

Fine-scale spatial patterns of parrotfish herbivory are shaped by resource availability

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Supplement 1. Rugosity measure and benthic cover categories: We measured rugosity at each point by measuring the difference in depth between the highest and lowest point within a 1.0 m x 0.5 m box around the point. The ‘live coral’ category included hard and soft corals. ‘Mixed algal turf’ is a nominal category that represents low lying (<2 cm tall), fleshy or filamentous algae and cyanobacteria. Larger algal species (>2 cm) were categorized as ‘fleshy macroalgae’.

Supplement 2. Multinomial analysis: We plotted each benthic transect in multi-dimensional space, with each axis representing a cover category and the observed percent cover determining its position along that axis. Conceptually, plotting this way creates a cloud of points for each site from which a centroid for each cloud may be calculated. We computed the Euclidean distance between the centroids which represents a relative measure of observed differences in the benthic resources available for *C. microrhinos* at each site. We then employed a randomized resampling technique to develop a null distribution of Euclidean distances to test the observed data for significance. To do this, we randomly assigned the site name to each transect and calculated the centroids and Euclidean distance between the randomly assigned transect data. We repeated this process 10,000 times and used the null distribution of Euclidean distances to test against the observed data. From the null distribution, we calculated a 95% confidence interval and if the observed data fell outside of that null 95% confidence interval, we considered the resulting difference to be significant.

Supplement 3. Pixel intensity histogram comparison and Earth Mover Distance (EMD) cost: We analyzed the artificial bite scar images using the ImageJ 1.48V photo analysis platform. We set the pixel per m scale for each photo using the 5 cm measuring tape present and outlined the artificial scar to calculate the area at day 0. We then outlined and compared the day 6 and day 12 areas to the day 0 area to ensure we captured regrowth from the edges as well as on the surface of the scar throughout the time series. We used these outlines to calculate the exact pixel intensity histogram (i.e. color histogram) for the recovering scar with the ‘histogram’ tool within ImageJ. The lower values of the histogram represent darker/black pixel values, while higher values represent lighter/white pixel values. We measured the relative recovery of the scar by moving the scar outline on to an untouched section of algal turf within the photo. We used the same outline to ensure that each histogram contained the same number of pixels (i.e. color values) and could be accurately compared.

We calculated an Earth Mover Distance (EMD) cost between each pixel histogram (i.e. the scar and the untouched algal turf) derived from a single photo (Rubner et al. 2000, Andoni et al. 2008). An EMD represents the minimal cost that must be paid to transform a histogram into another. Thus, we can calculate a proxy for the difference in color between recovering scar and the undisturbed algal turf. As this cost becomes less, the scar was assumed to be more recovered because the colors more closely match. We calculated EMD in R using the

‘emdlist’ v0.3-1 package and the ‘emd2d’ function (Urbanek & Rubner 2012). We calculated the average of three ‘costs’ (undisturbed algal turf to the left, right, and top/bottom within the photo) for each scar at each time point. We compared color of recovering artificial bite scars at day 0, 6, and 12 because we had a general timeline of recovery from natural bite scars in the bite scar time series (see *Fish abundance and behavior* in main text).

We tested the differences in color for significance at day 0, 6, and 12 at Penguin Spit and Western Terrace using the linear mixed effects model package ‘lme4’ in R (Bates et al. 2015). This model accounted for the lack of independence of data because each cage contained three groups of artificial scars. We tested for a significant site effect with cage denoted as a random effect, nested within site. To estimate the probability of site effect we compared the full and reduced model using a likelihood ratio test with the ‘anova’ function in R. We calculated the least squares means for both sites using the ‘lsmeans’ package and ‘ref.grid’ function in R (Lenth 2016) to estimate the magnitude and direction of the difference between sites.

