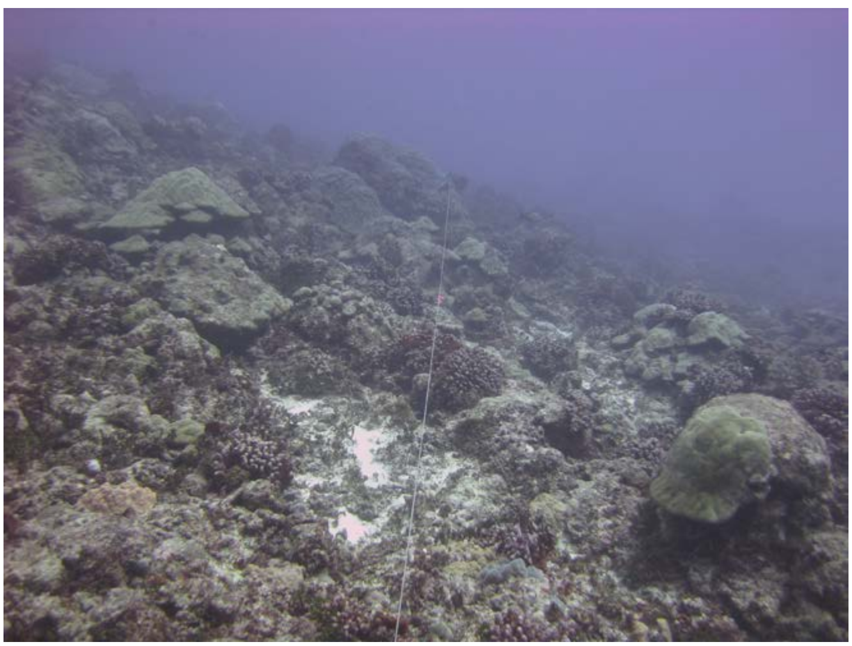
NOAA Technical Memorandum NMFS-PIFSC-33

August 2012

Status of Coral Reef Fish Assemblages and Benthic Condition Around Guam: A Report Based on Underwater Visual Surveys in Guam and the Mariana Archipelago, April-June 2011



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Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Williams, I., J. Zamzow, K. Lino, M. Ferguson, and E. Donham. 2012. Status of coral reef fish assemblages and benthic condition around Guam: a report based on underwater visual surveys in Guam and the Mariana Archipelago, April-June 2011. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-33, 22 p. + Appendices.

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Cover: A coral reef visual survey site. A 30-m line, marked at intervals with red flagging tape, helps divers establish a pair of 15-m cylinders for stationary point counts of fish.

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SUMMARY

Coral reef fish and benthos were surveyed at 133 coral reef sites around Guam in May and June 2011 during a Mariana Archipelago Pacific Reef Assessment and Monitoring Program Cruise (MARAMP 2011) and a supplemental survey mission accomplished using a chartered vessel. Both projects were conducted by the NOAA Fisheries, Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division (CRED) using consistent methods, survey design, and personnel.

The goals of the supplementary survey work were to (1) generate a more spatially comprehensive data set on the coral reefs around Guam than is possible based on a 4-5 survey day restriction, which has been the standard for biennial MARAMP cruises since 2003, around Guam, and (2) generate sufficient data to assess the status of reef fish assemblages in Guam's Marine Preserves (MPs) and to compare those reef fishes with assemblages in areas around Guam that are open to fishing ('open' sites). Recognizing differences in accessibility and ocean conditions on different sides of the island, Guam sites outside of the marine preserves are pooled at different times into 'all open' and separately for 'open-east' and 'open-west'.

In addition to specific statistical tests and synthesized results, this report contains many maps and figures intended to broadly represent the data rather than to test specific questions. All site-level data used in this study are available upon request.

Here are the key findings:

- Reefs along much of the southwestern coast of Guam tended to have low cover of calcifying benthos (corals and crustose coralline algae [CCA]), with much higher portions of substrate covered in non-calcifying algae than was typical of other reef areas around the island. Fine sediment was conspicuous and water was generally turbid on reefs across much of that part of the island. Southwestern Guam sites were also notable for generally having low fish biomass including of parrotfishes and surgeonfishes.

- Mean total reef fish biomass in Guam MPs was 2.4 times that in Guam sites open to fishing overall, but the difference between Guam MP and Guam West sites open to fishing was much larger than between Guam MP and Guam East sites open to fishing (biomass ratios of 3.0 and 1.8, respectively). MP sites also had higher mean biomass than sites in areas open to fishing for all families analyzed, but the MP-open differences were only statistically significant for surgeonfishes and parrotfishes. In contrast to fish assemblage data, there were no differences in benthic condition (coral or algal cover, structural complexity) between marine preserves and open areas.

- Pati Point Marine Preserve had notably more frequent sightings of fish taxa of particular interest, such as sharks, jacks, humphead wrasse, and large emperors), than other parts of Guam. Most species in those groups were only rarely recorded during the surveys around Guam.

- Comparison of reef fish assemblages around Guam at other islands in the Mariana Archipelago indicates that reef fish assemblages in Guam MPs were generally more similar in terms of size- and trophic-structure to those in the northern and lightly populated islands (i.e., from Sarigan northward) than to areas around Guam open to fishing, or to the other populated southern islands.

- Other archipelagic patterns of interest include a clear indication that parrotfish species composition differed sharply between northern and southern islands. Assemblages at all islands from Sarigan northwards were dominated by three large-bodied species: *Chlorurus microrhinos, Scarus forsteni*, and *S. rubroviolaceus*. In contrast, *Chlorurus sordidus*, which was rarely seen in the northern islands, was the dominant species by biomass at all of the southern islands (Guam to Saipan). Other species contributing to parrotfish biomass at southern islands – *S. schlegeli, C. frontalis*, and *S. altipinnis* – were also negligible components of northern parrotfish biomass recorded during surveys.

BACKGROUND

CRED surveys coral reef ecosystems in U.S. and U.S.-affiliated regions of the Pacific — American Samoa, the Commonwealth of the Northern Marianas (CNMI), Guam, Hawaii, and the Pacific Remote Island Areas — as part of the Pacific Reef Assessment and Monitoring Program (Pacific RAMP). The Pacific RAMP is designed to generate comparable island-scale metrics of reef condition (e.g., mean fish biomass by trophic group per island, mean coral cover per island) across all regions. As part of Pacific RAMP, coral reefs around Guam and the CNMI have been surveyed by means of approximately month-long survey cruises, conducted biennially since 2003.

Because survey activity on each Mariana Archipelago cruise is spread across multiple islands and reef areas, a typical Mariana Archipelago RAMP (MARAMP) cruise involves only 4-6 days of fieldwork around Guam. Prior to the 2011 surveys described in this report, the highest survey replication achieved around Guam was the 25 sites surveyed in 2009. While that effort level is adequate to meet the primary goals of Pacific RAMP, i.e., island-scale metrics, it is not generally a sufficient level of survey activity to draw robust conclusions about distinct subsectors or management units within an island. However, islands that have large human populations tend to have management concerns at spatial-scales well below island-scale, and the more populated islands also have considerable scope for within-island differences in human impacts based on, for example, differences in local population density, degree of urbanization and other land alteration, and in accessibility of nearshore waters. Therefore, where it has been possible to do so, CRED has initiated more intensive supplementary survey efforts around the main human population centers in each region. The first such effort was at Tutuila in 2010. As described in this report, supplementary surveys were conducted around Guam in 2011, and additional surveys around Oahu and Maui are currently planned for 2012.

The 2011 supplementary coral reef surveys around Guam were conducted with two main purposes: (1) to generate a spatially comprehensive assessment of coral reefs around the entire island (Fig. 1); (2) to quantify any differences in fish assemblages between reefs inside and outside of Guam's system of marine preserves, i.e., Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat, and Pati Point Marine Preserves. As part of the first objective, a companion spreadsheet of all Guam site-level data presented in this report has been produced. That and all other data gathered by CRED are available by request at any time. For the second objective, we focused on the system of marine preserves established in 1997 and where enforcement of fishing restrictions began in 2001 (Burdick et al., 2008). Other generally small parks, refuges, and ecological reserve areas around Guam contain coral reef habitat, but we did not specifically test effectiveness of those or group those with the marine preserves, because they generally had no or only very limited restrictions on fishing activity and because of limited management or enforcement within those areas (Burdick et al., 2008). We also did not survey any sites in Sasa Bay Marine Preserve or elsewhere within Apra Harbor because it seemed likely that sites within the harbor would not be readily comparable with reef areas elsewhere around the island.

It is important to highlight some limitations of these results. The intensive supplemental activities enabled us to survey a total of 133 sites around Guam in 2011 (including those surveyed during MARAMP 2011). That is more than five times the number of Guam sites surveyed by CRED in any previous year. Nevertheless, the total survey effort around Guam in 2011 consists of only 14 days of fieldwork by 4–5 survey divers per day. As shown below, the resulting data allow us to draw a number of statistically meaningful conclusions about the status and relative condition of reefs inside and outside of marine preserves and to put local results in the wider context of reefs across the Mariana Archipelago with data gathered using consistent survey methods and survey design and, to a large degree, collected by the same survey personnel (Appendix D). However, intensive short-term activities, such as the one described in this report, cannot take the place of the focused long-term, spatially concentrated survey programs conducted by local agencies and institutions, necessary to generate fine-scale information on condition and trends over time at particular locations of interest. Additionally, the 133 Guam sites included 48 sites within marine preserves and 85 sites outside the marine preserves (‘open’ sites). That level of replication is sufficient to characterize fish assemblages at that level (i.e., all open, all MP), but is not sufficient for us to generate robust results specific to individual preserves (e.g., we have a total of only 5 sites within Achang Reef Flat Marine Preserve, and only 10 within Piti Bomb Holes preserve). The main body of the report, therefore, presents data and statistical results for all MPs combined. Synthesized data on individual preserves are given in Appendix C, but it is important to recognize the rather low levels of replication at that scale.

The 2011 supplementary Guam survey effort and the MARAMP cruises were funded by grants from NOAA’s Coral Reef Conservation Program (http://coralreef.noaa.gov/) and with support from the NOAA National Marine Fisheries Service (NMFS).

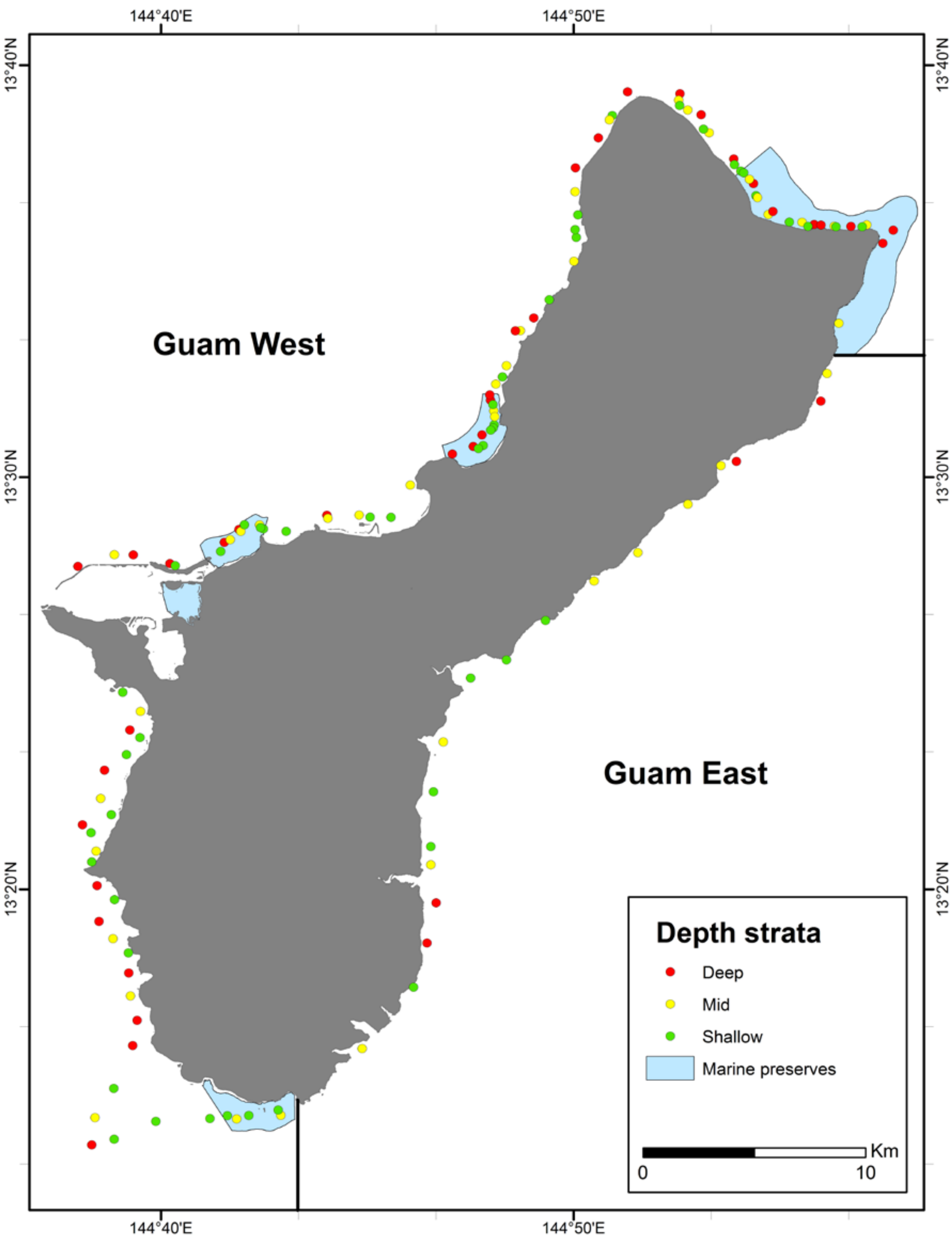

Figure 1.--Survey locations Guam 2011, includes all sites surveyed in 2011, i.e., during MARAMP 2011 cruise (visited Guam May 2011) and Guam shore-based surveys (June 2011). Lines at SE and NE indicate outer boundaries of the Guam East sector.

