The following supplement accompanies the article

Functional diversity among herbivorous sea urchins on a coral reef: grazing rate, dietary preference, and metabolism

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Supplement 1. Map of Study Site

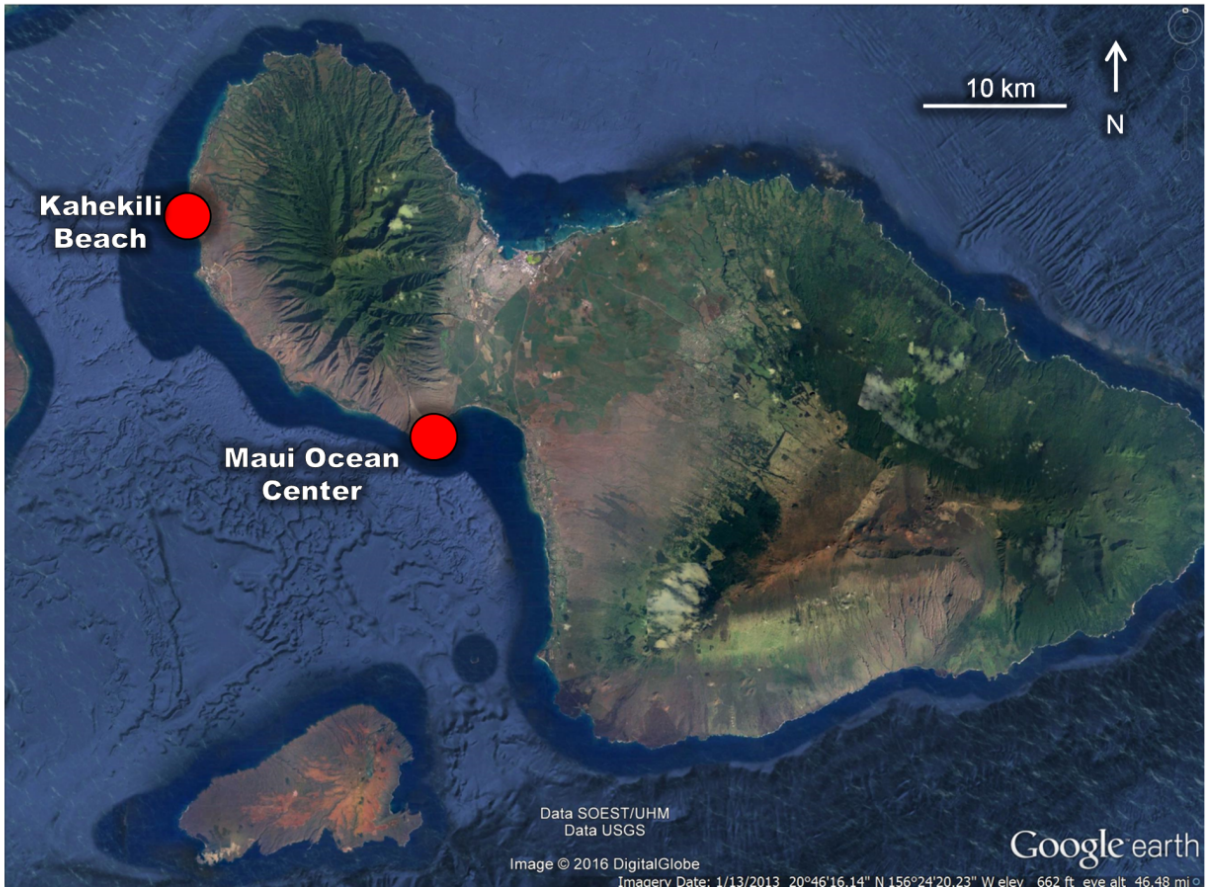

Figure S1. Map of the Island of Maui, Hawaii showing the location of the study site near Kahekili Beach and the Maui Ocean Center where metabolic analyses were conducted by Lewis et al. (2018).

