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Title: Quantifying parrotfish grazing on coral reefs: developing a metric for management and conservation

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Project summary

Herbivorous fish can benefit reef-building corals by controlling algae that compete with corals for space, but different species of herbivores have different and complementary impacts on benthic communities. Many herbivores are targeted in reef fish fisheries, and these fisheries can strongly impact the structure of herbivore assemblages. Therefore, managers need to know how changes in the herbivore assemblage scale-up to impact the overall health of a coral reef ecosystem. The objective of this study was to obtain quantitative estimates of grazing and browsing capacity for key turf grazing and macroalgal browsing parrotfishes on Caribbean coral reefs, and to use these metrics to quantify the combined grazing impacts of an entire assemblage of parrotfishes. Field work was carried out in the Florida Keys National Marine Sanctuary (FKNMS), where fishing on herbivorous fishes is prohibited and there are large populations of several species of parrotfishes that are rare or absent throughout much of the Caribbean.

1.0 Overall Project Findings

This project built on our previous work, which suggested that Caribbean parrotfishes could be categorized into at least three different functional groups based on their diet and feeding ecology and concomitant impacts on benthic communities. Using detailed descriptions of parrotfish bites combined with time budgets of parrotfish activity, we calculated quantitative species- and size-specific estimates of the grazing, browsing, and bioerosion capacities of nine species of Caribbean parrotfishes. We then combined these estimates with a 30-year time series of fish abundance and size structure collected by NOAA South East Fisheries Science Center (SEFSC) to estimate how the ecosystem-level impacts of parrotfish (i.e., algal consumption, areal grazing rates, bioerosion) vary among habitats and through time in the FKNMS. This work led to several major conclusions: 1) a functional group framework is essential for understanding the ecosystem-level impacts of Caribbean parrotfishes, 2) rates of key ecosystem-level processes carried out by parrotfishes vary greatly among reef-types (e.g., offshore versus inshore reefs) within the FKNMS and are not well predicted by the total biomass of parrotfish, 3) specific processes (e.g., bioerosion, macroalgal consumption, and areal grazing) are carried out by different species of parrotfishes on different reefs, and 4) rates of these processes vary among habitat types within a reef due to species-specific habitat preferences. In addition to these key insights, our study provides a quantitative framework that can be used to predict how reef fish fisheries alter the ecosystem-level impacts of parrotfish assemblages, an approach that we are currently extending to the U. S. Caribbean to predict the impacts of reef fish fisheries on coral reef ecosystems in the region.

1.1 Parrotfish functional groups and bite impacts

During June, July and August 2014 we quantified how parrotfishes were interacting with the benthos at the scale of an individual bite at four reefs in the FKNMS (Molasses, Carysfort, French, Conch). Observations of 2,165 individual bites indicated that parrotfishes can be categorized into three functional groups: 1) macroalgal browsers: *Sp. chrysopterum*, *Sp. rubripinne*, and *Sp. aurofrenatum*, which feed on large seaweeds, 2) excavating/bioeroding grazers: *Sp. viride*, *Sc. guacamaia*, and *Sc. coelestinus*, which feed on epilithic algal turfs and endolithic algae, and 3) scraping and cropping grazers: *Sc. vetula*, *Sc. taeniopterus*, and *Sc. iseri*, *Sc. coeruleus*, which feed by scraping and/or cropping diminutive algal turfs from the reef (Figure 1 and 2). Consistent with previous observations we found that macroalgae browsing parrotfishes also feed on filamentous turf algae (Figure 2). However, our analyses confirm that these species interact with the benthos in a fundamentally different way. Whereas *Sparisoma viride* and parrotfishes in the genus *Scarus* scrape and/or excavate algae from carbonate surfaces leaving a grazing scar on the reef, macroalgae browsing parrotfishes generally tear longer turf algae from the reef without scraping the substrate, and generally do not leave a grazing scar (Figures 1, 2, and 3). Further, the *Sparisoma* spp. also feed more on macroalgae in general than the *Scarus* spp (Figure 2). Thus our observations confirm that the functional role of the macroalgal browsing species is best understood in the context of the amount of algae they remove rather than the area of the reef they clear.

For scraping and excavating species, we used data from several hundred photographs of parrotfish bites to estimate the relationship between fish size and the area of the reef they clear of algae while grazing (see example photos in Figure 4). Analyses show that bite area is positively correlated with fish size for *Scarus coelestinus* and *Scarus guacamaia* (Figure 5). In addition, bites by *Sc. coelestinus* and *Sc. guacamaia* are 30 to 40% larger in area compared to bites by *Sc. vetula* of the same size. These data are critical for modeling the impacts of parrotfish on the benthos as previous models have assumed that the relationship between fish size and bite area was constant within genera.