METHODS

Survey Design

All data reported here were gathered as part of a coral reef monitoring cruise (MARAMP 2011) on the NOAA Ship *Hi'ialakai* in waters of Guam and CNMI led by the Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division during April–May 2011, or by means of a supplementary intensive survey effort around Guam in June of the same year using a chartered research vessel. In total, 133 sites were surveyed around Guam: 52 of those during MARAMP 2011 (5–9 May) and 81 during the supplementary survey effort, between 6 and 16 June. The surveys around Guam were based on a common stratified random sampling design, with site locations selected randomly within shallow (< 6 m), medium (6–18 m), and deep (18–30 m) forereef hardbottom habitat strata using CRED habitat and bathymetric maps.

Prior to MARAMP 2011, we expected that ~ 15 days of fieldwork would allow for the surveying of ~ 120–140 survey sites. Randomized primary and alternate site locations were therefore developed prior to MARAMP 2011 from GIS maps with the following targets: ~ 50 sites spread widely within Guam MPs; remaining effort distributed as widely as possible over both eastern and western coastal areas. Given our expectation that reef fish assemblages in areas open to fishing on the exposed and relatively inaccessible east side of Guam might differ substantially from those open to fishing on the west side of Guam, we also pooled Guam open sites separately into Guam East open and Guam West open (Fig. 1). Distribution of sites and sampling effort within strata and by sector and per MP is shown in Figure 1 and Table 1. We surveyed 48 sites within the MPs, and 85 in areas open to fishing. Based largely on logistical constraints, including that the charter vessel we used was unable to work on the east side of Guam, sampling effort was not evenly distributed across MPs and around the island. For example, the Guam West open sector has approximately twice the amount of target habitat (hardbottom < 30 m) as the Guam East open sector, but had nearly 4 times as many sampling sites (67 compared to 18, Table 1). However, as noted below, we pooled data from individual sectors and individual MPs into higher levels (e.g., to all MPs), weighting by area of habitat rather than by number of sites; hence, island-scale estimates were not biased by sampling intensity.

TABLE 1.--Area of hardbottom habitat < 30 m in each Guam marine preserve and the east and west Guam sectors open to fishing, and distribution of survey effort within depth strata.

Marine Preserve/Sector	Area < 30 m hardbottom hectares (% of island total)	# Survey Sites Shallow	Medium	Deep	Total
West Open	4004 (54.9)	27	19	21	67
East Open	2108 (28.9)	6	8	4	18
Total Open	***6112 (83.7)***	***33***	***27***	***25***	***85***
Pati Point MP	443 (6.1)	6	7	7	20
Sasa Bay MP	64 (0.9)	0	0	0	0
Tumon Bay MP	233 (3.2)	6	2	5	13
Piti Bomb Holes MP	232 (3.2)	4	3	3	10
Achang Reef Flat MP	213 (2.9)	3	2	0	5
Total MP	***1186 (16.3)***	***19***	***14***	***15***	***48***

Survey Methodology

Fish Counts

All sites were surveyed using CRED's standard coral reef fish assemblage survey method, stationary point counts (SPC). The SPC protocol closely follows that used by Ault and colleagues (Ault et al., 2006) and involves a pair of divers conducting simultaneous counts in adjacent, visually estimated 15-m-diameter cylindrical plots extending from the substrate to the limits of vertical visibility (Fig. 2). Prior to beginning each SPC pair, a 30-m line was laid across the substratum. Markings at 7.5 m, 15 m and 22.5 m enable survey divers to locate the midpoint (7.5 m or 22.5 m) and two edges (0 m and 15 m; or 15 m and 30 m) of their survey plots. Each count consisted of two components. The first of these was a 5-min species enumeration period in which the diver recorded the taxa of all species observed within their cylinder. At the end of the 5-minute period, divers began the tallying portion of the count, in which they systematically worked through their species listing for each species and recorded the number of fish and size (total length, TL, to nearest cm) of each individual fish. The tallying portion was conducted as a series of rapid visual sweeps of the plot, with one species-grouping counted per sweep. To the extent possible, divers remained at the center of their cylinders throughout the count. However, small and cryptic species, which will tend to be underrepresented in counts made by an observer remaining in the center of a 7.5-m radius cylinder, were left to the end of the tally period, at which time the observer swam through their plot area carefully searching for those species. In cases where a species was observed during the enumeration period but was not present in the cylinder during the tallying period, divers recorded their best estimates of size and number observed in the first encounter during the enumeration period and marked the data record as 'non-instantaneous.' Surveys were not conducted if horizontal visibility was < 7.5 m, i.e., when observers could not distinguish the edges of their cylinder.

Benthic Cover and Complexity Estimates

On completing the fish count within a cylinder, divers measured depth at the center of their SPC cylinder using their dive computer, visually estimated cover of benthos (coral, macroalgae, crustose coralline algae [CCA], turf, and sand) within their cylinders and then ranked habitat complexity on a 6-point scale (1 = very low complexity to 6 = very high complexity). Unpublished assessments by CRED indicated that, with adequate training, diver estimates of total live coral cover are comparable to those generated from photo-transects of the same sites and that estimates of other benthic elements could be made sufficiently well to distinguish gross differences among sites.

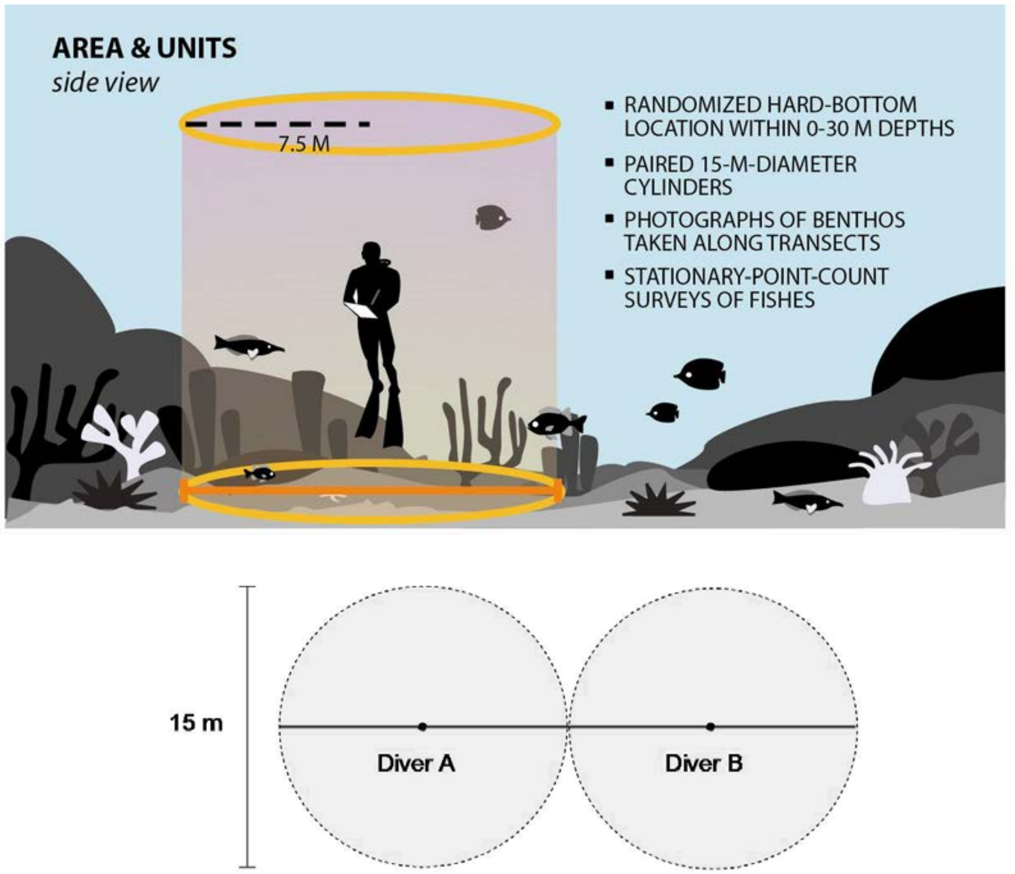

Figure 2.--Schematic of survey method.

Data Handling and Analysis

Estimating Fish Biomass from Visual Survey Data

The core measure used for this report is the estimated mass of fishes per unit area per site (hereafter “biomass”). Mass of individual fish was calculated using length to weight (LW) conversion parameters, and, where necessary, length-length (LL) parameters (for example, to convert TL to fork length [FL] for species with LW parameters based on FL). LW and LL conversion parameters were taken from a range of published and internet-based sources (Froese and Pauly, 2010; Kulbicki et al., 2005).

Fish Groupings and Species of Interest

Species data were pooled into “all fishes,” and into a number of trophic, taxonomic and size groupings. The four trophic groupings used were: “primary consumers” (herbivores and detritivores); “secondary consumers” (omnivores and benthic invertivores); “planktivores”; and “piscivores,” (see Appendix A for species classifications) based on diet information taken largely from FishBase (Froese and Pauly, 2010).

In addition, we examined distributions, size structures, and differences in biomass between marine preserves and areas open to fishing for "species of interest", taxa that are generally most targeted by fishing. This included all shark, jack, or emperor species, the humphead wrasse, and any additional species identified as being in the top 10 of reef species harvested in either Guam or the CNMI in a recently published study (Houk et al., 2012). We also presented family level data on groupers, goatfishes, parrotfishes, and surgeonfishes because of their general importance as fishery targets.

Pooling Site Level Data to Higher Spatial Levels

Because we used a stratified random survey design and have hierarchical spatial groupings (several marine preserves contributing to overall Guam MP values; and similarly, east and west open sectors contributing to Guam open areas overall), we calculated higher-level values (e.g., mean and variance) by first calculating those values within each depth stratum within a specific MP or open area sector and then pooling those up by using formulas taken from Smith et al., (2011), i.e.,

(1) pooled density *X* across S strata: $X = \sum_1^S (X_i * w_i)$ and

(2) pooled variance *VAR* across S strata: $VAR = \sum_1^S (VAR_i * w_i^2)$

where X_i is density within stratum *i*, VAR_i is variance within stratum *i* and w_i is the strata-weighting factor.

For example, to generate pooled values for a single MP, those formulas are applied using mean and variance of the three strata – *deep*, *mid-depth*, and *shallow* reefs, with each stratum weighted equally (each =⅓, thus total weighting across all component strata sums to 1). Depth strata were weighted equally to increase comparability between MPs and open areas, i.e., to ensure that differences between specific areas were not biased by differences in the relative amount of shallow, medium or deep habitat in each.

Similarly, to pool up individual MPs or open-sectors into pooled values for all MPs or all open areas, the same formulas are used with specific MPs or open areas in place of the strata, but weighted according to area of reefs. Thus, we have data from 4 MPs totaling 1122 ha of < 30 m deep hardbottom; Tumon Bay MP has 233 ha of hardbottom in that depth range (Table 1), and so weighting for Tumon Bay MP was 233/1122 = 20.8%.

To allow for greatest possible comparability among islands, island-scale values for other islands in the Mariana Archipelago, based on MARAMP 2011 surveys, were also pooled with depth strata weighted equally. In addition, to increase comparability among islands, we restricted all analyses to sites classified as forereef in the CRED habitat scheme (those were made up of nearly all sites surveyed in the archipelago, so only a few sites were excluded).

Calculating Quantile Ranges of Biomass Estimates and of MP: Open Biomass Ratios

For normally distributed data, it is relatively easy to calculate means and confidence intervals of biomass values or of differences between data sets. However, as is not uncommon for coral reef fish visual survey data, biomass densities of fish groups of interest were highly non-normally distributed both within depth strata and within sectors. To apply a consistent analytical approach across all fish groupings, a bootstrapping method was used to generate empirical distributions of biomass estimates and estimate their means and quantile ranges. The bootstrapping approach used for this report was very similar to that used for a recently published Pacific-wide analysis of Pacific RAMP survey data (Williams et al., 2011). More detail is also given in Appendix B.

To provide a statistical basis for assessing differences between MPs and open areas around Guam, biomass ratios were also calculated for each fish group of interest as the overall biomass in MPs divided by overall biomass in open fishing areas, with overall biomass weighted by habitat area, as described above. The bootstrapping approach was applied to the biomass ratios to estimate means and quantile ranges. The 95% quantile range [95%QR] includes all values that lie between the 2.5% and the 97.5% quantiles, i.e., within the middle 95% of the bootstrap distribution between these cutoff values. We calculated both 80% and 95% quantile ranges for biomass ratios to allow for interpretation of strength of evidence of differences. If a given quantile range does not overlap 1, this is interpreted as evidence of a difference in biomass between MPs and open areas at that level of confidence (80% or 95%). Specifically, if the lower cutoff of a quantile range of the MP:open biomass ratio is > 1, this is evidence that biomass is *higher* in MPs, and similarly, if the upper cutoff of a quantile range is < 1, this is evidence of *lower* biomass in MPs.

Analyses were performed using the R statistical program version 2.13.1 (R Development Core Team, http://www.r-project.org).

RESULTS AND DISCUSSION

Overview of Reef Benthos

Benthic cover derived from visual estimates made by survey divers indicated substantial variability among sites, with estimated coral cover varying from 0.5% to 72.5% and macroalgal cover ranging from 1.0% to 87.5% (Fig. 3). However, there were no clear differences in any measure of benthic cover between MPs overall and either Guam East or Guam West open sectors (Table 2). For example, coral cover within MPs overall was 20.9% (SE 1.8) nearly identical to cover in the two Guam open sectors: Guam West coral cover was estimated at 20.8% (SE 1.9) and Guam East open sector cover was 21.2% (SE 3.4) (Table 2). Similarly, mean cover values for CCA, macroalgae and turf algae, as well as mean site depths and estimated complexity were nearly identical in MP and open areas overall (Table 2).

Reefs across a large portion of the southwest coast of Guam, including nearly all those south of Facpi Point, appeared to have been impacted by sedimentation. At nearly all sites surveyed there, water seemed turbid compared to other sites around the island, and substantial amounts of fine sediment were evident. Well-developed, three-dimensional reef structure seemed to indicate previous healthy growth of corals on many of those reefs, but at the time of our surveys coral cover was generally low (< 10% on most reefs) and reef benthos was dominated by macro- and turf-algae. As a result, the benthic substrate ratio (ratio of accreting versus non-accreting cover) was notably very low along that stretch of coastline (Fig. 3). Results of these surveys, therefore, tend to corroborate concerns about sedimentation impacts on southern and southwestern Guam expressed in the 2008 Guam state of the reefs report (Burdick et al., 2008).

