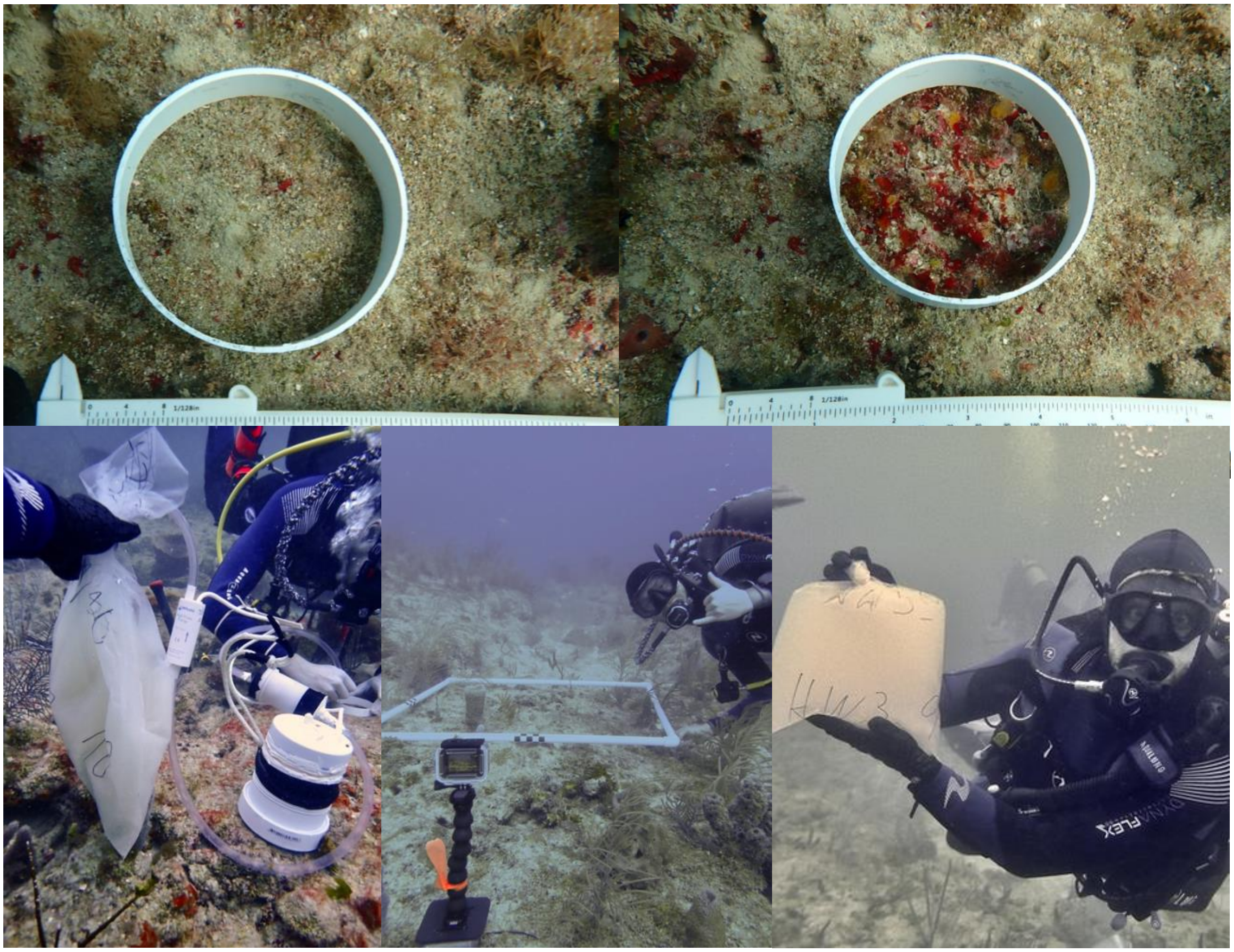
Putting algal turf sediments in perspective along Florida's Coral Reef



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Putting algal turf sediments in perspective along Florida's Coral Reef

Final Report

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Management Summary

Algal turfs—short (<2 cm tall), multispecies assemblages of macroscopic algae—are the most abundant benthic cover on Florida's Coral Reef (FCR). To improve restoration efforts and understand reef dynamics on the FCR, assessing algal turf communities, their associated sediments, and their impact on reef recovery is essential. Our goal was to examine algal turf communities and sediment dynamics to identify bottlenecks to reef recovery across monitoring sites and DEP priority restoration areas. We found high algal turf cover (mean 47% ± 1.2 SE), low coral cover (mean 2% ± 0.5 SE) and low recruitment (<1 recruit m^{-2}) across reefs, reef habitats, and priority restoration areas. Turf length showed a high degree of spatial variation, however most reefs across FCR including DEP priority restoration sites were dominated by long sediment-laden algal turfs (LSATs: > 5 mm) which can suppress coral settlement, growth, herbivory and ultimately recovery. Nearshore, inner, and middle reefs were dominated by LSATs relative to offshore reefs and the Florida Keys (mean lengths of 6.9, 5.1 and 3.7 mm respectively). Notably, greater turf length was positively associated with sediment depth suggesting high levels of sediment trapping are occurring on FCR. Sediment mass (g) was 7.5 times higher on reefs in the Coral AP compared to the Florida Keys, indicating significantly greater sediment accumulation and/or retention, consistent with sites proximal to land-based stressors. Grain size analysis across FCR sites revealed fine (<125 and 63 µm) to coarse sediments (1000 and 2000 µm). Coral AP sediments skewed slightly coarser (1000 and 2000 µm) whereas finer sediments were relatively common on the offshore sites, and more uniform sediments observed in the Florida Keys, suggesting differences in terrigenous land point sources, management, and distance from shore. Similar patterns were reflected in the herbivorous fish community, with more abundant and larger fishes on offshore reefs, while reefs closer to shore had depauperate and small herbivorous fish communities. Notably, patterns in total grazing rates (bites) decreased with increasing distance from shore despite higher abundance of fishes on the middle and outer reefs. Our findings highlight the need for management to include assessment of turf communities to identify LSAT dominated sites by expanding coral monitoring activities to include *in-situ* measurements of algal length and sediment depth. Importantly, we recommend that site selection for future restoration efforts focus on Florida's offshore reef systems where algal turf cover, length, and sediment accumulation are lower, and the herbivorous fish community is more intact.

Executive Summary

Over the last three decades, coral populations and cover have declined precipitously across Florida's Coral Reef (FCR), prompting increased focus on coral restoration efforts. Yet, little attention has been directed towards understanding potential demographic bottlenecks (e.g., low settlement rates, high mortality of coral recruits and juveniles, reduced herbivory, etc.) hindering both natural population recovery and restoration success. What efforts have been made to elucidate these bottlenecks thus far have focused primarily on scleractinian coral themselves, and, while important, may miss crucial changes in other aspects of the ecology of the FCR that contribute to, or impede reef recovery. Suitable site selection for coral restoration is requires understanding how which demographic bottlenecks dominate across multiple spatial scales and environmental gradients. Algal turf, and the sediments bound in the turf, is the dominant benthic cover on FCR, and can negatively influence coral survivorship and growth, but is generally not well researched. To address these gaps and provide guidance to reef managers, we examined algal turf-bound sediments across monitoring sites and priority restoration sites to identify recruitment bottlenecks and whether the potential for system recovery changes across environmental gradients. Specifically, we had four objectives: (1) characterizing benthic community composition and coral recruitment, (2) assessing the spatial distribution of algal turf communities (i.e., short productive algal turfs (SPATs) and long sediment-laden algal turfs (LSATs)), (3) characterizing algal turf sediments, and (4) quantifying grazing rates of algal turfs by herbivorous fish communities across and within coral reef monitoring and priority restoration sites along FCR. We found high algal turf cover (mean 47% ± 1.2 SE), low coral cover (mean 2% ± 0.5 SE) and low recruitment (<1 recruit m^{-2}) across reefs, reef habitats, and priority restoration areas of FCR. Turf length showed a high degree of spatial variation, however most reefs across FCR, including priority restoration sites, were dominated by long sediment-laden algal turfs (LSATs: > 5 mm) which can impede coral settlement and growth. Nearshore, inner, and middle reefs were dominated by LSATs relative to offshore reefs and the Florida Keys (mean lengths of 6.9, 5.1 and 3.7 mm respectively). Notably, greater turf length was positively associated with sediment depth due to accumulation of sediment in longer turfs, suggesting high levels of sediment trapping are occurring on Florida's reefs. Similar patterns were reflected in the herbivorous fish community, with more abundant and larger fishes (and thus more effective grazers) on offshore reefs, while reefs closer to shore had depauperate and small herbivorous fish communities. Our findings highlight the need for management to include assessment of turf communities to identify LSAT dominated sites by expanding coral monitoring activities to include *in-situ* measurements of algal length and sediment depth. Importantly, we recommend that site selection for future restoration efforts should focus on Florida's offshore reef systems where algal turf cover, length, and sediment accumulation are lower, and the herbivorous fish community is more intact.

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1. Introduction

Over the last three decades, coral populations and cover have declined precipitously across Florida's Coral Reef (FCR) due to a combination of disease outbreaks, thermal stress events, and chronic local stressors (Jones et al., 2022), prompting the expanding application of coral restoration efforts (e.g., Lirman and Schopmeyer 2016). Yet, little attention has been directed towards understanding potential demographic bottlenecks (e.g., low settlement rates, high mortality of coral recruits and juveniles, reduced herbivory) that may be hindering natural population recovery (Doropoulos et al., 2022). Demographic bottlenecks refer to key life history stages where strong regulatory processes result in low survival of individuals, restricting population recovery (e.g., Beck 1995). A key challenge for understanding reef recovery along FCR and ensuring suitable site selection for coral restoration is quantifying which demographic bottlenecks are present across multiple spatial scales and environmental gradients. While interactions between macroalgae and coral are understood to have negative impacts, the role of algal turf and the sediments bound in the turf, on coral mortality and growth may be significant, but is generally under-researched. On the FCR this is a significant gap, because algal turfs make up the majority of benthic cover. To address this gap and provide guidance to reef managers, we examined algal turf-bound sediments across monitoring sites, priority restoration sites, and modelled sink-source hotspots to identify recruitment bottlenecks and whether the potential for system recovery changes across environmental gradients.

Algal turfs are short (<2 cm tall), multi-species assemblages of macroscopic algae, that are often highly abundant on coral reefs (i.e., >50% cover). As coral populations decline, algal turfs are predicted to increase in abundance, dominating future reef systems (Bellwood et al., 2019; Bruno et al., 2019). This has been seen across FCR, as coral cover has declined, algal turfs have increased significantly, and now cover ~60–75 % of the hard substratum (N. Jones unpublished data). Algal turfs will play an increasingly important role in shaping key ecosystem processes along FCR, including coral settlement (Speare et al., 2019), community composition (Jones et al., 2022), and herbivory (Duran et al., 2019). Importantly, as algal turfs grow, they readily trap and accumulate more sediment, becoming long sediment-laden algal turfs ('LSATs'), representing a major reservoir of sediments on coral reefs. These LSATs are minimally productive, and elevated sediment retention can reduce and/or prevent coral settlement, growth, and increase mortality through enhanced microbial activity and disease transmission (reviewed in Tebbett and Bellwood 2019). Algal turfs are an important food resource for fish and invertebrates, but the build-up of unpalatable sediment could lead to reduced or changed feeding behavior, and contaminants (e.g., heavy metals) accumulated in the sediments and turfs may represent a key conduit through which metals enter food chains. As such, algal turf sediments represent a multi-faceted stressor on coral reefs, interacting with several ecosystem processes that may lead to demographic bottlenecks (i.e., reduced coral recruitment, herbivory) and reef recovery.

1.1. Project Goals

The overall goal of this project was to examine algal turf communities and algal turf sediment dynamics to identify bottlenecks to reef recovery across monitoring sites and DEP priority restoration areas on FCR. This project is part of a multi-phased program to: (1) investigate the distribution of algal turfs, sediment load and characteristics, and correlation with spatial patterns of coral settlement and herbivory on the FCR (this project); (2) algal turf sediment dynamics and heavy metal absorption but these sediments; and (3) the mechanisms by how different sediment characteristics influence early post-settlement survivorship and juvenile coral growth.

Our primary objectives were:
Objective 1: Characterization of benthic communities, coral recruitment and juvenile corals
Objective 2: Quantify the spatial distribution of algal turf communities and associated algal turf sediments
Objective 3: Characterization of algal turf sediments (sediment depth, loads, composition, and grain size)
Objective 4: Quantify herbivorous fish communities and grazing rates of algal turf communities

2. Methods

We used a combination of field surveys, collections and sediment analysis to examine the spatial dynamics of algal turf communities and algal turf-bound sediments along FCR. Twenty-one reef sites were selected and surveyed along the Coral AP and Florida Keys . (Table 1).

Table 1. Monitor and priority restoration sites surveyed during this project. Latitude and longitude are in decimal degrees. '*' indicates DEP priority restoration sites

Region	Site	Shelf position	Latitude	Longitude
Coral AP	West Palm Beach	Outer*	26.6839	-80.0184
	Hillsboro Beach	Middle*	26.3047	-80.0667
	Pompano	Nearshore	26.2352	-80.082
		Inner	26.2352	-80.079
		Middle	26.2352	-80.074
		Outer	26.2352	-80.0677
	Lauderdale	Nearshore	26.1535	-80.0958
		Inner*	26.1535	-80.0890
		Middle	26.1535	-80.0821
		Outer	26.1535	-80.0782
	Hollywood	Nearshore*	26.0078	-80.1075
		Inner	26.0073	-80.1018

		Middle	26.0061	-80.0970
		Outer	26.0056	-80.0883
	North Miami Beach	Inner*	25.8343	-80.0992
	Miami Beach	Nearshore*	25.8070	-80.1110
Florida Keys	Caryfort Reef	Fore reef	25.2201	-80.21075
	Cheeca Rocks	Patch reef	24.9040	-80.6149
	Sombrero Reef	Fore reef	24.6259	-81.1107
	Looe Key	Fore reef	24.5468	-81.4031
	Eastern Dry Rocks	Fore reef	24.4590	-81.84555