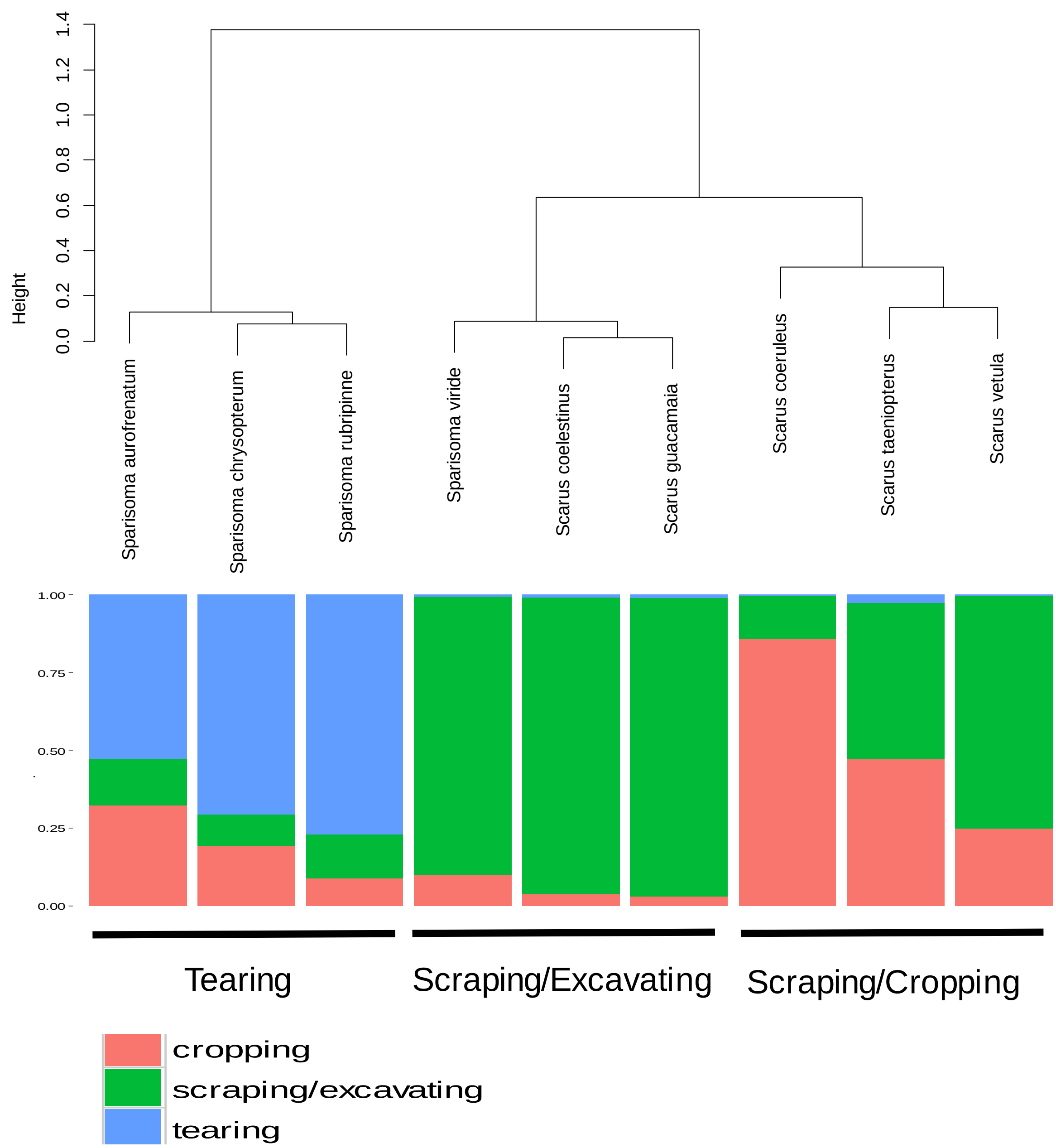

Figure 1. Dendrogram showing that parrotfish cluster into three groups based on bite type. The macroalgae browing parrotfish, *Sp. aurofrenatum*, *Sp. chrysopterum*, and *Sp. rubripinne* usually tear erect algae from the reef and rarely leave a grazing scar. *Sp. viride* and the two largest *Scarus* species, *Sc. coelestinus* and *Sc. guacamia* scrape and excavate algae from the reef removing reef calcium carbonate and leaving a grazing scar in the process. The three smaller species of *Scarus* scrape as well as crop algae from reef surfaces. Cropping bites refer to the removal of the tips of small filamentous algae without contacting the reef matrix.

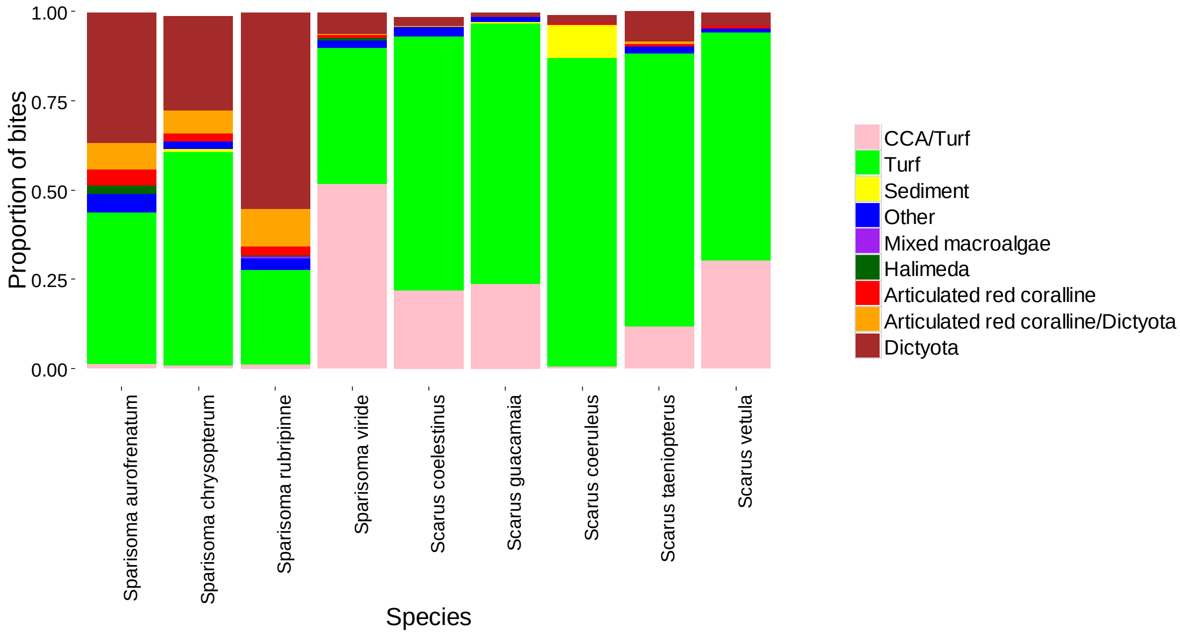

Figure 2. Proportion of different types of algae targeted by parrotfish species, showing clear separation in the diets of *Sparisoma* spp., which often feed on a variety of macroalgal species (excluding *Sparisoma viride*), and *Scarus* spp., which target turf algae and crustose coralline algae (CCA).