Supplement 2. Methods for Assessing Turf and CCA

Turf algae and crustose coralline algae (CCA) were presented as tightly adherent on calcium-carbonate rubble substrate (Fig. S2a,c). The wet mass of the substrate overwhelmed the wet mass of adherent algae; therefore, direct measurement of algal wet mass proved unreliable. Thus, we used changes in area to directly measure percent consumption and to estimate wet mass for turf and CCA (Fig. S2b,d).

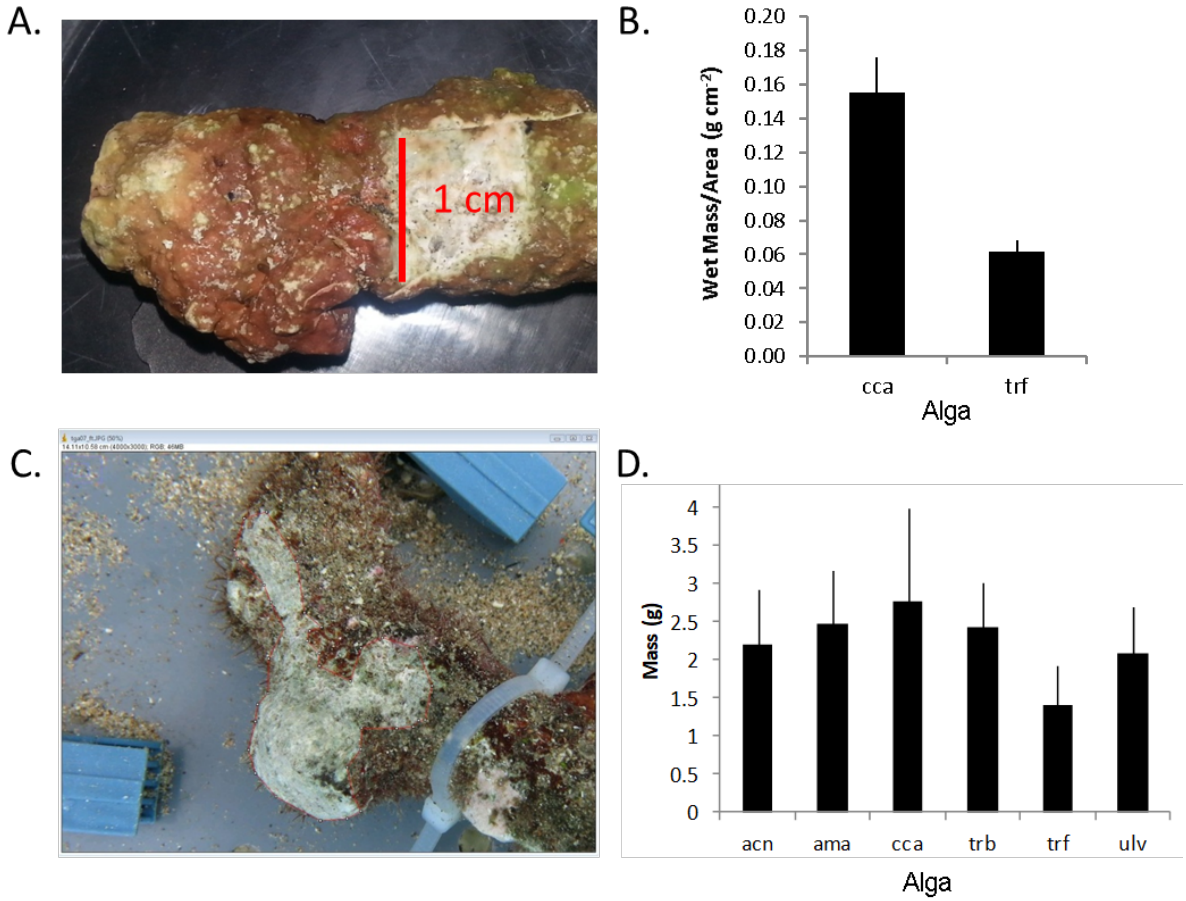

Figure S2. Method for estimating consumption of turf and CCA. (A) One cm^2 sections of CCA and TRF were scraped (to simulate urchin grazing) from ungrazed control samples. (B) Material was blotted dry, weighed wet (0.001 g) and used to estimate wet mass:area (g/cm^2) for each algal group. Total and grazed area of TRF (C) and CCA were then converted to wet mass using the mass:area ratios. (D) Initial mean (+SD) mass of all algae used in this study (N = 128). Algae codes as in Fig. 1.