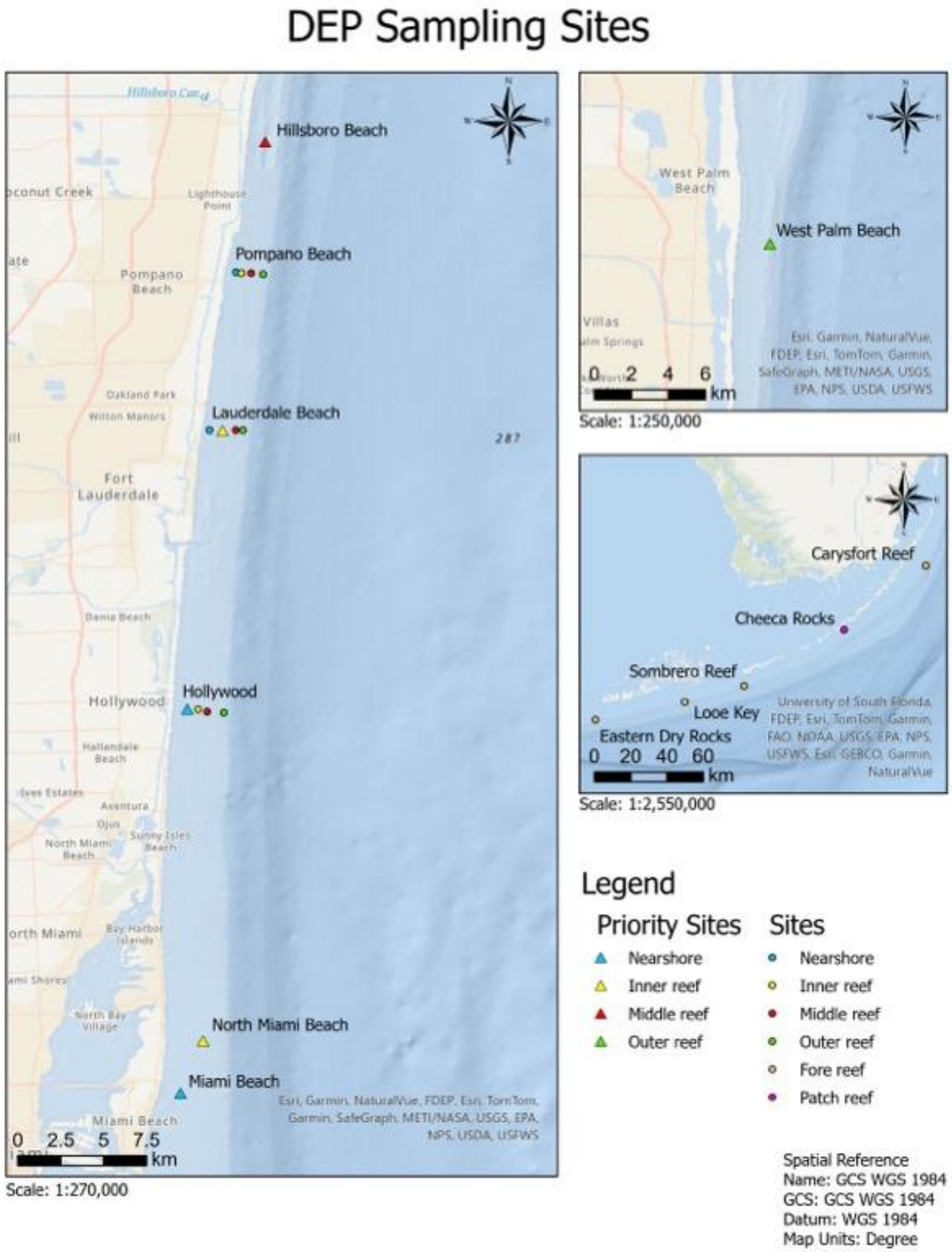

Figure 1. Geographic distribution of Florida's Coral Reef (FCR) survey sites (n=21), across the Kristin Jacobs Coral Aquatic Preserve (n=16 sites) and the Florida Keys (n=5), spanning ~360 km and 7° latitude. Reef sites include various reef formations (fore reef and patch reef), and cross shelf positions (nearshore ridge complex, inner, middle, and outer reefs). Sites are color-coded by shelf position, with State of Florida Department of

Environmental Protection (DEP) priority sites marked by triangles. Inset provide regional zooms for West Palm Beach and the Florida Keys. Basemap sources include ESRI, NOAA, USGS, and other state and federal agencies.

2.1. Characterization of benthic communities, coral recruitment and juvenile corals (Objective 1)

Benthic community cover was estimated on 21 reef sites across the Florida's Coral Reef including the Kristin Jacobs Coral Aquatic Preserve (Coral AP)) and Florida Keys (FK), see Table 1 and Figure 1) using four replicate 20 m belt-transects (fiberglass tape measures). Transects were laid parallel to the shore at 3–25 m depth depending on reef site shelf position, spaced 5 m apart, and the substrate directly beneath the transect tape was photographed within a 0.25 m^{-2} quadrat at 2 m intervals (40 quadrats $site^{-1}$). Composition and benthic cover was quantified within each quadrat using 30 randomly distributed points using CoralNet software (https://coralnet.ucsd.edu). Benthic cover was categorized into nine benthic groups: hard corals (scleractinian), octocorals (gorgonians), sponges, algal turfs (≤ 2 cm in height), macroalgae (> 2 cm in height), epilithic algal matrix (a conglomeration of turf, macroalgae and other materials), zoanthids, other taxa (e.g., hydroids, anemones), and abiotic substratum (sand, rubble and pavement). All hard corals were identified to species. Structural complexity was also estimated along each transect using a visual six-point scale, following Polunin and Roberts (1993). Along the same transects, the abundance of coral recruits (<2 cm diameter) and juveniles (~5 cm in diameter) was quantified to the lowest taxonomic level by visually inspecting 10 haphazardly placed 0.25 m^2 quadrats along each transect.

2.2. Spatial distribution of algal turf communities and associated algal turf sediments (Objective 2)

Within each reef site, algal turf communities and algal turf sediments were quantified using 10 replicate circular (58 cm^2) quadrats. Algal turf-bound sediments within each 58 cm^2 quadrat were collected from algal turfs using a submersible underwater vacuum, secured in plastic catch bags and/or bottles and transported to the NSU' Oceanographic Center (OC). This method is minimally invasive and removes all algal turf-bound sediments, with minimal to no impact on the reef benthos. No invertebrates or coral recruits were collected or harmed. Following the collection of algal turf sediments, algae turf length were quantified from within each 58 cm^2 quadrat by measuring 10 haphazardly selected algae turf filaments using vernier calipers. Photographs of each algae turf quadrat were taken before and after the collection of algal turf sediments to quantify turf filament cover and density. Percent cover of algal turfs within each circular quadrat were quantified using 30 randomly stratified points using CoralNet software (https://coralnet.ucsd.edu).

All sediment samples were transferred to 10 L plastic buckets and left to settle for at least four hours. All seawater was decanted and properly disposed of in NSU lab waste. The remaining sediment was rinsed with a 50/50 mixture of seawater and deionized (DI) water) and placed into small 235 ml plastic containers. Ten ml of 10% phosphate buffered formalin was added to each sample container. All samples were capped, secured with tape, gently agitated for 30 seconds to ensure the formalin was thoroughly mixed throughout the sediment and frozen for further processing.

2.3. Characterization of algal turf sediments (sediment loads, composition, grain size) (Objective 3)

Sediments and particulates collected from algal turf communities were processed to generate data on sediment depth, mass, composition (inorganic vs organic ratios), and grain size distributions (µm). All samples were thawed for ~48 hours at room temperature, sieved to remove >2 mm particulate materials and rinsed with DI water. All sediment samples were left undisturbed for ~24 hours to allow for consistent levels of compaction across samples. Sediment depth was measured five times within each sample container using digital calipers. All samples were dried at 60℃ in a drying oven for 24 hours, and the total sediment mass (organic material and inorganic sediment) measured using an analytical balance (0.001g accuracy). To determine the sediment composition (i.e., the proportion of organic vs. inorganic material), all organic materials were removed from each sample using hydrogen peroxide (H_2O_2). The amount of organic vs inorganic material was calculated for the change in sample weight post-H_2O_2 using the following formula:

Total mass = organic mass + inorganic mass

Trace-metal grade 35% hydrogen peroxide (H_2O_2) was added to each sample under a fume hood at a rate of approximately 10 ml per 2 days for 14 days, and then allowed to off gas the organics and H_2O_2. Each sample was rinsed 3 times with DI water, dried at 60℃ for 24 hours, and reweighed. To quantify the sediment size distribution (i.e. fractions), particle sizes are currently being categorized and quantified for each sediment sample using ATSM testing sieves (<63, 125, 250, 500, and 1000 units). Following sieving, each grain size sample was weighed. Following these processes, a homogenous 5 g sediment sample for each replicate was stored for future heavy metal analysis. As of June 13, 140 samples of 210 total samples have been fully analyzed for 14 of the 21 sites.

2.4. Spatial distribution of herbivorous fish communities and algal turf grazing rates (Objective 4)

Herbivorous fish communities were characterized across all 16 reef sites using stereo diver-operated video (stereo-DOVs) within four replicate 50 × 5 m belt transects at 3–25 m depth across the inner, middle and outer reefs within the Coral AP. Stereo-DOV surveys allow rapid, consistent, and accurate estimates of body-size and sampling area and provide a permanent record of the fish community. The stereo-DOV system consists of two GoPro Hero 12 cameras secured within specialist housings set 80 cm apart on an aluminum base bar. Videos were shot at 1920 × 1080 pixels, with a capture rate of 60 frames per second. At the Guy Harvey Oceanographic Center we used EventMeasures software (www.seagis.com.au) to view the paired videos to extract abundance and total length (to the nearest cm) of all roving herbivorous and nominally herbivorous fishes (i.e., Acanthuridae, Labridae (parrotfishes), Kyphosidae). Length was measured when the fish was at the closest point to the camera. Individual fish that did not approach within 8 m of the camera, or that were only captured within 1m of the camera were excluded due to potential inaccuracy with length calculations (Goetze et al., 2019). Density estimates were converted to biomass using published species length-weight relationships. As of June 13 stereo-DOV data have been fully analyzed for 10 of the 16 Coral AP sites.

Spatial variation in daily grazing rates (i.e., the removal of algal turfs) was assessed across the Coral AP, using a series of algal turf plots (1 m^2) spaced 5 m apart at eight selected reef monitoring sites: across Hollywood and Pompano's nearshore, inner, middle and outer reefs. Three underwater videos cameras were haphazardly deployed within each site and positioned 10 meters apart. Each site was sampled three times on non-consecutive days, for a total of 72 hours. Within each site, grazing rates of herbivorous fishes (i.e., grazers) on the benthos was quantified using five replicate 1 m^2 plots and three underwater video cameras (GoPro Hero 12). Each camera was mounted to a 2 kg weight and 25 cm tall gooseneck mount and positioned on low-complexity algal turfed covered sections of the reef free of corals, sponges and octocorals. At the start of each recording, a 1 m^2 quadrat was temporarily placed in front of each camera for about 15 seconds to provide a frame of reference. Cameras were left to record continuously for about 90 minutes. Following retrieval, the first 20 minutes and last 10 minutes was discarded to minimize potential diver interference. For each video, we will record the total number of bites, species and estimate TL to the nearest centimeter for each fish observed feeding on algal turfs. As of June 13 >50 hours of video have been fully analyzed.

3. Results

3.1. Spatial variation in benthic community composition across shelf position and habitat

Algal turfs were the dominant benthic taxa across all reefs, shelf positions, and habitats (Figure 2) except at one reef site (Lauderdale Beach middle reef) (Figures 3 and 4). Mean algal turf cover was high (47.1% ± 1.2 SE) across the Coral AP but varied spatially among reefs ranging from 67.1% (± 2.9 SE) on Miami Beach nearshore reef to 31% (± 2.5 SE) on Lauderdale Beach middle reef. Notably, combined algal turf and macroalgal cover accounted for >50% benthic cover across all reef sites. In contrast, mean coral cover was low (~2% ± 0.5 SE) at all reef sites but Cheeca Rocks (18% ± 4.9 SE). Moreover, Cheeca Rocks was the only site along the FCR with higher coral cover than octocoral cover. Macroalgal cover was also high (>20%) at most reef sites within the Coral AP and accounted for >50% on the middle reef offshore Fort Lauderdale. In contrast, macroalgal cover was comparatively low (<10%) at four of the five sites in the Florida Keys.

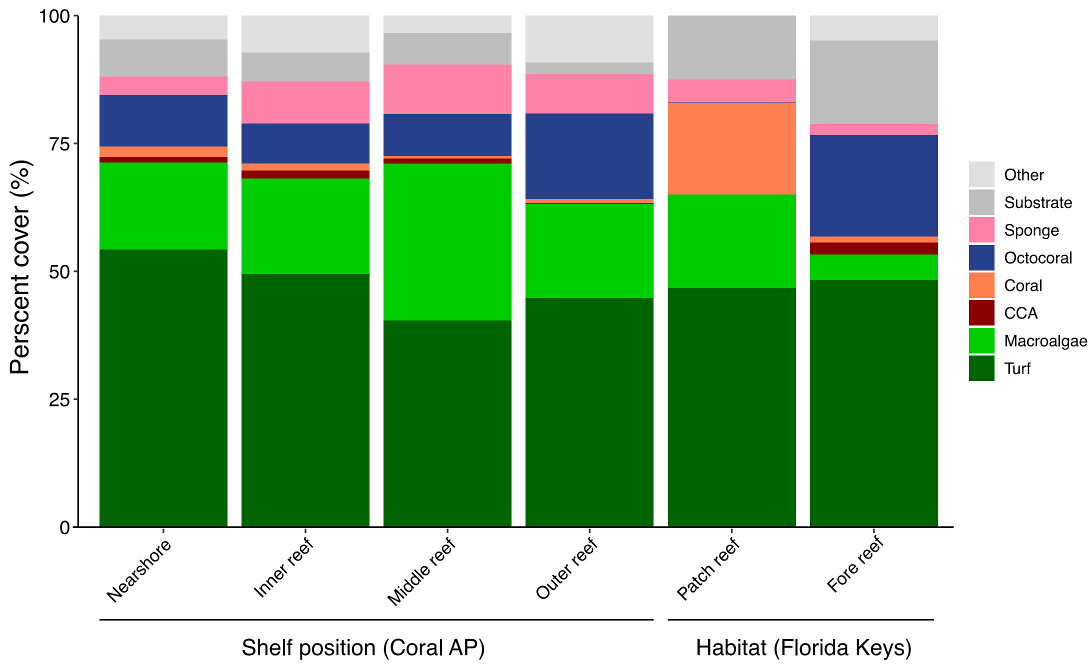

Figure 2. Relative abundance of benthic cover (percent cover) by shelf position (nearshore ridge complex, inner, middle, and outer reefs) within the Coral AP and by habitat (patch reef, fore reef) in the Florida Keys.

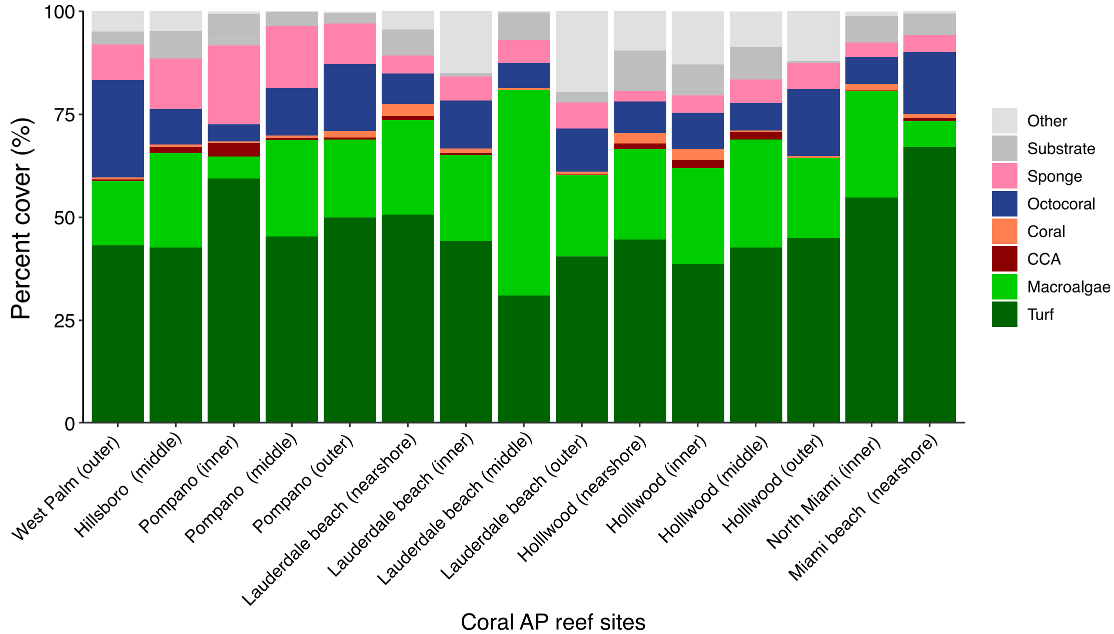

Figure 3. Mean benthic cover (proportion) of Coral AP sites (n=16) between sites. Site order, L-R, follows latitudinal gradient (north-to south) and shelf position (onshore to offshore). Benthic categories include scleractinian coral, octocoral, sponge, crustose coralline algae (CCA), algae turf (turf), macroalgae, substrate, and other.

