*The following supplement accompanies the article*

# Ecological risk and the exploitation of herbivorous reef fish across Micronesia

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## SUPPLEMENT

### Section 1. Assessment of the representativeness of the catch surveys

To determine if the catches measured here over 2 wk were representative of the catches observed over larger temporal scales, we compared them with historical data using 95% confidence intervals.

Firstly, we assessed how representative our surveys were of the catch landed on the month of our survey (Jul 2009). The total volume of *Naso unicornis* landed during our 2 wk survey (712 kg) was 55% of the total volume of this species sold in July (i.e. 1302 kg), suggesting that once the effect of the lunar cycle is accounted for our results are representative of the volumes landed in July 2009. Comparing our rabbitfish volumes with historical values also supports this conclusion; 62% of the total weight sold in July was accounted for in our 2 wk survey.

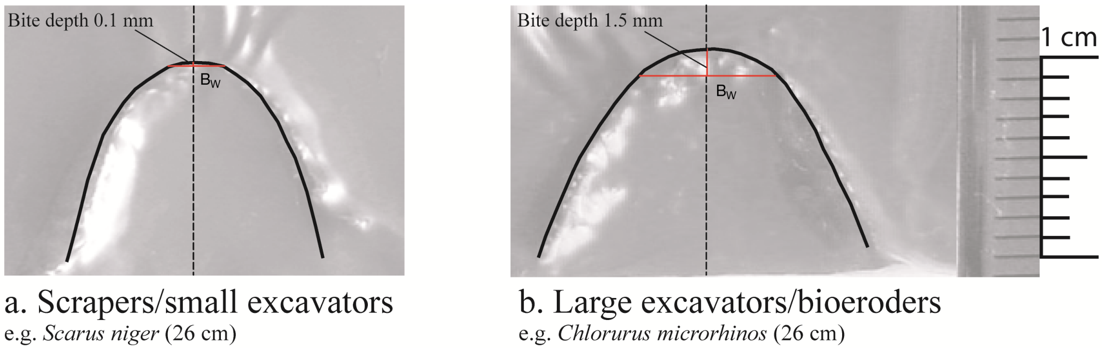
Secondly, we examined how representative the volumes sold in July were of the typical volumes observed in that month, and the rest of the year, over the last 6 yr. The volume of *Naso unicornis* sold in July 2009 (1302 kg) was slightly lower than the July mean during 2006–2011 (1611 ± 207 kg). However, confidence intervals around monthly means indicate that the volume of *N. unicornis* sold in July is not significantly different from volumes sold during most of the second half of the year through to January. This suggests that, at least for *N. unicornis*, results presented here are representative of the fishing pressure over the second half of the year. Higher *N. unicornis* catch volumes may be expected to occur during Feb–May (3195 ± 872 kg) and these may be associated with the species' seasonality (Johannes 1981). The representativeness of our surveys may be limited for those species with strong seasonality in their abundance. The volume of rabbitfishes landed in July 2009 (424 kg) was typical for that month during 2006–2011 (417 ± 215 kg). Except for a significant drop around February–March (which reflects the closed season for *Siganus canaliculatus*), confidence intervals around monthly means indicated that catch volumes of rabbitfishes do not vary significantly throughout the year (360–873 kg). Therefore, our rabbitfish catch volumes were representative of most of the year.

Lastly, our observed catch composition, calculated as percent of total weight comprised by *Naso unicornis*, rabbitfish and parrotfishes was compared to that calculated on a monthly basis using the 2011 market sales data. In 2011, 27–59% of the catch was comprised of parrotfishes, 36–53% by *N. unicornis* and 2–20% by rabbitfish. The catch measured in the 2 wk survey in July 2009 contained 45% parrotfishes, 42% *N. unicornis* and 13% rabbitfishes, and because values fall within the 2011 ranges, our composition data can be regarded as representative of most part of the year in Palau. Although for Pohnpei and Guam volumes presented here also represent a fraction of the total amount of herbivorous fish harvested within a year, the set of species present in the 2 wk catch surveys was similar to that found in longer term studies (i.e. Rhodes et al. 2008, Houk et al. 2012).