LITERATURE CITED

Bates D, Mächler M, Bolker B, Walker S (2015) Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67:48

Lenth RV (2016) Least-squares means: the R package lsmeans. *Journal of Statistical Software* 69:1-33

Urbanek S, Rubner Y (2012) emdlist: earth mover's distance. R package

Supplement 4. *Bite scar photos, image analysis, and ‘peak’ bite density calculation:* We photographed designated areas of the benthos (i.e. dead coral heads covered in mixed algal turf) every 4-5 d to track the arrival of new *C. microrhinos* bite scars. A 0.5 m x 0.5 m PVC quadrat was included in each photo for scale. The distance above the reef was approximately the same for each photo but was not fixed because the photos only need to capture the arrival of new bite scars. We kept the location and position of the PVC quadrat constant for each photo plot through time. We took photos perpendicular to the face of coral head so that area measurements for bite scar density calculations were as accurate as possible. We used a Canon G15 digital camera set to ‘underwater’ mode inside an underwater housing.

We analyzed the images from each plot using ImageJ 1.48V to track the arrival of new bite scars. For each image, we used one side of the 0.5 m x 0.5 m PVC frame to set the linear pixel/meter scale of each image. Once the linear scale was set, we traced the interior edge of the PVC quadrat and calculated the area. We then compared the calculated area to the known area (0.25 m²) to estimate the error of the pixel/m scale. We repeated this process until a pixel/m scale was within ± 0.02 m² of the 0.25 m² PVC frame was achieved. Using the acceptable pixel/m scale, we outlined the boundaries for each coral head in the photo using the ‘Freehand’ tool and calculated the area. We avoided areas of the benthos with high rugosity to ensure an accurate area measurement. We established boundaries for each particular coral head and used the same boundaries for all photos in a series. We then recorded bite scars within the boundaries using the ‘Multi-point’ tool and tracked this value through time. We only recorded bite scars that had occurred during each respective time interval as ‘new’, and reported them for the bite density measurement. We calculated bite density as the number of new bite scars per unit area. We took care not to over/under estimate the area tracked through time by avoiding areas of high rugosity.

We defined a ‘peak’ in bite density as any case where the absolute value of the difference between scar density at one time point and the preceding and/or the following time point was greater than the mean value of all bites recorded for that photo plot. This definition identified times when heavy feeding had either just started or ceased.

Supplement 5. *Spatial model parameters*

GPS error measurements: Each GPS was left unmoved for 1 h in ‘track’ mode (recording a location every 5 seconds) on Palmyra Atoll to estimate the GPS’s error. We calculated the 95% KUD and the pathway length (see below for specific model parameters) for each 1 h error test. Each GPS performed similarly in the error test and were treated the same in analysis (95% KUD error: GPS 1 = 12.56 m², GPS 2 = 9.01 m²; Pathway Length error ± SD: GPS 1 = 0.44 m ± 0.25, GPS 2 = 0.42 m ± 0.23).

95% kernel utilization distribution: We calculated the 95% kernel utilization distribution (KUD) for each 2 h trial; the area calculated represents the space used during that 2 h follow. The 95% KUD is a common space use metric that calculates the 95% probability that an animal will be found in a given area (Steury et al. 2010, Welsh & Bellwood 2012). To calculate the 95% KUD, the kernel density estimation (KDE) raster is first calculated using the ‘kde’ command line in Geospatial Modeling Environment (GME) 0.7.3.0. The bandwidth was set to “PLUGIN” and we used a 0.25 m² cell size. We then used the ‘isopleth’ command to draw a 95% isopleth around the KDE, with the ‘quantiles’ set to 0.95. We report the area of the isopleth as the 2 h area. We repeated the analysis for each two hour trial, and refer to the 2 h 95% KUD area as the ‘2 h area’.

Pathway length: We measured the distance an individual fish swam during each 2 h GPS track as a proxy for foraging behavior of *C. microrhinos* at Penguin Spit and Western Terrace. We used the ‘pathmetrics’ tool in GME to calculate the distance between each successive point (5 seconds) and we summed those distances to estimate the distance swam in one 2 h period.

Site fidelity: We calculated the centroid (center position) of every 2 h trial for a particular individual and measured the distances between all centroids as a measure of site fidelity. Smaller inter-centroid distances indicate a higher site fidelity while larger values indicate greater movement between trials, indicating less site fidelity. We divided each site fidelity value by the average 2 h area for each individual fish to control for the size of the foraging range.