Table 2.--Habitat characteristics of survey sites in marine preserves and open sectors. Complexity and benthic cover for corals, crustose coralline algae, macroalgae and sand are visually estimated by divers within survey cylinders on completion of a fish survey.

Marine Preserve /Sector		Habitat Characteristics: **Mean** (SE)					
	# Sites	**Depth (m)**	**Complexity**[1]	**Coral%**	**CCA%**	**Macro%**	**Sand%**
West Open	67	**12.7** (0.4)	**2.1** (0.1)	**20.8** (1.9)	**7.7** (0.9)	**25.3** (2.4)	**5.4** (0.9)
East Open	18	**13.5** (0.7)	**2.1** (0.2)	**21.2** (3.4)	**10.3** (1.8)	**25.0** (4.4)	**2.8** (0.7)
Pati Point MP	20	**13.8** (0.6)	**1.9** (0.2)	**21.9** (3.2)	**8.5** (1.8)	**24.0** (2.6)	**2.9** (0.9)
Tumon Bay MP	13	**13.7** (1.0)	**2.6** (0.2)	**20.5** (3.7)	**12.7** (3.2)	**13.8** (1.8)	**2.8** (0.6)
Piti Bomb Holes MP	10	**13.5** (0.5)	**1.9** (0.2)	**13.4** (2.0)	**6.4** (1.2)	**35.9** (3.5)	**5.3** (0.8)
Achang Reef Flat MP	5	**8.4** (1.5)	**2.1** (0.4)	**27.3** (4.8)	**11.0** (0.8)	**24.2** (1.7)	**4.2** (2.1)
Total Open	***85***	***12.9*** *(0.3)*	***2.1*** *(0.1)*	***21.0*** *(1.7)*	***8.6*** *(0.8)*	***25.2*** *(2.2)*	***4.5*** *(0.6)*
Total MP	***48***	***12.7*** *(0.4)*	***2.1*** *(0.1)*	***20.9*** *(1.8)*	***9.4*** *(1.0)*	***24.4*** *(1.4)*	***3.6*** *(0.6)*

Note ([1]) Complexity within survey cylinders is visually estimated by divers on a 6-point scale, from 1 = very low to 6 = very high.

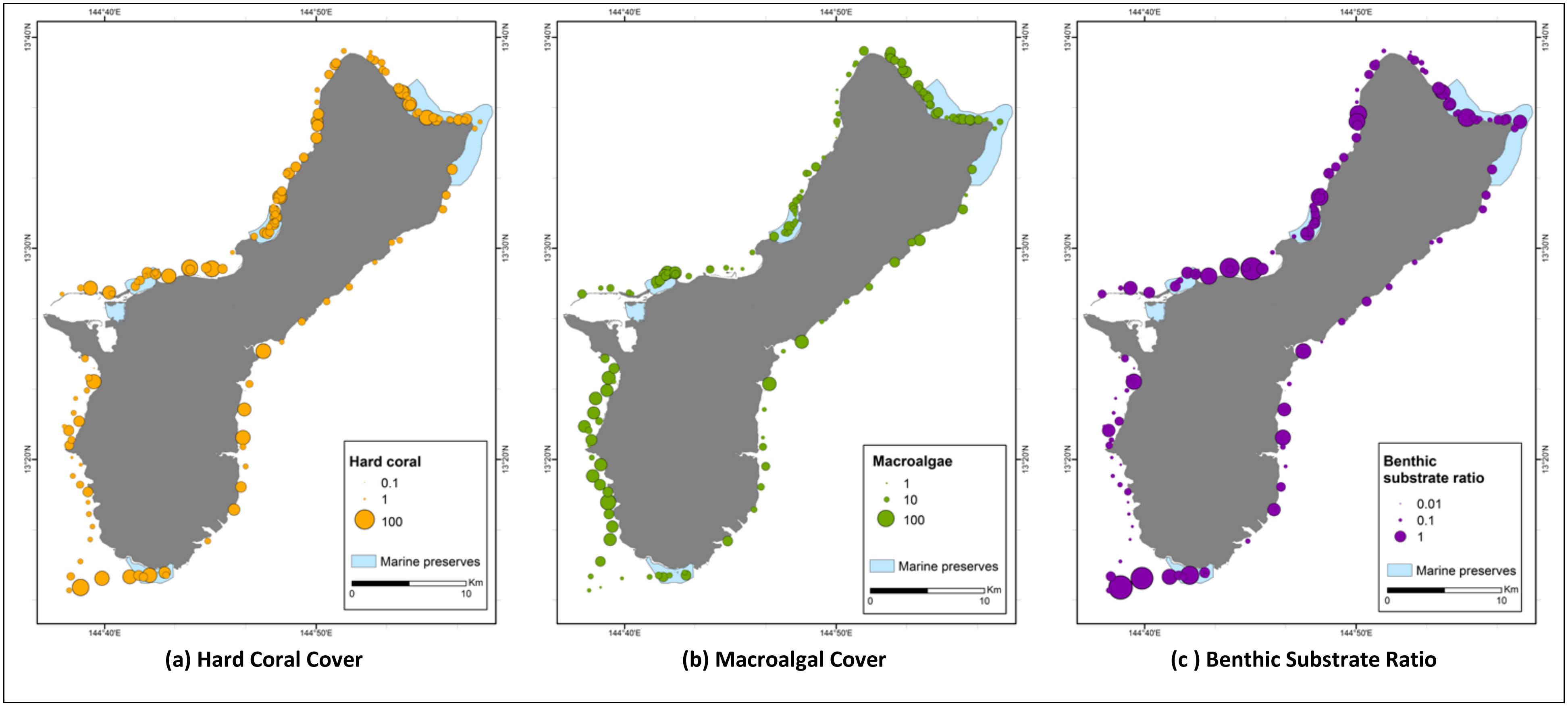

Figure 3.--Benthic Data. Benthic cover (%) per site for hard coral (a) and macroalgae (b), based on cover estimates within survey cylinders made by divers. Benthic substrate ratio (c) (Houk et al., 2010) is the sum of accreting cover (coral and crustose coralline algae) divided by the sum of non-accreting cover (turf and macroalgae); higher ratios, therefore, indicate reefs with substrate dominated by accreting organisms, whereas low ratios indicate sites where benthos is dominated by organisms that do not contribute to reef structural growth.

Reef Fish Assemblages

Total Biomass

Total fish biomass at the 133 surveyed sites varied between 2.1 g/m^2 and 369.7 g/m^2 (Fig. 4). Total biomass was very right-skewed, i.e., there were many sites with relatively low-to-moderate biomass and rather few at the high end of the scale; and the median value, i.e., the level at which half of sites had lower biomass and half of sites had higher biomass, was 20.6 g/m^2 (Figs. 4 and 5).

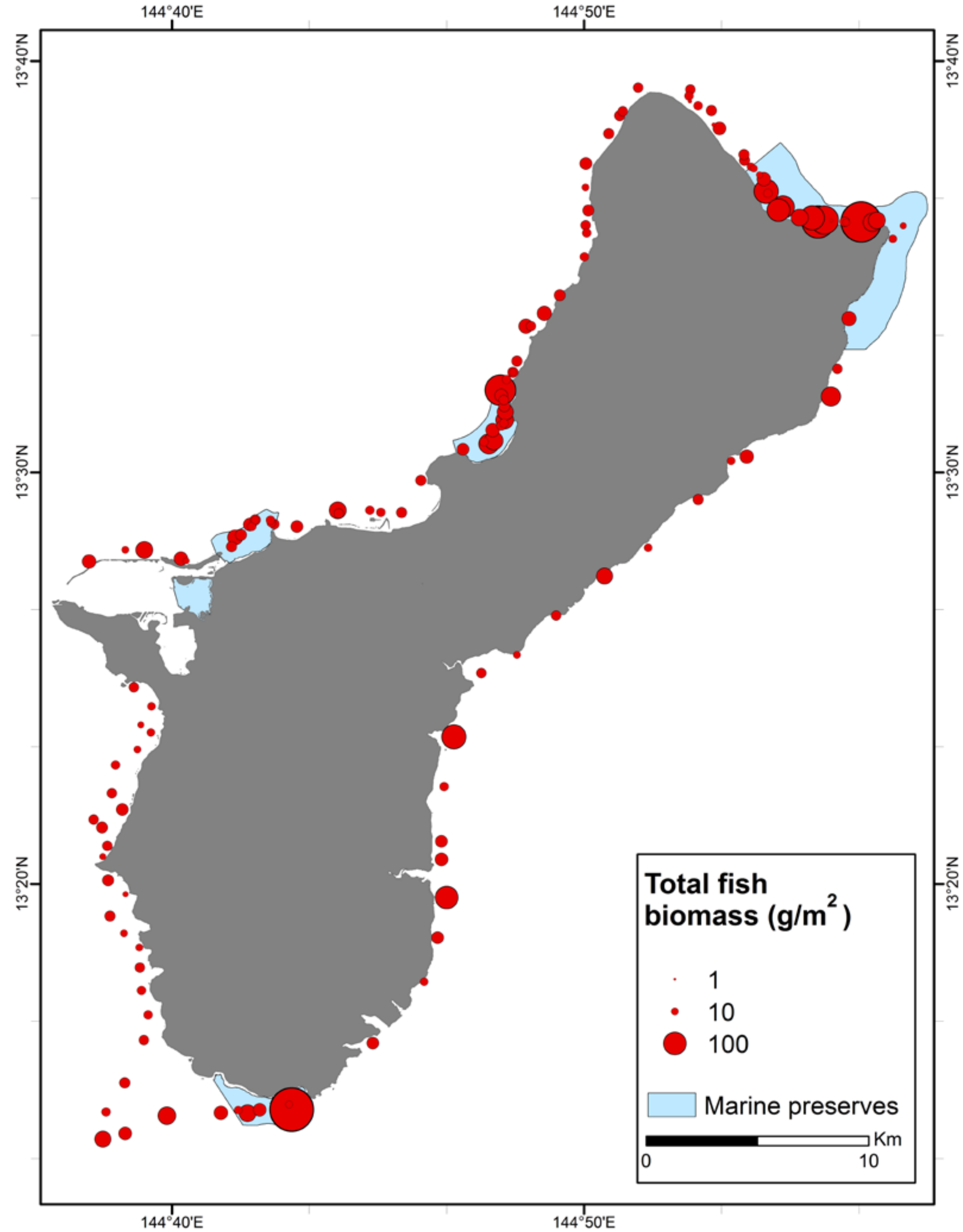

Figure 4.--Total fish biomass per survey site.

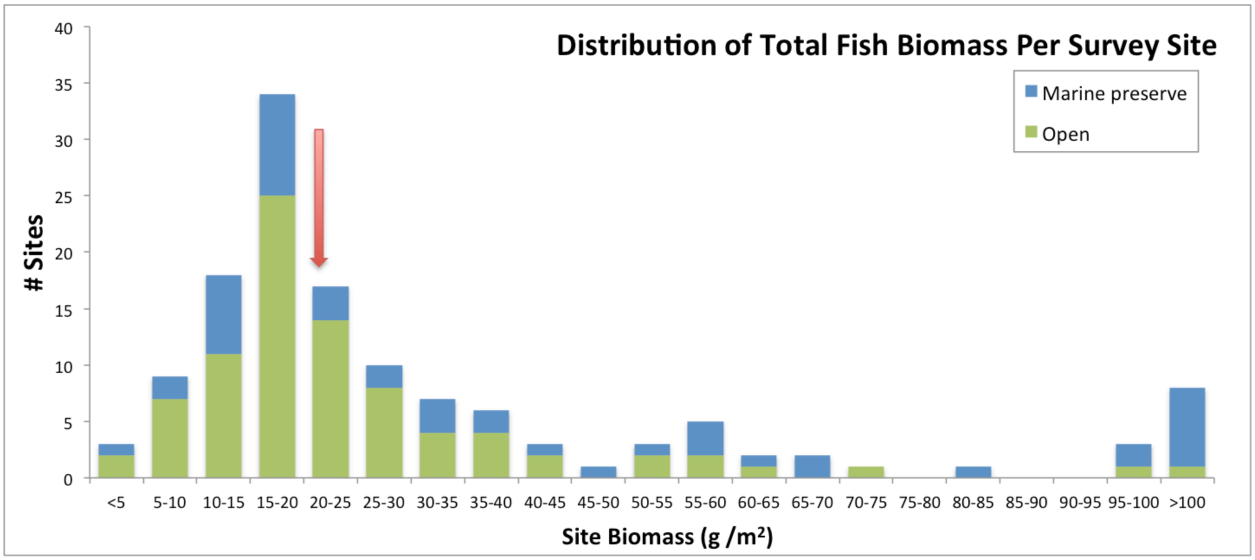

Figure 5.--Distribution of total fish biomass per site. Red arrow represents the median sites biomass of 20.6 g/m^2.

A majority of the highest biomass sites, including 15 of the top 20 were within MPs. This includes the 6 sites with highest biomass of those surveyed: 4 sites in Pati Point MP, 1 in Achang Reef Flat MP, and 1 in Tumon Bay MP (Figs. 4 and 5). In spite of many fewer open sites available on the east coast than on the west coast, the three open sites with highest biomass were all on the east coast of the island (Fig. 4).

Overall, the bootstrap mean total fish biomass in Guam MPs was 66.0 g/m^2 [95% quantile range (95%QR): 42.0 – 90.1 g/m^2]. In contrast, mean total fish biomass at Guam Open sites was 27.2 g/m^2 [95%QR: 23.0 – 31.8] (Fig. 6A). The MP:open biomass ratio of 2.4 [95%QR of 1.5 to 3.5] is equivalent to saying that our best estimate is that total fish biomass within MPs was 2.4 times that at open areas, and that we have 95% confidence that the interval [1.5–3.5] brackets the true MP:open ratio (Fig. 6B, rightmost panel). This result, therefore, represent a high degree of statistical confidence that biomass was higher within MPs.

The very narrow quantile ranges of total biomass at the Guam West open sites (Fig. 6A) reflect the fact that biomass varied relatively little among those sites. Only 6 of 67 of the Guam West open sites had total biomass > 40 g/m^2, and the highest biomass at any Guam West open site was 61.0 g/m^2 (Fig. 4), which was less than the mean of Guam MP sites.