In summary, total catch volumes may fluctuate throughout the year, and this may be more evident for certain species than others. However, rather than invalidating our results, these variations need to be considered when discussing the potential ecological implications of spearfishing on the grazing function.

**Section 2. Measuring parrotfish bite areas**

Fig. S1. Contour of the upper jaw of (a) *Scarus niger* and (b) *Chlorurus microrhinos* (26 cm TL) imprinted on moulding clay for indirect estimation of bite sizes. Bite depths of (a) 0.1 mm and (b) 1.5 mm were used to determine the portion of the jaw in contact with the substratum during a bite ($B_W$) for scrapers/small excavators and large excavators/bioeroders respectively



**Section 3. Dendrograms indicating fishing pressure across species in Palau, Pohnpei and Guam**

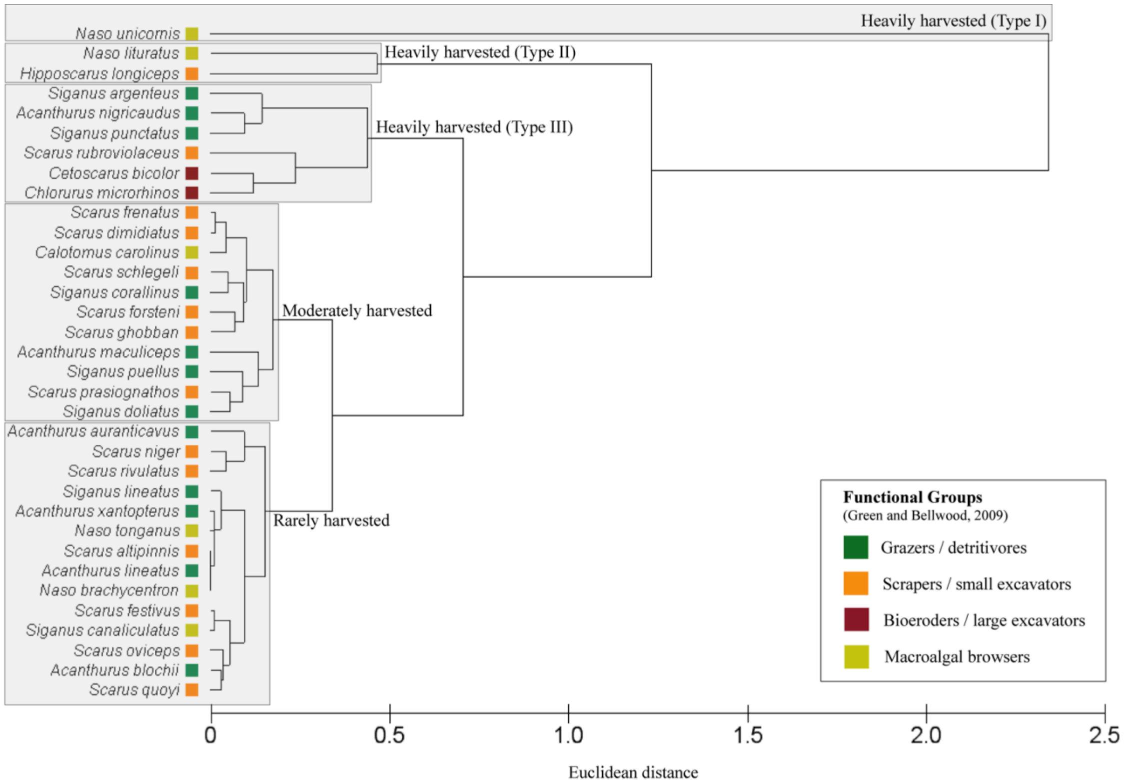



Fig S2. Fishing pressure across species in Palau. Heavily harvested (Type I) are species with high frequency of occurrence (80%), high $CPUE_N$ (1.9 individuals fisher$^{-1}$ h$^{-1}$), and high $CPUE_V$ (1.6 kg fisher$^{-1}$ h$^{-1}$); heavily harvested (Type II) are species with high frequencies (78%), high $CPUE_N$ (1.0–1.2 individuals fisher$^{-1}$ h$^{-1}$), and moderate $CPUE_V$ (0.3–0.7 kg fisher$^{-1}$ h$^{-1}$); heavily harvested (Type III) are species with high frequencies (62–88%), moderate $CPUE_N$ (0.2–0.7 individuals fisher$^{-1}$ h$^{-1}$), and moderate $CPUE_V$ (0.12–0.27 kg fisher$^{-1}$ h$^{-1}$); moderately harvested are species with moderate to high frequencies (33–62%), low $CPUE_N$ (0.01–0.2 individuals fisher$^{-1}$ h$^{-1}$), and low $CPUE_V$ (0.01–0.1 kg fisher$^{-1}$ h$^{-1}$); and rarely harvested are species with low frequencies (3–24%), low $CPUE_N$ (0.01–0.1 individuals fisher$^{-1}$ h$^{-1}$), and low $CPUE_V$ (0.01–0.03 kg fisher$^{-1}$ h$^{-1}$)