Supplement 3. Estimation of echinoid mass in grazing assays

An exponential model of the form $M = a*e^{(b*D)}$ was used to describe relationships between echinoid test diameter (D) and wet mass (M) of urchins used in metabolic assays (Lewis et al. 2018) supplemented with additional individuals of varying size ranges (JMP v. 21.0.1, SAS Institute Inc.). Results indicated good model fit (N=58, R^2 = 97.5%) and parameters (Table S1) were used to estimate the mass of urchins used in subtidal field grazing assays (Fig. S9a) using test diameters measured in the field.

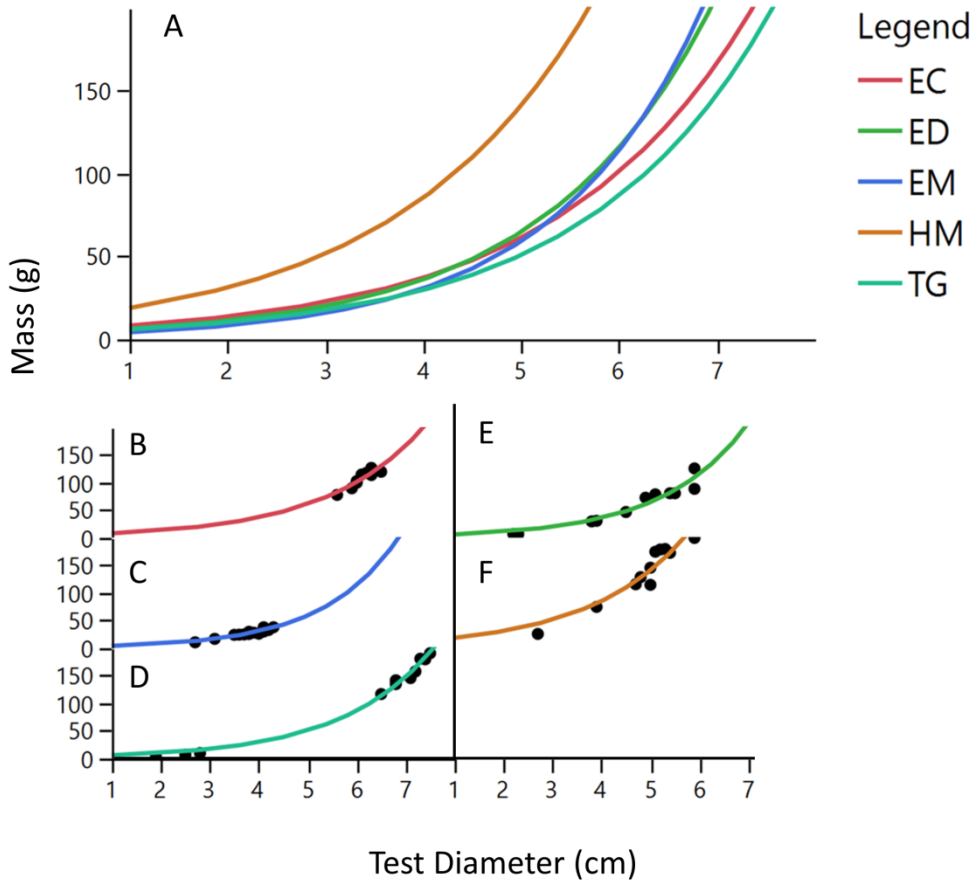

Figure S3. Modelled exponential relationships between wet mass and test diameter: (a) all curves combined and (b-f) EC, ED, EM, HM, TG with individuals as points, respectively. Mass (M) was modelled as an exponential function of test diameter (D) for each species, thus explaining 97.5% of the variance for 58 individual urchins (JMP v. 21.0.1, SAS Institute Inc.). Urchin codes as in Fig. 1.