As noted above, biomass tended to be higher at open sites on the east coast than at open sites on the west coast: Guam East mean biomass was 37.6 g/m^2 [95%QR: 26.5 - 49.8], whereas Guam West total biomass was 21.7 g/m^2 [95%QR: 19.2 - 24.3] (Figs. 4 and 6A). Guam MP:open biomass ratios were 3.0 [95%QR: 1.9 - 4.3] for Guam West open sites, and 1.8 [1.01-2.9] for Guam East open sites, indicating statistically higher biomass in MPs than in either Guam East or Guam West separately (Fig. 6B).

More detailed data on biomass by location and marine preserve are given in Appendix C.

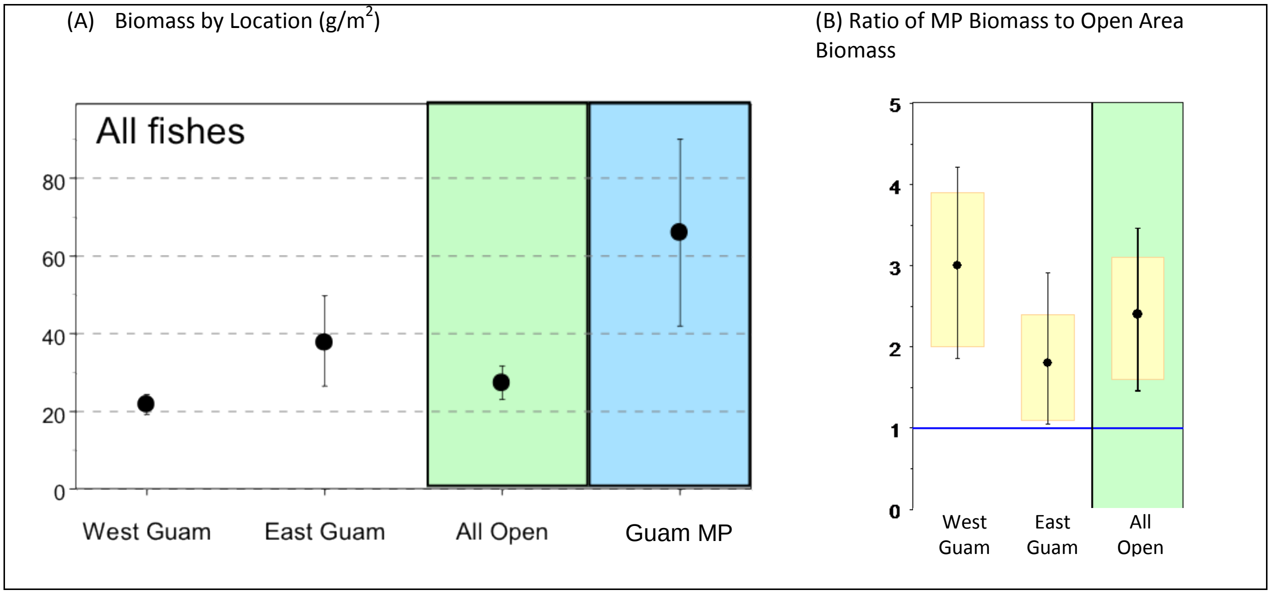

Figure 6.--Biomass per location, and differences between marine preserves and open areas. (A) Mean and 95% quantile range of biomass per location; (B) ratio of biomass between Guam MP:Guam Open areas for total fish biomass. Values represent mean and quantile ranges (yellow box = 80% range; errors bars are 95% range) of the ratio of biomass within MPs compared to biomass in open areas. The blue horizontal line represents a ratio of 1 (i.e., no difference in biomass between MP and open). In all three cases, the quantile ranges are completely above the blue line, indicating significantly higher biomass in MPs than in open areas.

Fish Biomass by Consumer Group

Consumer group classifications are given in Appendix A. In brief, ‘primary consumers’, are herbivores and detritivores (including most, and largely made up of, surgeonfishes and parrotfishes); ‘secondary consumers’ are species that are largely omnivorous or feed on invertebrates, and includes most wrasse, butterflyfish, triggerfish and filefishes; ‘planktivores’ include several unicornfishes, fusiliers, and several soldierfishes; and ‘piscivores’ are fishes that feed primarily on other fish, and include most jacks, groupers, emperors, barracuda and sharks, as well as smaller piscivores such as moray eels and lizardfishes.

Biomass, MP:open biomass ratios, and quantile ranges, are shown in Figure 7. For primary consumers, planktivores, and piscivores, mean biomass was higher in MPs than in Guam open areas overall, but the extent of the difference between MP and open area biomass varied considerably among those groups. Planktivores and primary consumers had around twice the biomass in MPs compared to open areas (biomass ratios of 1.7 [95%QR: 1.04–2.7] and 2.0 [95%QR: 1.3–2.8], respectively), but the MP:open biomass ratio was much larger for piscivores (6.8 [95%QR: 1.2–17.6], Fig. 7B). As piscivores include large-bodied species that tend to be rarely encountered during surveys (e.g., sharks, jacks) and/or which can be recorded in large aggregations during surveys (e.g., barracuda), it is not unusual for this functional group that there was a large degree of uncertainty about the absolute scale of difference between MP and open areas. There was no significant difference between MP and open areas for secondary consumers (biomass ratio of 1.3 [95%QR: 0.9–2.0]).

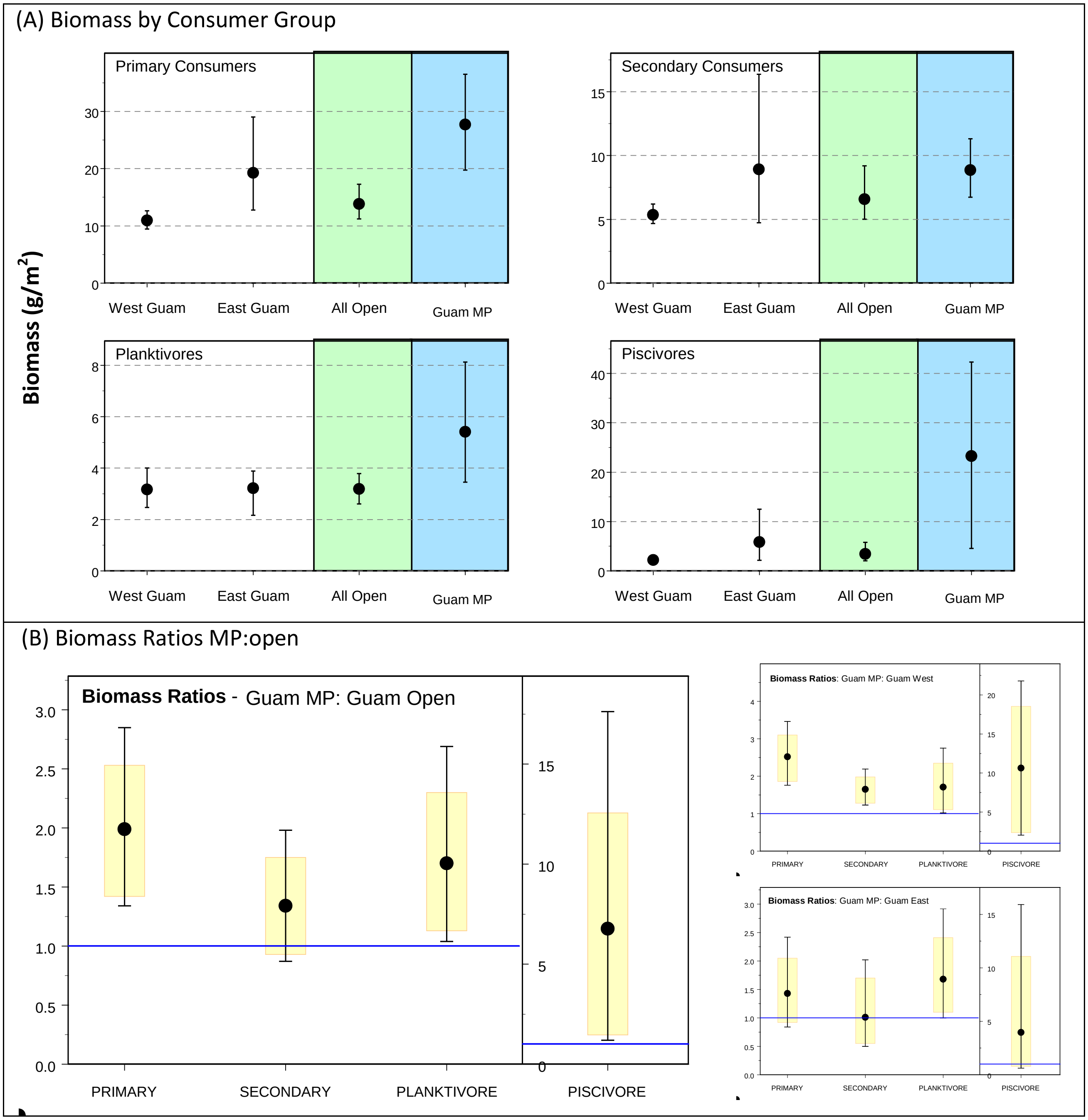

Figure 7.--Biomass and MP:open biomass ratios by consumer group (consumer group classifications are given in Appendix 1). Symbols and reference lines as in Figure 6.

As noted above, biomass tended to be higher at open sites on the east side of the island than at open sites on the west side (Figs. 4 and 7A). Although mean biomass was higher within MPs than in Guam-East open sites for primary consumers, planktivores and piscivores (biomass ratios of 1.4, 1.7 and 4.0 respectively), 80% and 95%QR overlap 1 for primary consumers and piscivores, indicating that the differences were only statistically significant for planktivores (Fig. 7B, lower graph in right panel). In contrast, biomass was higher in all consumer groups in Guam MPs than in Guam West open sites (Fig. 7B, upper graph in right panel).

Fish Biomass by Family

Biomass of surgeonfishes and parrotfishes was significantly higher in MPs than in Guam open areas overall (biomass ratios being 1.5 [95%QR:1.05–2.1] and 2.6 [95%QR: 1.6–4.3] respectively, Figs. 8 and 9). Differences between marine preserves and open areas were particularly clear for parrotfishes, with 9 of the 10 sites with highest parrotfish biomass being within MPs (6 in Pati Point MP, 2 in Tumon Bay MP, and one in Achang Reef Flat MP, Fig. 9), For other families analyzed, i.e., goatfishes, groupers, snappers, and emperors, biomass tended to be higher in MPs (biomass ratio of 1.4–1.5 for all families) but 80% and 95%QRs overlapped 1 in all cases, meaning that differences were not statistically significant (Fig. 8).

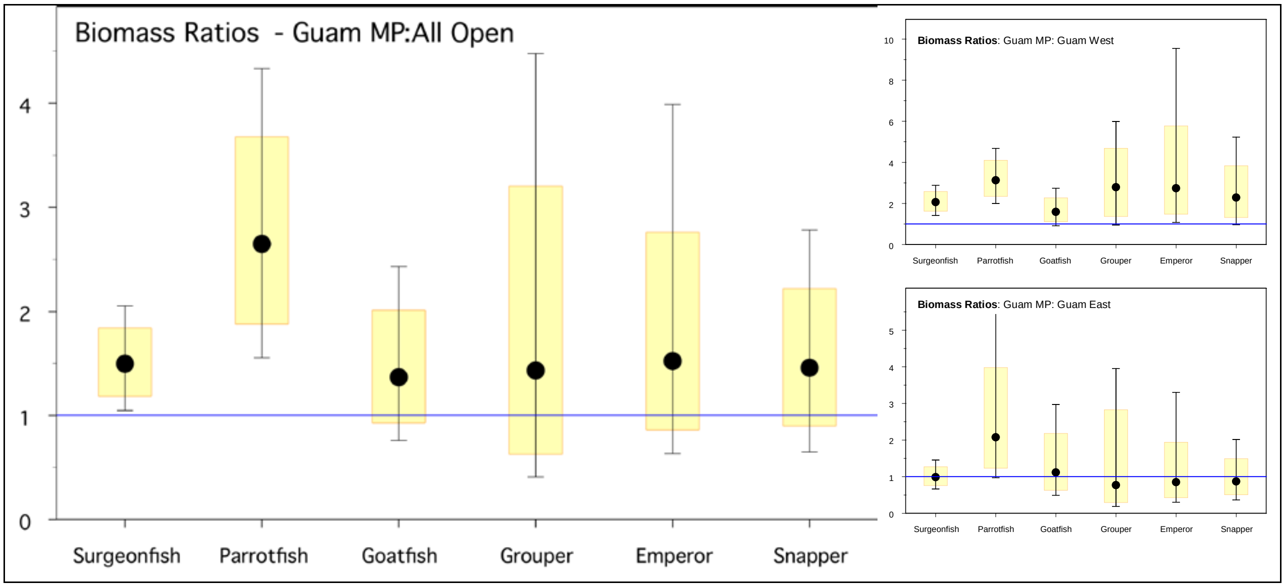

Figure 8.--Biomass ratio Guam MP:Guam Open areas by fish family. Symbols and reference lines as in Figure 6.

As with the majority of other ways we have pooled the data, family-level biomass tended to be higher at Guam East open sites than at Guam West open sites. Thus, biomass at Guam MP was significantly higher than at Guam West open sites for all families at the 80% level or above (95% for surgeonfishes, parrotfishes, and emperors; 80% for goatfishes, groupers, and snappers, biomass ratios ranging from 1.6 to 3.1); Figure 8, upper graph in right panel. But the only statistically significant difference between MPs and Guam East open sites was at the 80% level for parrotfishes (biomass ratio 2.1 [80%QR: 1.2–4.0]); Figure 8, lower graph in right panel. For other families, i.e., surgeonfishes, goatfishes, groupers, snappers, and emperors, there was considerable overlap between MP and Guam East open sites, with biomass ratios for those groups ranging from 0.8 to 1.1 (Fig. 8).