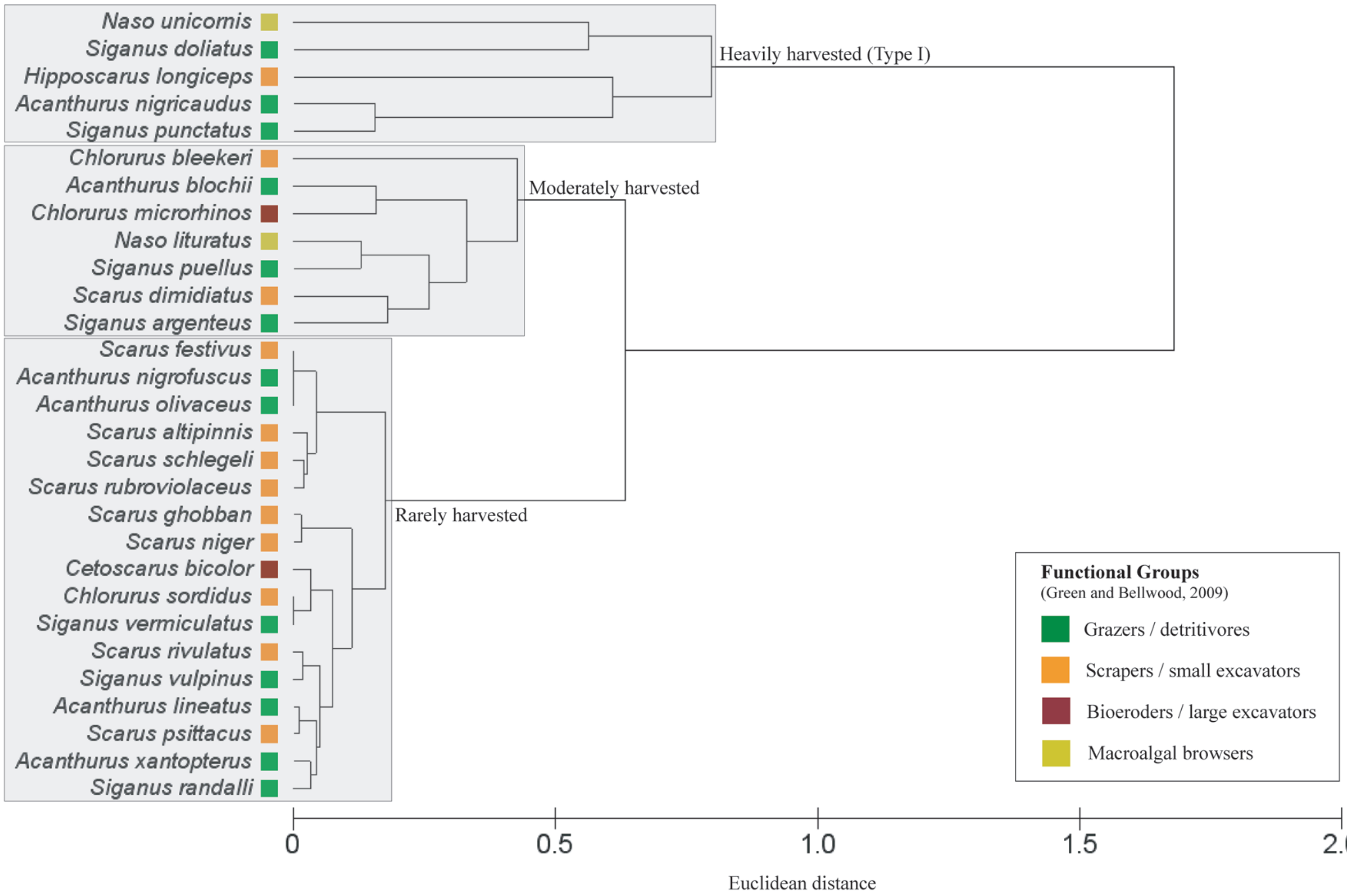



Fig S3. Fishing pressure across species in Pohnpei. Heavily harvested (Type I) are species with high frequency of occurrence (86–99%), high $CPUE_N$ (1.1–2.0 individuals fisher$^{-1}$ h$^{-1}$), and high $CPUE_V$ (0.2–0.9 kg fisher$^{-1}$ h$^{-1}$); moderately harvested are species with moderate to high frequencies (51–88%), moderate $CPUE_N$ (0.1–0.6 individuals fisher$^{-1}$ h$^{-1}$), and moderate $CPUE_V$ (0.05–0.2 kg fisher$^{-1}$ h$^{-1}$); and rarely harvested are species with low frequencies (1–29%), low $CPUE_N$ (0.1–0.6 individuals fisher$^{-1}$ h$^{-1}$), and low $CPUE_V$ (0.01–0.02 kg fisher$^{-1}$ h$^{-1}$)