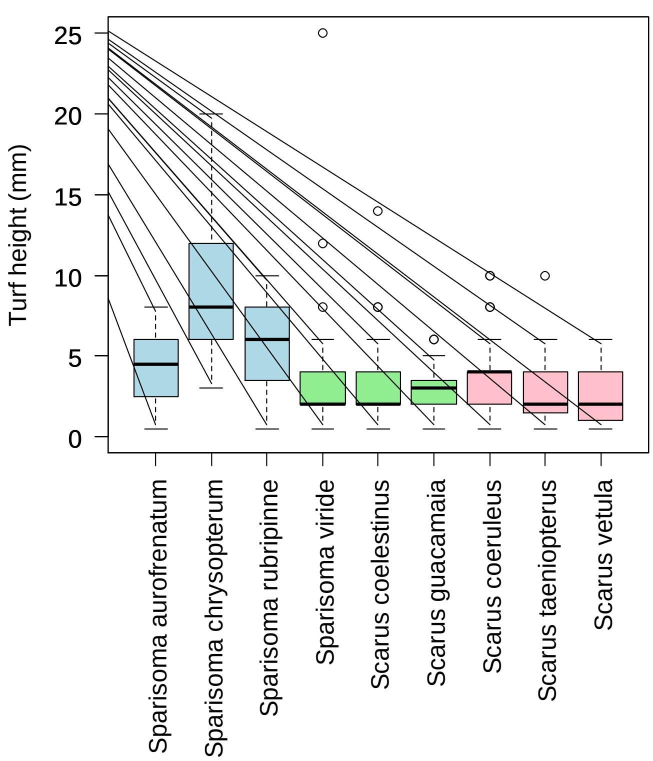

Figure 3. Box plots showing that when they feed on filamentous turf algae, the macroalgae browsing parrotfishes, *Sp. aurofrenatum*, *Sp. chrysopterum*, and *Sp. rubripinne*, target longer turfs (usually embedded in sediment) compared to parrotfishes which scrape, excavate, and/or crop algae from the reef.

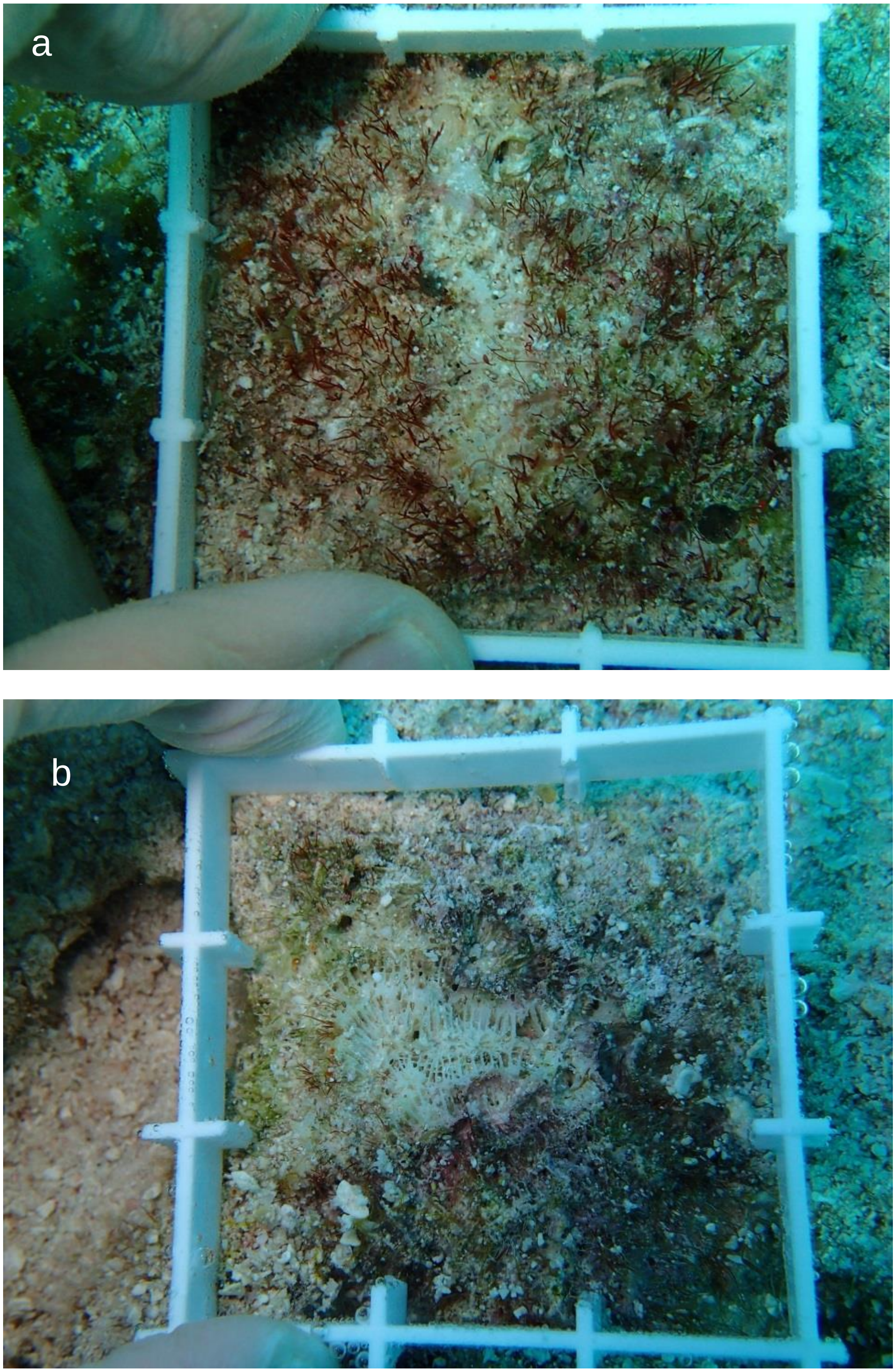

Figure 4. Bite scars from a (a) 55 cm *Scarus coelestinus* (bite scar area = 2.47 cm^2) and (b) 65 cm *Scarus guacamaia* (bite scar area = 3.12 cm^2)