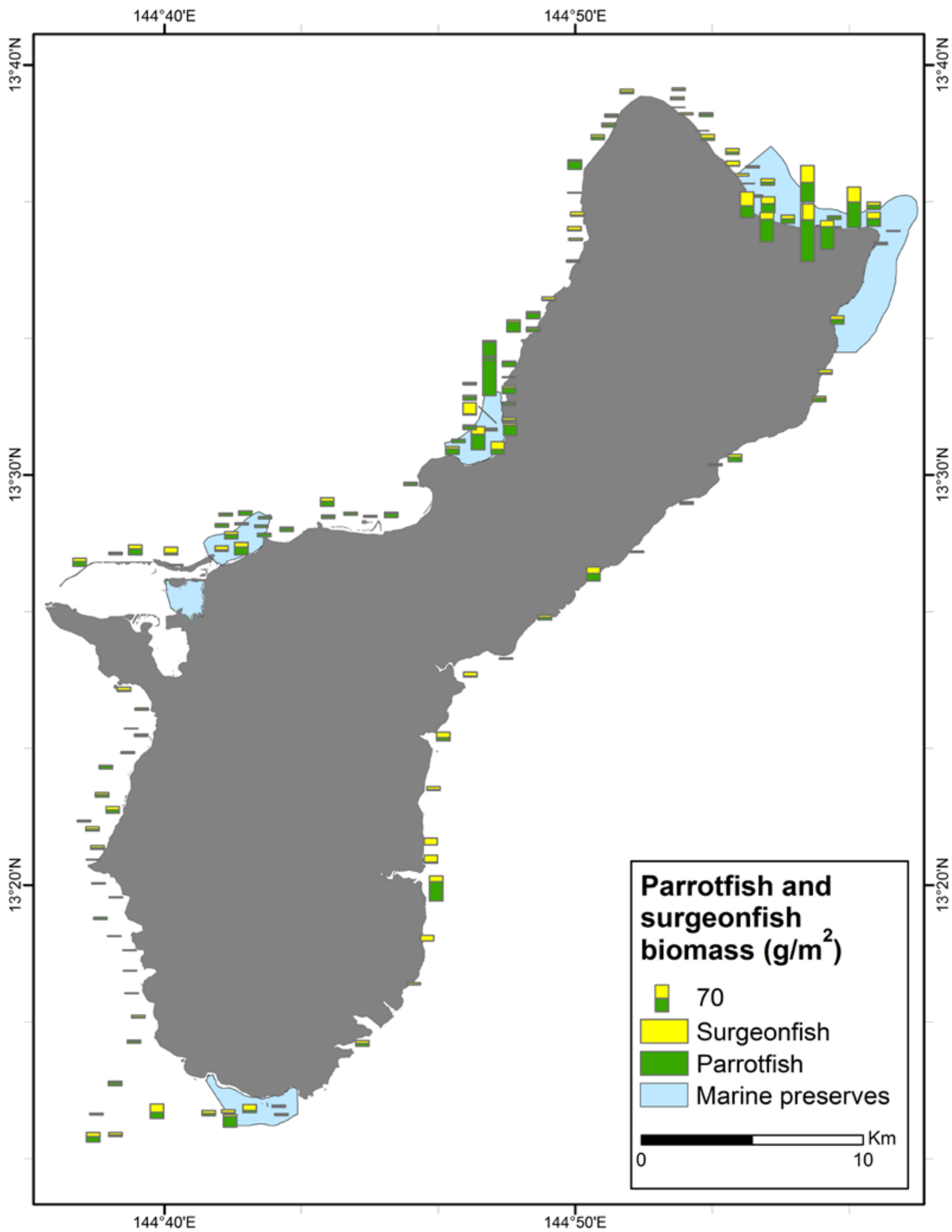

Figure 9.--Total estimated biomass of parrotfishes and surgeonfishes per survey site.

As shown in Figure 9, parrotfish and surgeonfish biomass was consistently low at all sites in the southwest portion of Guam where, as we noted above, reef benthos was dominated by turf and macroalgae with relatively low proportions of coral and CCA (Fig. 3). Low biomass of herbivores in that part of the island could be either a cause or a symptom (or both) of the relative domination of those reefs by non structure-forming algae.

Infrequently Encountered Fish Species of Interest

There were several species of interest that were encountered too seldom for statistical analysis. The numbers of encounters with some of those species, including all sharks, jacks, *Lethrinus* emperors, large-bodied groupers, the humphead wrasse (*Cheilinus undulatus*), and large-bodied parrotfishes are shown in Figure 10. Many of these species were encountered more frequently at sites in the Pati Point MP than elsewhere, including both instances in which a shark was recorded during surveys (one gray reef shark, *Carcharhinus amblyrhynchos*, and one blacktip reef shark, *C. melanopterus*). Similarly, three of the five sites at which humphead wrasse were recorded during surveys were in the Pati Point MP, as were 7 of 10 times a jack species was recorded, and 3 of the 7 times that a lyretail grouper (*Variola louti*) was recorded (Fig. 10).

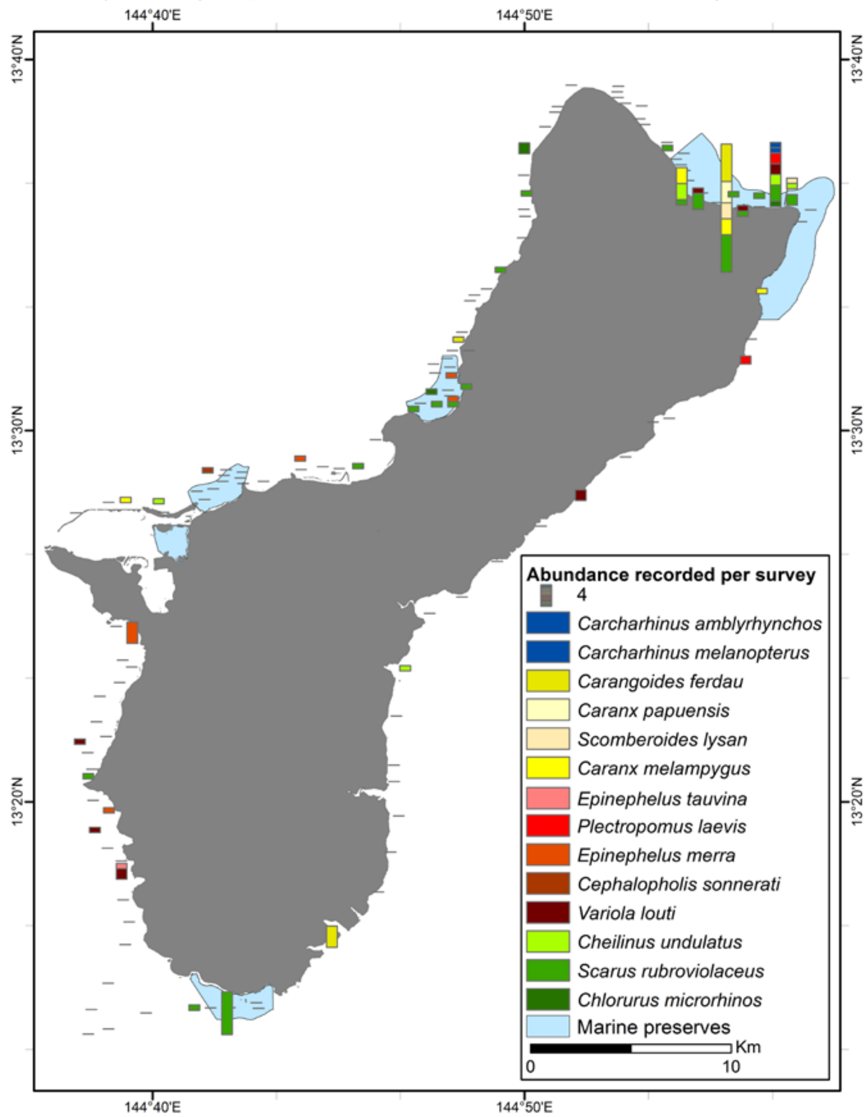

Figure 10.--Abundance of certain species of interest seldom encountered during the surveys. Abundance values are number of fish recorded per pair of adjacent SPC-cylinders per site, each cylinder having a diameter of 15 m. Species shown are all sharks, jacks, *Lethrinus* emperors, large-bodied groupers, humphead wrasse (*Cheilinus undulatus*), and large-bodied parrotfishes.

Size Distribution of Target Species Inside and Outside of Guam Marine Preserves

Size distributions of target species in and outside of Guam MPs are shown in Figure 11. Target species in this case are defined as all species highlighted as significant contributors to reef fish catch in either Guam or CNMI in a recently published study (Houk et al., 2012). Those were made up of 20 taxa: 8 species of parrotfishes (*Chlorurus frontalis, C. sordidus, C. microrhinos, Hipposcarus longiceps, Scarus altipinnis, S. forsteni, S. schlegeli, S. rubroviolaceus*); 5 species of surgeonfishes (*Acanthurus lineatus, A. triostegus, A. xanthopterus, Naso lituratus, N. unciornis*), 3 species of emperor (*Lethrinus harak, L. olivaceus, Monotaxis grandoculis*), 1 grouper (*Epinephelus merra*), 1 rabbitfish (*Siganus spinus*), 1 jack (*Caranx melampygus)*, and the species-cluster *Kyphosus* spp.

For nine of those species/clusters (*C. microrhinos, H. longiceps, A. xanthopterus, L. harak, Kyphosus* spp., *L. olivaceus, E. merra, S. spinus, C. melampygus*) we had very few encounters (< 25 fish of that species recorded in total), too few to support a size composition plot, but for all others, biomass by size category (5 cm slots) for marine preserves and open areas is shown in Figure 11, with data weighted by habitat area as described in the Methods section. For Figure 11, we added data for another species, the peacock grouper, *Cepholopholis argus*, as that was the largest grouper that was at all abundant in the surveys.

At this taxonomic level there were insufficient data for rigorous statistical analysis, but it was notable that for 11 of 12 species in this category, estimated mean biomass in MPs was higher than estimated mean biomass in open areas (Fig. 11). Archipelagic biomass patterns for target species are shown in Appendix D.

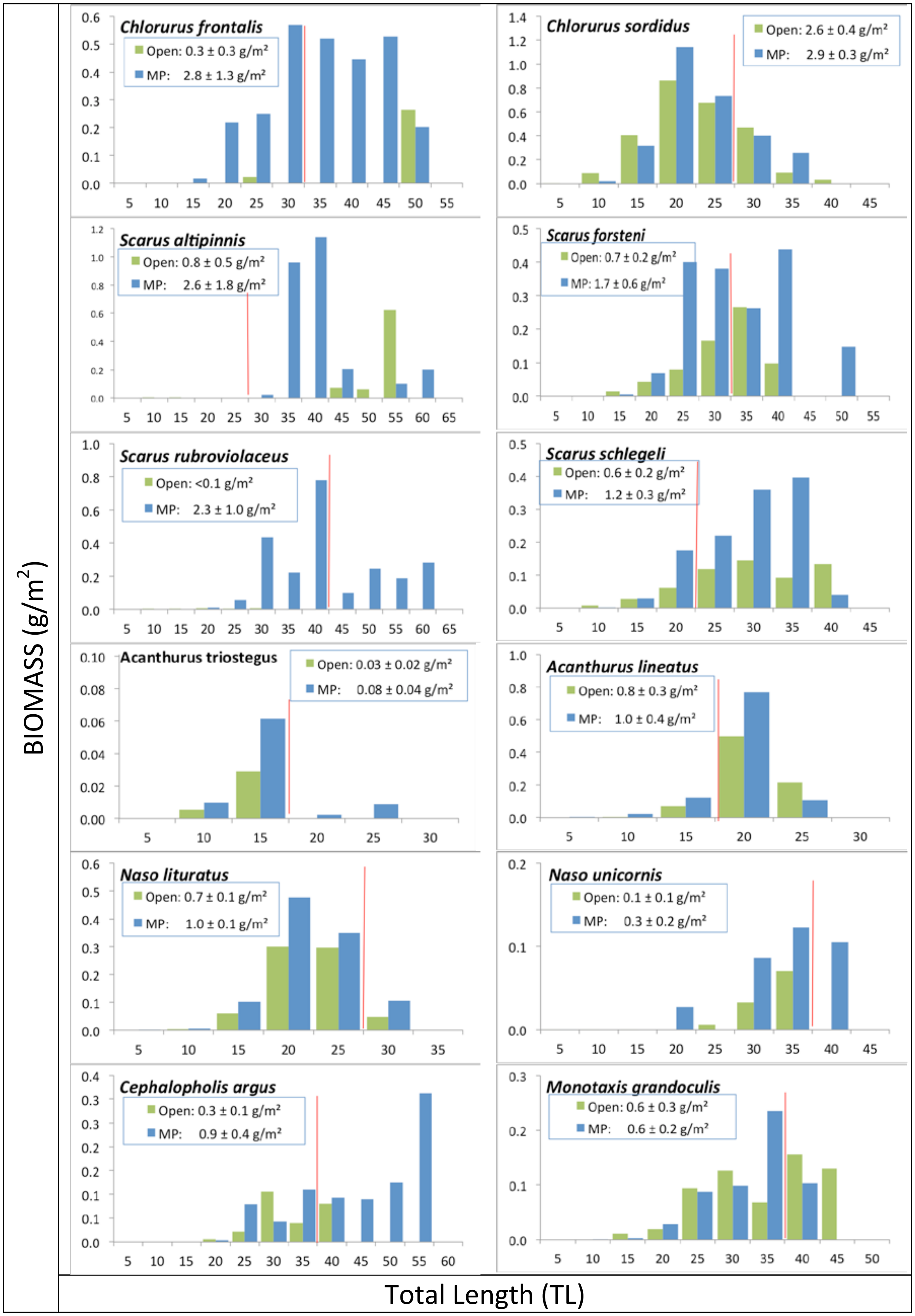

Figure 11.--Biomass by size class of target species in and out of Marine Preserves in Guam. Size on *x*-axes is upper limit of 5 cm slots (i.e., 5 cm is fishes of size 1–5 cm; 10 cm is fishes of size 6–10 cm). Red vertical bars are mean length at first maturity, taken from the FishBase Life-History tool (www.fishbase.org), rounded to nearest 5 cm to fit pooling of size data. Data in insets are mean +/- standard error of biomass for that species in MPs and open areas.