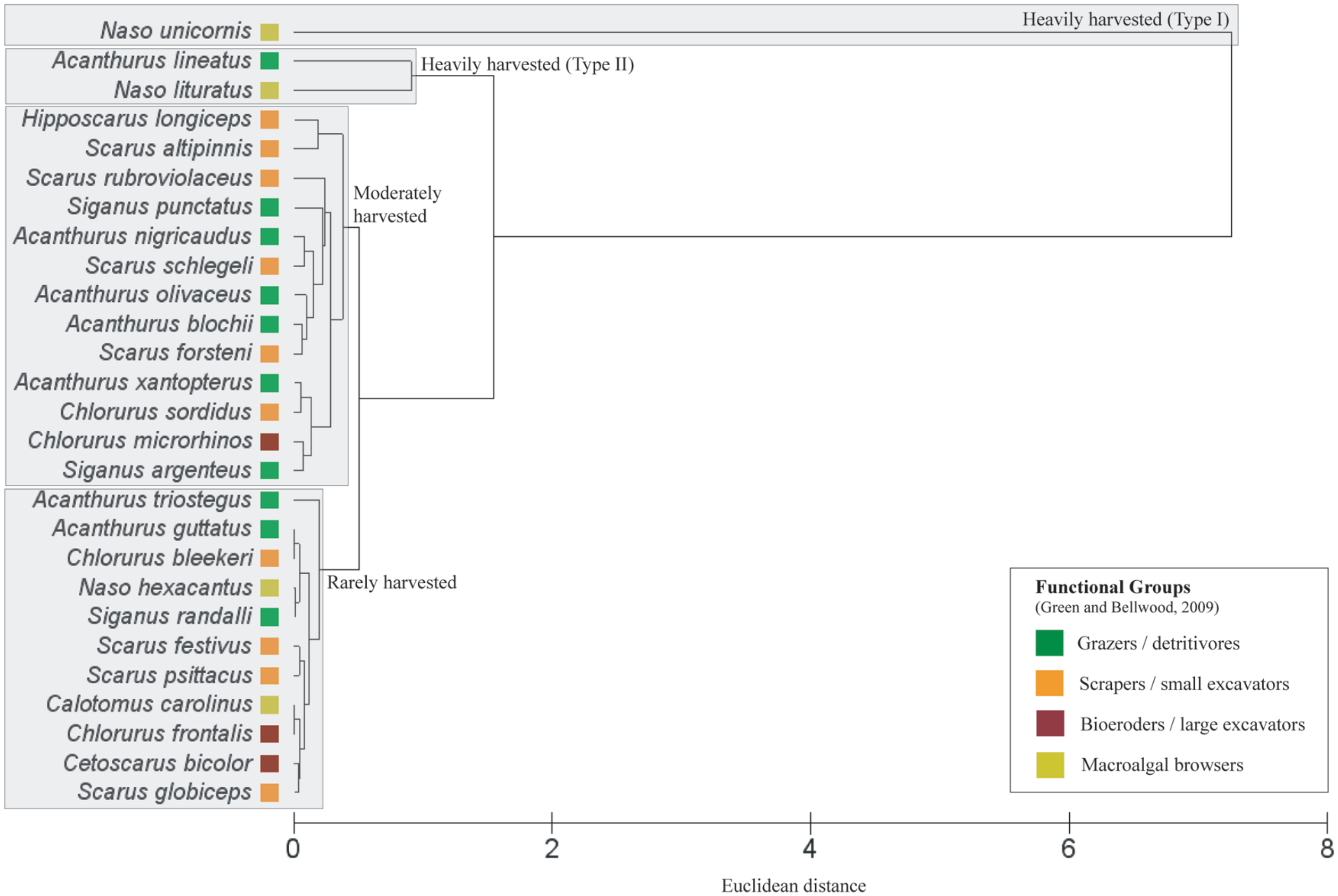



Fig S4. Fishing pressure across species in Guam. Heavily harvested (Type I) are species with high frequency of occurrence (100%), high $CPUE_N$ (5.2 individuals fisher$^{-1}$ h$^{-1}$), and high $CPUE_V$ (5.3 kg fisher$^{-1}$ h$^{-1}$); heavily harvested (Type II) are species with high frequency of occurrence (71–92%), high $CPUE_N$ (1.1–2.0 individuals fisher$^{-1}$ h$^{-1}$), and moderate $CPUE_V$ (0.2–0.5 kg fisher$^{-1}$ h$^{-1}$); moderately harvested are species with moderate to high frequencies (33–83%), moderate $CPUE_N$ (0.1–0.4 individuals fisher$^{-1}$ h$^{-1}$), and moderate $CPUE_V$ (0.02–0.4 kg fisher$^{-1}$ h$^{-1}$); and rarely harvested are species with low frequencies (4–25%), low $CPUE_N$ (0.01–0.2 individuals fisher$^{-1}$ h$^{-1}$), and low $CPUE_V$ (0.01–0.03 kg fisher$^{-1}$ h$^{-1}$)