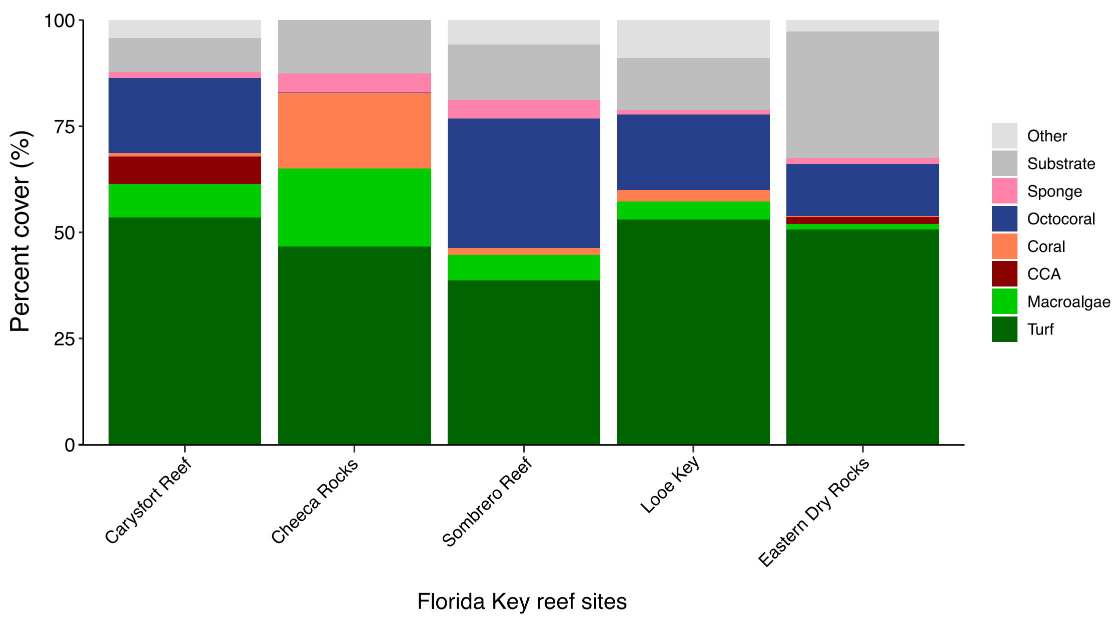

Figure 4. Relative abundance of benthic percent cover of Florida Key sites. Sites are ordered from East to West.

Multivariate analysis revealed that benthic communities exhibited clear spatial structuring by shelf position and site. Sites grouped by shelf position (Figure 5, 2D stress = 0.15) were driven primarily by the proportion of algal turf/ substrate /CCA to macroalgal cover. There was a higher proportion of algal turf, substrate (primarily sand and rubble) and CCA cover across Florida Keys forereef sites and a higher relative proportion of macroalgal cover at most Coral AP sites, particularly middle reef sites, and the single patch reef surveyed in the Florida Keys. Secondary differentiation between sites and habitats was driven by the proportion of coral and sponge cover at a site with that of octocoral or other faunal (e.g., hydroids, tunicates) and cyanobacterial cover. No clear latitudinal or longitudinal pattern was evident. Cheeca Rocks showed clear dissimilarity in benthic community composition compared to all sites.

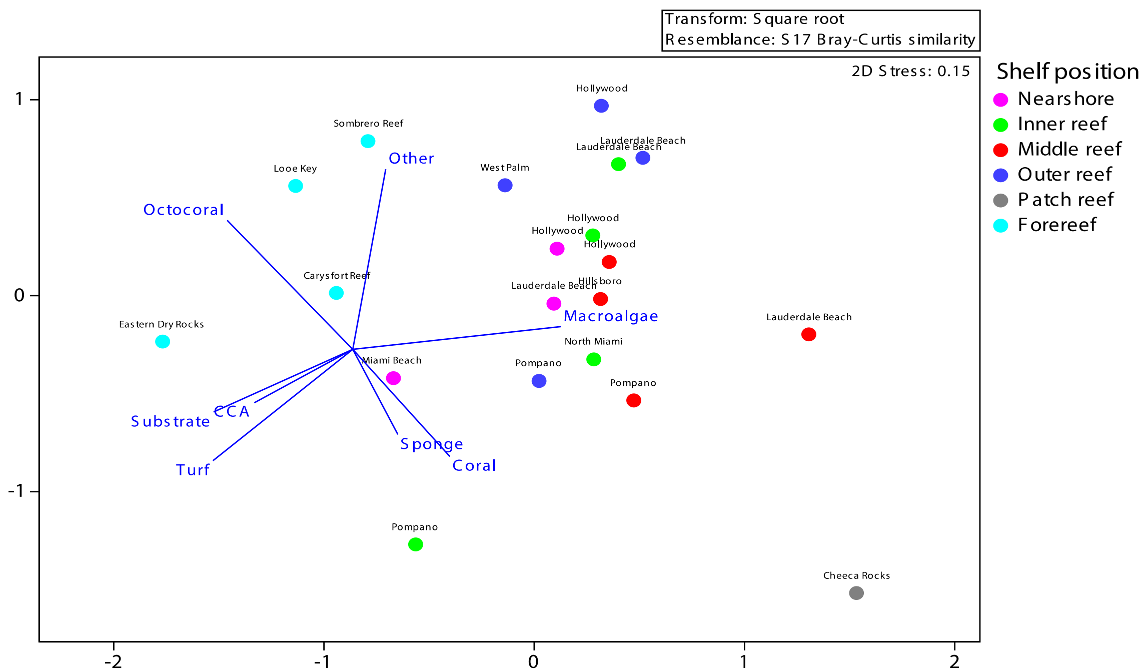

Figure 5. Non-metric multidimensional scaling (nMDS) ordination plot of benthic community composition for each site categorized by shelf position (i.e., nearshore, inner, middle and outer reef). Similarity calculated using Bray-Curtis similarity index on square-root transformed cover data. Vectors represent the direction and strength of the benthic taxa most strongly associated with community gradients including algal turf, CCA, macroalgae, sponges, scleractinian coral, octocoral and other.

3.2. Spatial variation in coral recruitment across shelf position

Overall, coral recruitment was extremely low (<1 recruit m^{-2}) but varied significantly among sites and shelf position (Table 2). Highest recruitment was recorded on the Hollywood inner reef site (2.65 recruits m^{-2}) and lowest recruitment was recorded on Fort Lauderdale Beach nearshore site (0.05 recruits m^{-2}). Mean recruit density was highest on inner reefs (1.01 ± 0.55 recruits m^{-2}), however this was heavily influenced by the number of recruits recorded on Hollywood. Recruit density was similar across shelf positions; lowest on the nearshore ridge complex (0.38 ± 0.17 recruits m^{-2}) and marginally, but significantly, higher on the middle (0.45 ± 0.16 recruits m^{-2}) and outer (0.53 ± 0.11 recruits m^{-2}) reef sites.

Table 2. Summary of coral recruits (<2 cm diameter) abundance and density (recruits m^{-2}) across monitoring and priority restoration sites on Florida's Coral Reef. '*' indicates DEP priority restoration sites

Region	Site	Shelf position	Total abundance	Density (recruits m^{-2})
Coral AP	Pompano Beach	Nearshore	0	0
Coral AP	Lauderdale Beach	Nearshore	1	0.05
Coral AP	Hollywood*	Nearshore	12	0.60
Coral AP	Miami Beach*	Nearshore	10	0.5
Coral AP	Pompano Beach	Inner	11	0.55
Coral AP	Lauderdale Beach*	Inner	9	0.45
Coral AP	Hollywood	Inner	53	2.65
Coral AP	North Miami Beach*	Inner	8	0.40
Coral AP	Hillsboro Beach*	Middle	5	0.25
Coral AP	Pompano Beach	Middle	11	0.55
Coral AP	Lauderdale Beach	Middle	17	0.85
Coral AP	Hollywood	Middle	3	0.15
Coral AP	West Palm Beach*	Outer	8	0.40
Coral AP	Pompano Beach	Outer	10	0.50
Coral AP	Lauderdale Beach	Outer	7	0.35
Coral AP	Hollywood	Outer	17	0.85

3.3. Spatial distribution of algal turf lengths and density (cover)

Algal turf lengths varied considerably across reef sites on FCR but showed a pronounced cross-shelf pattern of decreasing algal turf length with increasing distance from shore (i.e., inner to the outer reefs; Table 3). Nearshore reef sites had the longest algal turf lengths (mean 7.9 mm) compared to the outer reef sites (mean 4.6 mm; Figure 6). Most algal turf communities within the Coral AP sites (~68%) were recorded as long sediment-laden algal turfs (LSATs; Figure 7). In contrast, algal turf lengths in the Florida Keys were approximately 50% shorter (mean 3.9 mm) and all recorded as short productive algal turfs (SPATS, Figures 8 and 9)

Table 3. Mean algae turf length (mm ± SE) categorized into either SPAT (algae length <5 or LSAT (algae length >5 mm) following Tebbett and Bellwood 2019 by reef region, site, and reef position on FCR

Region	Site	Shelf position	Mean algal turf length (mm)	Standard Error (SE)	Algal turf community
Coral AP	Pompano Beach	Nearshore	10.30	0.87	LSAT
Coral AP	Lauderdale Beach	Nearshore	7.16	0.28	LSAT
Coral AP	Hollywood*	Nearshore	6.21	0.73	LSAT
Coral AP	Miami Beach*	Nearshore	7.94	0.45	LSAT
Coral AP	Pompano Beach	Inner	7.82	0.53	LSAT
Coral AP	Lauderdale Beach*	Inner	6.49	0.36	LSAT
Coral AP	Hollywood	Inner	4.72	0.15	SPAT
Coral AP	North Miami Beach*	Inner	5.99	0.36	LSAT
Coral AP	Hillsboro Beach*	Middle	7.06	0.45	LSAT
Coral AP	Pompano Beach	Middle	8.57	0.44	LSAT
Coral AP	Lauderdale Beach	Middle	6.28	0.46	LSAT
Coral AP	Hollywood	Middle	4.92	0.46	SPAT
Coral AP	West Palm Beach*	Outer	4.42	0.19	SPAT
Coral AP	Pompano Beach	Outer	4.73	0.32	SPAT
Coral AP	Lauderdale Beach	Outer	5.29	0.40	LSAT
Coral AP	Hollywood	Outer	4.28	0.25	SPAT
Florida Keys	Carysfort Reef	Fore reef	3.13	0.26	SPAT
Florida Keys	Cheeca Rocks	Patch reef	4.09	0.46	SPAT
Florida Keys	Sombrero Reef	Fore reef	3.56	0.41	SPAT
Florida Keys	Looe Key	Fore reef	3.98	0.40	SPAT
Florida Keys	Eastern Dry Rocks	Fore reef	3.50	0.39	SPAT

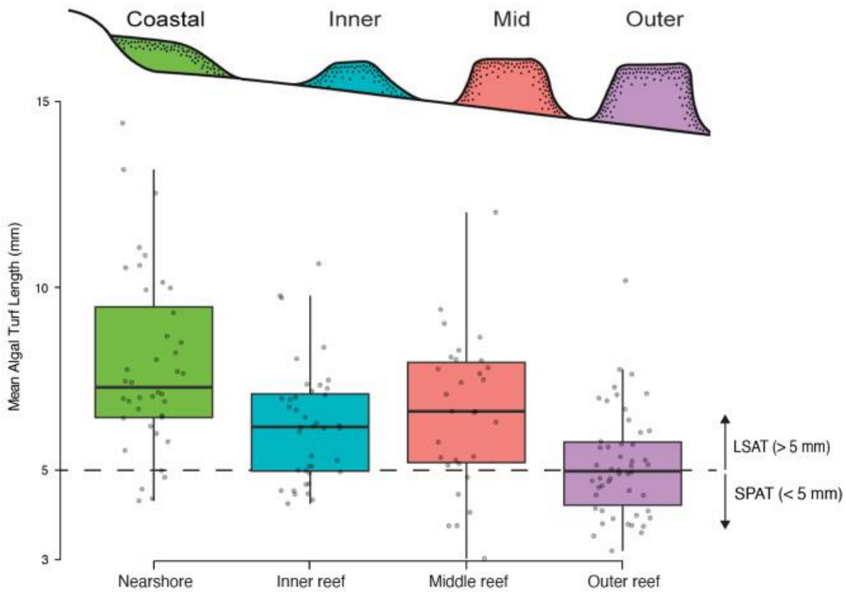

Figure 6**.** Mean algal length (mm) across shelf position within the Coral AP. For all figures containing boxplots; thick horizontal lines indicate median value, top and bottom of each box indicates 75th and 25th percentiles; vertical lines show ranges; black points indicate each replicate sample.

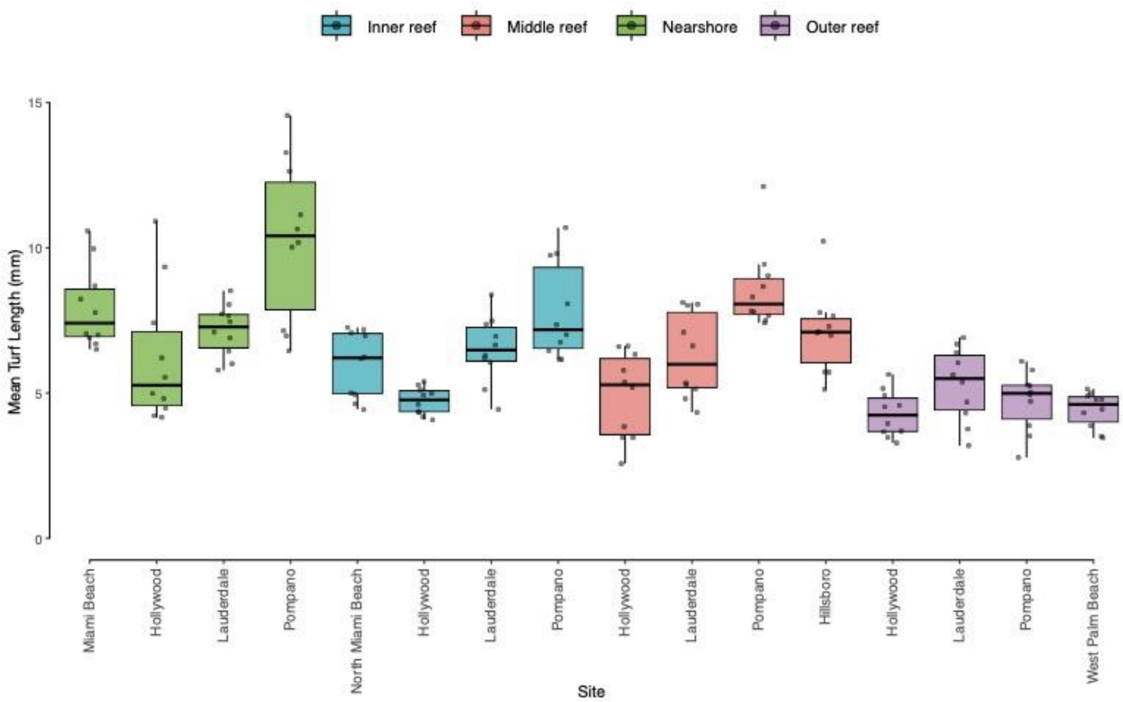

Figure 7. Mean algal turf length (mm) across reef sites and shelf position in the Coral AP.

