficient power. The last column is the percent difference between the marine preserve and its paired fish site.

North Tumon Biomass						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	17.2 (10.9)	5.2 (1.5)	233	0.006	1	N/A
Parrotfish	5.3 (2.2)	1.2 (1.9)	177	0.006	1	N/A
Acanthurids	3.5 (0.9)	1.2 (0.7)	60	0.037	0.996	N/A
Primary Consumer	8.9 (2.2)	4.8 (2.1)	121	0.002	1	N/A
Secondary Consumer	5.7 (10.7)	0.8 (1.2)	623	0.138	0.832	N/A
Piscivore	2.5 (2.6)	0.3 (0.2)	588	0.012	0.963	N/A
Fished	4.7 (1.6)	2.6 (0.9)	92	0.032	0.998	N/A
Target	4.3 (1.6)	2.0 (0.9)	114	0.006	0.999	N/A
High Value	6.2 (10.1)	0.7 (1.2)	1092	0.009	0.995	N/A
Most Wanted	5.0 (1.5)	1.9 (0.8)	165	0.002	1	N/A

North Tumon Abundance						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	88.9 (13.6)	50.7 (12.8)	75	0.003	1	N/A
Parrotfish	31.6 (8.8)	20.0 (8.8)	58	0.039	0.984	N/A
Acanthurids	34.9 (6.6)	24.0 (5.7)	46	0.033	0.989	N/A
Primary Consumer	68.9 (14.3)	44.1 (10.6)	56	0.045	0.999	N/A
Secondary Consumer	13.1 (12.1)	3.9 (6.2)	232	0.121	0.8	N/A
Piscivore	6.9 (2.8)	2.7 (2.2)	151	0.011	0.995	N/A
Fished	40.5 (10.4)	27.1 (8.1)	50	0.036	0.975	N/A
Target	28.2 (6.9)	20.7 (9.1)	36	0.044	0.828	N/A
High Value	20.2 (7.3)	2.9 (2.4)	589	0.001	1	N/A
Most Wanted	31.9 (8.1)	20.5 (9.6)	55	0.018	0.980	N/A

South Tumon

Many groups showed no difference in biomass between South Tumon and its paired fish site (Table 8). Overall biomass was greater within the preserve (p=0.026). Both parrotfish and acanthurids showed no difference in biomass, as did all consumer groups. Biomass for fished species did not differ between the preserve and fished sites. Target species did not show any biomass difference. Biomass for high value species was greater values within the preserve (p=0.021), as was most wanted species (p=0.015).

South Tumon showed similar results for abundance (Table 8). Overall abundance was not different between the two sites. Both parrotfish and acanthurids showed no difference in numbers between the preserve and fished site, as did all three consumer groups. Both fished and target species groups showed no difference in abundance. However, more sought after species showed positive results for the preserve. High value species showed greater numbers within South Tumon's preserve (p=0.022). Abundances of most wanted species were also greater within the preserve (p=0.012).

Table 8: Statistical results from all biomass and abundance tests performed between South Tumon and its paired fish site, East Agana Bay. The theoretical number of transects needed to achieve sufficient statistical power (0.8) is listed for tests that did not achieve sufficient power. The last column is the percent difference between the marine preserve and its paired fish site.

South Tumon Biomass						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	15.7 (8.3)	8.0 (5.5)	96	0.026	0.971	N/A
Parrotfish	2.9 (1.7)	1.1 (2.4)	21	0.404	0.124	136
Acanthurids	3.2 (0.9)	2.4 (1.7)	31	0.192	0.689	20
Primary Consumer	6.6 (3.0)	5.2 (1.9)	46	0.107	0.773	17
Secondary Consumer	4.7 (6.7)	2.1 (5.3)	129	0.489	0.701	16
Piscivore	4.0 (4.8)	1.1 (1.0)	254	0.231	0.545	28
Fished	3.8 (1.6)	2.8 (1.0)	36	0.151	0.948	N/A
Target	2.6 (1.7)	2.4 (1.4)	8	0.873	0.059	1451
High Value	9.3 (8.3)	2.8 (5.4)	230	0.021	0.961	N/A
Most Wanted	6.0 (4.2)	2.3 (0.7)	160	0.015	0.995	N/A

South Tumon Abundance						
Metric	**MPA Value (SD)**	**Non-MPA Value (SD)**	**Percent Difference**	**p Value**	**Power**	**n for 0.8 Power**
Overall	73.1 (18.6)	52.2 (23.3)	F	0.057	0.774	17
Parrotfish	17.5 (5.4)	17.2 (7.6)	2	0.943	0.051	9528
Acanthurids	29.6 (5.2)	20.2 (11.3)	47	0.156	0.836	N/A
Primary Consumer	50.9 (10.4)	40.1 (18.8)	27	0.078	0.767	17
Secondary Consumer	12.8 (13.6)	5.4 (9.2)	137	0.059	0.774	18
Piscivore	9.3 (7.7)	6.5 (4.6)	43	0.538	0.15	141
Fished	30.3 (7.7)	22.9 (7.0)	32	0.177	0.786	16
Target	18.7 (12.2)	19.6 (15.9)	-4	0.996	0.05	4954463
High Value	24.0 (15.9)	9.7 (10.8)	148	0.022	0.956	N/A
Most Wanted	28.7 (10.4)	16.8 (5.5)	71	0.012	0.993	N/A

Species Richness

Both North and South Tumon showed greater food fish species richness within the preserve compared to their respective fished sites [(p=0.01 and p=0.05, respectively) Fig. 8]. No other preserve showed a significant difference. The most species observed during a single transect was 19, occurring at both Achang and Pati. The least number counted was 13, which occurred at both East Agana and Tanguisson.

Size Class Distributions

All preserves had significant differences ($p < 0.001$) in size class distributions compared to their respective fished sites, with the exception of Achang (Fig. 9). These differences indicate that there are a greater number of larger individuals inside the preserve. Pati, Piti, and North Tumon had clear differences for all tested groups (Table 9). Tested groups for South Tumon showed varying significance. Results for parrotfish, primary consumers, and fished species indicate no differences in size class distributions between preserve and fished sites.

These results show positive differences in size classes between most preserves and nearby fished sites. For Pati, Piti, and North Tumon, this finding holds true for all food fish groups tested in this study (Table 9 and Supplementary Figs. S7-10). Therefore, across all consumer groups and fishermen desirability, larger individuals were present within the preserves' boundaries.

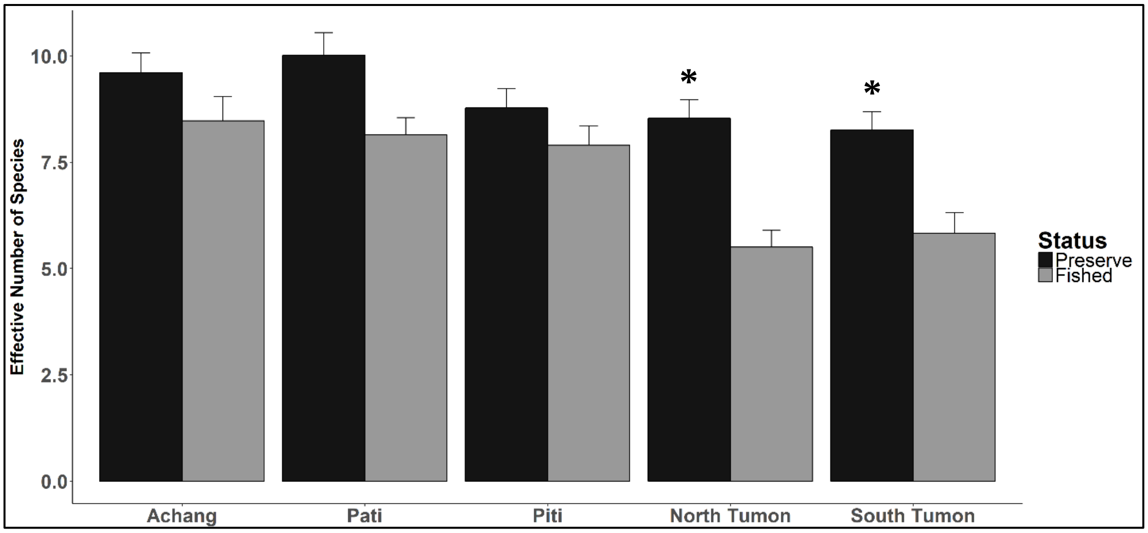

Figure 8: Comparisons of species richness between marine preserves and fished sites. Test results of p<0.05 are noted by *.