**Section 4. Mean parrotfish abundance and bite rate and area**

Table S1. Mean values (±SE) of abundance and size (within marine reserves) of species moderately to heavily harvested in Palau, Pohnpei and Guam. Mean bite rate per species and modelled bite area were determined for individuals of the given mean size

| **Country** *Species* | **Mean abundance** (ind. 120 $m^2$) | **Mean size** (cm TL) | **Mean bite rate** (bites $min^{-1}$) | **Individual bite area** ($cm^2$ $bite^{-1}$) |
|---|---|---|---|---|
| Palau | | | | |
| *Cetoscarus bicolor* | 0.49 ± 0.12 | 38 ± 2 | 7.1 ± 0.6 | 1.19 |
| *Chlorurus microrhinos* | 0.47 ± 0.05 | 35 ± 2 | 6.6 ± 1.5 | 0.89 |
| *Chlorurus sordidus* | 1.92 ± 0.90 | 15 ± 1 | 16.2 ± 1.4 | 0.09 |
| *Chlorurus bleekeri* | 0.03 ± 0.05 | 22 ± 1 | 10.1 ± 2.2 | 0.17 |
| *Hipposcarus longiceps* | 0.61 ± 0.45 | 31 ± 1 | 9.2 ± 3.4 | 0.31 |
| *Scarus rubroviolaceus* | 0.41 ± 0.39 | 37 ± 2 | 10.2 ± 4.6 | 0.62 |
| *Scarus prasiognathos* | 0.07 ± 0.05 | 40 ± 1 | 17.8 ± 8.0 | 0.54 |
| *Scarus altipinnis* | 0.06 ± 0.05 | 29 ± 1 | 5.8 ± 1.3 | 0.39 |
| *Scarus ghobban* | 0.02 ± 0.02 | 25 ± 1 | 12.0 ± 2.5 | 0.34 |
| *Scarus dimidiatus* | 0.19 ± 0.19 | 26 ± 2 | 19.0 ± 9.5 | 0.22 |
| *Scarus schlegeli* | 0.27 ± 0.08 | 22 ± 2 | 21.4 ± 3.1 | 0.19 |
| *Scarus forsteni* | 0.17 ± 0.14 | 26 ± 2 | 8.6 ± 2.9 | 0.22 |
| *Scarus frenatus* | 0.03 ± 0.02 | 28 ± 1 | 12.7 ± 2.3 | 0.24 |
| Pohnpei | | | | |