Table S1. Functions used to estimate urchin biomass from test diameter. Exponential functions of the form $M = a*e^{(b*D)}$, where M = mass (g) and D = test diameter (cm). Urchin codes as in Fig. 1.

Species	N	D_{mean}	D_{SE}	Parameter	Estimate	Std Error
EC	9	6.1	0.1	a	5.03	4.16
				b	0.50	0.13
ED	11	4.5	0.4	a	3.53	1.49
				b	0.58	0.08
EM	15	3.8	0.1	a	2.23	2.74
				b	0.66	0.31
HM	11	4.8	0.3	a	11.44	2.58
				b	0.50	0.04
TG	12	5.9	0.6	a	3.54	1.49
				b	0.53	0.06

Supplement 4. Oceanographic Variation

In order to contrast ocean conditions in summer 2012 and 2014, we conducted data searches for continuous timeseries of oceanographic data in the Maui and greater Hawaii region. Three data sources (Figs. S4a-c) were identified that provided data on summer ocean conditions in the region during summer 2012 and 2014. These datasets indicated that wave height and salinity were indistinguishable among years while summer temperatures were approximately 1.4 °C warmer and dissolved CO_2 concentrations were approximately 20 µatm higher in 2014 relative to 2012 (Figures S9-S11).

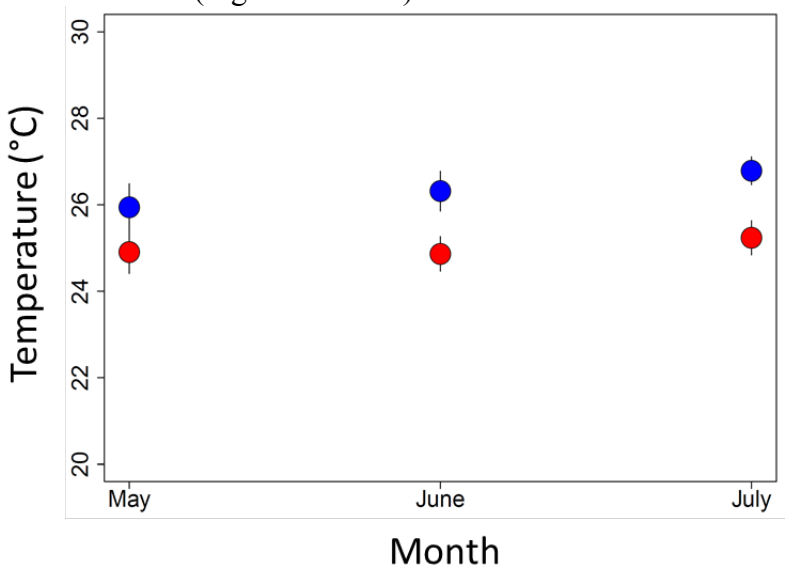

Figure S4.1. Temperature data from the NOAA National Data Buoy Center KLIH1 - 1615680 - Kahului, Kahului Harbor, HI. This station provides water temperatures measured every 6 minutes from the Kahului Harbor, Maui, HI. This provides the best estimate of nearshore temperatures likely to be observed on shallow fringing reefs such as those where assays were conducted. Here, data in May-July indicate approximately 1 °C difference in mean temperatures between 2014 (blue) and 2012 (red). Error bars are 1 s.e. https://www.ndbc.noaa.gov/station_history.php?station=klih1