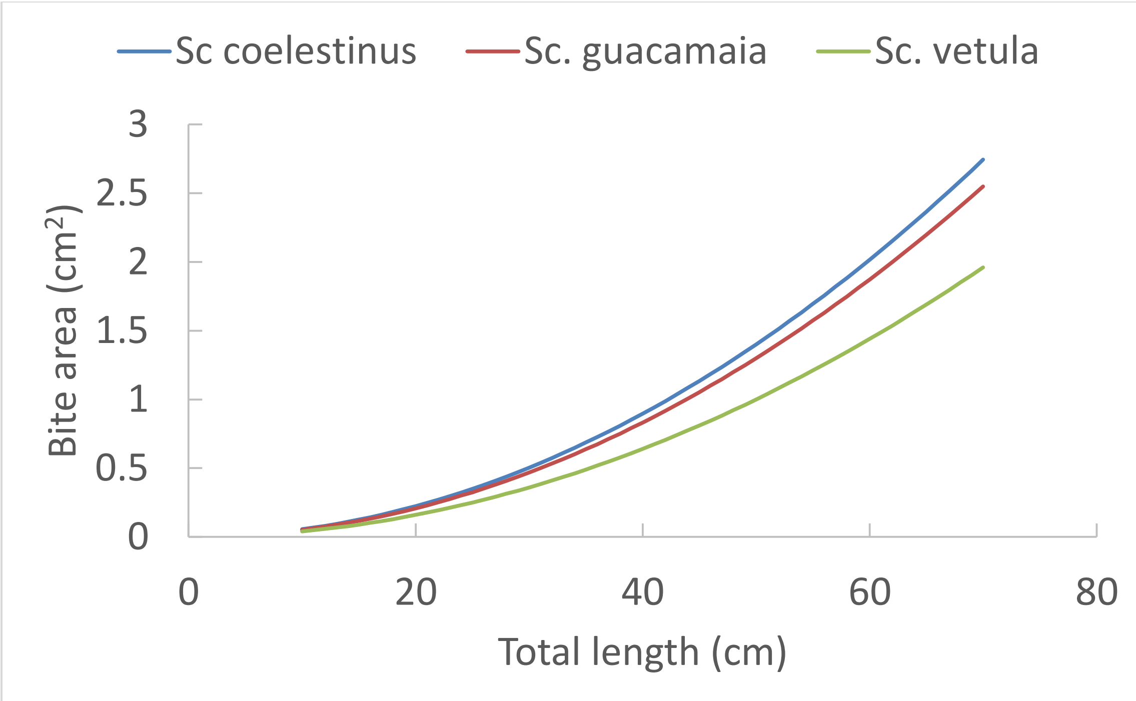

Figure 5. Bite area (cm^2) as a function of fish TL for *Scarus coelestinus*, *Scarus guacamaia*, and *Scarus vetula*. Note that for a given size, bites by *Sc. coelestinus* and *Sc. guacamaia* are 30 to 40% larger than bites by *Sc. vetula*.

For macroalgal browsing species, we used assays of palatable macroalgae (*Sargassum* spp.) to estimate bite yields. These assays confirmed that the only species that commonly fed on macroalgae were *Sparisoma aurofrenatum*, *Sparisoma chrysopterum*, and *Sparisoma rubripinne.* Bite yield of *Sargassum* was positively related to fish size, but there was a high degree of variability in the relationship. In addition, relationships between fish size and bite yield were more difficult to obtain for turf algae and less palatable species of macroalgae (*Dictyota* spp. and *Halimeda* spp.). Due to these logistical constraints we decided to use established metabolic relationships to estimate algal consumption rather than bite yield. Finally, we conducted several hundred focal behavioral observations of parrotfishes to obtain estimates of bite rate as a function of size for all ten species of turf grazing and macroalgal browsing parrotfishes. These bite rate estimates were not used in calculations of algal consumption (due to the difficulty in obtaining reliable bite yield data), but were used to calculate areal grazing rates.

1.2 Spatial and temporal patterns of parrotfish grazing and bioerosion in the FKNMS

1.2a Large-scale spatial patterns across the Florida Keys

In order to determine how parrotfish grazing varies across space in the FKNMS, we combined the bite level data with the bite rate data to calculate reef-wide metrics of macroalgal removal, areal grazing, and bioerosion using fish survey data from the SEFSC's Reef Visual

Census (RVC), an ongoing monitoring program in the Florida Keys. The RVC surveys use a stratified random sampling design to estimate habitat-specific densities and size-structures of reef fishes which can be used in combination with our grazing metrics to estimate parrotfish impacts in different habitat types throughout the Florida Keys. These data show that several species of macroalgae browsing and scraping and excavating parrotfishes, including *Sp. viride*, *Sp. rubripinne*, *Sc. coelestinus*, and *Scarus vetula*, achieve highest biomasses on the high-relief forereef, and that overall parrotfish biomass in this habitat is ~ 2 to 4 times higher than it is in other habitats (Figure 6). Notably, different types of reefs often have different dominant species (by biomass), with *Sc. guacamaia* dominating on inshore patch reefs while *Sc. coeruleus* is the most abundant on deeper forereefs for example (Figure 7).

These differences in species distribution led to vast differences in rates of macroalgal removal, areal grazing, and bioerosion across the different types of reefs in the Florida Keys (Figures 8). The high-relief forereef had the highest overall grazing rates, more than doubling other reef types (Figure 8a). Different species dominated the grazing rates in different areas with *Scarus* spp. typically the most important species. For example, on the high-relief reef, *Sp. viride*, *Sc. vetula*, and *Sc. coelestinus* were the most important grazers while *Sc. guacamaia* was by far the most important grazer for inshore patch reefs and *Sc. iseri* and *Sc. taeniopterus* dominated grazing on deeper forereefs.