| *Cetoscarus bicolor* | 0.01 ± 0.01 | 29 ± 2 | 8.1 ± 0.7 | 0.90 |
| *Chlorurus microrhinos* | 0.31 ± 0.16 | 32 ± 1 | 6.4 ± 1.4 | 0.81 |
| *Chlorurus sordidus* | 3.94 ± 0.40 | 14 ± 1 | 18.2 ± 1.5 | 0.08 |
| *Chlorurus bleekeri* | 0.13 ± 0.07 | 26 ± 1 | 8.6 ± 2.1 | 0.25 |
| *Hipposcarus longiceps* | 0.61 ± 0.45 | 31 ± 1 | 9.2 ± 3.4 | 0.31 |
| *Scarus rubroviolaceus* | 0.02 ± 0.02 | 35 ± 1 | 10.2 ± 4.6 | 0.59 |
| *Scarus altipinnis* | 0.06 ± 0.05 | 30 ± 1 | 5.8 ± 1.3 | 0.41 |
| *Scarus ghobban* | 0.02 ± 0.02 | 25 ± 1 | 12.0 ± 2.5 | 0.34 |
| *Scarus dimidiatus* | 0.25 ± 0.16 | 17 ± 1 | 23.3 ± 6.7 | 0.15 |
| *Scarus schlegeli* | 0.17 ± 0.07 | 20 ± 2 | 29.2 ± 6.1 | 0.17 |
| *Scarus forsteni* | 0.17 ± 0.11 | 26 ± 1 | 8.6 ± 2.9 | 0.22 |
| *Scarus frenatus* | 0.03 ± 0.02 | 28 ± 1 | 8.5 ± 3.9 | 0.24 |
| Guam | | | | |
| *Cetoscarus bicolor* | 0.02 ± 0.02 | 25 ± 1 | 12.2 ± 6.5 | 0.78 |
| *Chlorurus microrhinos* | 0.41 ± 0.36 | 29 ± 2 | 9.6 ± 2.3 | 0.73 |
| *Chlorurus sordidus* | 2.11 ± 0.32 | 14 ± 1 | 18.2 ± 1.5 | 0.08 |
| *Hipposcarus longiceps* | 0.04 ± 0.02 | 26 ± 3 | 9.0 ± 2.6 | 0.19 |
| *Scarus rubroviolaceus* | 0.29 ± 0.15 | 25 ± 2 | 13.1 ± 4.4 | 0.42 |
| *Scarus altipinnis* | 0.12 ± 0.12 | 25 ± 4 | 5.8 ± 1.3 | 0.34 |
| *Scarus ghobban* | 0.02 ± 0.02 | 25 ± 1 | 12.0 ± 2.5 | 0.34 |
| *Scarus schlegeli* | 0.62 ± 0.39 | 22 ± 1 | 21.4 ± 3.1 | 0.19 |
| *Scarus forsteni* | 0.23 ± 0.12 | 24 ± 2 | 8.1 ± 3.7 | 0.21 |