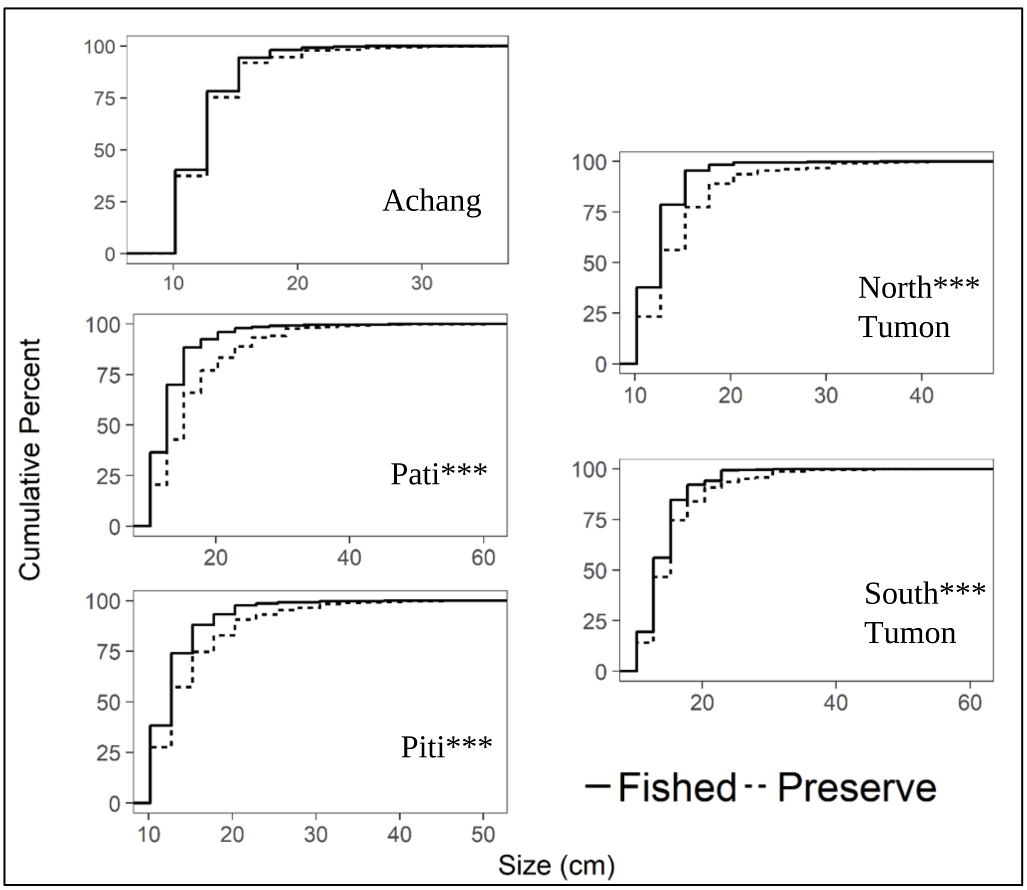

Figure 9: Size-class distributions for all fishes between marine preserves and paired fished sites. Significance is defined as: *p < 0.05, **p < 0.01, ***p < 0.001 via K-S tests.

Table 9: Size class distribution results for all groups for marine preserves that showed overall significance, including K-S statistic, *D*, and p-values. Note: plotted results can be found in supplement material (Figs. S1, S2, S3, S4 for Pati, Piti, North Tumon, and South Tumon, respectively).

Pati K-S Results					
Metric	**D**	**p-Value**	**Metric**	**D**	**p-Value**
Overall	0.2719	$p < 0.001$	Fished	0.1554	$p < 0.001$
Parrotfish	0.2787	$p < 0.001$	Target	0.1864	$p < 0.001$
Primary Consumer	0.2511	$p < 0.001$	High Value	0.3831	$p < 0.001$
Secondary Consumer	0.2528	$p < 0.01$	Most Wanted	0.2399	$p < 0.001$
Piscivore	0.2759	$p < 0.05$			

Piti K-S Results					
Metric	**D**	**p-Value**	**Metric**	**D**	**p-Value**
Overall	0.1664	$p < 0.001$	Fished	0.1245	$p < 0.001$
Parrotfish	0.2874	$p < 0.001$	Target	0.1577	$p < 0.001$
Primary Consumer	0.1889	$p < 0.001$	High Value	0.1757	$p < 0.01$
Secondary Consumer	0.1942	$p < 0.05$	Most Wanted	0.1550	$p < 0.001$
Piscivore	0.2412	$p < 0.01$			

North Tumon K-S Results					
Metric	**D**	**p-Value**	**Metric**	**D**	**p-Value**
Overall	0.2244	$p < 0.001$	Fished	0.1109	$p < 0.01$
Parrotfish	0.2199	$p < 0.001$	Target	0.2151	$p < 0.001$
Primary Consumer	0.1490	$p < 0.001$	High Value	0.2975	$p < 0.01$
Secondary Consumer	0.4750	$p < 0.001$	Most Wanted	0.2399	$p < 0.001$
Piscivore	0.5043	$p < 0.001$			

South Tumon K-S Results					
Metric	**D**	**p-Value**	**Metric**	**D**	**p-Value**
Overall	0.1003	$p < 0.001$	Fished	0.0627	$p = 0.4$
Parrotfish	0.0668	$p = 0.6$	Target	0.2045	$p < 0.001$
Primary Consumer	0.0507	$p = 0.35$	High Value	0.1570	$p < 0.05$
Secondary Consumer	0.2256	$p < 0.01$	Most Wanted	0.1295	$p < 0.01$
Piscivore	0.4540	$p < 0.001$			

The difference in size class distributions between South Tumon and the paired sites was found in only certain groups (Supplmentary Fig. S9). Piscivores and target species showed strong significance, while high value and most wanted species were to a lesser degree.

DISCUSSION

The results of this study indicate that a majority of Guam's marine preserves appear to have larger and more abundant populations of fish species that are targeted by Guam's fishery than reefs that are fished. Overall, biomass within the marine preserves was more than double that of the fished sites. Abundance was also greater within the preserves by an average of 45%. North Tumon showed the greatest difference of all preserves, with significantly greater biomass and abundance in nearly every group (Table 7). Biomass within North Tumon was more than triple that of its paired fish site. In fact, nearly all groups showed double the biomass within North Tumon's boundaries. Furthermore, high value species had 1092% more biomass inside North Tumon, by far the greatest difference of any group tested in this study. Abundance for high value species within North Tumon were also significantly greater, showing over six-times more individuals than the paired fish site. Piti also showed positive results, with six out of ten groups having high numbers within the preserve for both biomass and abundance (Table 6). Piti showed triple the amount of parrotfish biomass compared to its fished site, which was the greatest difference of parrotfish biomass, compared to all other site pairings. Biomass of high value and most wanted species was four and three times greater, respectively, inside Piti's boundaries. These findings are due to the high number of large, adult *Chlorurus microrhinos* and *S. rubroviolaceus* individuals encountered inside Piti.

Abundance results were not as pronounced. Pati mirrored the biomass results of Piti, with six groups having higher biomass within the preserve. High value and most wanted species showed triple and double the biomass observed in Pati's fished site. For abundance, however, numbers were greater within the preserve for only parrotfishes and piscivores. Overall, Pati only showed 19% more abundance. This suggests that the fish present within Pati's boundaries were larger than those in the fished site.

South Tumon and Achang exhibited results that are not consistent with a properly working preserve. Both showed little difference in food fish biomass and abundance when compared to their respective fished sites. In South Tumon, few groups showed greater abundance and biomass (three for biomass, and two for abundance). However, two groups that did show greater abundance within South Tumon were high value and most wanted species; ones that typically have the highest fishing desirability (e.g. *C. melampygus*, *Kyphosus cinerascens*, *L. harak*). For Achang, only acanthurid biomass was significantly greater within the preserve, 78% more than its fished site. Biomass for high value species within Achang was more than double that outside the preserve's boundaries. High variability, however, precluded significant differences. Abundances for acanthurids and primary consumers were greater within Achang.