Estimating the amount of mixed algal turf within the two hour area: We were not able measure the benthic composition (i.e. resource availability) within each individually delineated 2 h 95% KUD area but we did quantify a site-level estimate of the mixed algal turf present. We multiplied the proportion of mixed algal turf at the site (from the UPC benthic data) by each 2 h 95% KUD area to get an estimate of the amount of mixed algal turf present.

Average feeding foray time: We estimated the amount of time an individual’s feeding forays lasted at a particular location from the spatial behavioral 2 h focal-follow data. The end of a feeding episode was considered any time a fish ceased feeding and started another behavior (i.e. directed swimming, territorial defense, cleaning, etc.).

LITERATURE CITED

- Steury TD, McCarthy JE, Roth TC, Lima SL, Murray DL (2010) Evaluation of root-n bandwidth selectors for kernel density estimation. *J Wildlife Manage* 74:539-548
- Welsh J, Bellwood D (2012) Spatial ecology of the steephead parrotfish (*Chlorurus microrhinos*): an evaluation using acoustic telemetry. *Coral Reefs* 31:55-65

Supplement 6. Physical characteristics: Western Terrace and Penguin Spit show similarities in the depth and rugosity indicating that habitat structure at each site was similar. The mean depth at Western Terrace and Penguin Spit was $3.2 \text{ m} \pm 0.79 \text{ SE}$ and $2.6 \text{ m} \pm 0.86 \text{ SE}$, respectively. Relief was also similar between the sites, with the majority of relief measurements falling in the 0.5 - 1.0 m and 1.0 - 2.0 m categories for both sites.

Supplement 7: Figures

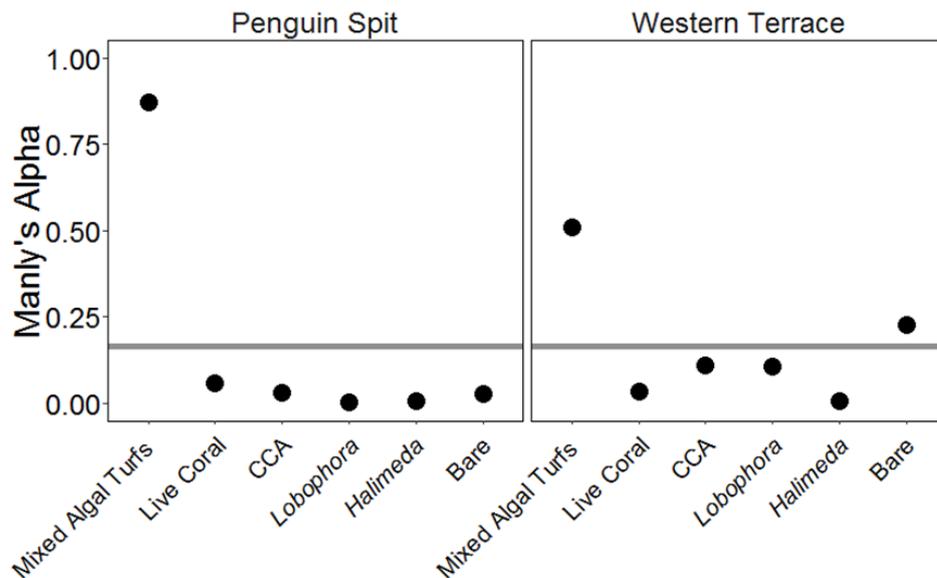


Fig. S1. *Manly's alpha of selectivity*: Manly's α selectivity index for *Chlorurus microrhinos* feeding on six different substrate types at Penguin Spit and Western Terrace. Grey line at $\alpha = 0.166$ is the null expectation of equal selectivity for each substrate based on its availability in the environment. A value above the α threshold indicates preference for a particular substrate, points below indicate avoidance. CCA: crustose coralline algae, *Lobophora*: *Lobophora variegata*, *Halimeda*: *Halimeda opuntia*, Bare: bare calcium carbonate.