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APPENDIX A. Consumer Group Species

Fishes were categorized into four functional trophic groups: **primary consumers** (herbivores and detritivores); **secondary consumers** (omnivores and benthic invertivores); **planktivores**; and **piscivores**. Because diets of species change ontogenetically and with environment, and because there are few comprehensive diet studies of many coral reef fish species, it is difficult to develop more sophisticated trophic categorization. However, these broad and robust groupings are consistent with classifications used for other studies and by CRED for previous reports (Williams et al., 2011; DeMartini et al., 2008; Williams et al., 2008; Friedlander et al., 2010).

Primary Consumers (herbivores and detritivores; includes most surgeonfish and parrotfish, plus smaller primary herbivores such as pygmy angels, and sharpnose puffers, herbivorous damselfish, and others) *Acanthurus blochii, Acanthurus guttatus, Acanthurus lineatus, Acanthurus nigricans, Acanthurus nigricauda, Acanthurus nigrofuscus, Acanthurus nigroris, Acanthurus olivaceus, Acanthurus pyroferus, Acanthurus triostegus, Acanthurus xanthopterus, Ctenochaetus binotatus, Ctenochaetus cyanocheilus, Ctenochaetus hawaiiensis, Ctenochaetus striatus, Naso brachycentron, Naso lituratus, Naso tonganus, Naso unicornis, Zebrasoma flavescens, Zebrasoma scopas, Zebrasoma veliferum, Melichthys vidua, Cirripectes variolosus, Chaetodon mertensii, Chaetodon semeion, Amblygobius phalaena,* Kyphosidae spp., *Cantherhines pardalis, Centropyge flavissima, Centropyge heraldi, Centropyge shepardi, Centropyge vrolikii, Abudefduf septemfasciatus, Abudefduf sordidus, Chromis amboinensis, Chrysiptera biocellata, Chrysiptera brownriggii, Chrysiptera glauca, Chrysiptera traceyi, Plectroglyphidodon leucozonus, Plectroglyphidodon phoenixensis, Stegastes albifasciatus, Stegastes fasciolatus, Stegastes nigricans, Calotomus carolinus, Cetoscarus ocellatus, Chlorurus frontalis, Chlorurus microrhinos, Chlorurus sordidus, Hipposcarus longiceps, Scarus altipinnis, Scarus dimidiatus, Scarus festivus, Scarus forsteni, Scarus frenatus, Scarus fuscocaudalis, Scarus globiceps, Scarus oviceps, Scarus psittacus, Scarus rubroviolaceus, Scarus schlegeli, Siganus argenteus, Siganus punctatus, Siganus spinus, Canthigaster amboinensis, Canthigaster coronata, Canthigaster epilampra, Canthigaster janthinoptera, Canthigaster solandri*
Secondary Consumers (omnivores and invertivores; includes most wrasse, butterflyfish, goatfish, triggerfish, filefish, pufferfish, hawkfish, snapper, several soldierfish and squirrelfish) *Cheilodipterus artus, Cheilodipterus quinquelineatus, Balistapus undulatus, Balistoides conspicillum, Balistoides viridescens, Rhinecanthus rectangulus, Sufflamen bursa, Sufflamen chrysopterum, Aspidontus taeniatus, Exallias brevis, Plagiotremus laudandus, Plagiotremus tapeinosoma, Bothus mancus, Caracanthus maculatus, Chaetodon auriga, Chaetodon bennetti, Chaetodon citrinellus, Chaetodon ephippium, Chaetodon lineolatus, Chaetodon lunula, Chaetodon lunulatus, Chaetodon melannotus, Chaetodon meyeri, Chaetodon ornatissimus, Chaetodon pelewensis, Chaetodon punctatofasciatus, Chaetodon quadrimaculatus, Chaetodon reticulatus, Chaetodon trifascialis, Chaetodon ulietensis, Chaetodon unimaculatus, Forcipiger flavissimus, Forcipiger longirostris, Heniochus chrysostomus, Heniochus monoceros, Heniochus singularius, Amblycirrhitus bimacula, Cirrhitichthys falco, Cirrhitus pinnulatus, Neocirrhites armatus, Paracirrhites arcatus, Valenciennea strigata, Plectorhinchus picus, Myripristis violacea, Neoniphon opercularis, Neoniphon sammara, Sargocentron caudimaculatum, Sargocentron diadema, Sargocentron microstoma, Sargocentron spiniferum, Sargocentron tiere, Anampses caeruleopunctatus, Anampses meleagrides, Anampses twistii, Bodianus axillaris, Cheilinus chlorourus, Cheilinus fasciatus, Cheilinus oxycephalus, Cheilinus trilobatus, Cheilinus undulates, Cheilio inermis, Coris aygula, Coris gaimard, Epibulus insidiator, Gomphosus varius, Halichoeres biocellatus, Halichoeres hortulanus, Halichoeres margaritaceus, Halichoeres marginatus, Halichoeres ornatissimus, Halichoeres trimaculatus, Hemigymnus fasciatus, Hemigymnus melapterus, Hologymnosus annulatus, Hologymnosus doliatus, Labroides bicolor, Labroides dimidiatus, Labroides pectoralis, Labropsis xanthonota, Macropharyngodon meleagris, Novaculichthys taeniourus, Oxycheilinus bimaculatus, Pseudocheilinus evanidus, Pseudocheilinus hexataenia, Pseudocheilinus octotaenia, Pseudocheilinus tetrataenia, Pseudodax moluccanus, Pseudojuloides atavai, Pseudojuloides cerasinus, Pteragogus enneacanthus, Stethojulis strigiventer, Thalassoma lutescens, Thalassoma purpureum, Thalassoma quinquevittatum, Thalassoma trilobatum, Gnathodentex aureolineatus, Lethrinus harak, Monotaxis grandoculis, Lutjanus fulvus, Lutjanus gibbus, Lutjanus kasmira, Hoplolatilus starcki, Malacanthus brevirostris, Malacanthus latovittatus, Amanses scopas, Cantherhines dumerilii, Paraluteres prionurus, Pervagor janthinosoma, Mulloidichthys flavolineatus, Mulloidichthys vanicolensis, Parupeneus barberinus, Parupeneus insularis, Parupeneus multifasciatus, Parupeneus pleurostigma, Scolopsis lineatus, Ostracion meleagris, Parapercis clathrata, Parapercis millepunctata, Apolemichthys trimaculatus, Centropyge multifasciata, Pomacanthus imperator, Pygoplites diacanthus, Amblyglyphidodon curacao, Plectroglyphidodon dickii, Plectroglyphidodon imparipennis, Plectroglyphidodon johnstonianus, Pterois antennata, Belonoperca chabanaudi, Grammistes sexlineatus, Arothron hispidus, Arothron meleagris,*

Arothron nigropunctatus, Zanclus cornutus
Planktivores *Acanthurus nubilus, Acanthurus thompsoni, Naso brevirostris, Naso hexacanthus, Naso vlamingii, Pseudanthias pascalus, Apogon angustatus, Apogon fraenatus, Apogon novemfasciatus, Canthidermis maculata, Melichthys niger, Odonus niger, Xanthichthys auromarginatus, Blenniella chrysospilos, Ecsenius bicolor, Ecsenius opsifrontalis, Meiacanthus atrodorsalis, Caesio teres, Pterocaesio marri, Pterocaesio tile, Decapterus macarellus, Chaetodon kleinii, Hemitaurichthys polylepis, Myripristis amaena, Myripristis berndti, Myripristis kuntee, Cirrhilabrus katherinae, Pseudocoris yamashiroi, Stethojulis bandanensis, Thalassoma amblycephalum, Thalassoma hardwicke, Macolor macularis, Macolor niger, Pempheris oualensis, Abudefduf sexfasciatus, Abudefduf vaigiensis, Amphiprion chrysopterus, Amphiprion clarkii, Amphiprion melanopus, Amphiprion perideraion, Chromis acares, Chromis agilis, Chromis alpha, Chromis margaritifer, Chromis vanderbilti, Chromis xanthura, Dascyllus reticulatus, Dascyllus trimaculatus, Plectroglyphidodon lacrymatus, Pomacentrus vaiuli, Pomachromis guamensis, Nemateleotris magnifica, Ptereleotris evides, Ptereleotris heteroptera, Ptereleotris microlepis, Ptereleotris zebra*
Piscivores (includes sharks, large jacks, mackerel, tuna, most groupers, some larger snappers and emperors, moray eels, assorted smaller piscivores such as lizardfishes, trumpetfish, and others) *Aethaloperca rogaa, Aphareus furca, Aprion virescens, Aulostomus chinensis, Carangoides ferdau, Carangoides orthogrammus, Caranx lugubris, Caranx melampygus, Caranx papuensis, Caranx sexfasciatus, Caranx* sp.*, Carcharhinus amblyrhynchos, Carcharhinus melanopterus, Cephalopholis argus, Cephalopholis leopardus, Cephalopholis sexmaculata, Cephalopholis sonnerati, Cephalopholis spiloparaea, Cephalopholis urodeta, Cheilodipterus macrodon, Elagatis bipinnulata, Epinephelus fasciatus, Epinephelus hexagonatus, Epinephelus howlandi, Epinephelus macrospilos, Epinephelus maculatus, Epinephelus melanostigma, Epinephelus merra, Epinephelus* sp.*, Epinephelus tauvina, Fistularia commersonii, Gracila albomarginata, Grammatorcynus bilineatus, Gymnosarda unicolor, Gymnothorax flavimarginatus, Gymnothorax javanicus, Gymnothorax meleagris, Gymnothorax* sp.*, Lethrinus olivaceus, Lethrinus xanthochilus, Lutjanus bohar, Lutjanus monostigma, Lutjanus semicinctus, Nebrius ferrugineus, Oxycheilinus digramma, Oxycheilinus unifasciatus, Paracirrhites forsteri, Paracirrhites hemistictus, Parupeneus cyclostomus, Plectropomus laevis, Pogonoperca punctata, Scomberoides lysan, Scorpaenopsis diabolus, Scorpaenopsis* sp.*, Serranidae* sp.*, Sphyraena helleri, Sphyraena qenie, Synodontidae* sp.*, Synodus binotatus, Synodus variegatus, Trachinotus baillonii, Triaenodon obesus, Tylosurus crocodilus, Variola louti*

APPENDIX B. Bootstrapping Approach to Estimate Quantile Ranges

Bootstrapping involves repeated resampling with replacement from an existing data set, in this case, from the biomass densities of all sites within a stratum, to generate pseudo samples of the same size as the original data set (Henderson, 2005). Multiple such bootstrap samples provide the basis for calculating distribution statistics and drawing inferences based on the empirical distribution of the survey data, rather than assumptions about the form of that distribution, such as assuming that the data are normally distributed.

To illustrate this, for an island with *m* strata there are *m* data sets – one for each strata, each set being a random sample consisting of all sites in that strata. For a stratum *i* with *n* samples, the original data set (e.g., a variable such as biomass) can be represented as $X^i = (x_1^i, x_2^i, x_3^i, .., x_n^i)$. Random resampling of that data set with replacement gives a bootstrap sample also of length *n*: $X^{i*} = (x_1^{i*}, x_2^{i*}, x_3^{i*}, .., x_n^{i*})$, with mean of $\overline{x^{i*}}$. Doing that for all strata gives bootstrap sample means for the *m* strata of $\overline{x^{1*}}$ to $\overline{x^{m*}}$. Those bootstrapped strata means can then be used to generate bootstrap sample means at higher levels of pooling – e.g., per sector, per MP, all MPs, all areas open to fishing- as described in the Methods section. By repeating the bootstrapping process many times (in this case 5000 times) per fish group of interest, we can generate empirical distributions of the stratum means, other stratum statistics, and derived values for higher levels of aggregation, essentially simulating results that could be expected if the survey program were repeated many times.

Most usefully, the values from the multiple bootstrap runs allow for the calculation of *quantile ranges* of the variable of interest. For example the 95% quantile range of 5000 bootstrap runs would be calculated by ranking the 5000 runs from low to high, and calculating where the cutoff value is for the bottom 2.5% and the top 2.5% of values. Ninety-five percent of bootstrap runs fall within the high and low cutoffs. Therefore, the 95% quantile range represents the range of values we would expect from 95% of survey efforts with same amount of replication and distribution of effort as used for the base sample set. Quantile ranges are therefore comparable to confidence intervals that can be produced from parametric methods.

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APPENDIX C. Biomass Statistics for Consumer Groupings and Fish Families by Marine Preserve/Sector and Pooled to 'all open' and 'all MP'

Table C1.--Fish biomass and standard error per consumer group per marine preserve and sector and for 'all MP' and 'all open' categories. As described in the methods, values from different sectors and MPs are pooled up to island-wide totals by weighting by the total area of hardbottom < 30 m in each sector (values given in Table 1).

Marine Preserve /Sector	Fish Biomass By Consumer Group[1]: **Mean** (SE) (g/m²)				
	Primary	**Secondary**	**Planktivore**	**Piscivore**	**Total (All fish)**
West open	**11.0** (0.8)	**5.4** (0.4)	**3.2** (0.4)	**2.2** (0.3)	**21.7** (1.3)
East open	**19.5** (4.9)	**9.2** (3.5)	**3.2** (0.5)	**5.9** (3.3)	**37.8** (6.8)
Pati Point MP	**38.4** (10.1)	**13.6** (3.1)	**8.2** (3.2)	**12.5** (6.1)	**72.7** (18.3)
Tumon Bay MP	**31.5** (9.9)	**7.3** (1.3)	**5.3** (1.1)	**3.7** (1.8)	**47.8** (12.3)
Piti Bomb Holes MP	**13.0** (2.5)	**5.2** (0.2)	**2.6** (0.8)	**2.5** (1.5)	**23.3** (2.8)
Achang Reef Flat MP	**17.4** (7.6)	**4.8** (0.8)	**3.2** (1.5)	**90.4** (84.3)	**115.8** (78.5)
All Open	***13.9*** *(1.8)*	***6.7*** *(1.2)*	***3.2*** *(0.3)*	***3.5*** *(1.2)*	***27.3*** *(2.5)*
All MP	***27.7*** *(4.8)*	***8.9*** *(1.3)*	***5.5*** *(1.3)*	***23.4*** *(16.2)*	***65.5*** *(16.8)*

Note ([1]) Consumer groups are defined in Appendix A. In brief, 'primary consumers' are herbivores and detritivores; 'secondary consumers' are omnivores and invertivores, 'piscivores' are species that feed primarily on fish.