Comparing results to other MPAs

Meta-data studies have examined large numbers of MPAs around the world in an attempt to discover trends in ecological benefits (Halpern & Warner 2002, Halpern 2003, Micheli et al. 2004, Claudet et al. 2008). Many of these studies showed that the time needed for MPAs to show benefits to the local fish populations, such as increased biomass, abundance, and diversity, varies greatly. Halpern & Warner (2002) noted increased biomass and abundance in MPAs that had been established only six months prior to surveying. Micheli et al. (2004) suggested that, for some groups, decades may pass before positive trends are observed. One theme common amongst the studies was that the protection offered by the MPAs appeared to assist targeted species quickly. Results from this study suggest this is occurring on Guam. The species composing the most wanted group are ones that experience the most fishing pressure. The five preserves had, on average, 153% more biomass and 45% greater abundance. Additionally, biomass and abundance were greater within four and three preserves, respectively, for the most wanted species. Positive effects may take longer for higher trophic level species. Micheli et al. (2004) showed studies that suggested benefits for piscivores may take decades. Piscivore biomass and abundance was 274% and 107%, respectively, greater inside the preserves. However, only Pati and North Tumon showed significantly greater biomass and abundance compared to their fished sites. Guam's marine preserves had been protected for roughly sixteen years. Therefore, increases in piscivore biomass and abundance should begin to be observed in the near future, if protection remains intact or is strengthened. Size is also considered to be an important factor in impacting fish populations. Halpern (2003) analyzed 69 MPAs for their quantitative benefits. Over half of these MPAs were smaller than 10 km^2. Guam's marine preserves surveyed in this study average 6.6 km^2 in size. The 69 MPAs had, on average, 192% more biomass than their reference sites, more than the 134% observed in this study. Abundance was also greater in Halpern's study, 91%, compared to this study, 45%. The study showed that larger MPAs did produce more benefits. This study's findings, however, did not show disproportionately greater benefits occurring in Pati, by far the largest preserve on Guam.

Edgar et al. (2014) ranked 87 MPAs based on their ecological benefits to local fish populations. The four top-tier MPAs were: Cocos Island, Costa Rica; Malpelo, Colombia; Kermadec Islands, New Zealand; and Middleton Reef, Australia. Compared to fish sites, total fish biomass, total large fish biomass, and shark biomass were 244%, 840%, and 1990% greater inside the MPAs. These MPAs were noted for being naturally isolated from human development, which researchers suggested may strongly influence observed benefits. Bonaldo et al. (2017) paired three MPAs in Fiji that were near fished sites. The MPAs sites were surveyed approximately a decade after being established. Results showed, on average, 230% greater abundance of primary consumers in the MPAs compared to the nearby fished sites. The difference in primary consumer abundance is much more pronounced than what was found in this study, a difference of only 38%. Total biomass was 210% greater inside the Fijian MPAs. It should be noted that Bonaldo et al. (2017) surveyed all fishes, target and non-target species. However, MPAs typically do not result in significant increases of non-target species (Micheli et al. 2004). Therefore, much of the 210% difference in biomass between the MPAs and fished sites observed could be considered target species. This finding also exceeds the biomass differences observed in this study, an average of 134% on Guam. These comparisons suggest the three Fijian MPAs are providing greater ecological benefits than Guam's marine preserves. Fiji's human presence, however, is quite different from Guam's. Fiji has a population density of only approximately 49 persons per km^2, much lower than the approximately 350 person per km^2 on Guam. A study done by Fidler et al. (2017) examined survey results of 39 pairings of MPAs and fished sites in the Visayas region of the Philippines. The surveyed MPAs were all smaller than 1.5 km^2 and established between 1997 and 2009. The population density of the Visayas region is comparable to Guam's. The MPAs were surveyed, on average, five years after they were established. Abundance of target species were 43% greater within the MPAs compared to the fished sites, similar to the 45% in this study. Size class results from the study showed no difference between MPAs and fished sites for target species and all consumer groups. This varies greatly from the size class results of this study, which showed significant differences in four preserves (Fig. 9). Therefore, it can be suggested that Guam's preserves would exhibit greater biomass when compared to the MPAs in the Philippines, when both are compared to their reference fished sites. Guam's preserves appear to be showing more benefits to local fish populations when compared to MPAs of approximately the same age and population density. Jennings et al. (1996) surveyed four MPAs in the Seychelles. One MPA, Baie Ternay, showed so little ecological benefits for local fish populations, the researchers declared it a "protected area in name only." A near absence of enforcement and heavy poaching were considered the main contributors to the poor performance of the MPA. Overall, these studies shed light on the difficulty of comparing fishery benefits between two MPAs. Many factors come into play when discussing effectiveness of an MPA, and it can be difficult to account for all of them when comparing two different locations.

The Williams et al. (2012) study is the most comprehensive reef fish analysis performed on Guam to date. As mentioned before, their survey included non-food fish species. When examining only target species encountered at depths ranging from 8-12 m (comparable to this study) Guam's preserves had 1.6-times more biomass compared to non-protected sites, less than the 2.2-times difference found in this study. Another results discrepancy between the Williams study and this one is in regards to individual sites. The most biomass observed in the Williams study was surveyed in Achang. This study saw low biomass for all sites within Achang.

Gauging Marine Preserves Performance

It is important to put these results into perspective when discussing each preserve's individual performance. For example, out of the ten groups tested for biomass and abundance, Pati failed to show greater numbers than its reference site in four and eight, respectively (Table 5). Acanthurids and secondary consumers, as well as fished and target species, were not larger inside Pati's boundary compared to outside. Overall abundance did not differ amongst the two sites. By considering these results in isolation, one would derive that the Pati MP is not working well for these fish groups. However, Ritidian, Pati's paired fished site, is a difficult area to access and noted for strong currents and heavy wave action. Ritidian's waters border US military-owned property, limiting land-based access. By boat, the nearest entry ramp is over 27 km away. Therefore, Ritidian may experience less fishing pressure than other paired fished sites in this study. For all fished sites, average abundances of most fish groups were typically greatest for Ritidian (see Fig. 7C and 7D). When that is considered, it is understandable why Pati appeared to be less effective as a marine preserve.

The opposite may be occurring between North Tumon and its paired fish site, Tanguisson. North Tumon showed greater biomass and abundance in all but one group. Using the same litmus test that suggested Pati was performing poorly, North Tumon would be considered a well-working preserve. However, Tanguisson may experience the highest fishing pressure of all sites surveyed in this study (Taylor et al. 2014). It is easily accessible, and its position on the leeward side of the island allows for good water conditions for much of the year. Therefore, it is uncommon to see Tanguisson devoid of fishermen at any time of day. Tanguisson showed lower levels, on average, of abundance on several fish groups compared to other fished sites (see Figs. 6 and 7C). Tanguisson's heavy fishing intensity should be considered when it is compared to North Tumon's preserve. North Tumon's success may be inflated by Tanguisson's heavy fishing pressure.

Evaluation of the use of transects in UVC

The decision to collect fish data using strip transects, rather than SPCs, was made because of the fish species of interest in this study. Fishes that are targeted by fishers may become wary of divers, regardless of the diver's activity (Kulbicki 1998). This negative reaction may be greater in areas that are regularly fished (Gotanda et al. 2009). Studies have shown that large, mobile species, typically targeted by fishers, may remain out of SPC boundaries, which results in an underrepresentation during censusing (Colvocoresses & Acosta 2007). Local researchers on Guam have anecdotally suggested similar behaviors. The methods employed in this study aimed to prevent underrepresentation by prioritizing which species to count first. By looking ahead along the transect researchers attempted to count species before they swam beyond the transect boundaries. However, it should be noted that there are downsides to employing strip transects. By covering a large amount of area, strip transects may result in low precision and high variance between repeated surveys (Samoilys & Carlos 2000).

The data collected, however, demonstrated that large fish species were still uncommon and rarely encountered at most survey sites, both preserve and fished. The largest fishes encountered were only 61 cm. Most of the individuals seen at this length were sub-adult *C. undulatus*, which typically exceed 1 m in length at maturity (Sadovy et al. 2003). Furthermore, these individuals were easily determined to be juveniles from their color patterns. Additionally, no sharks were recorded in this study (one 2 m *Carcharhinus melanopterus* was encountered during a benthic survey at Tangussion). The absence of shark encounters support claims of Guam's preserves failing to aid in the recovery depauperate shark populations. Martin et al. (2016) suggested the decline of sharks on Guam is primarily due to overfishing and increasing human impact, among other reasons. Unfortunately, it is not possible to confidently discern whether these infrequent encounters with large fishes were due to observer presence or to low abundance of large fishes within the study area. However, a recent study in Hawaii by Gray et al. (2016) suggests that the presence of divers using open-circuit scuba equipment appears to reduce encounters with some targeted fish groups (e.g., surgeonfishes, targeted wrasses, and snappers) and not others (e.g., parrotfishes, groupers, and goatfishes). In addition, this effect was not observed in moderately to lightly fished areas, and appears to be limited to only heavily fished sites. The results suggest that in areas that are visited by fishers on an infrequent basis, such as remote areas or effectively managed preserve areas, one would not expect reef fish to actively avoid divers. Thus, the lack of large individuals across most areas visited in this study suggests that taxa that achieve large body sizes may not be effectively protected by the preserves as managed in their current form.