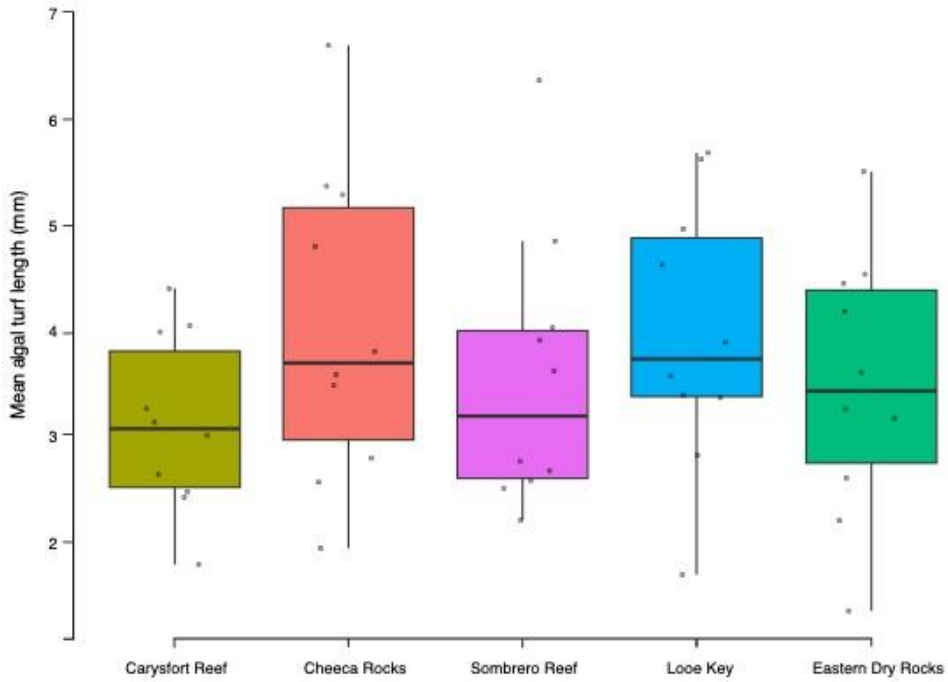

Figure 8. Mean algal turf length (mm) at each reef site in the Florida Keys.

Mean algae turf cover from 58 cm^2 vacuumed circular quadrats varied across shelf position ranging from 25–36% algal turf cover (mean 28.9%). Nearshore and inner reefs had relatively higher algal turf cover (31.8% and 34.1%, respectively; Figure 9) than the middle (12.2%) and outer (25.7%) reefs

The category of "others" (i.e., everything other than algae turf) dominated the benthic cover at smaller spatial scales. Lauderdale Beach sites had the highest cover of "others" (~76%) indicating low algae turf cover at smaller spatial scales. Sites in the Florida Keys displayed lower variance in algal turf and other density data (Figures 10 and 11) with 53% turf cover and 47% other cover. Looe Key displayed the highest algae turf density (58%) and Eastern Dry Rocks displayed the lowest algae turf density (42%). These patterns indicate widespread proliferation of long, sediment-associated algal turfs (LSATs), suggesting a regional shift toward algae turf dominated reef states (Figure 12).

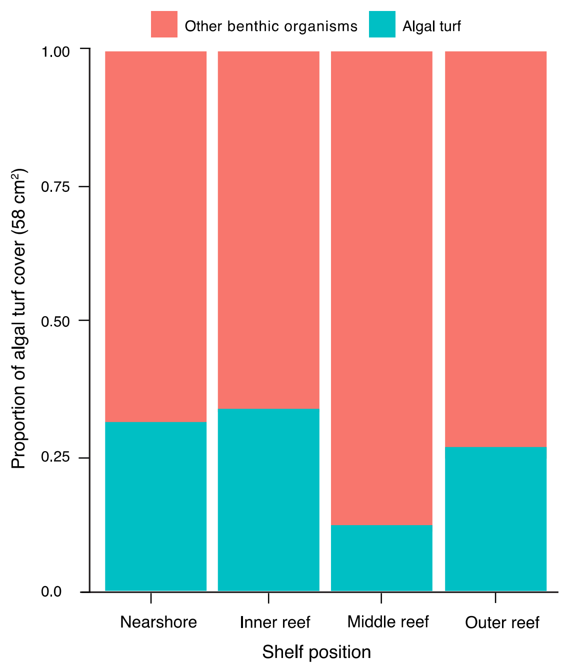

Figure 9**.** Proportion of algae turf cover and all other benthic cover types within vacuumed sampling areas by shelf position for Coral AP sites.

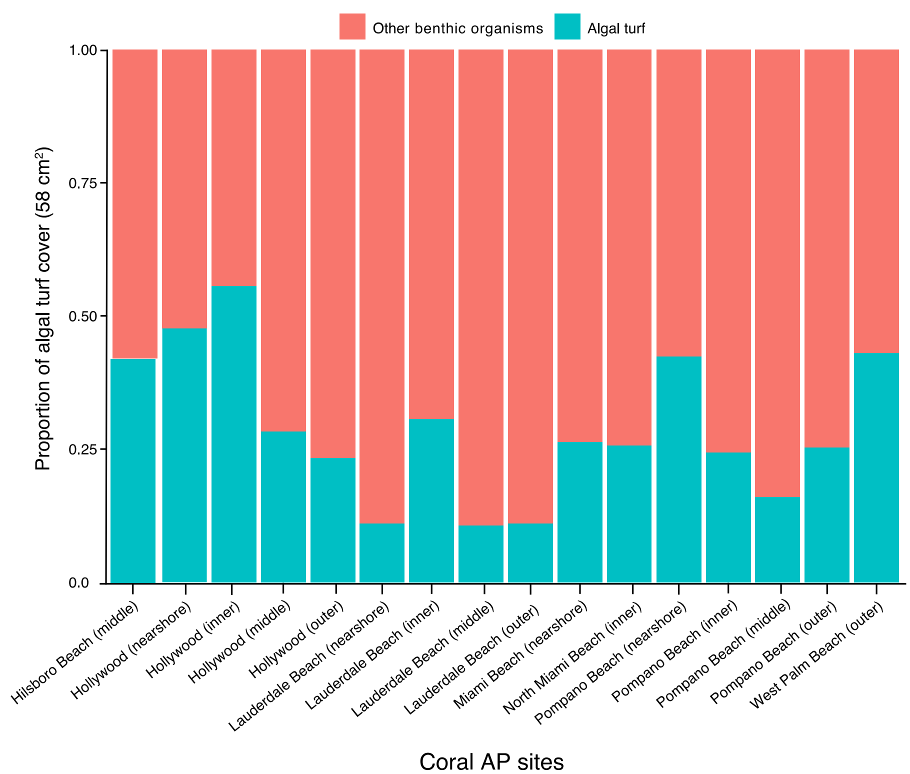

Figure 10. Proportion of benthic cover within vacuumed sampling areas by individual site across the Coral AP.

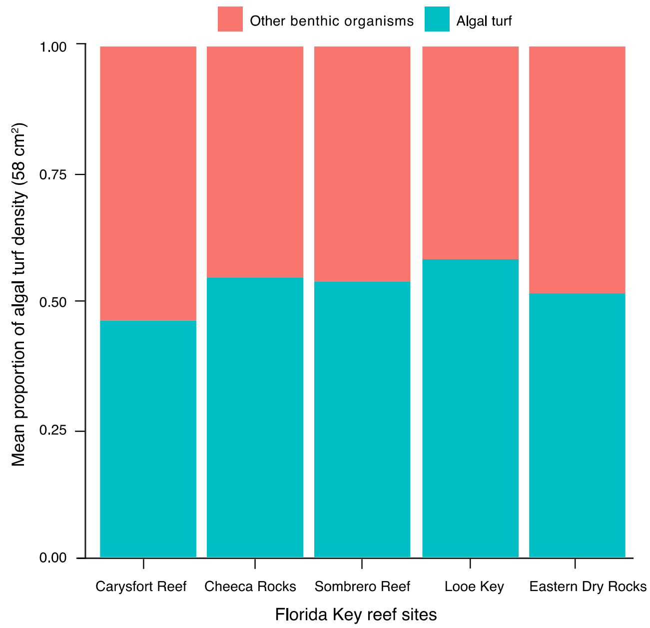

Figure 11**.** Proportion of benthic cover and algal turfs within 58 cm^2 vacuumed circular quadrates in the Florida Keys.

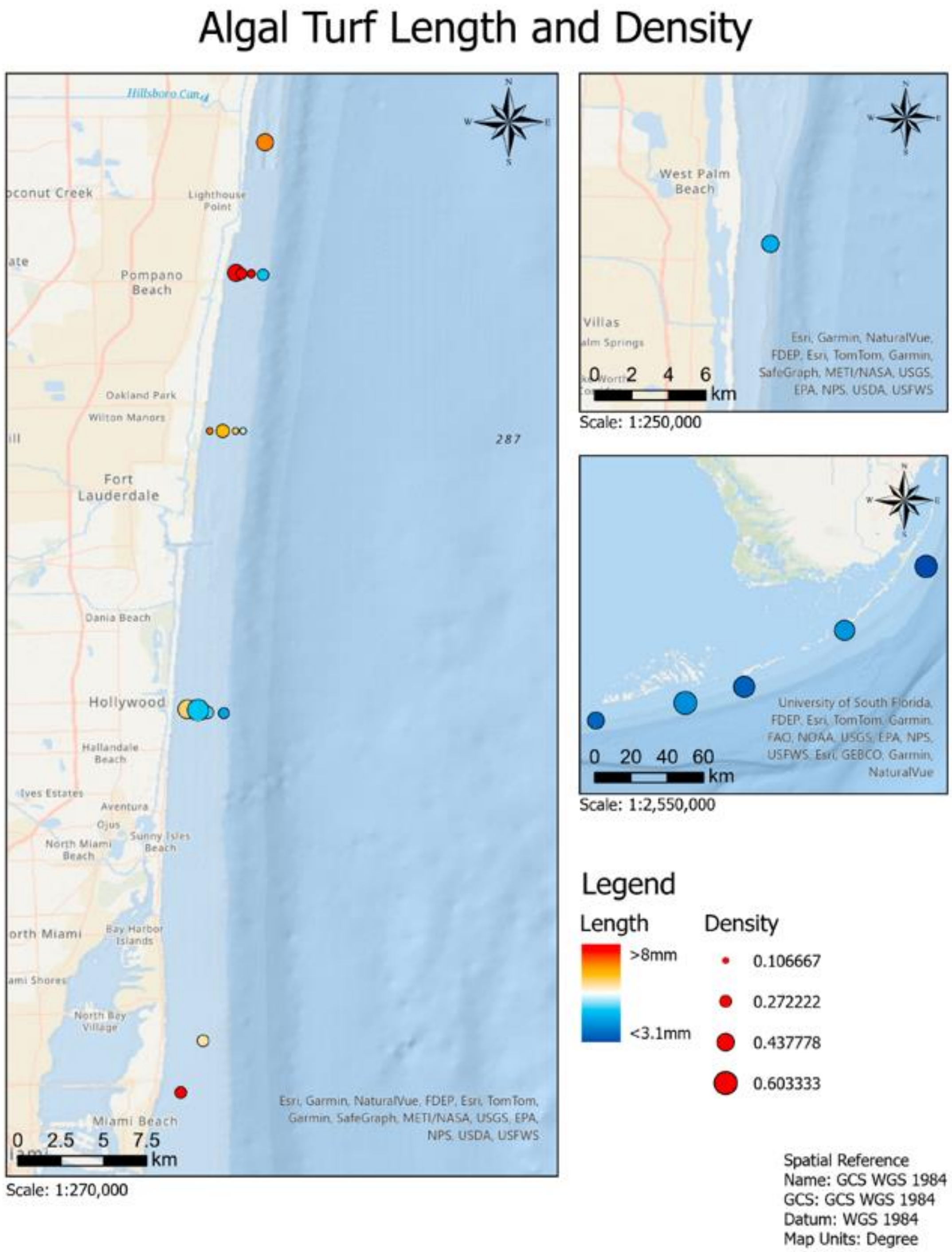

Figure 12. Hotspot map illustrating algae turf length (mm) and cover (proportion) across reef sites (n=21), highlighting sustainability and resiliency of sites with respect to algae turf characteristics. Point color represents mean turf length: blue (<3.1 mm, SPATs), light blue and orange (~3.1-8.0 mm SPATs and LSATs), and red (>8 mm, LSATs). Point size corresponds to relative turf density values within vacuum-cleared 58 cm^2 benthic quadrats. Base maps include bathymetry and coastal reference features.

3.4. Sediment depth and algal turf length

Across the Coral AP sites, turf length was positively associated with sediment depth (Pearson's correlation, $r = 0.4$, $p < 0.001$). Mean algal turf length increased with increasing sediment accumulation, suggesting a potential feedback where longer algae turfs are enhancing local sediment trapping (Figures 13). Mean sediment depth was substantially higher on reefs in the Coral AP compared to the Florida Keys. Interestingly, even reef sites within the Coral AP with shorter turfs (<5 mm) showed elevated sediment accumulation 4.26 mm (± 0.15 mm) compared to reefs in the Florida Keys 0.66 (± 0.08 mm), signifying stronger sediment retention in turf-dominated reefs (Figure 13).

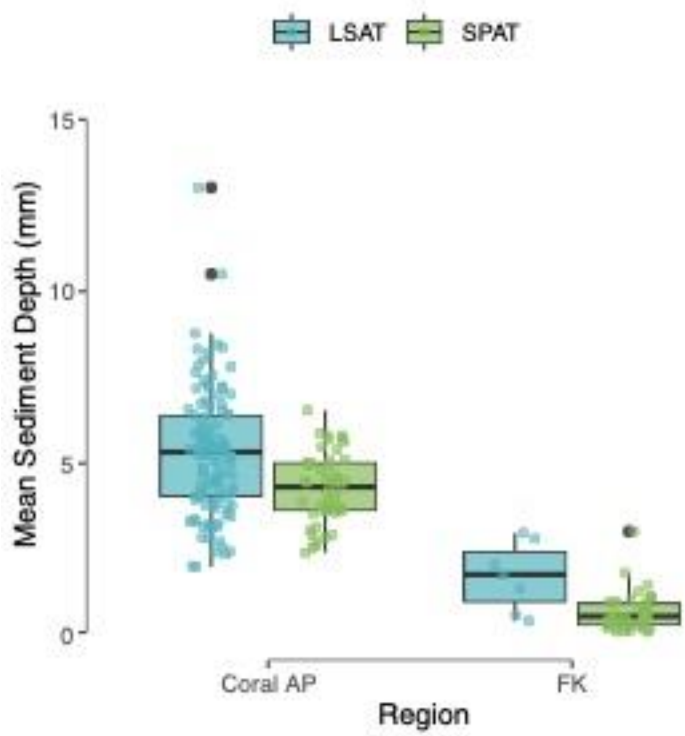

Figure 13. Mean sample sediment depth across the Coral AP and Florida Keys in long sediment laden turfs (LSATs ≥5 mm) and short productive algal turfs (SPATs <5 mm).