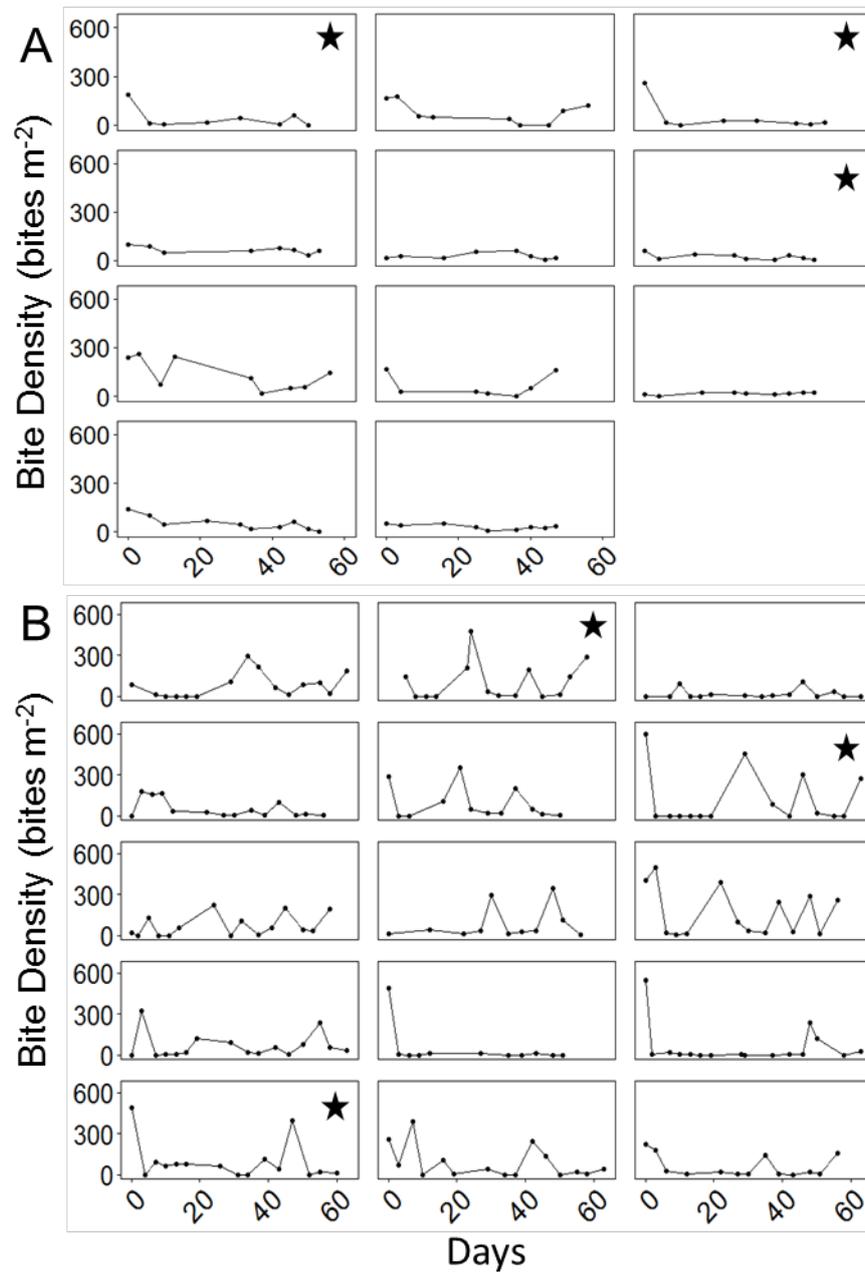


Fig. S2. *Bite scar density time series: Chlorurus microrhinos* bite scar density (bites m⁻²) through time measured at two sites, Western Terrace (A) and Penguin Spit (B). Each panel is a unique location (coral head) within each site. Each location was photographed every 4-5 days and only new bite scars within the prescribe area boundaries were recorded and reported here. Stars (★) represent locations also shown in main text.