One site that was a clear exception to not encountering large individuals was Piti. Large parrotfishes (typically >30 cm) appeared unconcerned with the researchers' presence, swimming at times within a meter of the divers. This behavior was first encountered at the site closest to the Fish Eye underwater observatory where fish feeding occurs. Thus, results from this site were initially thought to be influenced by the fish feeding. However, similar encounters with large individuals were experienced throughout the preserve, at distances exceeding 1.5 km from the fish feeding. These encounters are of particular interest when compared to personal observations of the conservation officers. The officers report that Asan Point, which divides the Piti preserve from Asan Bay (commonly known as Camel Rock) is a popular entrance point for poachers to access Piti's waters. Conservations officers report recent increased poaching activity in Piti. With this reported increase in fishing activity occurring in the preserve, it is interesting that large fishes are showing no avoidance behavior. This absence of avoidance behavior may make these large parrotfishes easier prey for poachers. This can have damaging effects to the local population with increased poaching in the preserve.

Some groups, however, were not encountered often enough to reach the desired 0.8 power benchmark to perform statistical tests, which may be due to the UVC technique. Secondary consumers were not well-represented in many sites due to low encounter rates. In fact, the theoretical sample size of strip transects needed to achieve 0.8 power to test secondary consumers biomass at some sites were so high that it was impossible to complete that amount of fieldwork. For example, 758,253 transects would have been necessary to test secondary consumer biomass differences between Achang and its paired fished sites (Table 4). Species that made up secondary consumers varied greatly in size, and therefore biomass, which resulted in a high standard deviation. The high standard deviation had a domino effect, resulting in a small effect size (Cohen's *d*), and thus low statistical power. Based on these results, two recommendations are suggested to investigate secondary consumers. For biomass, the group should be split into several sub-groups, based upon ecological size, such as large- and small-bodied secondary consumers. This would eliminate the large difference seen between typical sizes of species collectively grouped. When investigating abundances of secondary consumers, this study's results suggest strip transects performed well for three of the five pairings. While Pati and South Tumon did not reach sufficient power with the performed sampling effort, it is theorized that 0.8 power would have been achieved with another sampling day. Unfortunately, logistical constraints prevented further sampling. Strip transects, however, did not perform well in Achang and Piti. Therefore, to sample secondary consumer abundances in the future, a pilot study collecting preliminary data using several UVC techniques may be beneficial to researchers in determining the correct sampling technique to employ.

Implications for Management

While this study does not aim to identify what is responsible for low performance of a preserve, poaching is certainly a candidate that may help explain the underperformance of Achang. Data from Achang show biomass and abundance numbers of many fish groups to be lower than the other preserves around the island. Size class data showed no difference between Achang and its paired fished sites. These data indicate illegal fishing may be occurring. Fishers typically target larger individuals, known as size-selective fishing (Birkeland & Dayton 2005, Conover et al. 2009). This fishing practice can lead to reductions in body size of target species (Bianchi et al. 2000, Olsen et al. 2004). Poaching could explain the size class results; the illegal fishing is selectively removing large individuals. Therefore, size class data for Achang closely resemble data from nearby fished waters. Protection of larger fishes can result in increased sustainability. Larger individuals typically have greater fecundity and spawning success (Bobko & Berkeley 2004, Birkland & Dayton 2005). Furthermore, Berkeley et al. (2004) showed that larger females of a species can produce larvae that grow faster and survive starvation longer than smaller females, increasing the success of the next generation.

Anecdotal observations from local fishermen who live near Achang confirm frequent poaching. Boats fishing inside the preserve's boundaries have been reported to have their reflective indicators removed by local conservation officers. This, coupled with the keeping all lighting turned off, makes spotting them at night difficult. Furthermore, these boats hide behind rock formations that can be found throughout the preserve near the reef break. These rocks, coupled with the dense tree line that dominates much of the preserve's shoreline, makes detection difficult. As mentioned before, conservation officers describe logistical constraints with the enforcement of the Achang preserve. When the environmental difficulties are considered with the logistical hurdles, it is plausible to assume that poaching may be occurring in Achang, and is being underreported.

A report by Starmer et al. (2008) examined how management differences can affect marine protected areas in Saipan and Rota, two islands that are part of the Commonwealth of the Northern Mariana Islands. Saipan and Rota established MPAs in 2000 and 1994, respectively. A lack of funding for effective MPA enforcement was an issue for both islands. In 2002, funding was provided to Saipan for additional staff and equipment. In addition to increased enforcement, the funding supported education efforts in the forms of ads, brochures, school presentations, and fishermen's forums. Research shows positive increases of fish populations, including species important to Saipan's local fishery. Researchers suggested this positive trend was due to an increase in management and enforcement of Saipan's MPAs. In Rota, however, supplemental funding was never provided. The positive trends seen in Saipan's MPA have not been observed in Rota's MPA. While it is difficult to ascertain all factors playing a role in the difference between the two MPAs, researchers suggest varying levels of enforcement and education efforts account for a majority of the difference. This shows the importance of government-derived enforcement and management techniques. If efforts can be increased for Guam's preserves, data suggest similar positive fish population trends may occur.

Recommendations

Overall, data suggest increased management and enforcement would be beneficial island-wide. One inexpensive change that could benefit the local enforcement agency would be more detailed record keeping. Guam has a hotline number to report illegal fishing and hunting, and to provide information regarding laws and regulations. No details are recorded for calls to the hotline, other than the numbers of calls, which average over 1,500 per year. When discussing the call log, the conservation officers mentioned that most calls are in regards to illegal fishing, but had no further details. Keeping detailed records of the calls regarding illegal fishing would assist the agency in addressing which preserve needs more enforcement attention. Additional officers and equipment (i.e., vehicles, boats) would also help the enforcement of the preserve, although funding for such things has historically been difficult to obtain.

If government commitment of resources cannot be increased, it may be beneficial to consider the addition of community-based management support. Establishing community groups to assist and engage with government enforcement would not only help with the oversight of the preserves, but also instill a sense of stewardship pride in the community by assisting in the management of their local resources (de Lara & Corral 2017). Community-involved management also introduces local fisheries knowledge which could benefit the preserves' resources (Olsson & Folke 2001, Chirico et al. 2017). One such example of local support of marine preserves is Palau, which has become a posterchild for coral reef fishery management (Golbuu et al. 2005). Before Palau's marine preserves were established, traditional temporary closures of fishing areas would occur (Golbuu et al. 2010). These closures, known as *bul*, were determined by local island chiefs. Historical records never suggest local fish populations ever neared low numbers (Johannes 1981, Graham & Idechong 1998). Since the adoption of more government-based conservation techniques, local support has remained high, and positive fishery conservation has continued (Gruby & Basurto 2013).

One could counter this argument by suggesting that the illegal fishing on Guam is being done by fishermen who live near the preserve. In this case, community involvement may actually sabotage management. However, studies have shown that in areas where illegal fishing of MPAs occurred, there was a positive link between community participation in MPA management and compliance (Andrade & Rhodes 2012, Arias et al. 2015). On Guam, a "Piti Pride Campaign" was conducted from 2012-2014. This outreach plan targeted local stakeholders, primarily local fishers, to assist with management of the Piti preserve. Although creating such community management groups would require initial investment, such as additional resources and training, the aid that could be realized could show real benefit to the local enforcement agency, and to fish resources in the marine preserves.

Since the preserves were established, a small portion of local fishers have been vocal on gaining more access to the closed fishing grounds. Within the last decade there have been several attempts to open Guam's preserves to additional fishing methods. Some have proposed the fishing within the preserves be allowed only to indigenous people of Guam. Others have proposed rotational openings of the preserves. The results from this study show that areas that are currently open for fishing have low biomass and abundance. This is especially true for heavily targeted species. Opening the marine preserves, even on a rotational basis, would likely result in the rapid decline of targeted fish populations within the preserves, and to the elimination of any spillover effects that may have been provided by the preserves to adjacent fished areas. With the exception of Pati, all of the preserves are easy to access by land and by boat. Easy access, coupled with the small size of Guam's preserves, would certainly put them at risk of being overfished. Furthermore, rotational openings would not benefit large species that typically have slow growth rates and long life spans (Williams et al. 2006, Claudet et al. 2008). For example, *C. undulatus* may not reach sexual maturity until 5 years of age (Sadovy et al. 2013). Taylor et al. (2012) modeled how different management strategies would affect populations of *L. harak* on Guam. *L. harak* is a heavily targeted species; listed in the high value and most wanted groups in this study. Using data from Achang and Piti preserves, along with paired fished sites, the model predicted biomass and abundance to remain stable when the preserves remained in place. When the preserves were hypothetically opened on a 3-year rotational basis, however, biomass and abundance dropped 70% and 30%, respectively, after just five years. More pronounced declines were predicted when the preserves were permanently opened. The model predicted a 50% drop in biomass after the first year, and a 95% decline of the original population a decade after the preserves were opened. Total abundance was predicted to decline over 90% after 20 years. Overall, if fishing was permitted in the marine preserves, it is likely that biomass and abundance of targeted fishes inside preserve boundaries would quickly resemble those populations found outside.