Mean sediment depth (mm) across the Coral AP ranged from 4.2 (± 0.1 mm) to 7.6 mm (± 0.4 mm; Figure 14). The highest mean sediment depths were observed at the Hollywood inner reef (7.6 ± 0.3 mm) and Lauderdale Beach inner reef (7.1 ± 0.3 mm) sites, while West Palm and Pompano Beach outer reef sites had among the lowest means, each <4.5 mm, respectively. Mean sediment depth across Florida Keys sites ranged from 0.45 mm (± 0.04 SE) at Eastern Dry Rocks to 1.51 mm (± 0.35 SE) at Cheeca Rocks, which also showed the greatest within-site variation (Figure 15).

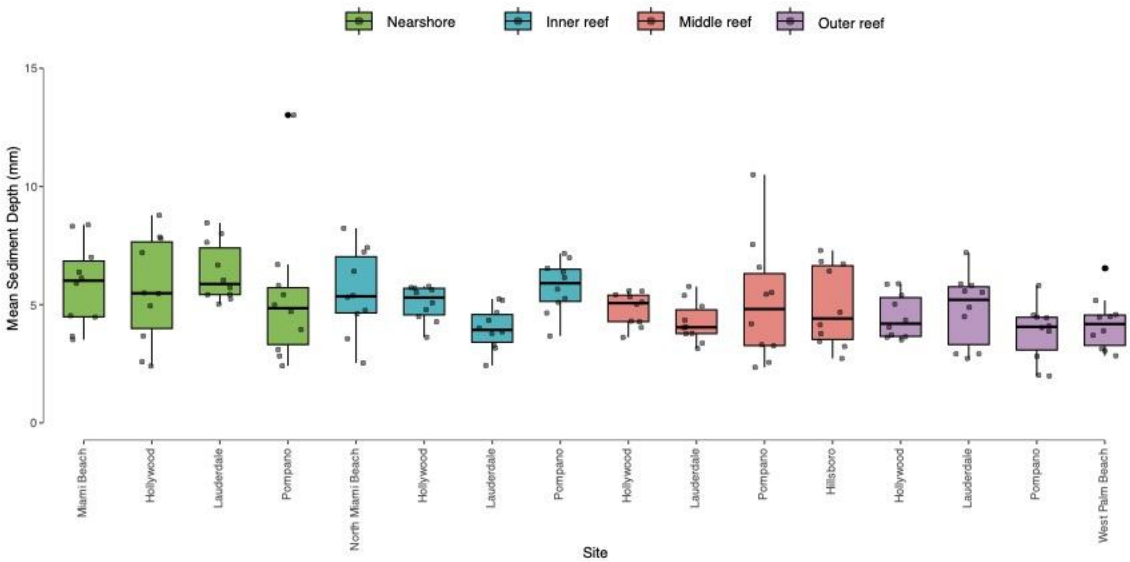

Figure 14. Mean sediment depth (mm) across Coral AP reef sites

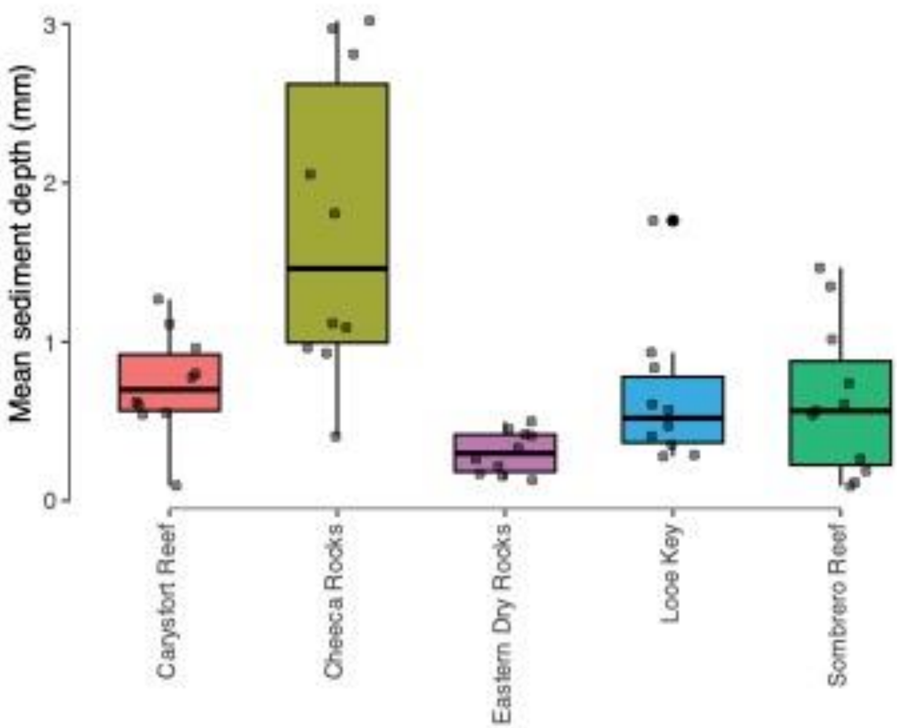

Figure 15. Mean sediment depth (mm) across five Florida Key reef sites.

Patterns in sediment mass (Figures 16 and 17) mirrored those for sediment depth. Across the Coral AP mean sediment mass varied considerably across reef sites and position, with nearshore sites consistently displaying the highest sediment mass (36.0 ± 2.6 g) with values decreasing with distance from shore. Inner reef and middle reef zones had means of 30.0 ± 1.8 g and 28.0 ± 1.9 g, respectively, while outer reef sites averaged 24.2 ± 1.5 g. The highest mean sediment mass was recorded at Pompano Beach nearshore (38.6 ± 7.4 g), followed closely by Hollywood nearshore (35.2 ± 6.0 g). Outer reef sites, such as Hollywood outer reef (22.5 ± 2.5 g) and Pompano Beach outer reef (20.8 ± 2.6 g) had notably lower sediment mass, consistent with observed cross-shelf and latitudinal trends.

In the Florida Keys, results showed that sediment loads varied greatly among sites but that sites closer to the mainland of Florida had relatively higher sediment loads (3.71 ± 0.54 g). Cheeca Rocks had the greatest sediment mass (range 1.8–12.5 g), while Carysfort Reef and Eastern Dry Rocks ranged lower (~2–3 g, see Figure 17).

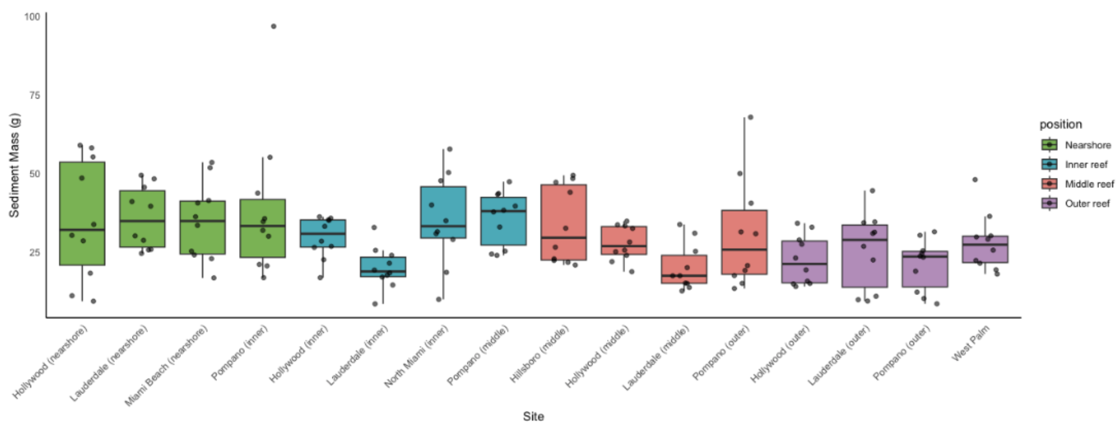

Figure 16. Mean sediment mass (g) across Coral AP reef sites. Sites are ordered latitudinally from north (West Palm Beach) to south (Miami Beach), with boxes colored by reef position.

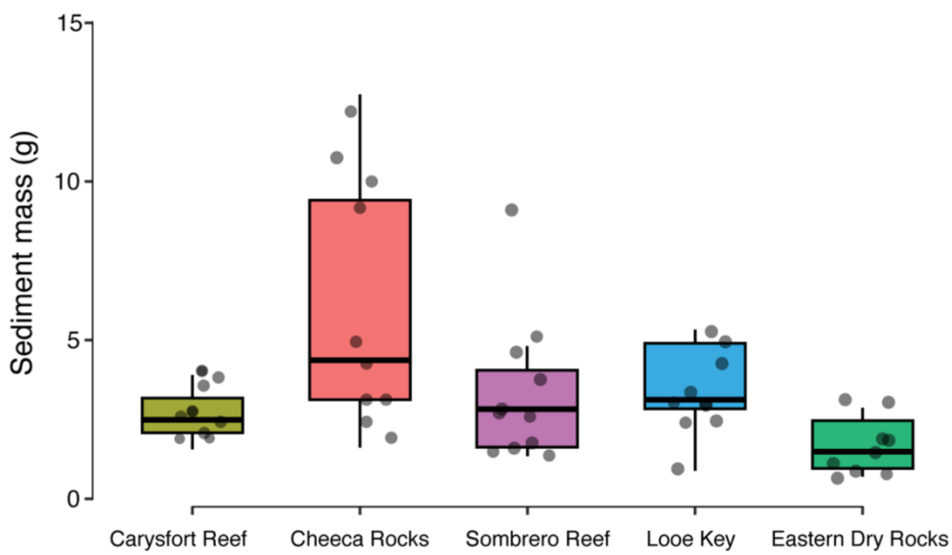

Figure 17. Mean sediment depth (mm) at Florida Keys reef sites.

Sediment mass in the Coral AP (26.7 ± 1.10 g) was 7.5 times greater than sites in the Florida Keys (3.56 ± 0.61 g, see Figure 18). In the Coral AP, long sediment-laden algal turfs (LSATs ≥ 5 mm) held an average of 36.90 ± 1.16 g of sediment per sample, more than twice the amount retained by short productive algal turfs (SPATs ≤ 5 mm) in the same region (17.97 ± 0.64 g). Only 8 algae turf samples in the Florida Keys were classified as LSATs. These findings indicate that turf structure and region strongly influence sediment retention, with LSATs in the Coral AP trapping significantly more sediment than SPATs in the Florida Keys (Figure 19).

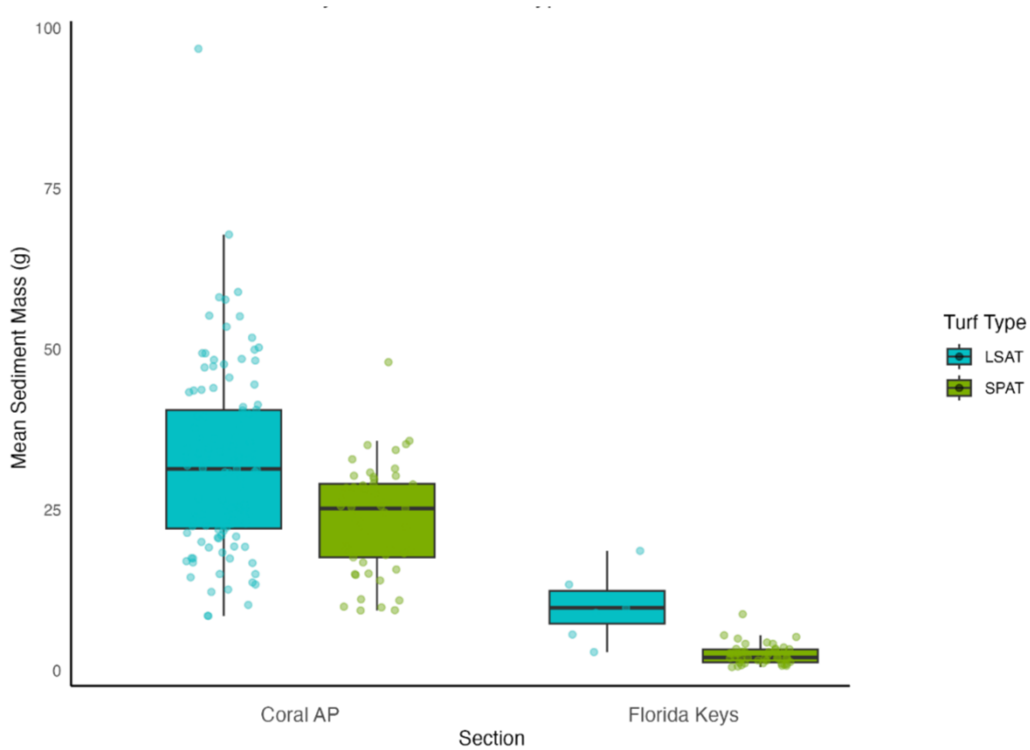

Figure 18. Comparison of mean sediment mass (g) between Coral AP and Florida Keys sites in long sediment-laden turfs (LSATs ≥ 5 mm) and short productive algal turfs (SPATs ≤ 5 mm).

