



Supporting Online Material for

Fishing, Trophic Cascades, and the Process of Grazing on Coral Reefs

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Materials and methods

Field sampling

Fish species, sexual phase (for parrotfish) and length were recorded using visual fish censuses (S1), with the parrotfishes and piscivores each being consistently sampled by the same observers. Fish lengths were converted to biomass using the allometric relationships of Bohnsack and Harper (S2). Benthic composition and rugosity (vertical relief inside 1 m² quadrat) were sampled using forty 1m² quadrats at each site in The Bahamas Archipelago. The cover of coral, macroalgae, algal turfs, encrusting coralline red algae and other substrata were quantified by randomly sub-sampling fifty 1 m² quadrats inside the reserve and both to the north and south of the reserve.

Statistical methods

Patterns of parrotfish community structure were explored using non-metric Multidimensional Scaling (MDS) of biomass data, with square root transformation. Tests for significant variation in community structure were conducted with multiple comparisons using nested ANOSIM (S3) with data from smaller spatial scales nested within larger. ANOSIM returns a statistic R, which is a measure of separation between groups where 0 indicates complete mixing and 1 represents full clustering in which all samples within groups are more similar to one another than to any sample in another group. Patterns in the total grazing of parrotfishes were analysed using nested GLM ANOVA with Box-Cox transformation and sites as random factors. Each site's mean rugosity was also added as a covariate for nested GLM so that mean biomass and rugosity were included from the level of island system to site (but not within site transects / quadrats). Correlations between rugosity and parrotfish grazing were examined using Pearson Product-Moment correlation among sites within each island system. Grazing was not correlated to rugosity in the Exuma Cays, largely because variations in rugosity were low (coefficient of variation of mean rugosity per reef was 6% for the Exuma Cays and >20% for other island systems).

Effect of Nassau grouper on parrotfishes

To investigate the feasibility of grouper consuming parrotfishes of various sizes, we established two allometric scaling relationships. Firstly, the relationship between gape width (G) and total length (TL) was established for the dominant predator, *E. striatus*, using seven anaesthetised individuals within the reserve.

Gape width, $G = -0.5998 + (0.167 \times TL)$ with a coefficient of determination, r^2 , of 0.96.

Secondly, at least three individuals of *Scarus iserti*, *Sc. vetula*, *Sparisoma viride* and *Sp. aurofrenatum* were photographed in both their terminal- (TP) and intermediate- phases (IP) to determine the relationship between fork length (FL) and maximum dorso-ventral height (H). Dimensions of the fish in each photograph were digitally analysed and the resulting scaling relationships used to estimate the maximum height of each parrotfish surveyed *in situ*.

Grazing behaviour of parrotfishes

We adapted the statistical model of Bruggemann (*S4*) on grazing by two species of parrotfishes in Bonaire (*Sparisoma viride* and *Scarus vetula*) by extending it to multiple scarid species. The model assumes that allometric relationships between fork length and both bite rate and mouth size can be extrapolated within genera.

$$\text{Bite rate, } r, \text{ of } \textit{Scarus spp.} = C_{Sc} ((1088 - (17.12 \text{ FL})) - \text{Species offset}) \quad (1a)$$

$$\text{Bite rate, } r, \text{ of } \textit{Sparisoma spp.} = C_{Sp} ((3329 - (33.00 \text{ FL})) - \text{Species offset}) \quad (1b)$$

Bite rate, r , (h^{-1}) is calculated as a function of species (s), length (l), and life phase (p) using (1a or 1b) where FL is the fork length (cm), C is a weighting factor for life phase such that values for the genus *Scarus* (C_{Sc}) are 0.85 for TP and 1 for IP and juveniles and those for *Sparisoma* (C_{Sp}) are 0.80 for TP, 1 for IP and 0.84 for juveniles. Species-level offsets in the genus *Scarus* are 0 for *vetula*, 1196 for *taeniopterus*; 1714 for *iserti*. Offsets in the genus *Sparisoma* are 260 for *aurofrenatum*, 142 for *rubripinne*, 264 for *chrysopterus*, and 56 for *viride*. Offsets were based on 20 minute observations of grazing intensity in Belize ($n=18$ per species).

Total grazing intensity, expressed as area of a reef grazed per unit time, is calculated as a function of size- and species-specific bite rates and bite sizes (*S4*).

$$\text{Bite size (allometrically scaled to length), } m, (\text{cm}^2) = M \cdot 0.001 (\text{FL}^2) \quad (2)$$

$$\text{Total grazing intensity, } TG (\text{cm}^2 \text{ h}^{-1}) = \sum_{s=1}^S \sum_{l=1}^{F_s} \sum_{p=1}^P r_{s,l,p} m_{s,l,p} \quad (3)$$

where S is the number of species, F_s is the number of size categories for species s , and P is the number of phases for species s . M is a constant that takes the value 4.013 in *Scarus* and 5.839 in *Sparisoma*.

Grazing intensity is then rescaled to the percentage of reef (2-dimensional area) grazed per hour, G , where ta is the area of a sampling unit (m^2), which, in this case, was 120 m^2 .

$$G(\% \text{ hr}^{-1}) = \left(\frac{TG}{10000} \right) \left(\frac{1}{ta} \right) \quad (4)$$

A final level of the model apportioned G into four food types (algal turfs, encrusting corallines, macroalgae and coral) but these more detailed results are not reported here.

Tests of the bite-rate portion of the model were conducted in Roatan (Honduras) and the Exuma Cays (inside and outside the reserve). Individual fish were observed for five-minute periods and their length, life phase, species and number of bites were recorded ($n>5$ fish observations per species / life phase combination). A total of nine species / life-phase tests were carried out. In Roatan, these were *Sc. iserti* (TP and IP), *Sp. viride* (TP and IP) and *Sc. taeniopterus* (TP and IP). In the Exuma Cays, these were *Sc. iserti* (TP) inside the reserve and *Sp. aurofrenatum* (TP) inside and outside the reserve.

Predicted bite rates for *Sc. iserti* and *Sp. aurofrenatum* in the Exuma Cays were all within the 95% confidence interval of the mean for observed bite rates (in fact, with a disparity of

less than 2 bites per 5 minute observation; 64.3 [obs.] versus 65 [pred.] for *Sc. iserti* and 24.6 [obs.] vs. 26.5 [pred.] for *Sp. aurofrenatum*). Note that neither of these species were used to derive the genus-specific allometric scaling relationships between FL and bite rate / bite size, making this a conservative choice of species for testing. The model predicted observed bite rates (within a 95% CI of the mean) in all but one of the six species / life phase combinations tested in Roatan. The exception was *Sp. viride* IP where the model overestimated bite rates by 36% of the upper 95% CL (predicted bite rate 50.4 five min⁻¹ vs. observed mean and upper 95% CL of 30.4 and 36.8). Bite rates of *Sp. aurofrenatum* (TP) did not differ across reserve boundaries ($p>0.80$), suggesting that differential predator abundance has little impact (if any) on the grazing rates of prey.

The extrapolation of morphometric relationships between FL and mouth size (m) within scarid genera was not tested. However, whilst departures from this assumption are likely to influence absolute grazing rates, they are unlikely to affect our conclusions which are based on relative levels of total grazing inside and outside the reserve. Moreover, the scarid species used to generate the morphometrics are, by biomass, the most abundant representatives of each genus.

References

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