Future studies could continue progress of examining Guam's marine preserves. Another avenue to advance knowledge would be research on illegal fishing in the preserves. Conversations with local fishermen on Guam revealed that many have witnessed poaching occurring in at least one marine preserve. Hard data on this issue, however, are lacking. This would require working closely with Guam's enforcement agency, which would almost certainly be a mutualistic partnership. Personal interactions with conservation officers during this study showed their wealth of knowledge with the marine preserves. Findings could benefit the enforcement agency by providing data that could assist with campaigning for additional, and necessary, funds. Results could aid studies by providing additional perspective on how external influences are affecting data observed inside Guam's marine preserves.

Future research on biomass and abundance of fishes on the reef flats could widen the scope of knowledge of the preserves. This study, and nearly all past studies concerned with fishes of Guam's marine preserves, was conducted along the seaward slope. This leaves out a considerable amount of the preserve, ignoring fishes that prefer reef flats and back reefs. Additional work could also be performed in Pati. Due to the preserve's size and location, it has been the subject of fewer studies than other preserves on Guam. Little work has also been done in the only marine preserve not selected in this study: Sasa Bay. As mentioned, Sasa Bay's benthic composition is unlike the other four preserves on Guam; in fact, it would be difficult to find a comparable fished site for statistical comparisons.

Continued research throughout the coming years and decades could provide insight on the long-term success of Guam's preserves. Positive ecological effects, such as increased fish density and species richness within marine protected waters have been shown to be linked to the time elapsed since the protection was established (Claudet et al. 2008, Friedlander et al. 2017). Some studies have found increases in fish abundance and species richness in protected waters occurring after only 3 years (Halpern & Warner 2002, Russ et al. 2005), while others have showed results may takes decades to be realized (Micheli et al. 2004). It would be interesting for future research to investigate the degree of positive ecological effects that can be realized in Guam's preserves in the near future.

CONCLUSION

This study investigated the success of Guam's marine preserves in protecting populations of fish species that are regularly targeted by Guam's local fishery. Most of the preserves were marked by greater biomass and abundance within the preserve when compared to the paired fished site. This is a positive for Guam's fish stocks. While beyond the scope of this study to assess for Guam's marine preservers, past research has suggested that preserves that have greater biomass of a fish species can benefit nearby waters through an increase of reproductive output and subsequent spillover (Taylor & McIlwain 2010, Taylor et al. 2012, Taylor & Mills 2013). Therefore, the high levels of biomass observed in the preserves may have a positive effect in supplementing the fish populations around Guam.

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SUPPLEMENTAL TABLES AND FIGURES

Table S1: List of all species encountered in this study, measurement data of interest, and fishing desirability (from Bejarano et al. 2013, Lindfield et al. 2014). Length values are in cm. Species in bold represent the most wanted group.

Name	n	Mean Length (SD)	Max	Min	Fishing Level
Acanthurus blochii	190	14.1 (2.0)	20.3	10.2	Target
Acanthurus guttatus	95	11.3 (1.9)	17.8	10.2	Target
Acanthurus lineatus	**16**	**14.3 (3.1)**	**20.3**	**10.2**	**High Value**
Acanthurus nigricans	181	12.2 (1.7)	17.8	10.2	Fished
Acanthurus nigrofuscus	1544	11.8 (1.7)	17.8	10.2	Fished
Acanthurus nigroris	8	10.2 (0)	10.2	10.2	Fished
Acanthurus olivaceus	421	13.4 (2.1)	20.3	10.2	Target
Acanthurus triostegus	**360**	**10.2 (0)**	**10.2**	**10.2**	**High Value**
Acanthurus xanthopterus	**3**	**14.4 (1.5)**	**15.2**	**12.7**	**High Value**
Aphareus furca	27	18.5 (3.9)	25.4	15.2	High Value
Aprion virescens	2	55.9 (7.2)	61	50.8	High Value
Calotomus carolinus	20	16.6 (3.6)	25.4	12.7	Target
Carangoides ferdau	19	29.1 (2.3)	30.5	25.4	High Value
Caranx melampygus	**67**	**22.5 (6.6)**	**45.7**	**12.7**	**High Value**
Cephalopholis argus	20	23.2 (7.0)	45.7	15.2	High Value
Cephalopholis urodeta	210	13.9 (2.2)	25.4	10.2	Fished
Cetoscarus bicolor	1	22.9 (-)	22.9	22.9	High Value
Cheilinus fasciatus	56	18.1 (5.0)	33	10.2	Fished
Cheilinus trilobatus	7	22.5 (5.9)	30.5	15.2	Fished
Cheilinus undulatus	7	46.1 (9.7)	61	33	High Value
Chlorurus frontalis	244	19.6 (3.4)	30.5	10.2	High Value
Chlorurus microrhinos	**47**	**31.7 (6.0)**	**40.6**	**17.8**	**High Value**
Chlorurus sordidus	**2628**	**12.7 (2.6)**	**25.4**	**10.2**	**Target**
Chlorurus spilurus	**8**	**19.7 (5.9)**	**33**	**15.2**	**Target**
Coris aygula	11	21.9 (6.1)	30.5	15.2	Fished
Ctenochaetus striatus	1760	11.8 (1.6)	15.2	10.2	Fished
Epibulus insidiator	94	16.5 (4.2)	30.5	10.2	Fished
Epinephelus fasicatus	5	22.9 (1.8)	25.4	20.3	High Value
Epinephelus maculator	1	30.5 (-)	30.5	30.5	High Value
Gnathodentex aurolineatus	131	14.9 (2.3)	20.3	12.7	Fished
Gymnocranius microdon	2	16.5 (1.8)	17.8	15.2	High Value
Halichoeres hortulanus	8	15.2 (1.9)	17.8	12.7	Fished
Hemigymnus melapterus	87	17.0 (4.4)	35.6	10.2	Fished
Hipposcarus longiceps	**100**	**17.0 (6.3)**	**40.6**	**10.2**	**High Value**
Kyphosus cinerascens	**71**	**16.9 (2.5)**	**25.4**	**12.7**	**High Value**
Lethrinus harak	**99**	**19.0 (5.7)**	**30.5**	**10.2**	**High Value**
Lethrinus olivaceus	99	24.8 (6.7)	43.2	15.2	High Value

Lutjanus bohar	2	48.3 (3.6)	50.8	45.7	High Value
Lutjanus fulvus	150	17.5 (3.5)	27.9	10.2	High Value
Lutjanus gibbus	37	16.2 (3.0)	27.9	12.7	High Value
Lutjanus monostigma	28	21.8 (7.5)	38.1	15.2	High Value
Macolor macularis	4	20.3 (0)	20.3	20.3	High Value
Macolor niger	18	21.7 (5.0)	33	15.2	High Value
Monotaxis grandoculis	346	21.4 (5.4)	45.7	10.2	High Value
Mulloidichthys flavolineatus	30	16.4 (1.7)	17.8	10.2	Fished
Mulloidichthys vanicolensis	39	15.5 (0.8)	17.8	15.2	Fished
Naso annulatus	4	12.7 (0)	12.7	12.7	High Value
Naso lituratus	**563**	**13.1 (2.1)**	**22.9**	**10.2**	**High Value**
Naso tonganus	16	33.2 (13.1)	48.3	15.2	Target
Naso unicornis	**162**	**15.4 (3.4)**	**33**	**10.2**	**High Value**
Naso vlamingii	2	16.5 (1.8)	17.8	15.2	High Value
Oxycheilinus unifasciatus	298	15.1 (3.2)	27.9	10.2	Fished
Parupeneus barberinus	40	14.9 (2.6)	22.9	10.2	Fished
Parupeneus ciliatus	3	19.5 (2.9)	22.9	17.8	Fished
Parupeneus insularis	19	19.0 (4.1)	30.5	12.7	Fished
Parupeneus multifasciatus	103	14.3 (2.7)	25.4	10.2	Fished
Plectorhinchus lineatus	1	38.1 (-)	38.1	38.1	High Value
Plectorhinchus picus	1	45.7 (-)	45.7	45.7	High Value
Plectropomus laevis	6	27.9 (8.9)	40.6	20.3	High Value
Scarus altipinnis	**68**	**18.7 (6.2)**	**38.1**	**10.2**	**High Value**
Scarus forsteni	117	18.4 (5.4)	40.6	10.2	Target
Scarus fuscocaudalis	2	20.3 (0)	20.3	20.3	Target
Scarus ghobban	3	17.8 (5.1)	22.9	12.7	Target
Scarus globiceps	7	18.5 (2.4)	22.9	15.2	Target
Scarus oviceps	2	25.4 (7.2)	30.5	20.3	Fished
Scarus psittacus	306	13.4 (3.2)	30.5	10.2	Fished
Scarus rubroviolaceus	158	21.6 (6.8)	40.6	10.2	High Value
Scarus schlegeli	**239**	**16.8 (4.4)**	**30.5**	**10.2**	**Target**
Scolopsis lineata	66	14.6 (1.3)	15.2	10.2	Target
Siganus argenteus	49	14.2 (2.2)	20.3	12.7	High Value
Siganus randalli	11	14.8 (1.0)	15.2	12.7	Fished