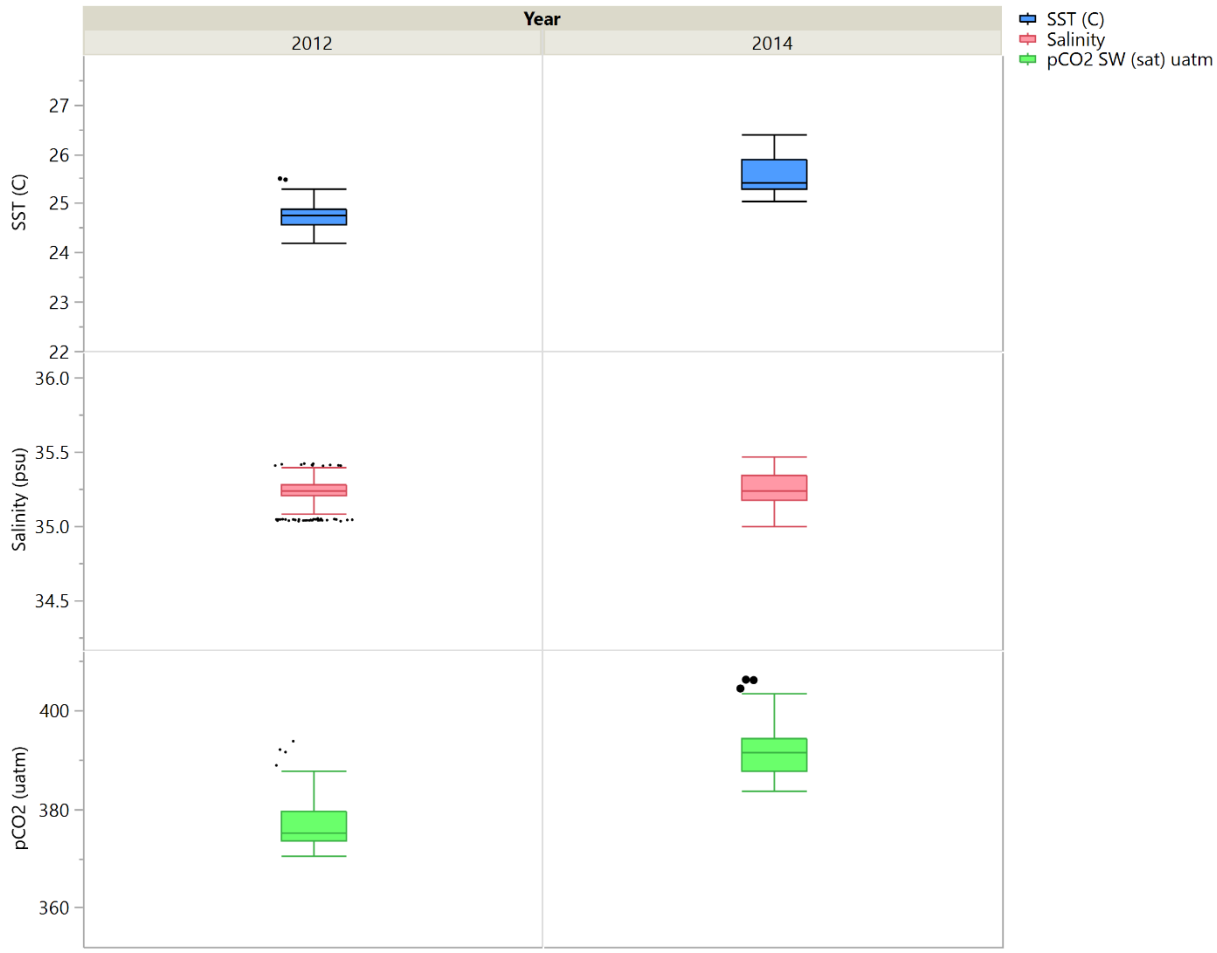

Figure S4.2. Temperature, Salinity, and CO_2 data from the Woods Hole Hawaii Ocean Time Series (WHOTS) buoy. This time series is measured from a buoy moored in offshore waters near the island of Oahu. Here, boxplot of salinity (psu), sea surface temperature (SST, °C), and partial pressure of carbon dioxide ($_pCO_2$, µatm) are shown for June-July in 2012 and 2014. Results indicate no differences in salinity and slightly higher $_pCO_2$ (~20 µatm) and temperature (~1 °C) in 2014.
https://www.nodc.noaa.gov/archive/arc0051/0100080/6.6/data/0-data/