For macroalgal removal rates, the *Sparisoma* spp. were the dominant species across all reef types. Again, the high-relief forereef, due to its high fish biomass, had at least double the macroalgal removal rates as did any of the other reef types (Figure. 8b). Different *Sparisoma* spp. played different dominant roles in macroalgal removal depending on the reef type. *Sp. rubripinne* was the top macroalgal remover on many reef types including high-relief forereefs and inshore patch reefs. *Sp. aurofrenatum* was an important macroalgal remover on all reef types, and was particularly important on the deep forereef. *Scarus* spp. were relatively unimportant for macroalgal removal, although *Sc. guacamaia* appeared to be the most important Scarus spp. for removing macroalgae, especially on inshore patch reefs.

Like grazing and macroalgal removal rates, bioerosion rates varied significantly among reef types, with some species being relatively more important in particular habitats. Bioerosion rates were nearly three times higher on the high-relief forereef than on any other reef type (Figure 8c). On all reefs, *Sp. viride* was the dominant bioeroder, except for the inshore patch reef where *Sc. guacamaia* was the dominant bioeroder. On the high-relief forereef, *Sc. coelestinus* and *Sc. vetula* also play important roles as bioeroders, whereas *Sc. taeniopterus* plays a significant role on the deep forereef.

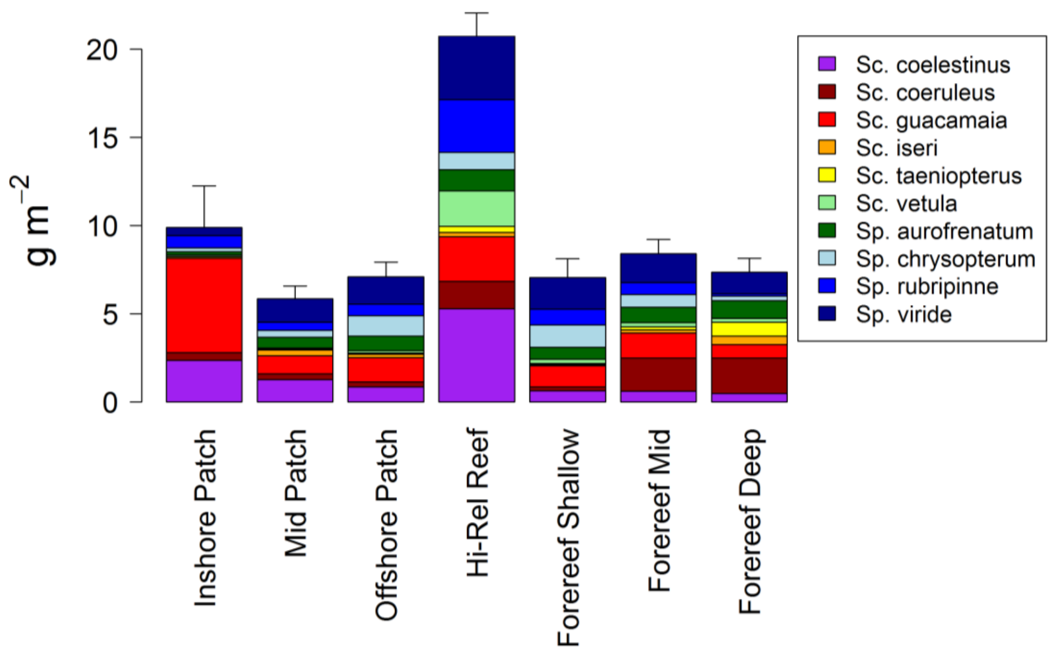

Figure 6 Biomass of different species of parrotfishes across different reef types in the Florida Keys. All plots show means plus one standard error for the summed biomass. Means and SEs are based on n = 10 years of data (2003-2012) from the NOAA SEFSC RVC surveys.

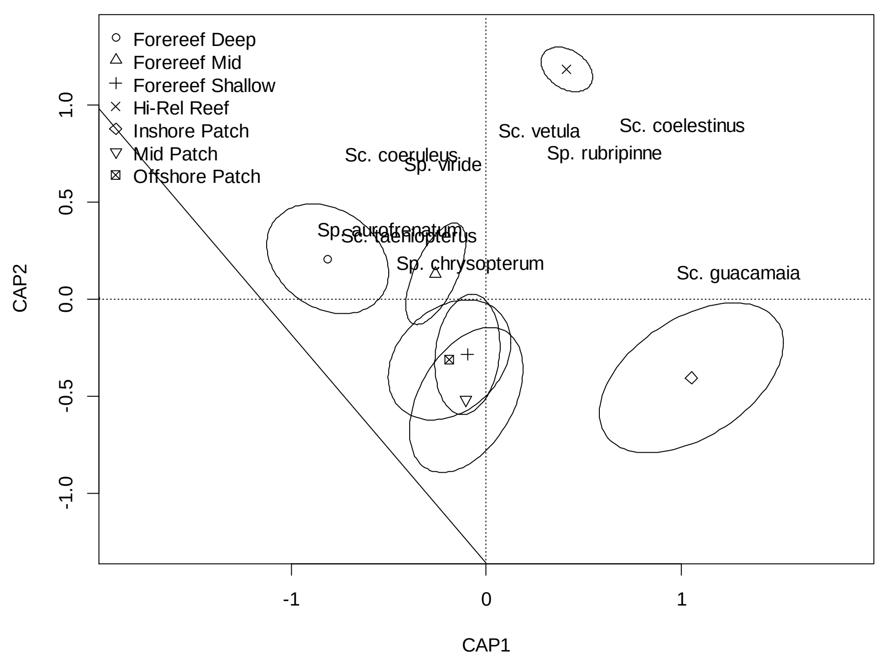

Figure 7. Constrained analysis of principle coordinates showing how reefs differ in parrotfish assemblage structure (points are site centroids based on n = 10 years of samples with 95% confidence ellipses). Note the high relief forereef (Hi-Rel Reef) and Inshore patch reefs have the most distinct assemblages.