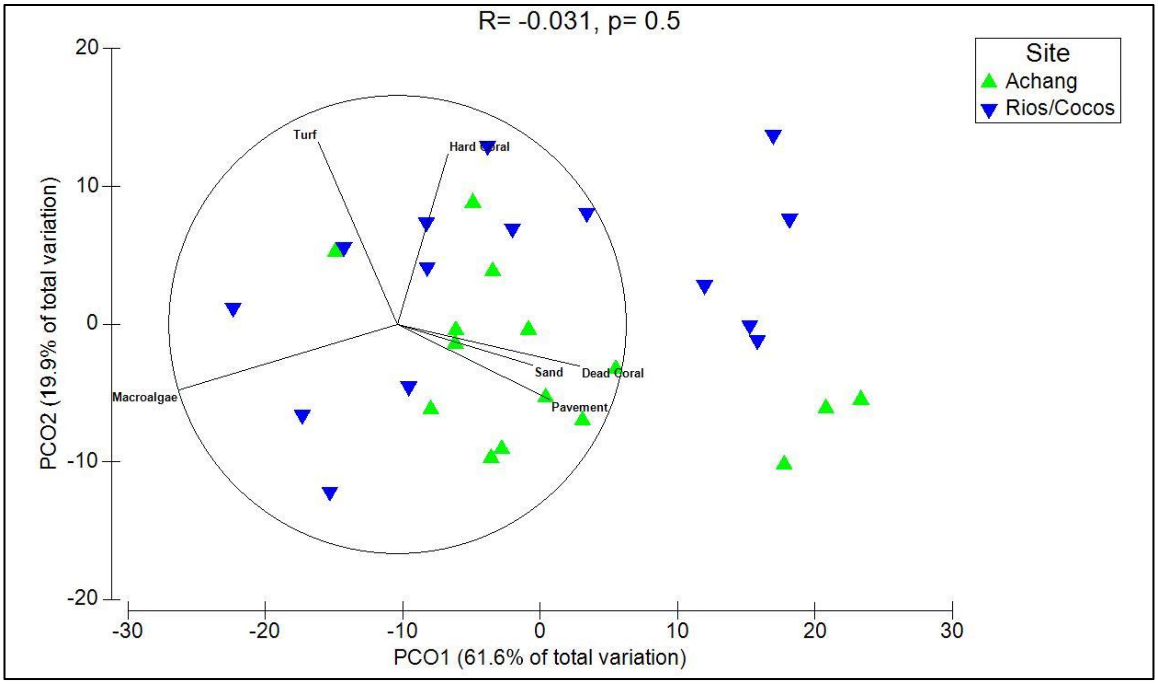

Figure S1: Principal coordinate analysis for benthic type at Achang (preserve) and Rios Bay and Cocos (fished sites).

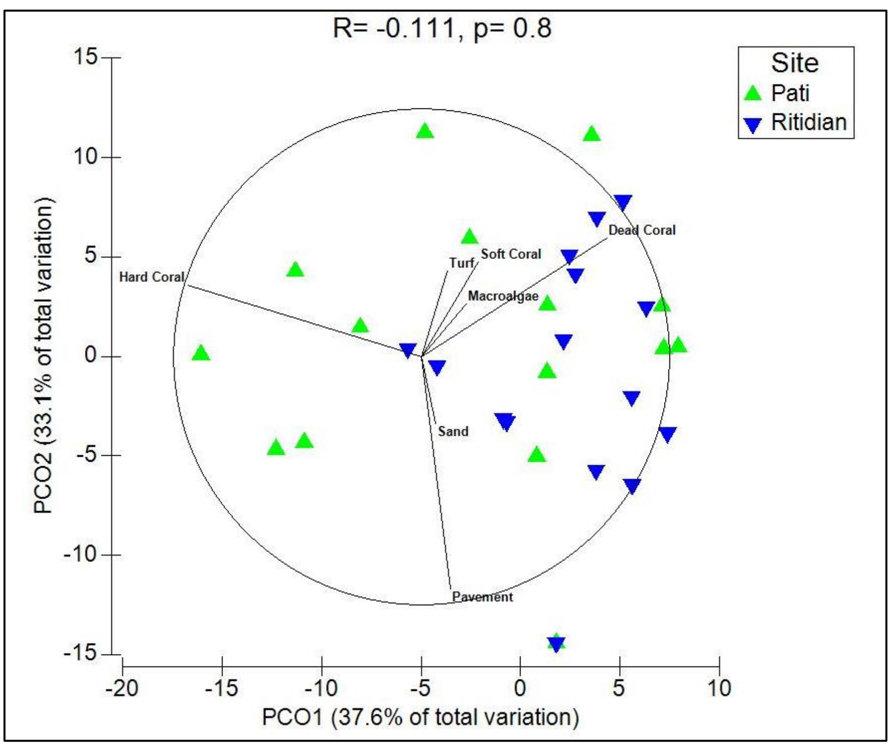

Figure S2: Principal coordinate analysis for benthic type at Pati (preserve) and Ritidian (fished site).

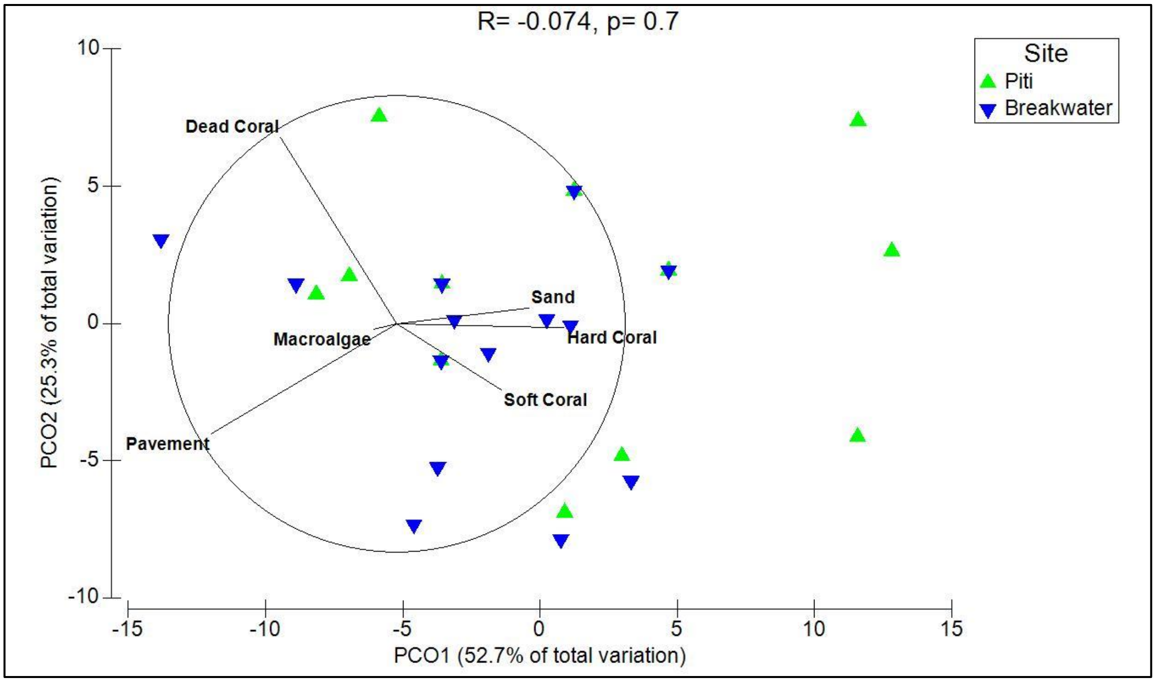

Figure S3: Principal coordinate analysis for benthic type at Piti (preserve) and Breakwater (fished site).