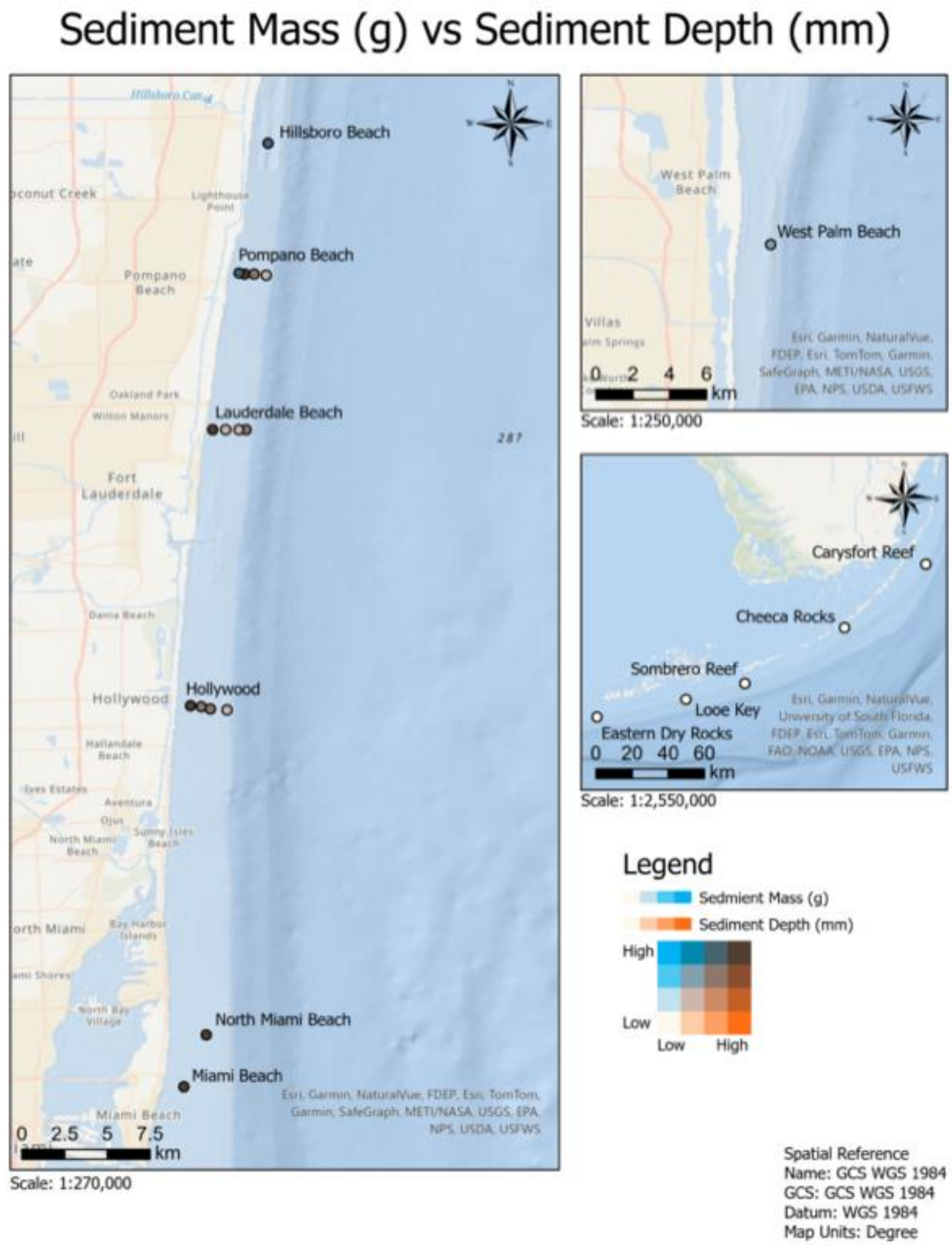

Figure 19. Hotspot map illustrating algae turf sediment mass (g) and depth (mm) across reef sites (n=21), highlighting sustainability and resiliency of sites with respect to algae turf sediment loads. Main map and two inset panels are used to provide geographic context and spatial distribution of sampling sites. Data are visualised using a bivariate colour scale representing sediment mass (g) and sediment depth (mm). Base maps include bathymetry and coastal reference features.

3.5. Organic and inorganic sediment composition

Sediment mass was positively correlated with organic content across all sites (Figures 20 and 21) and algae turf-bound sediment consisted heavily of inorganic sediment. Organic content was consistently low across all reef zones, ranging from 0.02 to 0.19 (± 0.05 g). Inorganic content closely mirrored the sediment mass values (Figures 22 and 23). In the Coral AP, although minor in mass, organics showed a weak but positive association with total sediment mass ($y = 0.07 + 0.001$, $R^2 = 0.19$). Inorganics composed nearly all of the total sediment mass at each reef position, ranging from 25.97 ± 1.50 g at outer reef sites to 35.93 ± 2.60 g at nearshore sites. The dominance of inorganics resulted in nearly a perfect linear correlation between sediment mass and inorganic mass in both pooled and position-specific analyses

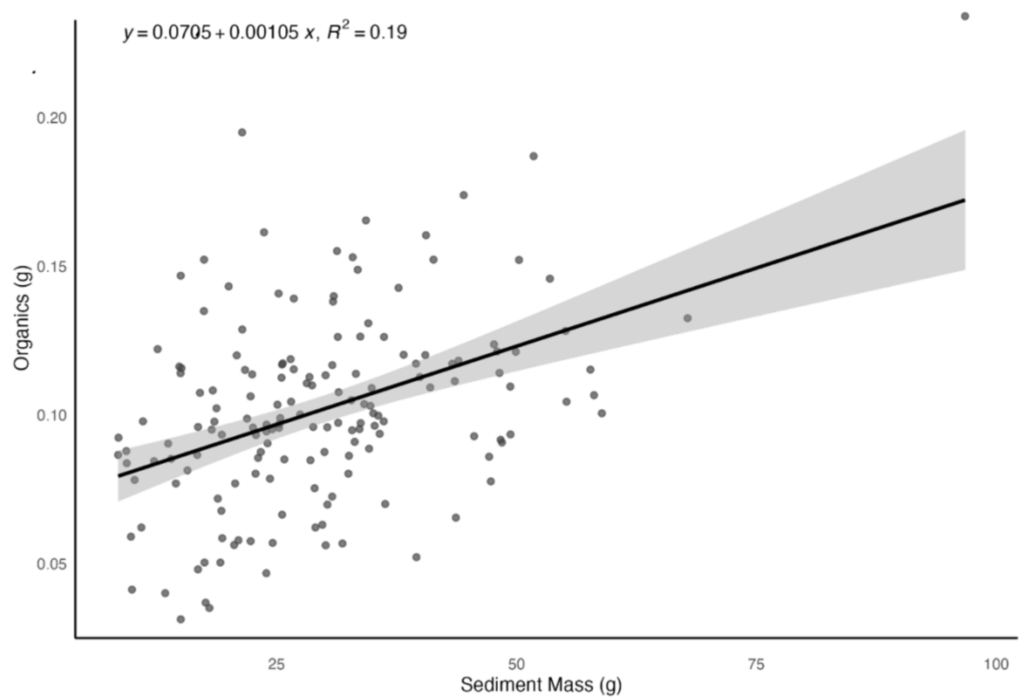

Figure 20. Scatterplot with regression displaying a positive relationship between total sediment mass (g) and organic mass (g) ($R^2 = 0.19$) for the Coral AP region.

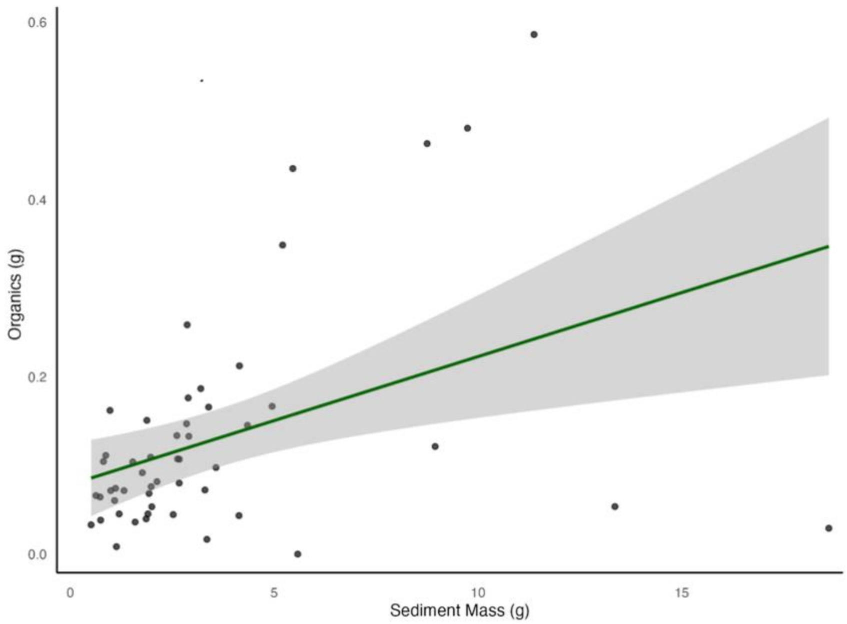

Figure 21. Scatterplot with regression illustrating the relationship between total sediment mass and organic mass for the Florida Keys region.

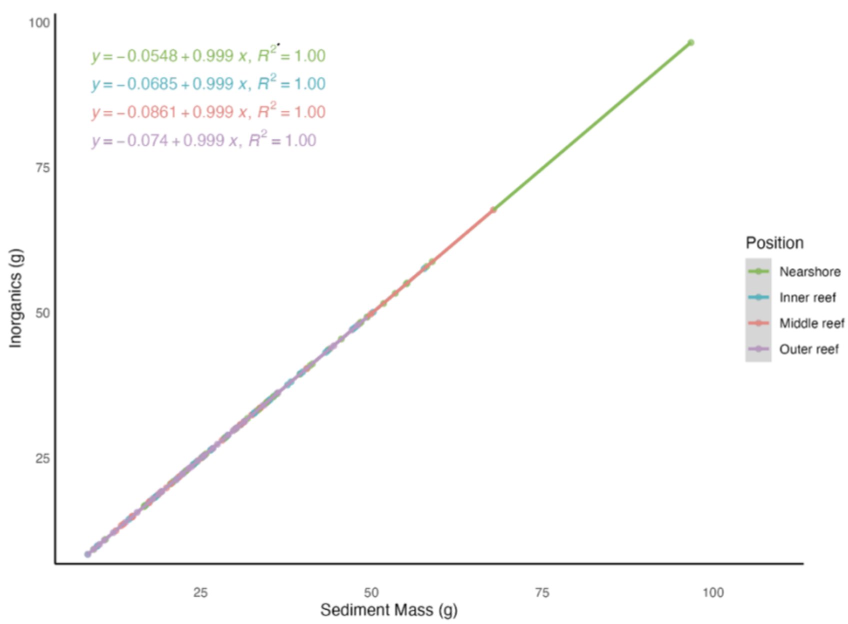

Figure 22. A tight linear relationship between sediment mass and inorganic content (R^2 = 1.00) across Coral AP shelf positions, indicating that sediment mass is almost entirely composed of inorganics.

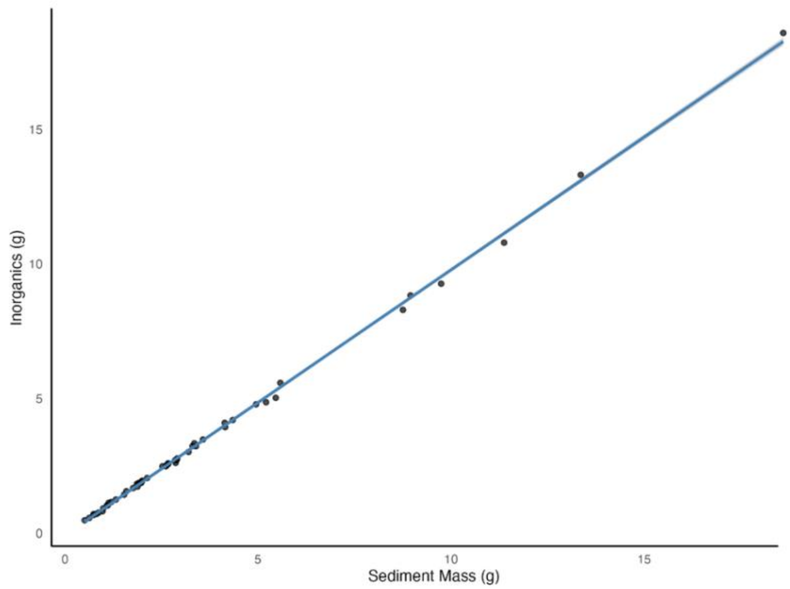

Figure 23. Scatterplot with regression showing the relationship between total sediment mass and inorganic mass for the Florida Keys region.

3.6. Sediment grain size fractions

Results showed that nearshore and inner reef sites had relatively larger sediment size distributions with relatively more coarse particles (500–2000 µm) trapped within algae turf patches compared to the middle and outer reefs which were dominated by finer grains (<63–125/63 µm; Figure 24). Across all sites, 250/125 µm and 500/250 µm fractions made up the majority of sediment mass. For example, Hollywood nearshore had 56.9% of its sediment in the 250/125 µm class size, followed by 16.7% in 125/63 µm and 13.4% in 500/250 µm (Figure 25).

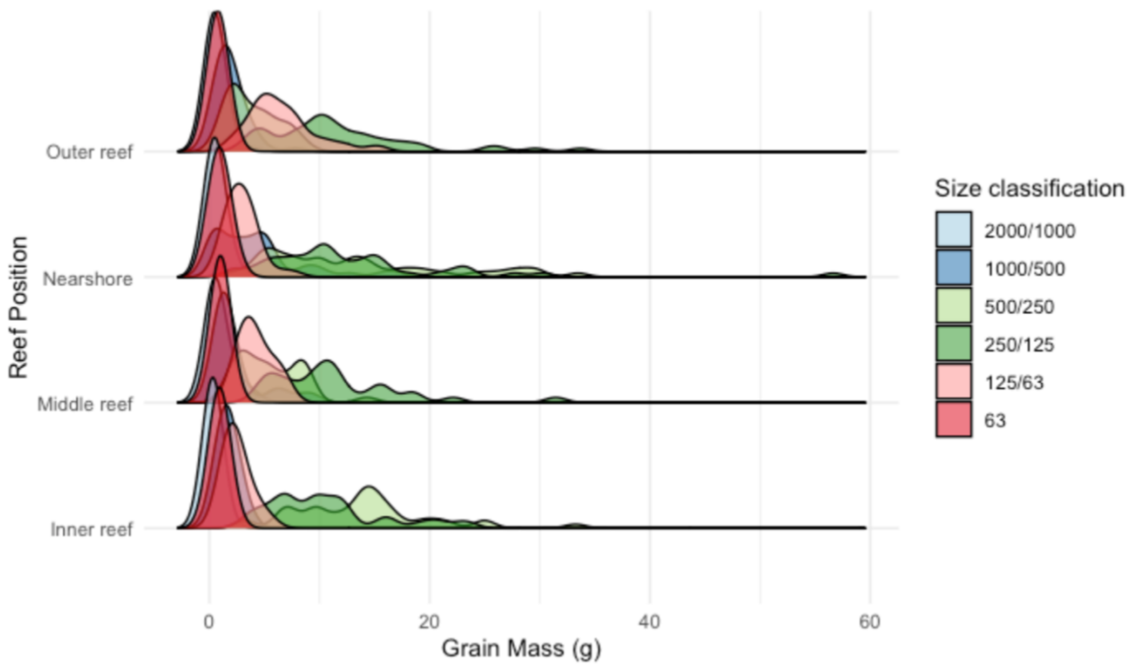

Figure 24. Position-level ridge density plots depicting the distribution of sediment mass (g) across six grain size bins at Coral AP sites.