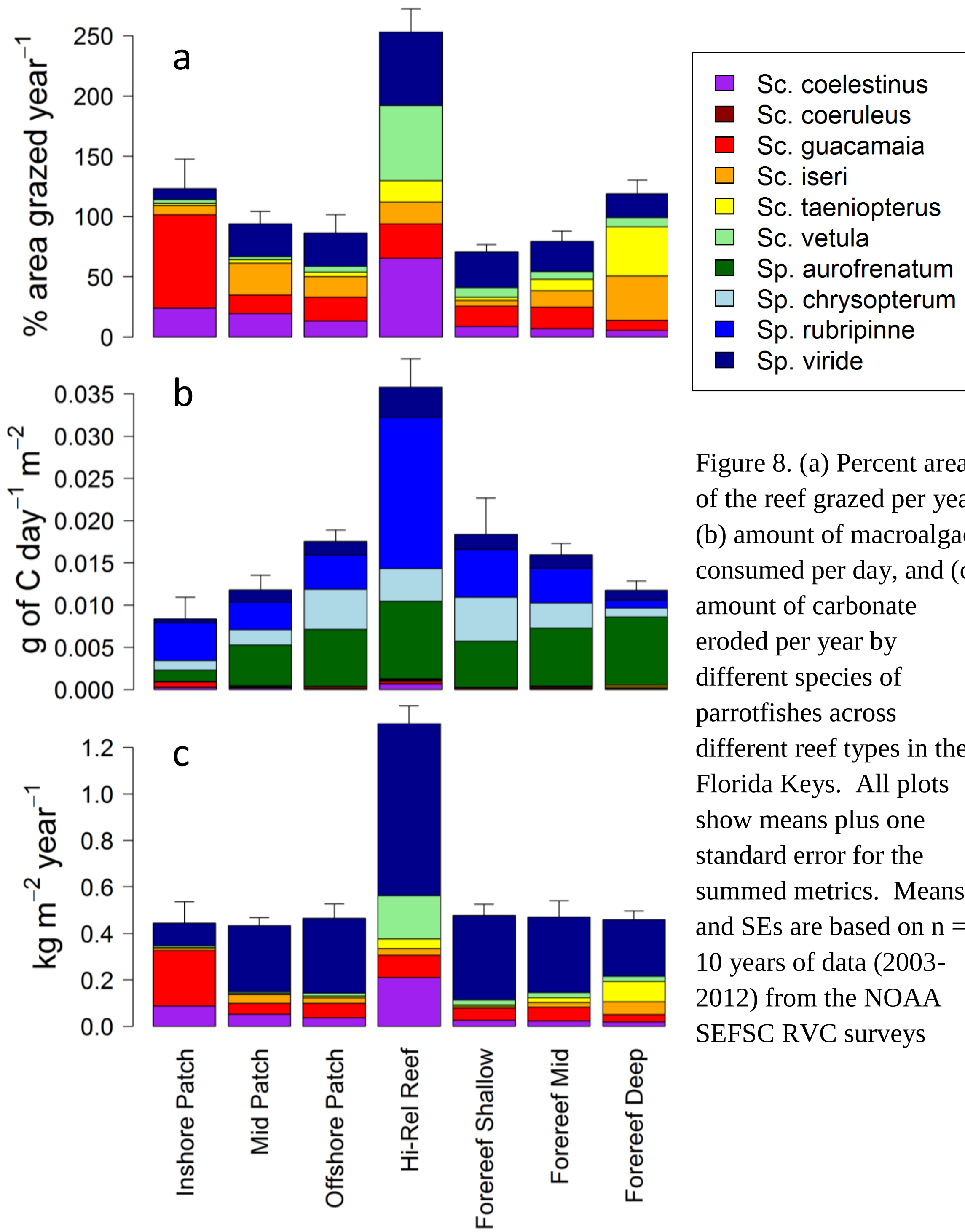

Figure 8. (a) Percent area of the reef grazed per year, (b) amount of macroalgae consumed per day, and (c) amount of carbonate eroded per year by different species of parrotfishes across different reef types in the Florida Keys. All plots show means plus one standard error for the summed metrics. Means and SEs are based on n = 10 years of data (2003-2012) from the NOAA SEFSC RVC surveys

1.2b Small-scale within reef spatial patterns on high relief forereefs

In addition to estimating differences in key ecosystem processes among reef types a secondary objective of the project is to quantify small-scale spatial variability in the intensity of herbivory. We took two approaches to quantifying small-scale differences that occur among habitats within a single reef. First, we conducted fine-scale surveys of parrotfish in different habitat types on high relief spur and groove reefs (see figure Figure 9 for main habitat types). After calculating parrotfish density and size structure in these different habitat types we used our grazing metrics to scale up the impacts of the parrotfish assemblage with these habitats.