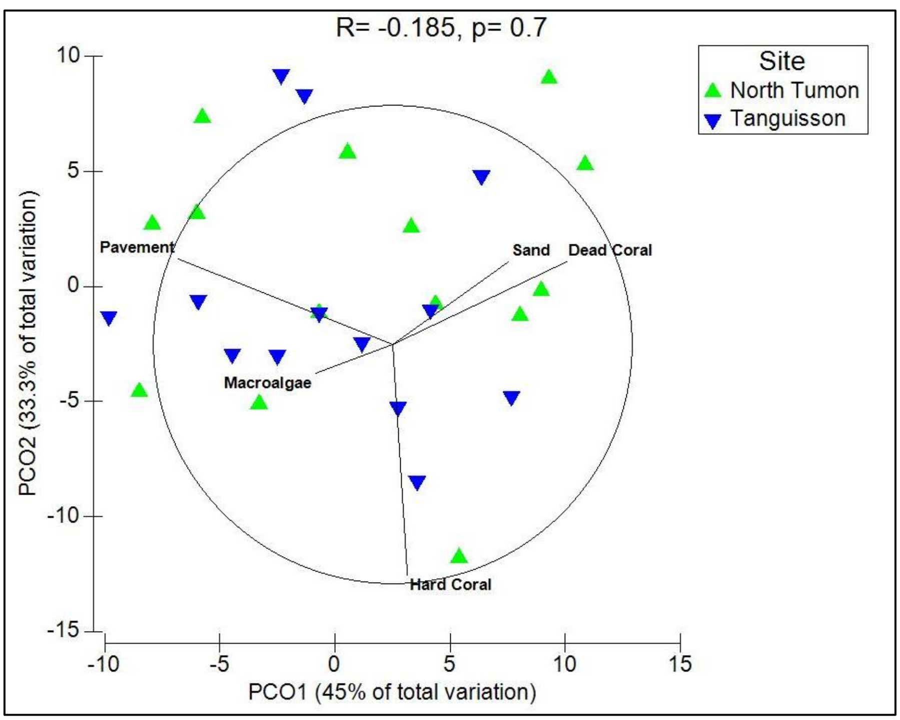

Figure S4: Principal coordinate analysis for benthic type at North Tumon (preserve) and Tanguisson (fished site).

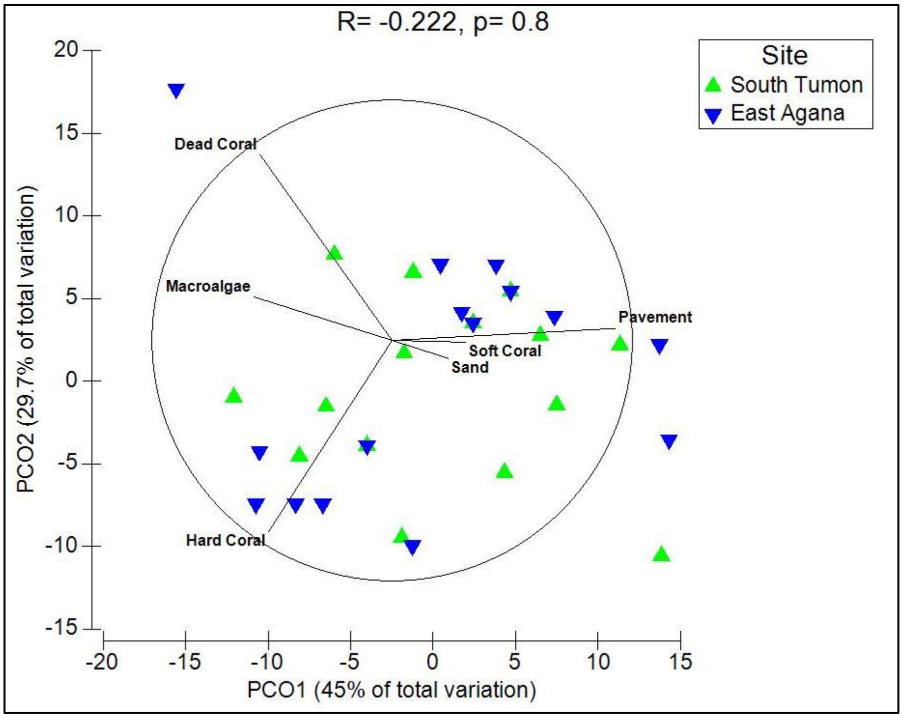

Figure S5: Principal coordinate analysis for benthic type at South Tumon (preserve) and East Agana Bay (fished site).

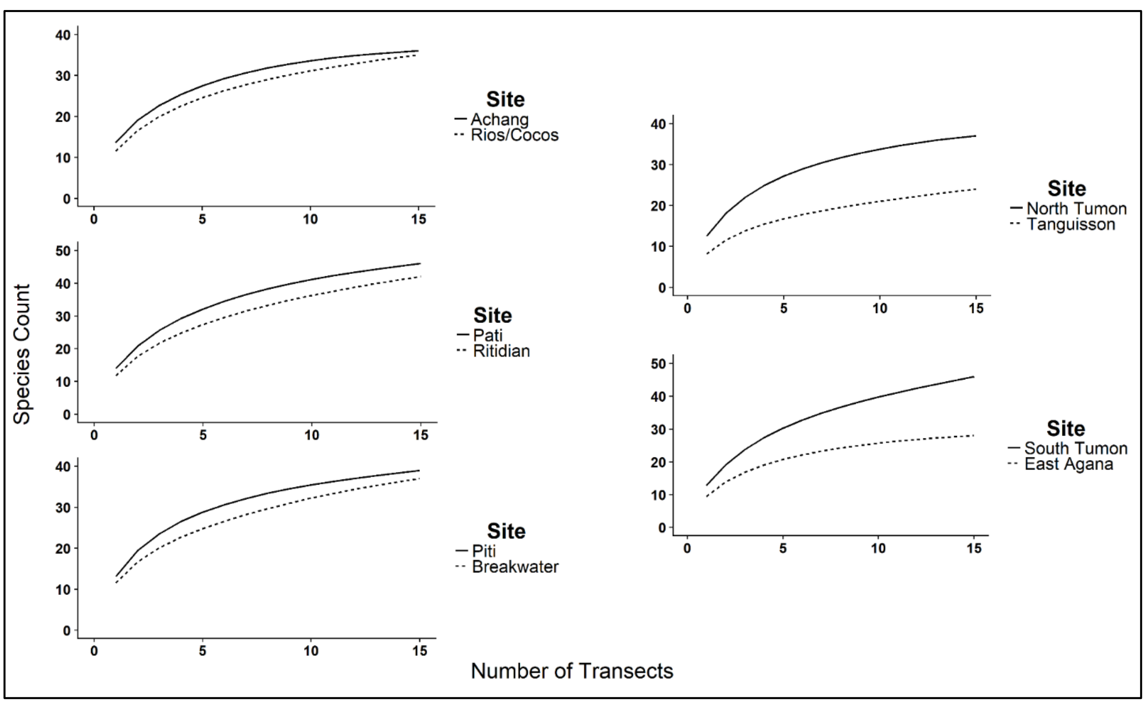

Figure S6: Rarefaction curves for all preserves and paired fished sites.

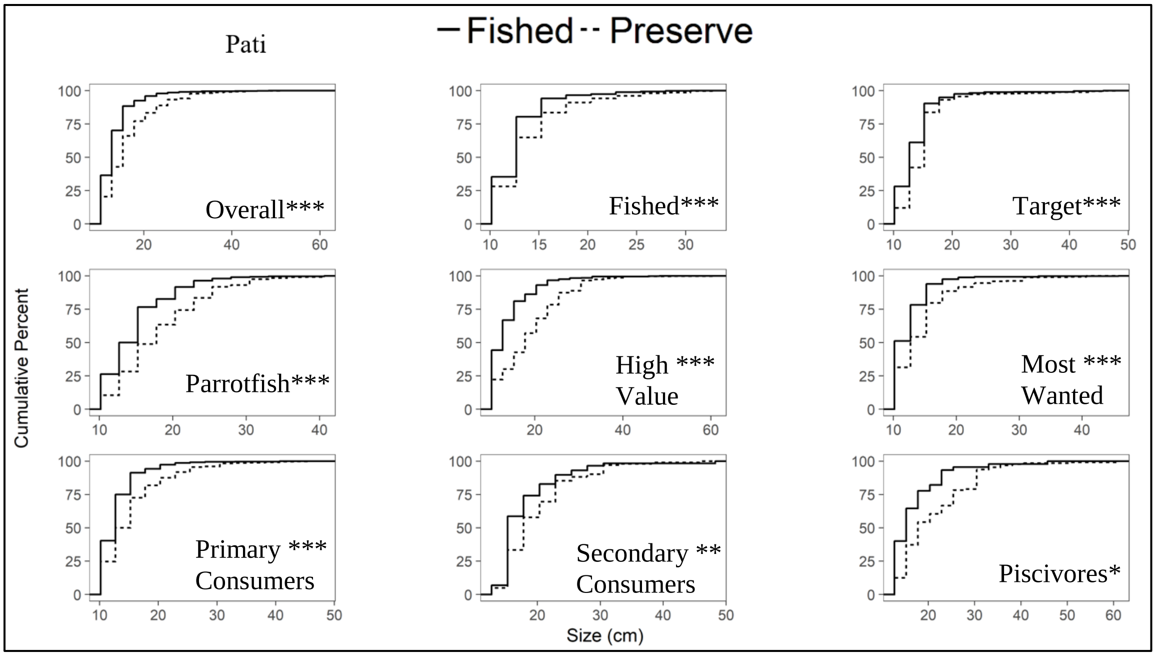

Figure S7: Size-class distribution plots for all groups between Pati and paired fished site. Significance is defined as: *p < 0.05, **p < 0.01, ***p < 0.001 via K-S tests.