**Section 5. Comparison of direct and indirect measurements of parrotfish bite area**

Table S2. Comparison of parrotfish bite areas estimated from bite marks on the substratum (see references) and calculated as the product between gape size and jaw width which were measured on fished individuals (this study)

| **Species** | **Total length** (cm) | **Mean bite area** ($cm^2$) | **Reference** |
|---|---|---|---|
| *Chlorurus sordidus* | 15 - 34 | 0.23 | Bellwood & Choat (1990) |
| | 19 - 25 | 0.20 – 0.23 | Bellwood (1995) |
| | **15-34** | **0.09 – 0.53** | **This study** |
| | **19-25** | **0.13 – 0.23** | |
| *Chlorurus microrhinos* | 15 - 34 | 0.12 | Bellwood & Choat (1990) |
| | 46 - 58 | 1.45 – 1.94 | Bellwood (1995) |
| | 40 - 45 | 1.19 | Bonaldo & Bellwood (2009) |
| | **15-34** | **0.38 – 0.86** | **This study** |
| | **46-58** | **1.16 – 1.47** | |
| | **40-45** | **1.01 – 1.14** | |
| *Scarus rivulatus* | 5 - 10 | 0.03 | Fox & Bellwood (2007) |
| | 11 - 25 | 0.28 | Fox & Bellwood (2007) |
| | > 25 | 0.69 | Fox & Bellwood (2007) |
| | 35 - 40 | 0.44 | Bonaldo and Bellwood (2009) |
| | **5 - 10** | **0.04 – 0.09** | **This study** |
| | **11-25** | **0.09 – 0.22** | |
| | **35-40** | **0.30 – 0.34** | |

## LITERATURE CITED

Bellwood DR (1995) Direct estimate of bioerosion by two parrotfish species, *Chlorurus gibbus* and *C. sordidus*, on the Great Barrier Reef, Australia. Mar Biol 121:419–429

Bellwood DR, Choat J (1990) A functional analysis of grazing in parrotfishes (family Scaridae): the ecological implications. Environ Biol Fish 28:189–214

Bonaldo RM, Bellwood DR (2009) Dynamics of parrotfish grazing scars. Mar Biol 156: 771−777

Fox RS, Bellwood DR (2007) Quantifying herbivory across a coral reef depth gradient. Mar Ecol Prog Ser 339:49–59

Houk P, Rhodes K, Cuentos-Bueno J, Lindfield S, Fread V, McIlwain J (2012) Commercial coral-reef fisheries across Micronesia: a need for improving management. Coral Reefs 31:13–26

Johannes R (1981) Words of the lagoon: Fishing and marine lore in the Palau district of Micronesia. University of California Press, Berkeley, CA

Rhodes K, Tupper M, Wichilmel C (2008) Characterization and management of the commercial sector of the Pohnpei coral reef fishery, Micronesia. Coral Reefs 27:443–454