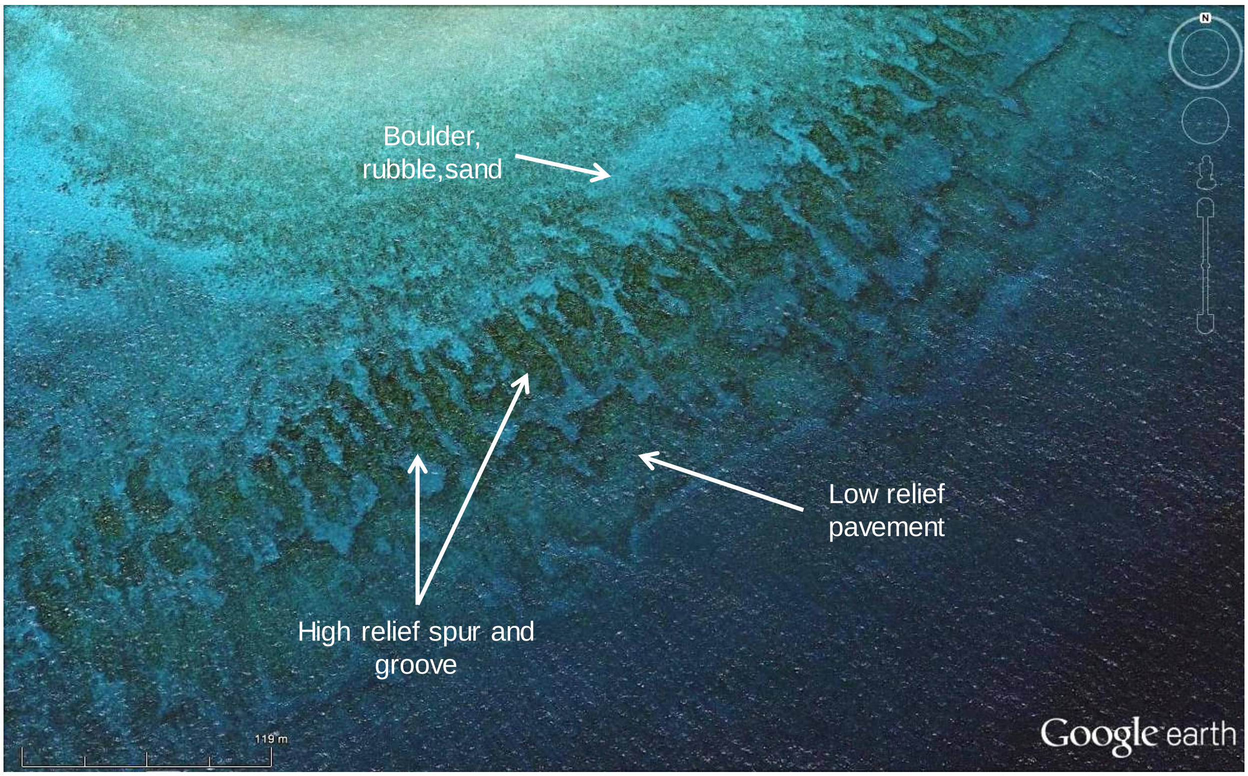

Figure 9. Satellite image of Molasses reef off of Key Largo, FL, USA showing major habitat types occupied by parrotfishes. Scale bar in lower left corner is 119 m.

We found that on high relief reefs, total parrotfish biomass was highest in the shallow areas dominated by architecturally complex stands of dead *Acropora palmata* (Figure 10a). These areas of the reef experienced much higher levels of grazing than the other habitat types, with *Sc. vetula* being a major driver of areal grazing rates in this habitat (Figure 10b). In contrast to areal grazing rates, macroalgal consumption was higher on low relief pavement compared to the higher relief areas of the reef (Figure 10c). Bioerosion was highest in the high relief areas and was dominated by *Sp. viride* in all three habitat types (Figure 10d). In addition, at the scale of an individual bite, *Sp. viride* tended to target convex substrates while all other scraping and bioeroding parrotfishes tended to target flat substrates (Figure 11). This means that *Sp. viride* will be the most important species eroding architecturally complex coral structures, while other scrapers and excavators primarily erode flat coral pavement.