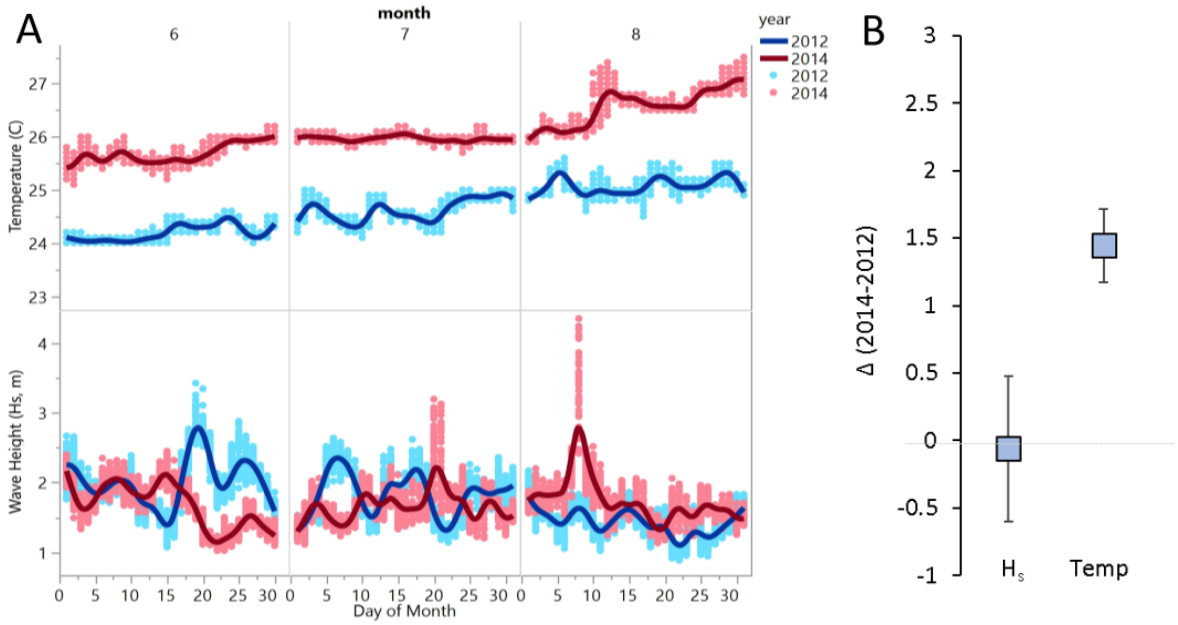

Figure S4.3. Time series (A) and interannual differences (B) in summer (June-August) significant wave height (m) and temperature (°C) for 2012 and 2014 from the UCSD Coastal Data Information Program (CDIP) Buoy 187 - Pauwela, Maui, HI. This is a buoy in coastal waters off the island of Maui, providing time series of temperature and significant wave height. Wave intensity was similar among years whereas 2014 appeared to be 1.5 °C warmer than 2012, in general agreement with WHOTS and the NDBC Kahului temperature records. http://cdip.ucsd.edu/themes/cdip?d2=p70&pb=1&u2=p_id:p70:mode:all:s:187:st:1:v:pm_download_table:dt:201203