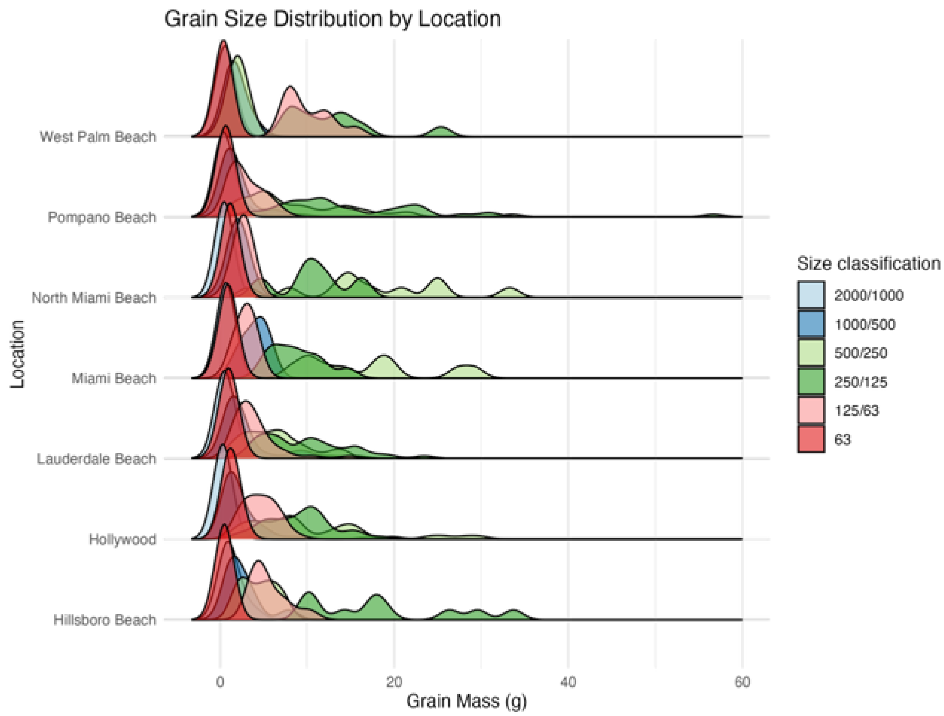

Figure 25. Ridge density plots depicting the distribution of sediment mass (g) across six grain size bins pooled across Coral AP reef sites for each location.

In the Florida Keys, grain size distributions showed consistent differences by reef formation and site (Figures 26). Patch reefs and inner reef sites showed greater proportions of finer particles (e.g., 125/63 and 63 µm fractions). Site-level grain distributions (Figure 27) mirrored patterns with Cheeca Rocks and Looe Key having multimodal distributions across grain size bins, and Carysfort Reef and Eastern Dry Rocks dominated by finer fractions. Overall, sediment size distribution was skewed toward intermediate grain sizes (250–500 µm), with site-specific variation highlighting environmental and geomorphological differences along the Florida's Coral Reef.

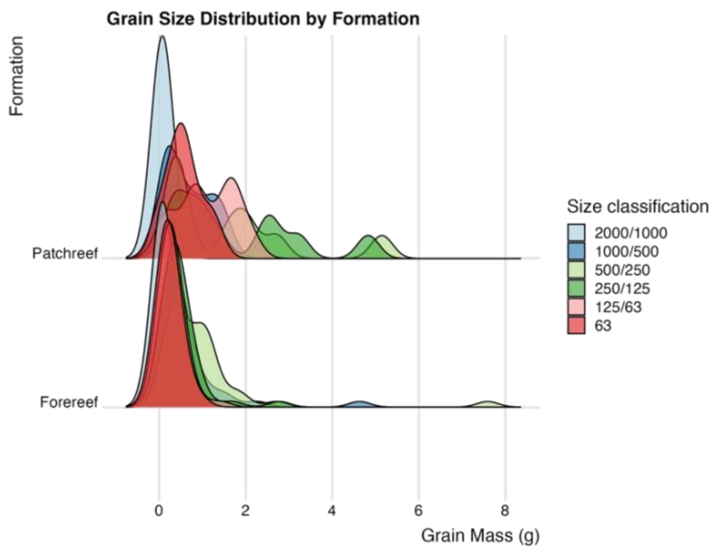

Figure 26. Formation-level ridge density plots depicting sediment grain mass (g) across size bins for patch reef and fore reef formations in the Florida Keys region

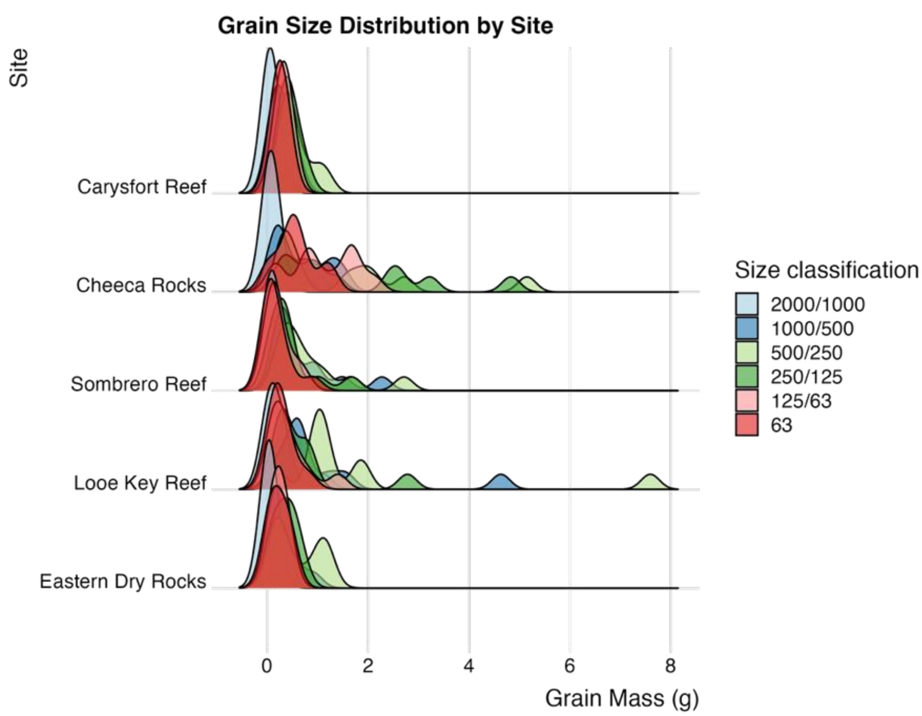

Figure 27. Site-level ridgeline plots showing grain size distributions (g) across six size classes from five Florida Keys reef sites.

3.7. Herbivorous fish communities and grazing rates

A total of 1574 individual herbivorous fishes were recorded for 16 nominally herbivorous species. Acanthurids (surgeonfish) were the more abundant grazing fish family, with ~ 8% of individuals recorded being surgeonfish (Table 4). The excavating parrotfish *Sparisoma aurofrenatum* was the most abundant parrotfish accounting for 52% of parrotfish recorded.

Table 4. Herbivorous fish species present on stereo-DOV transects across the Coral AP.

Family	**Species**	**Shelf Position**				
		Nearshore	**Inner**	**Middle**	**Outer**	**All**
Acanthuridae	*Acanthurus*			2		2
	Acanthurus chirurgus	1	1	5	1	8
	Acanthurus coeruleus	3	29	28	23	83
	Acanthurus sp	46	69	66	51	232
	Acanthurus tractus	68	169	231	112	580
Kyphosidae	*Kyphosus sectatrix*	1				1
	Kyphosus sp			1		1
Pomacentridae	*Microspathodon chrysurus*		5			5
	Stegastes partitus		4	10	22	36
	Stegastes sp	4	23	4	6	37
Scaridae	*Scarus coeruleus*	2			3	5
	Scarus guacamaia		1			1
	Scarus iseri	26	42	6	11	85
	Scarus sp	6	27	8	19	60
	Scarus taeniopterus	2	23	15	53	93
	Scarus vetula	2	4		2	8
	Sparisoma aurofrenatum	56	72	32	148	308
	Sparisoma chrysopterum	1				1
	Sparisoma rubripinne			1		1
	Sparisoma sp		1		1	2
	Sparisoma viride		13	6	6	25

Mean herbivorous fish biomass in the Coral AP was 14.9 g m^{-2} (± 3.2 SE) and increased across the shelf from nearshore to outer reefs (Figure 28A). Mean fish biomass on outer reef sites was more than triple (21.7 g m^{-2} ± 3.41 SE) that recorded on nearshore reef sites (6.0 g m^{-2} ± 1.47 SE). Within reef zones there was substantial spatial variation at the site level, with Pompano middle reef having the highest biomass (44.5 g m^{-2} ± 21.50 SE; Figure 28B), significantly greater than other middle reef sites. This is due to an outlier transect that recorded the highest biomass of any transect at 108 g m^{-2}. Relatively low fish biomass at other middle reef sites which ranged from 7–9 g m^{-2} suggests that middle reef sites are similar in herbivore biomass to inner reef sites which ranged from 0.4 g m^{-2} (± 0.34 SE) at Pompano to 13.6 g m^{-2} (± 2.89 SE) at Lauderdale. Outer reef sites showed consistently higher biomass than sites in any other shelf position. Of the DEP priority sites in this data set (West Palm Beach, Lauderdale inner reef, and North Miami Beach), only West Palm Beach had herbivorous fish biomass greater than the mean biomass across all sites (Figure 28B).

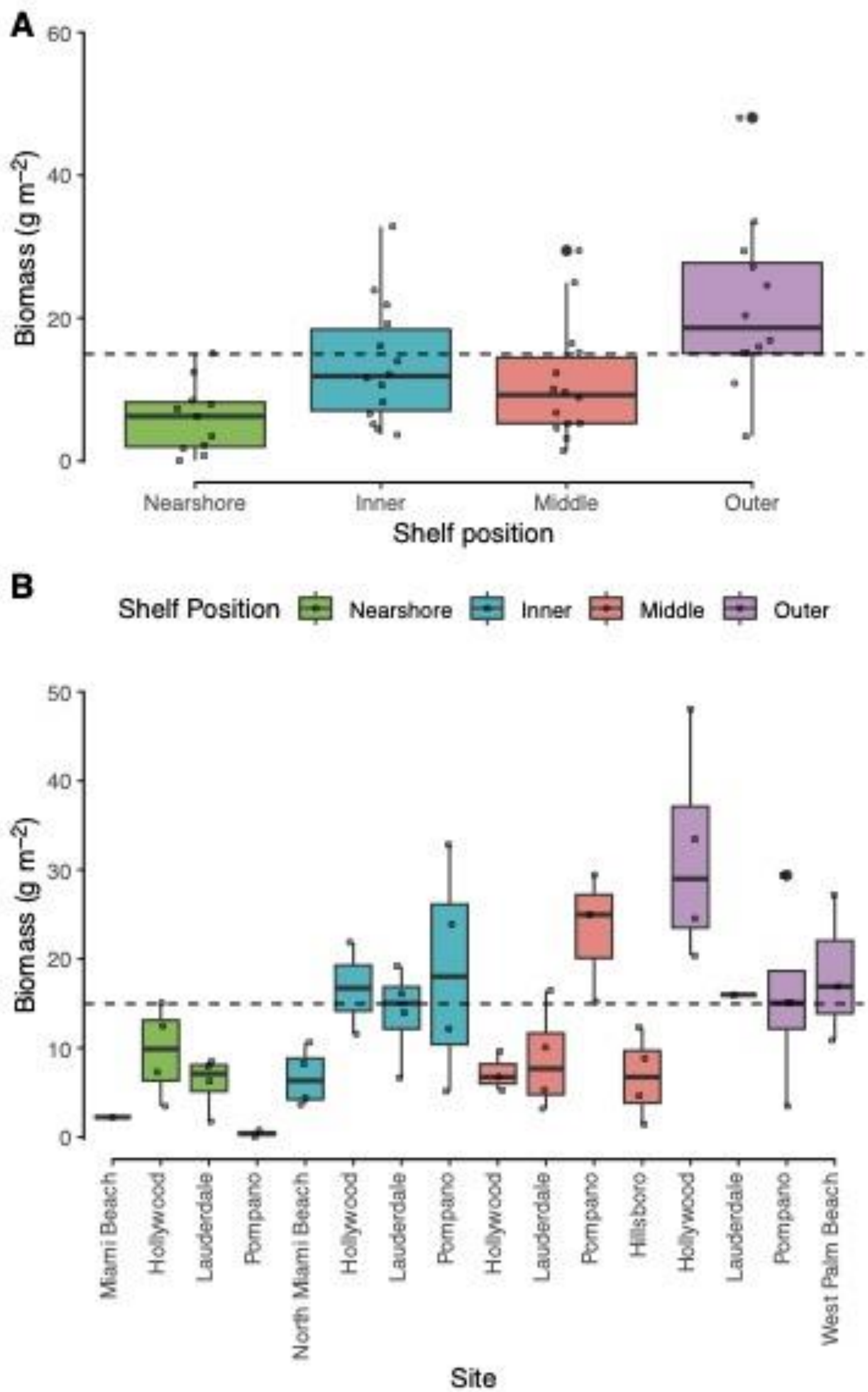

Figure 28. Biomass of herbivorous fishes (g m^{-2}) across shelf position (A) and site (B) in the Coral AP. Dashed line in (B) indicates overall mean herbivorous fish biomass. One outlier removed from middle reef zone and Pompano middle reef not shown for display purposes.

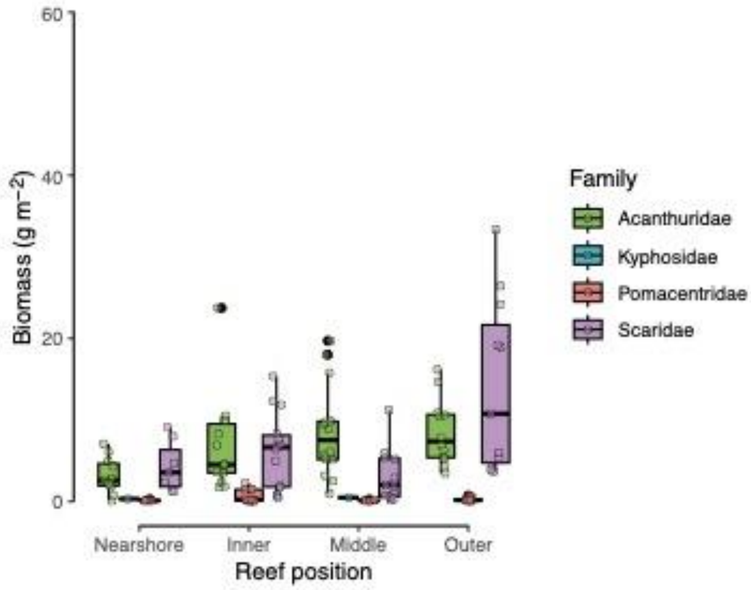

Figure 29. Biomass of herbivorous fishes by family across shelf position on the Coral AP.

At the family level, acanthurids (surgeonfishes) had similar biomass across the middle and outer reefs, but showed declines on inshore reefs (Figure 29). On the outer reef parrotfishes accounted for 62% of herbivorous fish biomass (Figure 29), and this was substantially greater both in absolute biomass and relative biomass of herbivores than at any other shelf position. No significant departure from this pattern was observed at individual reef sites with the exception of Pompano middle reef (Figure 30).