Table C2.--Fish biomass and standard error per family per marine preserve and open sector. Pooling of individual MPs and Guam sectors to the whole-island 'all MP' and 'all open' totals involves weighting by area of habitat [< 30 m deep hardbottom] in each sector.

Marine Preserve /Sector	Fish Biomass By Family: **Mean** (SE) (g/m²)					
	Surgeonfishes	**Parrotfishes**	**Goatfishes**	**Groupers**	**Emperors**	**Snappers**
West open	**4.5** (0.4)	**5.5** (0.6)	**0.4** (0.1)	**0.9** (0.1)	**0.4** (0.2)	**0.9** (0.3)
East open	**9.4** (1.4)	**8.6** (3.8)	**0.6** (0.3)	**3.6** (2.5)	**1.4** (0.7)	**2.4** (0.8)
Pati Point MP	**14.3** (3.5)	**23.9** (7.3)	**0.9** (0.4)	**4.6** (3.0)	**1.9** (0.7)	**2.8** (0.9)
Tumon Bay MP	**7.6** (1.5)	**21.7** (9.3)	**0.6** (0.2)	**2.8** (1.7)	**1.5** (0.8)	**1.2** (0.7)
Piti Bomb Holes MP	**3.9** (1.6)	**8.4** (1.5)	**0.4** (0.1)	**1.0** (0.4)	**0.4** (0.3)	**0.7** (0.7)
Achang Reef Flat MP	**6.4** (2.0)	**8.9** (6.2)	**0.4** (0.1)	**0.3** (0.4)	**0.0**	**3.1** (3.0)
Total Open	***6.2*** *(0.6)*	***6.6*** *(1.4)*	***0.5*** *(0.1)*	***1.8*** *(0.9)*	***0.8*** *(1.3)*	***1.4*** *(0.3)*
Total MP	***9.3*** *(1.5)*	***17.4*** *(3.7)*	***0.6*** *(0.2)*	***2.7*** *(1.2)*	***1.2*** *(0.3)*	***2.1*** *(0.7)*

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APPENDIX D. Fish Assemblage Archipelagic Comparisons

The 2011 MARAMP cruise covered the entire archipelago (Fig. D1), using the same standard underwater visual survey methods and survey design. Accordingly, we can place the Guam survey findings in a much wider context, i.e., relative to coral reef areas throughout the Mariana Archipelago (Figs. D2-D6). Consideration of the Guam results in comparison with those for other islands and atolls in the Mariana Archipelago should take into account differences in factors that can affect fish biomass. There are substantial geological and physical differences among islands, including a relatively recent history of volcanic activity at several of the northern islands, which means that type and quality of habitat varies considerably among different parts of the archipelago (Houk and Starmer, 2010). In addition, there are geographic and historical differences in anthropogenic impacts. Such differences make it difficult to draw simple conclusions about the likely causes of patterns of biomass and other biological characteristics evident at the archipelagic scale. The aim of this section is largely to provide perspective to the Guam results presented above, by placing them in the context of survey data from other parts of the archipelago.

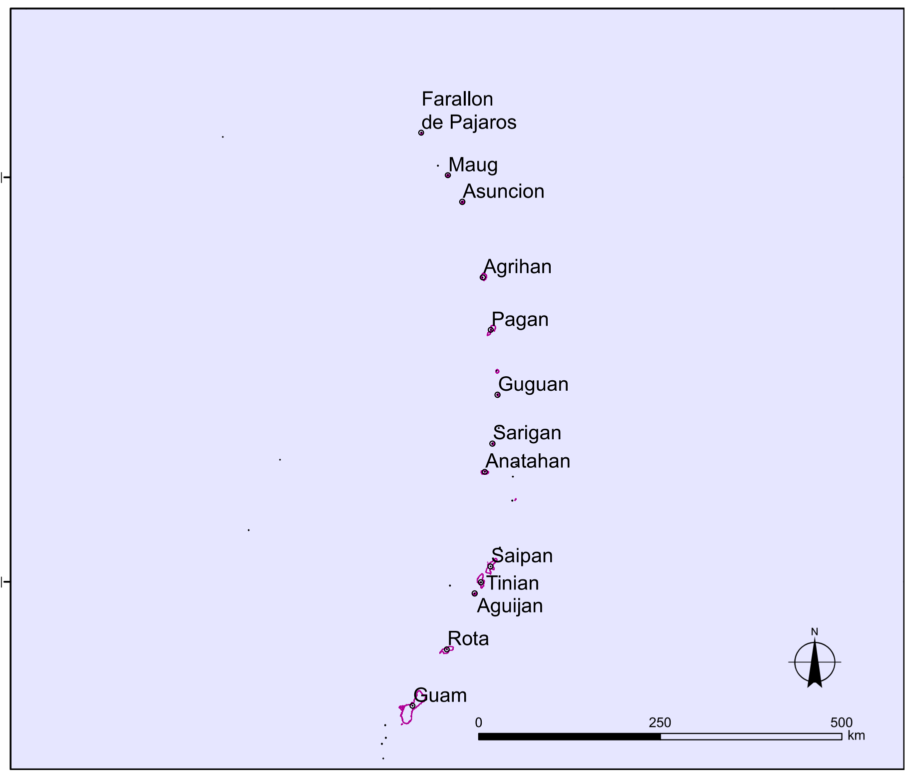

Figure D1.—Mariana Archipelago. Islands at the southern end of the chain, from Guam to Saipan have permanent human populations. The northern islands, from Anatahan to Farallon de Pajaros have no or very small human populations.

Note that for all archipelagic figures shown in this section, data from Sarigan, Guguan, and Alamagan have been pooled into a combined entity ('Sari-Gugu-Alam') giving equal weight to overall values for the three islands. Because of the total length of MARAMP cruises, it has only been possible to allocate one day of survey work at each of these islands per cruise, sufficient for ~ 8–10 site surveys per island. Given that level of replication, a decision was made prior to

MARAMP 2011 to treat these three adjacent small islands as a single unit for sampling and analysis purposes, with a total of ~ 25+ survey sites within the unit.

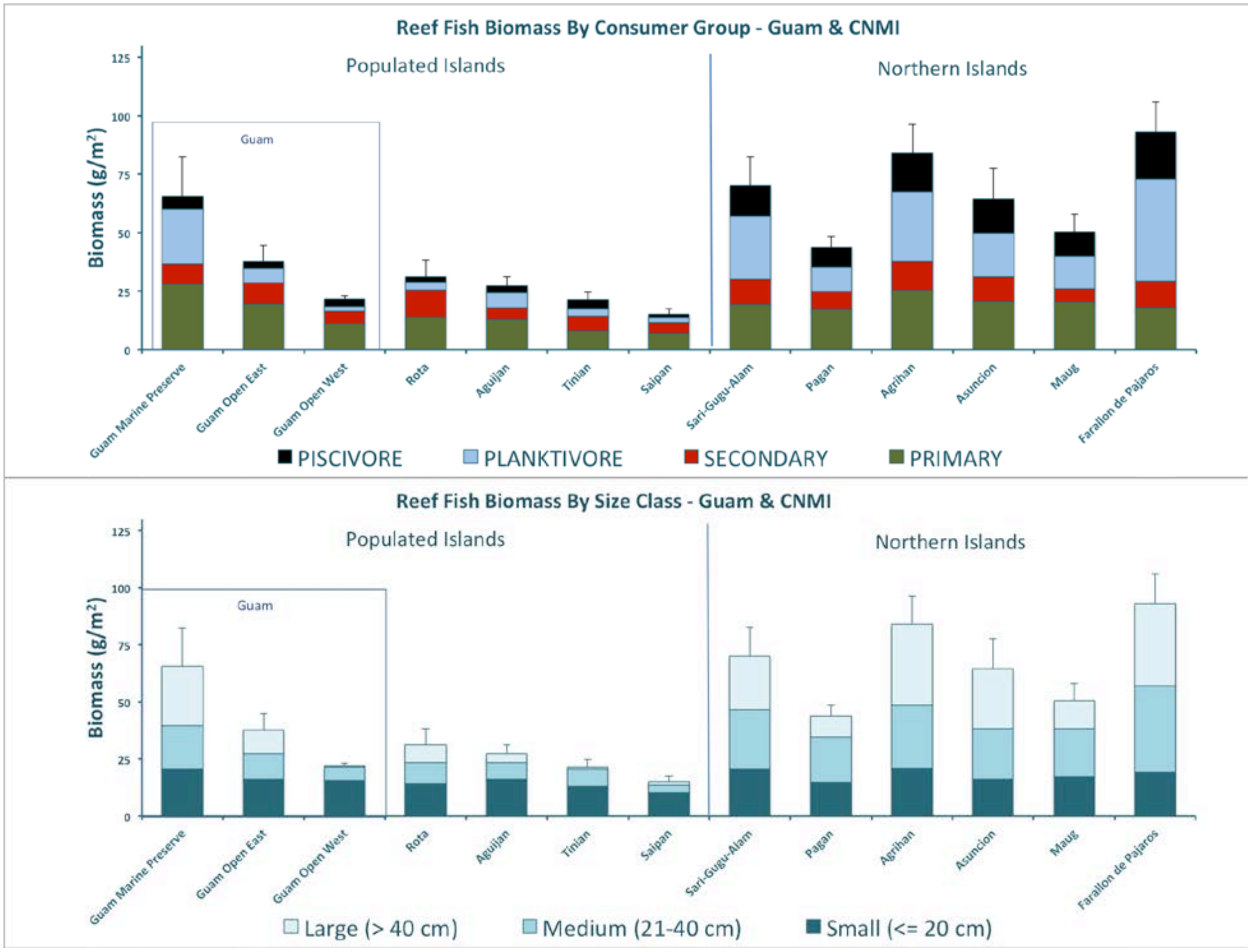

Figure D2.--Archipelagic Comparisons of reef fish biomass, pooled by consumer group and by size class. Consumer group classifications are given in Appendix A, but, in brief, 'primary' consumers are herbivores and detritivores; 'secondary' consumers are omnivores and invertivores; 'piscivores' are fishes that feed predominantly on other fishes. Size class is based on estimated total length as recorded by divers during fish surveys.

Guam reefs outside of marine preserves were broadly comparable with those at the other populated islands at the southern end of the Mariana chain (Rota, Saipan, Aguijan and Tinian), all of which had relatively low total reef fish biomass and few large fishes. In contrast, reef fish assemblages within MPs around Guam were much more comparable to those at the remote, sparsely populated or unpopulated islands in the northern portion of the chain (Sarigan through Farallon de Pajaros), with the remote islands and Guam MPs having relatively high total reef fish biomass and a substantial portion of total biomass being made up of fishes in larger size classes (Fig. D2). Additionally, while Guam marine preserves tended to have higher biomass of piscivores than other locations among the populated islands, Guam MP biomass was only around half to a third of piscivore biomass at remote islands (Fig. D2).

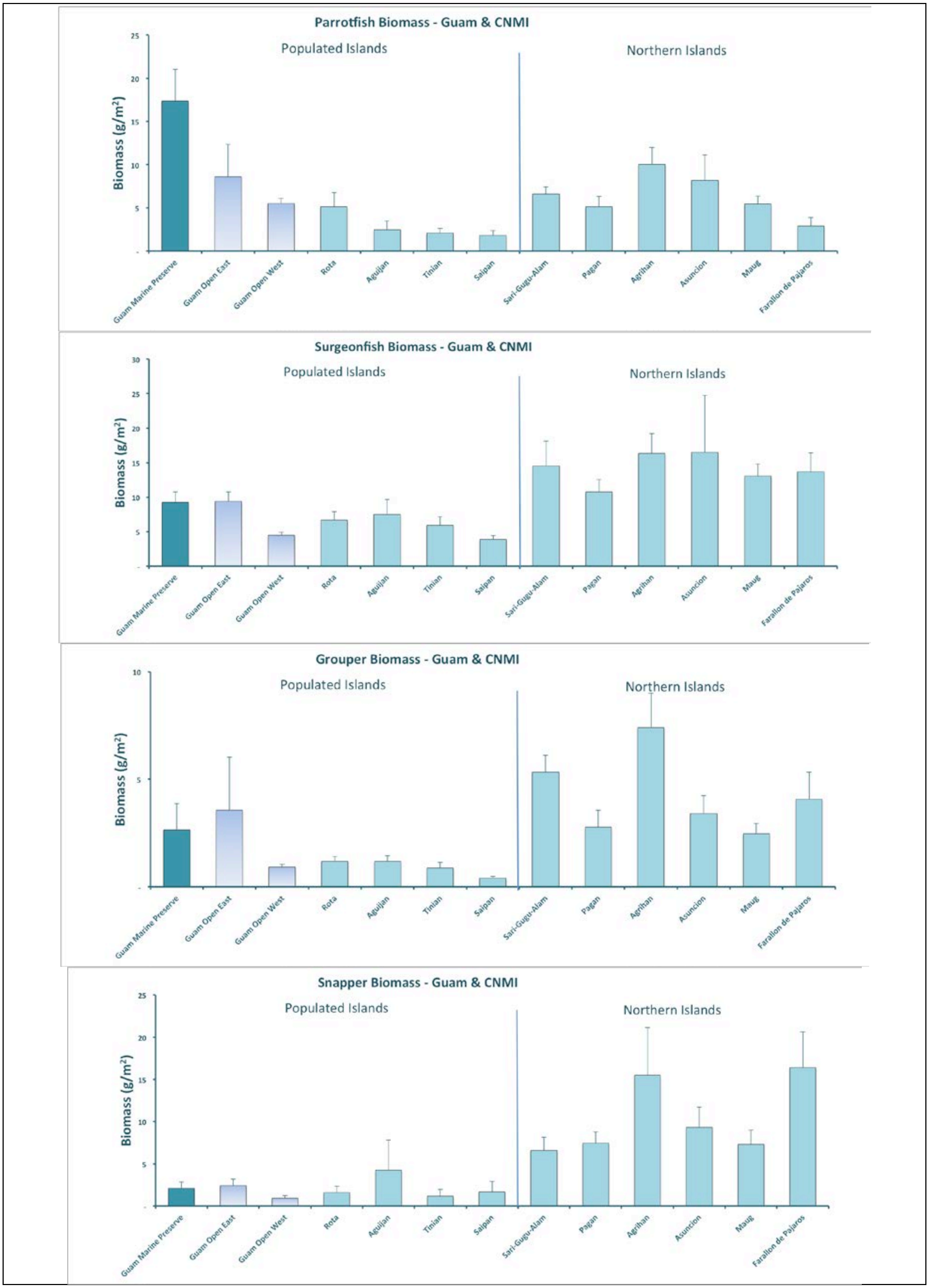

Figure D3.--Archipelagic comparisons of reef fish biomass, pooled by family.