Supplement 5. Echinoid Size and Assay Controls

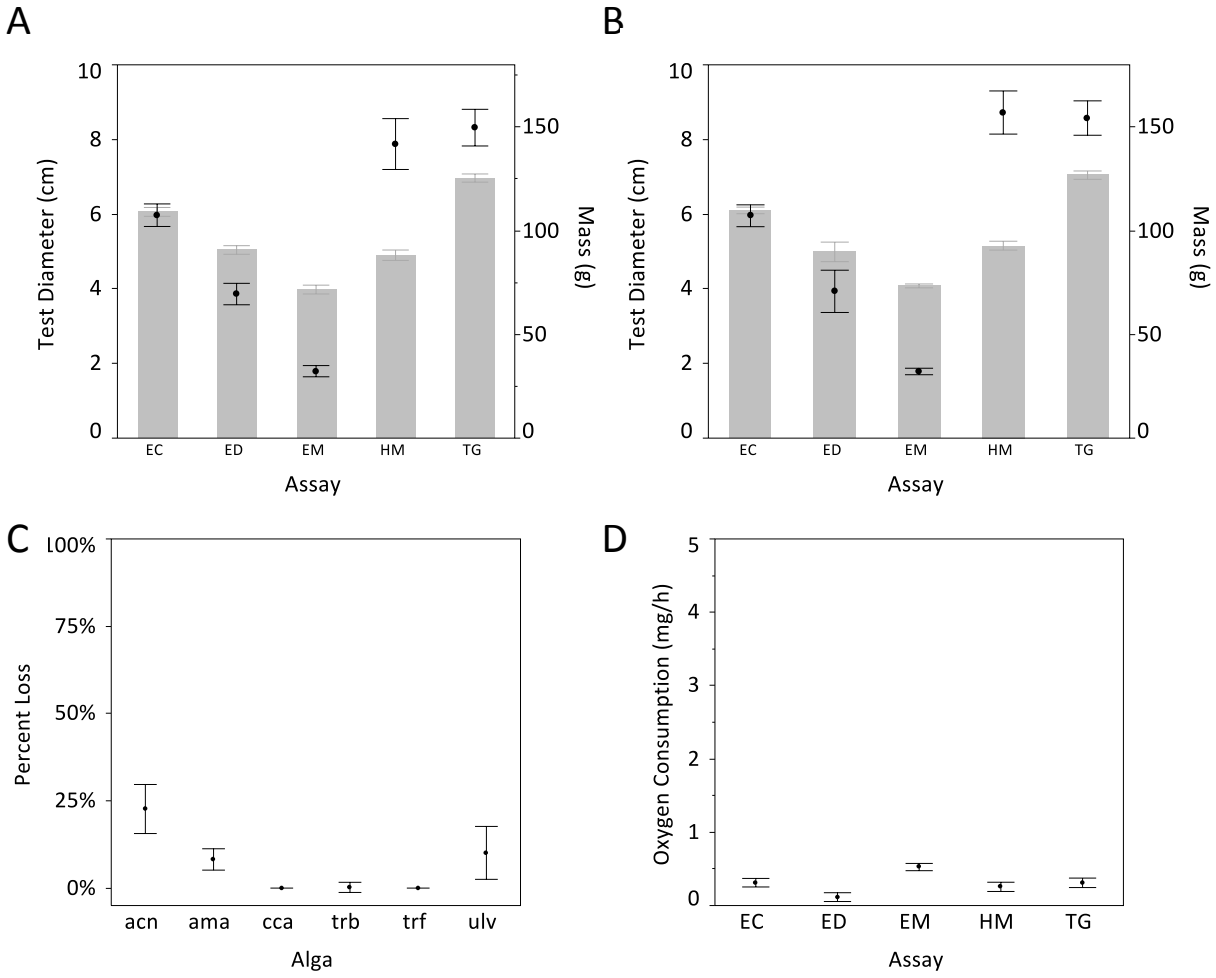

Figure S5. Echinoid sizes and assay controls. Test diameter (bars) and mass (points) of echinoids used in (a) grazing and (b) metabolic assays; and control values for (c) grazing and (d) metabolic assays. Metabolic data are from Lewis et al. 2018. Mass was estimated in (a) using allometric scaling relationships developed from (b) (see Fig. S3, Table S1 in Supplement 3). Mean ± SE shown. Urchin and algae codes as in Fig. 1.