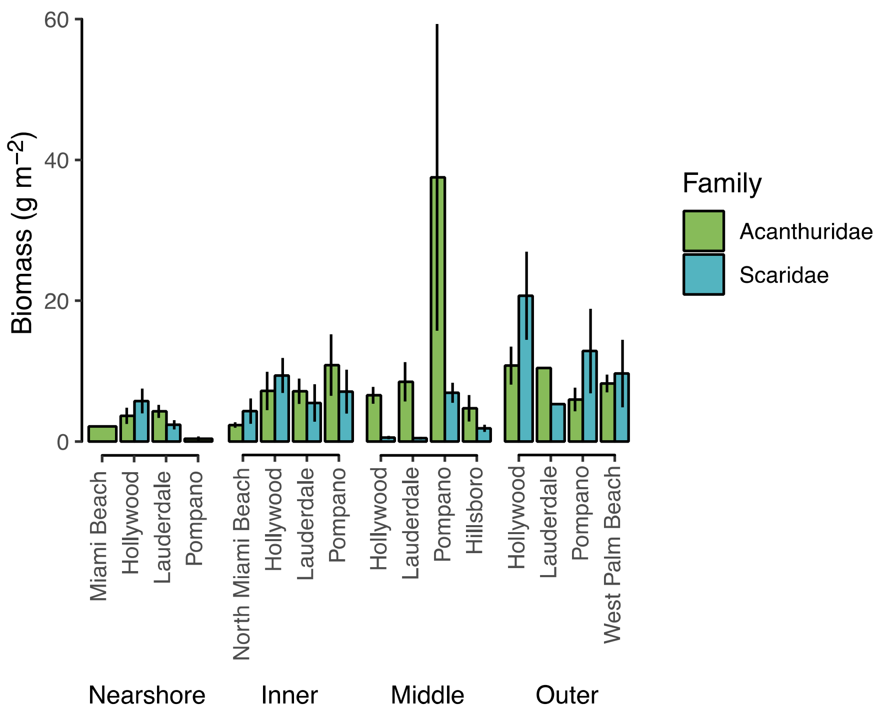

Figure 30**.** Biomass of herbivorous fishes by family across Coral AP sites.

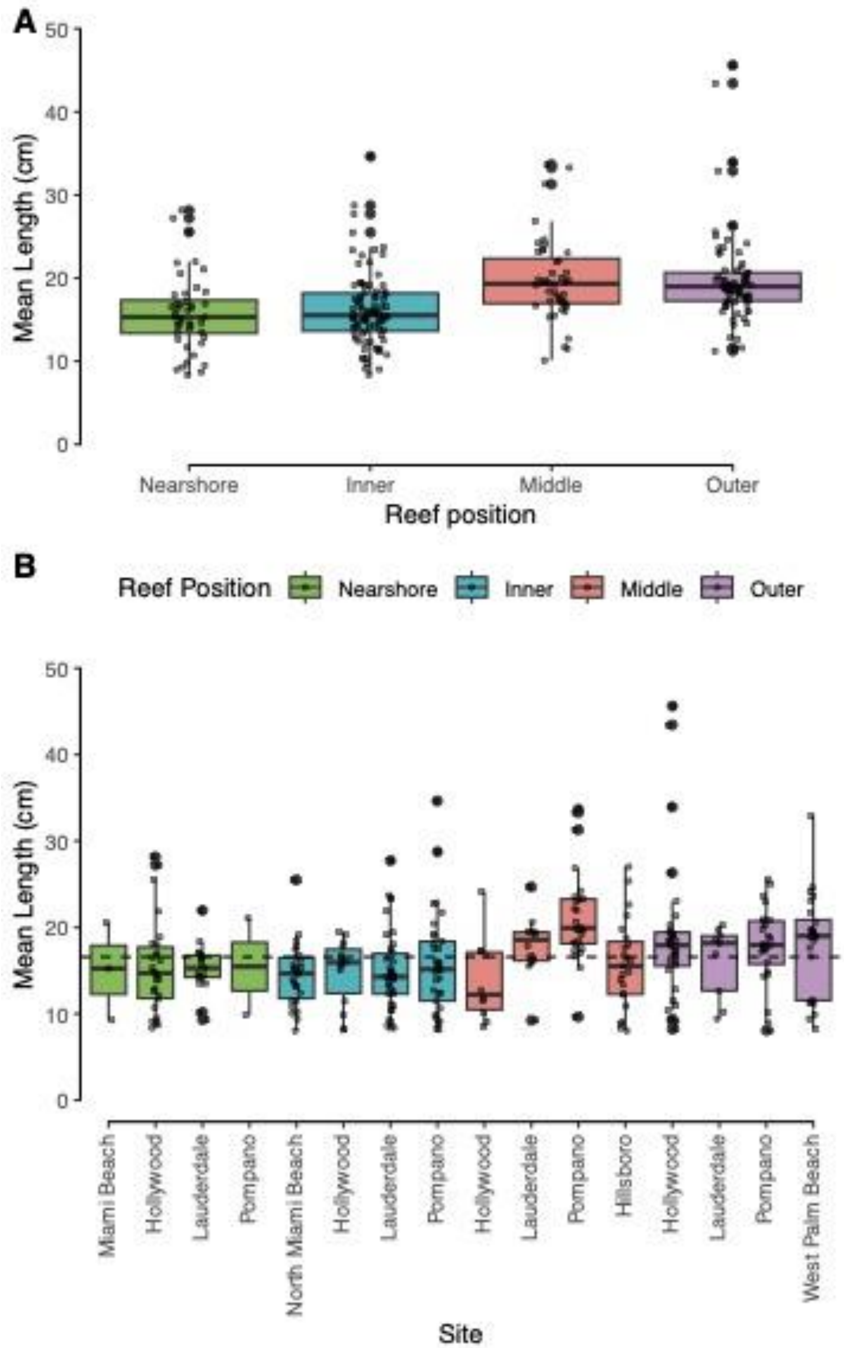

Figure 31. Mean total length (cm) of herbivorous fishes across each reef site (A) and site (B) in the Coral AP. Dashed line in (B) indicates mean length of herbivores across the Coral AP.

In the Coral AP, the mean length of herbivores was greater in both the middle (17.9 cm ± 0.7 SE) and outer (18.1 cm ± 0.7 SE) reef zones than the nearshore (15.3 cm ± 0.5 SE) and inner (15.1 cm ± 0.6 SE) reef zones (Figure 31). At the site level, all outer reef sites had mean herbivore lengths greater than the Coral AP mean (16.6 cm ± 0.32) as did middle reefs at Pompano and Lauderdale.

Of the DEP priority sites analyzed to date, only West Palm Beach had a mean herbivore length greater than the Coral AP mean.

A total of 7,912 bites from 9 fish species were recorded grazing across reefs in the Coral AP (Table 5). The total number of bites differed significantly across the shelf, with decreasing total bites with increasing distance from shore. There was substantially higher feeding rates on the inner (4,709 bites) and nearshore reefs (1,965) compared to the middle and outer reefs combined (total. 1,238 bites). A single species, *Acanthurus tractus*, was responsible for the majority of the grazing, accounting for 81% of the total bites, and was recorded feeding within every shelf position. *Acanthurus chirurgus* was the only other grazer recorded to take a substantial number of bites, accounting for 10.6% of the total biters. However, *A. chirurgus* was recording feeding mainly on the nearshore reefs of Lauderdale Beach.

Table 5. Total number of bites of herbivorous fish across the Coral AP by shelf position.

Family	**Species**	**Shelf Position**			
		Nearshore	**Inner**	**Middle**	**Outer**
Acanthuridae	*Acanthurus coeruleus*	5	77	0	7
	Acanthurus tractus	1285	4146	814	177
	Acanthurus chirurgus	517	66	71	150
Kyphosidae	*Kyphosus vaigiensis*	0	24	0	0
	Kyphosus sectatrix	0	5	0	0
Pomacentridae	*Stegastes partitus*	0	94	16	3
	Stegastes pictus	17	0	0	0
	Stegastes adustus	141	200	0	0
	Stegastes xanthurus	0	97	0	0
Total bites		1,965	4,709	901	337

4. Discussion and Management Recommendations

Results from this project show that reefs in the Coral AP are currently in a heavily degraded benthic state characterized by high sediment loads, opportunistic turf algae and relatively low herbivorous fish abundance. Notably, results indicate a clear onshore-offshore gradient in habitat quality, with lower turf algae length, lower sediment loads and higher herbivore abundance on offshore, outer reef sites. While algae is still the dominant benthic cover on most outer reefs sites, a significant proportion of algal turfs measured was <5 mm in length and had relatively lower sediment depths and loads. Importantly, most reefs within the Coral AP are not conducive to current restoration efforts, or to natural recovery compared to the Florida Keys, where algal turfs were shorter, and accumulated less sediment laden.

Benthic community structure on FCR was strongly influenced by both geographic region (i.e., Coral AP and Florida Keys) and shelf position (nearshore, inner, middle, and outer reefs). There was a pronounced offshore gradient with offshore reefs having higher benthic diversity and coral cover. In contrast, nearshore reefs were generally dominated by algae turfs, suggesting severe reductions in reef health from poor water quality (e.g., sedimentation and eutrophication). Coralline crustose algae (CCA) cover peaked slightly in middle and outer reef zones, consistent with potential conditions more favorable to calcifying algae. Coral recruit across FCR reflects a chronic demographic bottleneck that appears strongly linked to the prevalence and condition of algal turfs, and higher sediment loads. These findings suggest that long, sediment-laden algal turfs (LSATs) function as a key limiting factor for early coral life stages, and is consistent with evidence that increased turf length and sediment accumulation significantly reduces coral recruitment and survival. By examining algal turf and sediment dynamics at multiple scales, our study reveals that many sites within the Coral AP are trapped in a negative feedback loop where higher sediment accumulation (load) promotes algal turf proliferation, trapping more sediment, further suppressing coral settlement further reducing fish herbivory. Within heavily sedimented reefs (i.e., fore reef and low-relief patch habitats) algal turf mats can smother suitable settlement substrates and outcompete corals for space, especially in areas with elevated benthic diversity from bioeroders and turf-associated taxa. In contrast, habitats with shorter, actively grazed turfs (i.e., the Florida Keys), sustain higher juvenile coral densities, potentially due to enhanced algal turf productivity and reduced competitive exclusion. This spatial mosaic underscores the importance of managing sedimentation and herbivory simultaneously to restore recruitment potential.

Algal turf length patterns across the shelf in the Florida Keys are similar to patterns observed on the Great Barrier Reef. Shorter turfs at Mission Iconic Reef (M:IR) sites may reflect more effective management strategies (i.e., well enforced MPAs) and higher herbivore abundance, while longer turfs within the Coral AP sites are from a combination of reduced herbivory (i.e., low grazing rates), elevated sediment loads, and greater land-based impacts (e.g., Port Everglades, Port of Miami, and coastal development). Most sites in the Florida Keys are farther from land and lower population density areas with less anthropogenic stress. Strengthening links between herbivore biomass and turf dynamics is key to understanding sediment-algae-recruit feedbacks. Algal turf density exhibited fine-scale variability (mm-scale), shaped by similar ecological drivers that govern algal turf length. Lower densities along the Coral AP may reflect sediment accumulation that smothers turf algae, creating bare substrate patches. In contrast, FK sites exhibited higher turf density, potentially due to sustained herbivory, which maintains short, productive turfs while limiting bio-eroding competitors.

Fish biomass and size (total length) showed a similar pattern on offshore reefs in the Coral AP, with herbivore biomass increasing with distance from shore, with generally larger on the outer reefs. Yet, despite lower herbivorous fish biomass on nearshore and inner reef sites, grazing (total bites) was substantially higher within these reef positions. Surgeonfish dominated these sites, particularly *Acanthurus tractus* which as a sediment sucker feeds over sediment and have dentition and a stomach adapted to process large quantities of particulate matter, from which they obtain the majority of their nutrition than from algal matter (Tebbett et al., 2022). As with *Acanthurus chirurgus* (another sediment sucker), they are unlikely to remove significant amounts of algal turfs even when present in large numbers. Parrotfishes, which are not adapted to process large quantities of sediment, are relatively rare on nearshore and inner-reefs, and are only present in significant abundances on outer reefs where turf lengths are shorter, but importantly sediment load is also lower. However, parrotfish biomass is still low, and the mean total length recorded on outer reefs is small. Parrotfish size is an important indicator of grazing ability, with larger individuals grazing exponentially more surface area than smaller individuals (Lange et al. 2020). Therefore, it is unlikely that the parrotfish on the outer reefs, or surgeonfish on the inner reefs will be able to maintain shore algae turfs (SPATs) through grazing (realized function). Moreover, the current abundance of LSATs on the Coral AP are likely the result of increased anthropogenic influences on the reef over multiple decades that have increased sediment transport to the reef (e.g., through coastal development). It is likely that increased sediment loads reduce the quality of algal food resources on reefs, leading to a loss of herbivores rather than loss of herbivores releasing SPATs from grazing pressure and the development into LSATs.

4.1 Significance and Future Directions

Our research findings highlight the potential of algal turf–sediment systems as powerful ecological indicators for evaluating reef condition, environmental stress exposure, and resilience. Despite their widespread occurrence and clear relevance to conservation and restoration efforts, influence on coral abundance, and role in demographic bottlenecks and benthic community structure, algal turfs remain understudied in throughout most of Florida, and are underrepresented in reef management frameworks. As such, distinguishing between short productive algal turf (SPAT) and long sediment-laden algal turf (LSAT) provides a critical yet underutilized metric for coral monitoring programs. While turf cover is often recorded, our findings highlight that variation in turf morphology, specifically its relationship with sediment load, offers valuable insight into coral recruitment dynamics and reef condition.

From a methodological standpoint, our research underscores the importance of quantifying algal turf abundance at multiple spatial and morphological scales because coarse metrics such as percent cover fail to capture the full extent of variation. By capturing fine-scale differences in algae abundance, length, and density with comparison of different methodologies (e.g., vacuum sampling area, quadrat, and transects), are important modulators of sediment retention and influences coral recruitment replenishment, and recovery.

Our research can assist reef managers in identifying priority locations, and avoiding unfavorable reefs sites within the Coral AP to optimize future restoration activities. Additionally, our findings provide a framework for reef managers to include complimentary resilience-based metrics (algal turf heights and densities) into existing long-term survey protocols to strengthen their capacity to predict future reef conditions and their responses to disturbances. Importantly, we recommend that site selection for future restoration efforts should focus on Florida's middle and offshore reef systems where algal turf cover, length, and sediment accumulation are lower, and the herbivorous fish community is more intact.

Future studies should assess 1) interactions between algae turf sediments, herbivory, and cleared plots 2) coastal (terrestrial and marine) drivers of sedimentation and algae turf communities across spatial and temporal scales, 3) impacts between algae turf and sediments across life history states (recruits, juveniles, and adults). Algal turf sediments can shape key ecosystem processes including recruitment and early survival of juvenile corals, underpinning coral resilience on FCR. Our goal was to examine the dynamics and ecological impacts of algal turf sediments within reef monitoring sites, priority restoration areas, and sink-source hotspots along FCR to identify demographic bottlenecks to coral recovery, and potential coastal ecosystem stressors.

Our future objectives are to investigate: 1) spatial dynamics among suspended sediments, sedimentation, and algal turf sediments (i.e., sediment deposition); 2) accumulation capacity and spatial dynamics of heavy metal concentrations (e.g., Al, Fe, Pb) within algal turf sediments; 3) relationships between sediment dynamics and abundance of juvenile corals and herbivorous fishes; and 4) how sedimentation and metals influence benthic calcification and productivity. We will use these spatially explicit data to produce heat maps of sedimentation rate, contaminants and productivity across FCR. Sediment deposition will be quantified using a combination of TurfPods and sediment removal experiments using an underwater vacuum. Heavy metals in collected sediments will be identified, and concentrations measured using triple quadrupole inductively coupled plasma mass spectrometry to determine heavy metal concentrations that impact reef biota. Herbivorous fish and benthic composition were quantified during Phase I. Results from these small-scale experiments and complementary surveys across FCR will provide insights into coastal sediment stress, (bio)indicators of water pollutants, and facilitate location-specific management.

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