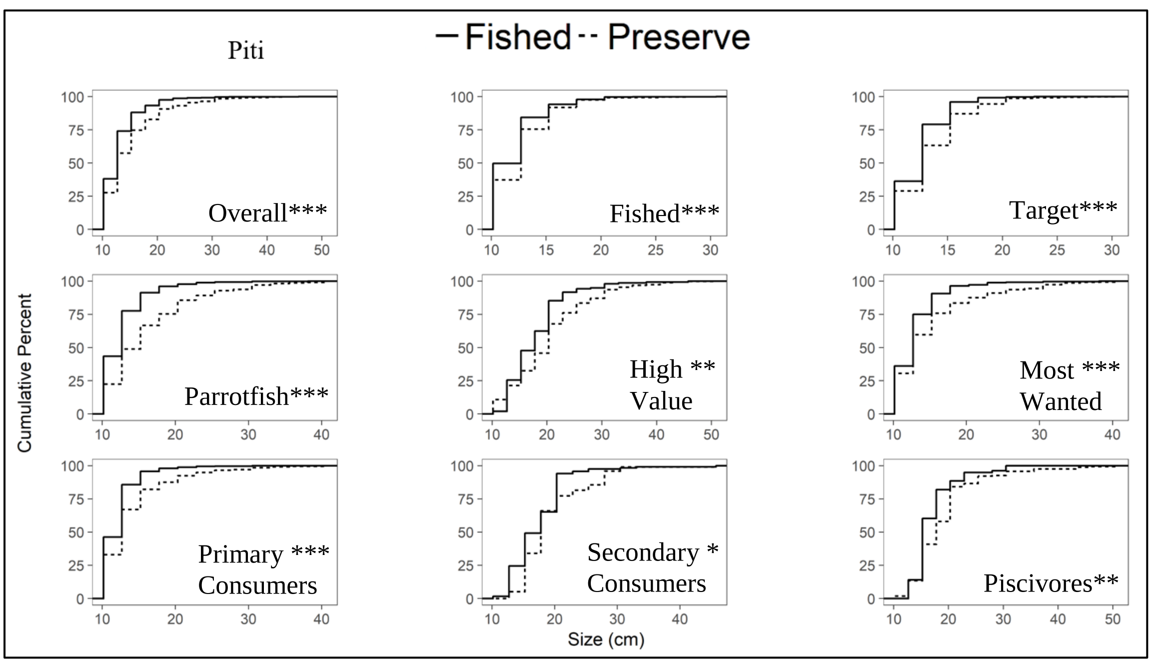

Figure S8: Size-class distribution plots for all groups between Piti and paired fished site. Significance is defined as: *p < 0.05, **p < 0.01, ***p < 0.001 via K-S tests.

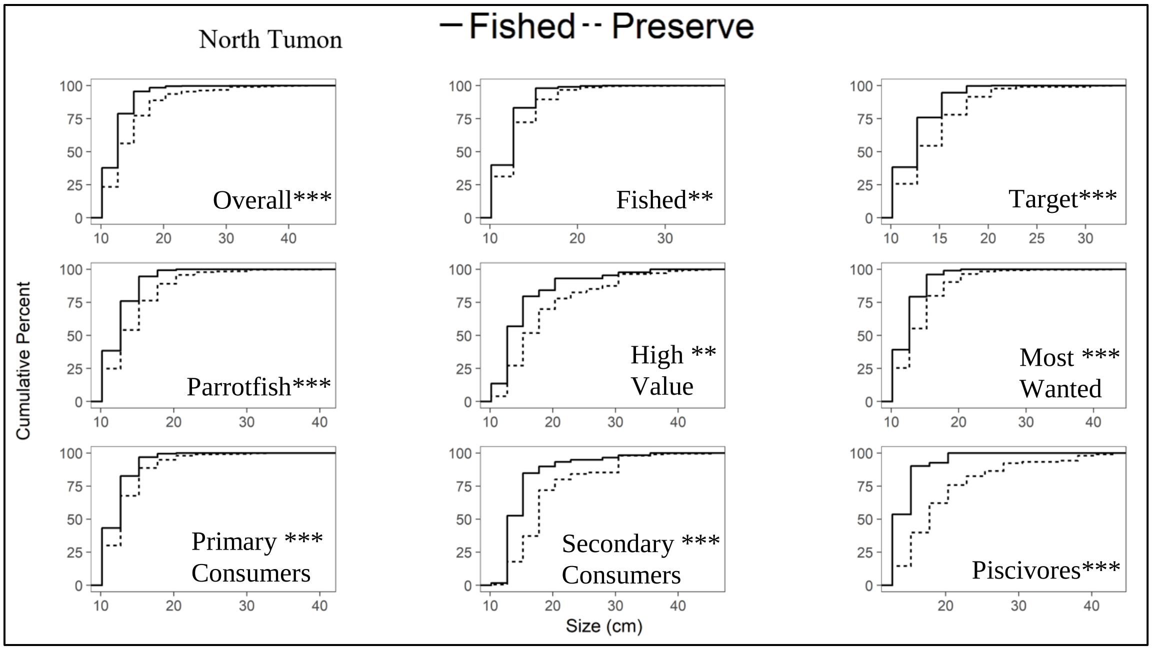

Figure S9: Size-class distribution plots for all groups between North Tumon and paired fished site. Significance is defined as: *p < 0.05, **p < 0.01, ***p < 0.001 via K-S tests.

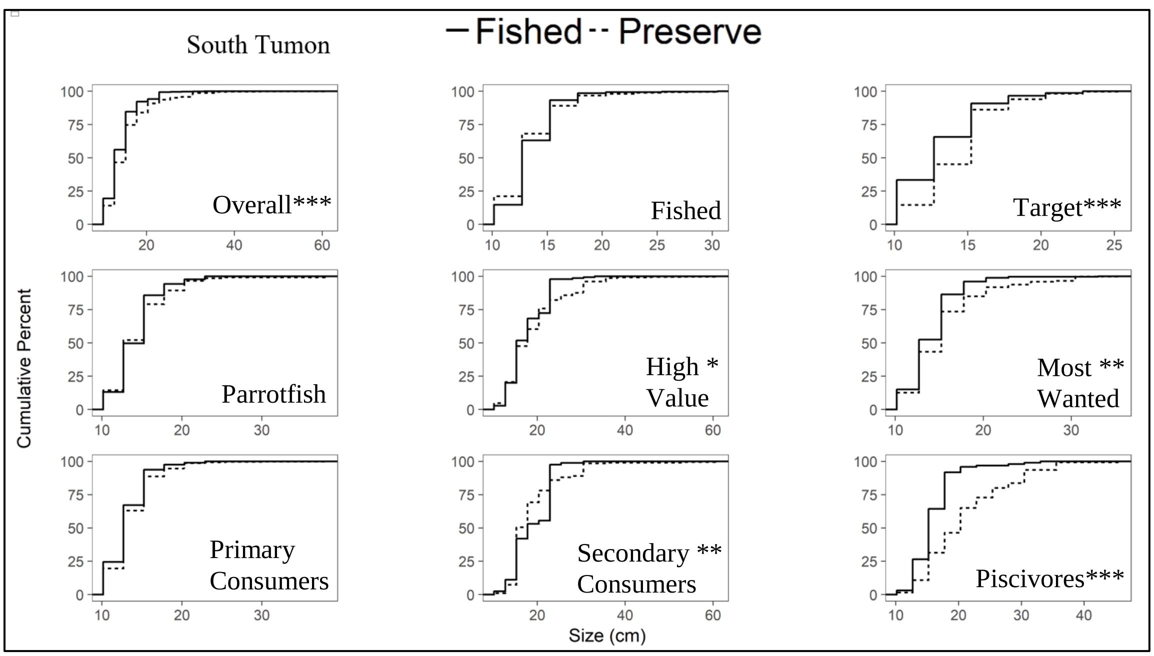

Figure S10: Size-class distribution plots for all groups between South Tumon and paired fished site. Significance is defined as: *p < 0.05, **p < 0.01, ***p < 0.001 via K-S tests.