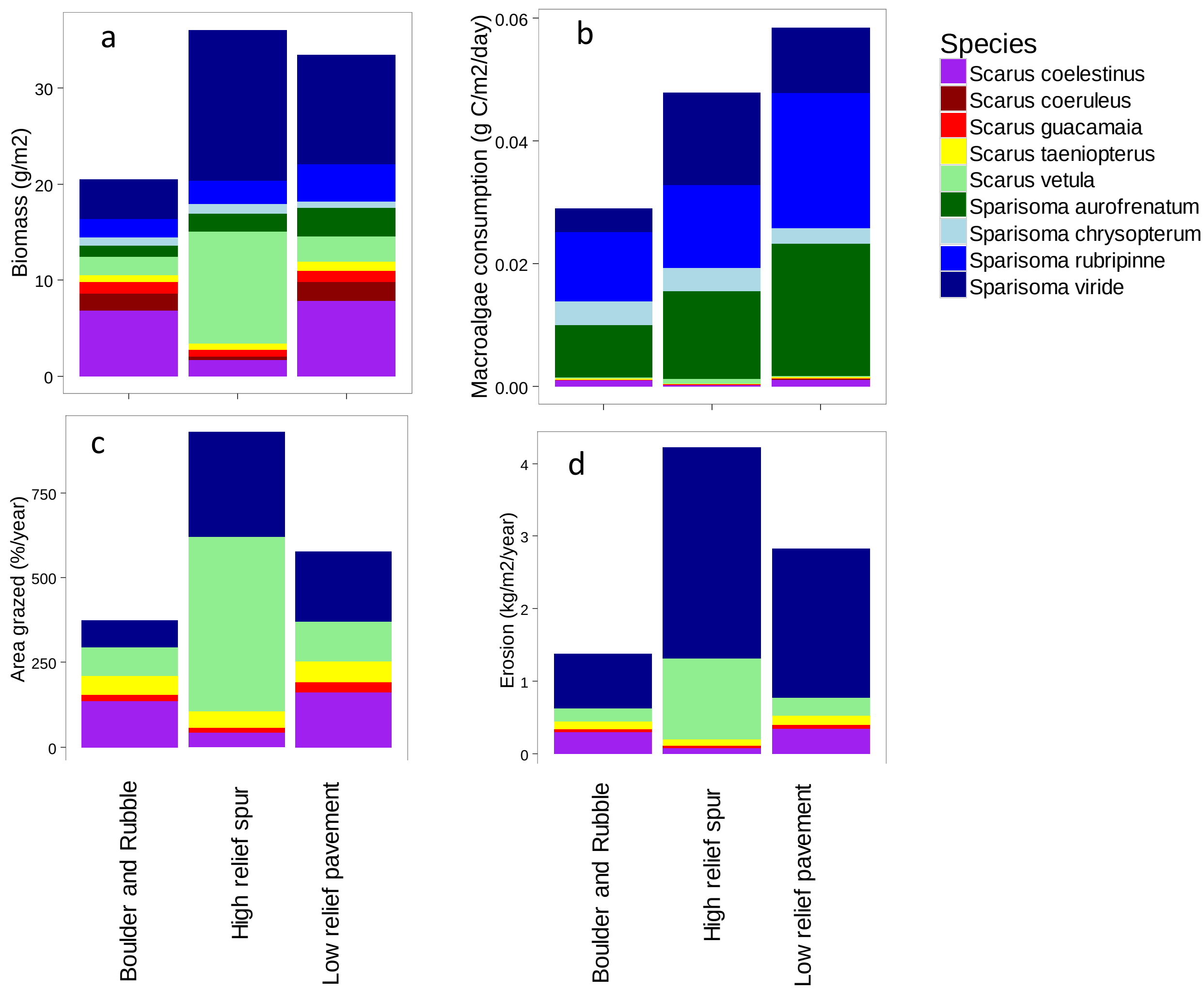

Figure 10. (a) Biomass, (b) amount of macroalgae consumed per day, (c) Percent area of the reef grazed per year, and (d) amount of carbonate eroded per year by different species of parrotfishes across different habitat types on high relief spur and groove reefs in the Florida Keys. Bars are means of 4 sites (Molasses reef, French reef, Carysfort reef, and Elbow reef)

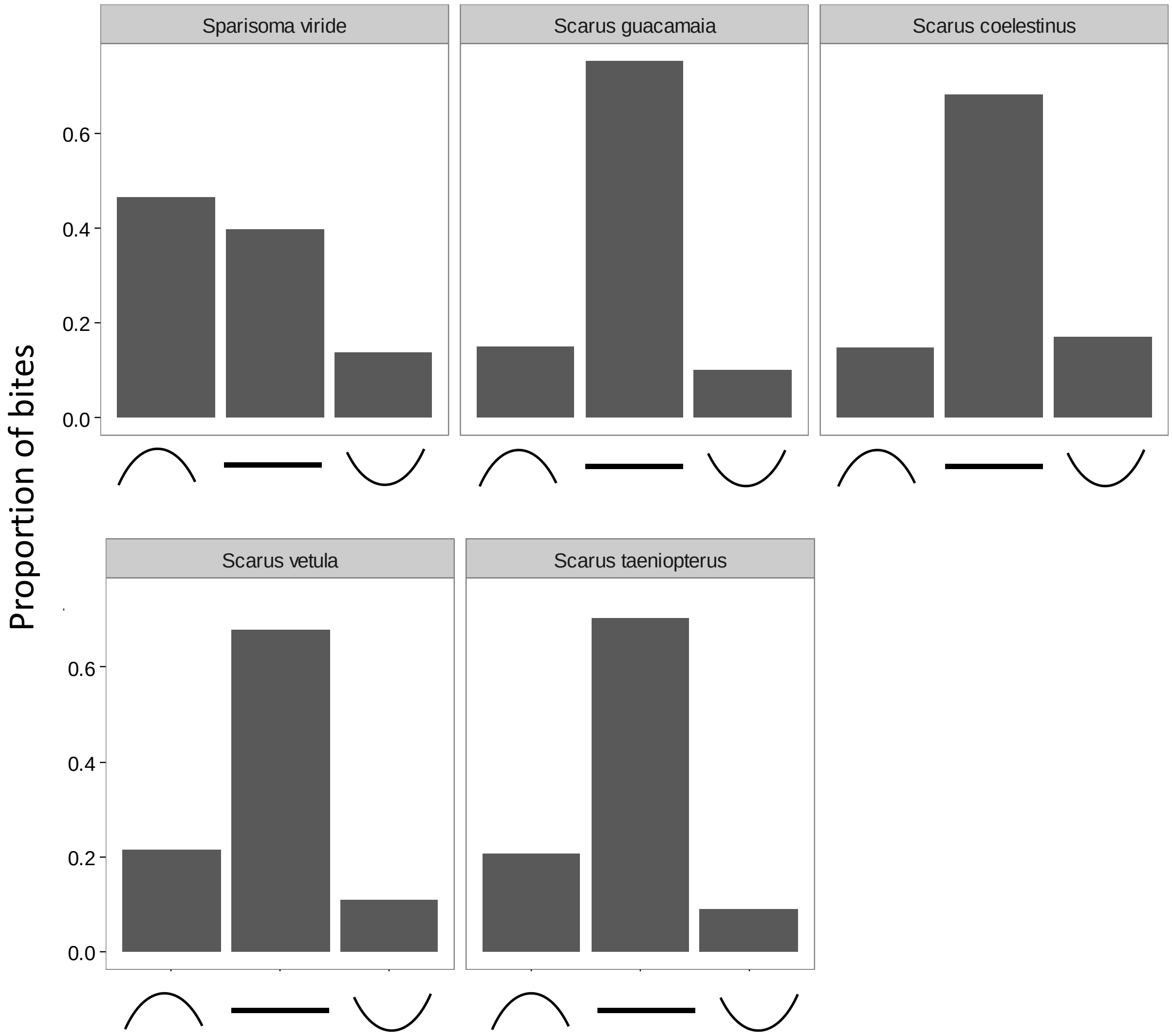

Figure 11. Distribution of bites on convex, flat, or concave reef surface for the common parrotfish scraping/excavating parrotfish species. With the exception of *Sp. viride*, which targeted convex surfaces, scraping and excavating parrotfishes tended to focus bites on flat surfaces.

The second approach we used to quantify small-scale spatial variability in the intensity of herbivory was to video of grazing and browsing by herbivores in different microhabitats on the reef. This approach resulted in the collection of several hundred hours of which are currently being analyzed by undergraduates in Dr. Ruttenberg's lab and via undergraduates at Dr. Burkepile's new institution UC Santa Barbara.