Patterns evident with data pooled by family indicate that the biomasses of parrotfishes in MPs and on Guam-East open sites were high by the standards of the rest of the archipelago (Fig. D3). Grouper biomass and, to a lesser extent, surgeonfish biomass were also relatively high in Guam MPs and Guam East-open sites compared to the other southern islands, but was moderate in comparison to the northern islands (Fig. D3). Snapper biomass was much higher in the northern islands than in southern locations, including within Guam MPs, and a substantial contribution to that difference was the elevated biomass of *Lutjanus bohar* at northern islands, ranging from 3.1 ± 0.8 g/m^2 (Sarigan-Guguan-Alamagan island-group mean ± SE) to 9.8 ± 2.8 g/m^2 (Farallon de Pajaros) at northern islands, but generally being around 1 g/m^2 or less at southern islands, other than Aguijan (3.7 ± 3.4 g/m^2).

Target Species – Archipelagic Patterns

Figures D3 though D6 show distributions of Guam and CNMI 'target species' identified above and taken from (Houk et al., 2012) at locations throughout the archipelago. As above, data are not shown for species that were rarely recorded or not recorded during the CRED surveys – the emperors, *Lethrinus harak* and *L. olivaceous*, the rabbitfish *Siganus spinus*, and the grouper *Epinephelus merra*. Both of those *Lethrinus* species appear to be particularly wary of divers, a characteristic of the genus that means they are likely undercounted by visual survey methods (Jennings and Polunin, 1995). Also as above, the grouper *Cephalopholis argus* is shown, being the most commonly recorded medium-to-large grouper species.

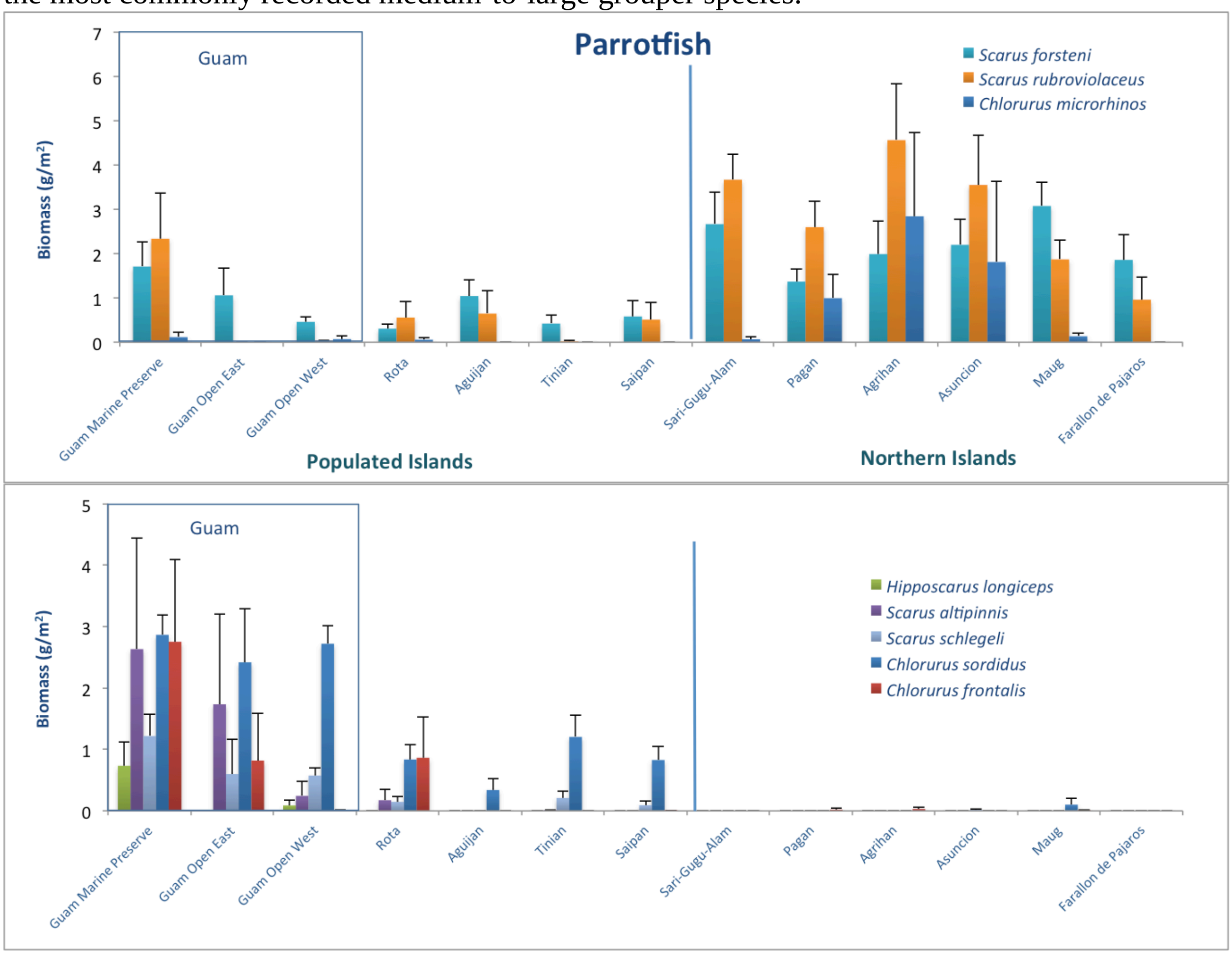

Figure D4.--Parrotfish biomass by species per island and per sector in Guam.

There was a very clear divide in parrotfish species' distributions in the southern-populated islands and the northern-remote islands, namely that northern islands' parrotfish assemblages were dominated by three large-bodied species (*Scarus rubroviolaceus*, *S. forsteni*, and to a lesser extent *Chlorurus microrhinos*) (Fig. D4). In contrast, parrotfish biomass at southern islands was largely dominated by a completely different set of species: *C. sordidus*, *S.schlegeli*, and in some locations *S. altipinnis* and *C. frontalis* (Fig. D4). Notably, Guam MPs were the only part of the southern islands where *S. rubroviolaceus* was commonly encountered; and were where the highest biomass of another 'northern-dominant' species, *Scarus forsteni*, occurred. In addition, sites in Guam MPs were virtually the only locations in the archipelago where CRED survey staff recorded *Hipposcarus longiceps*.

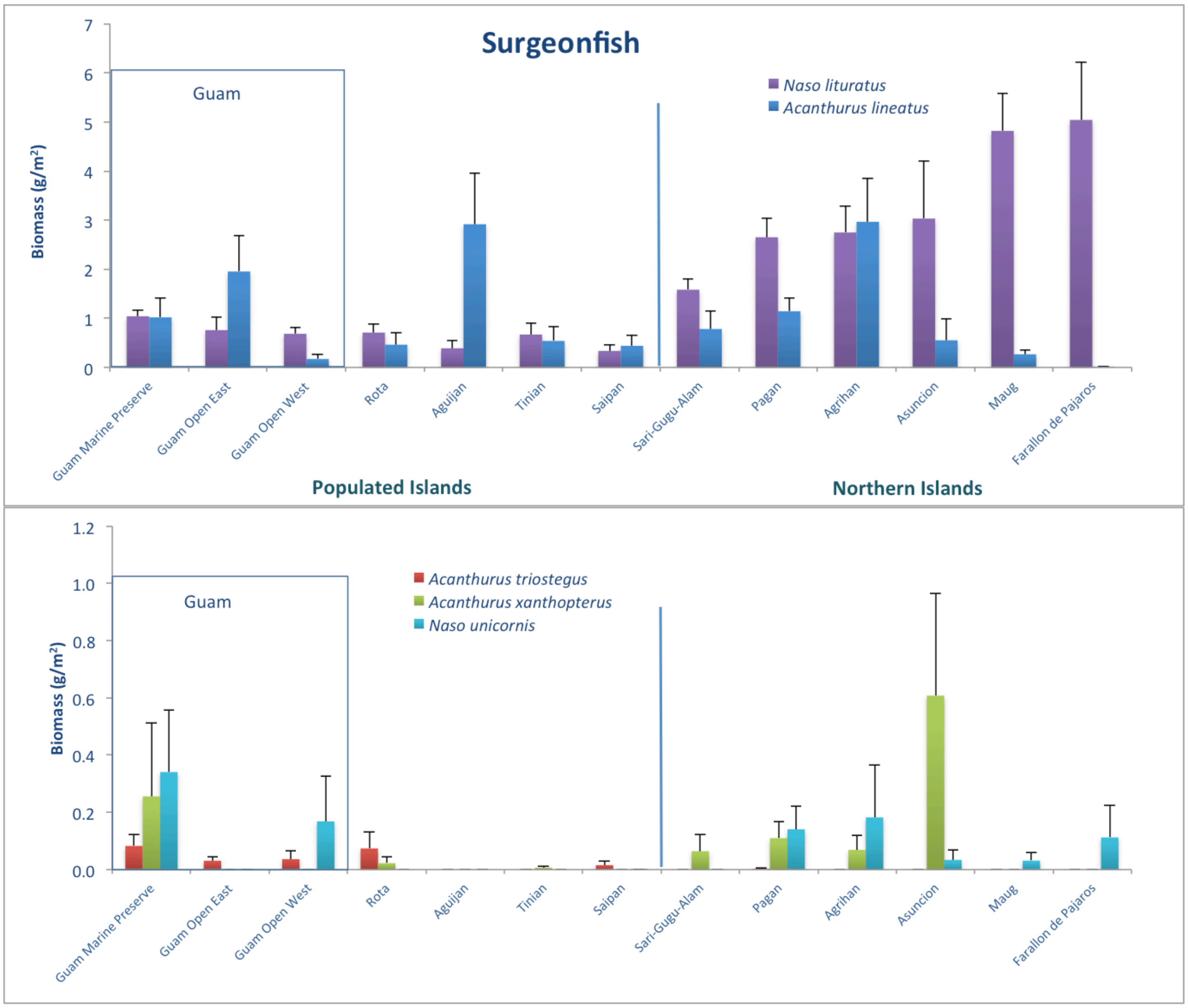

Figure D5.--Surgeonfish biomass by species per island and per sector in Guam.

Among the target species listed in Houk et al., (2012), *Naso unicornis*, *Acanthurus triostegus*, and *A. xanthopterus* were not recorded in large numbers at any CRED locations (Fig. D5). In the case of *A. triostegus*, the low number of survey observations is likely an indication of the generally highly clumped distribution of this species in shallow water meaning that the species is infrequently encountered by a program which spreads survey effort across the entire < 30 m hardbottom range. Similarly, *A. xanthopterus* tends also to have a highly clumped distribution and appears to be frequently found on compacted sediment around the edge of reef areas, and thus it is also not frequently encountered by the Pacific RAMP surveys, which are exclusively conducted on hardbottom habitats. The lack of sightings of these species highlights some limitations, particularly for species-level data, inherent in a very broad-scale survey program such as Pacific RAMP. Other target surgeonfish species, *Naso lituratus* and *A. lineatus*, were more commonly observed during surveys, with resulting data giving some indication of increased biomass of *Naso lituratus* at northern islands, particularly the most northerly of those (Fig. D5). Of other target species, biomass of the jack, *Caranx melampygus*, and the chub species-complex, *Kyphosus* spp., was higher at northern islands. The grouper, *Cephalopholis argus,* also tended to have higher biomass at northern islands (Fig. D6). There was no obvious pattern in biomass of the emperor *Monotaxis grandoculis* (Fig. D6).

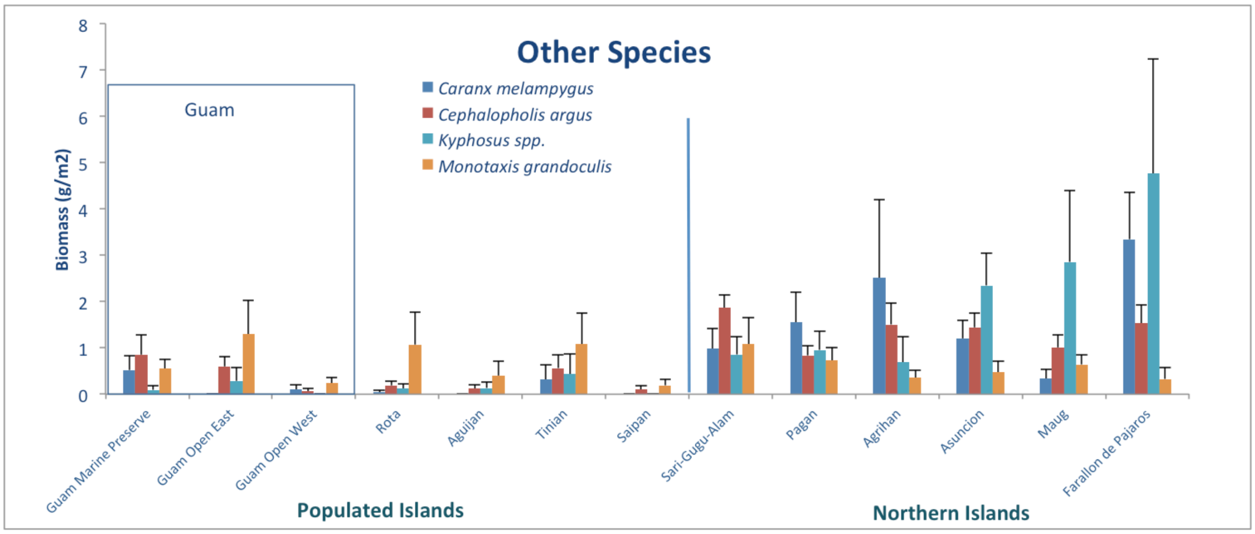

Figure D6.**--**Biomass of other species per island and per sector in Guam.

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