Supplement 6. Relative Consumption Profiles

Percent consumption was measured as the corrected percent loss of each alga consumed in echinoid treatments. Relative consumption (RC) was calculated by normalizing percent consumption of each alga as a proportion of the most consumed alga for each individual, reducing the effects of individual variability in total consumption (Fig. S5). Thus, the percent consumption of the maximally consumed alga for each urchin was normalized (divided by unity) to 1.0 and percent consumption values of all other taxa were also rescaled relative to this value (from 0.0-1.0). This allowed for the assessment of different patterns in relative consumption profiles, including uniform and variable non-selective grazing.

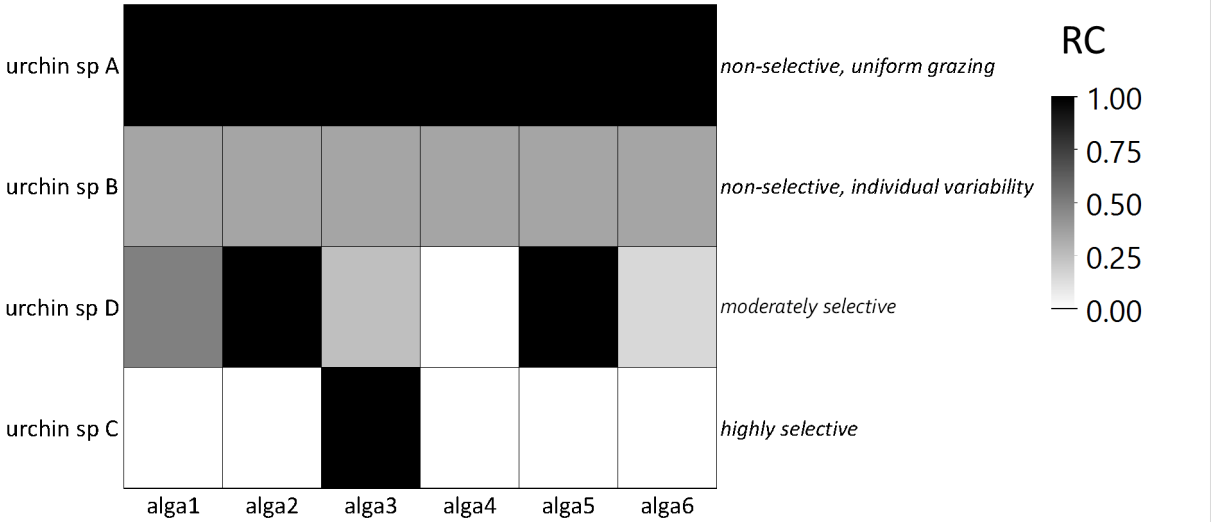

Figure S6. Hypothetical urchin-algal relative consumption (RC) heat map. All individuals of Species A uniformly consumes all algae equally (all algae equally preferred, no selectivity, all black). Individuals of Species B each consume a different alga (individual variability, no selectivity, all grey). Individuals of Species D exhibit intermediate selectivity, primarily consuming two taxa (black), avoiding one (white), and occasionally consuming all others (grey). All individuals of Species C exhibit strong and consistent selectivity, consuming only one algal type (black).

Supplement 7. Energy equivalents of algal mass

Water content for each of the six algal taxa was empirically assessed by measuring the dry weights (dried for 48 h at 60°C) of frozen specimens collected from ungrazed control assays and contrasting these with respective prior measurements of their wet masses (N = 15 for each macroalga and N=11 for CCA and TRF) (Table S2, Fig. S6a). Next, we conducted a literature search to collate estimates of dry algal energy content (kcal/g dry mass) of congeneric or closely-related algal taxa from the literature (Fig. S6b, Table S3). Last, water content values were used to convert alga-specific estimates of energy content per gram dry mass into energy equivalents per gram wet mass (Table S2), and these were later used to convert alga-specific mass consumption rates for each assayed urchin into alga-specific hourly energy ingestion rates (J/h).

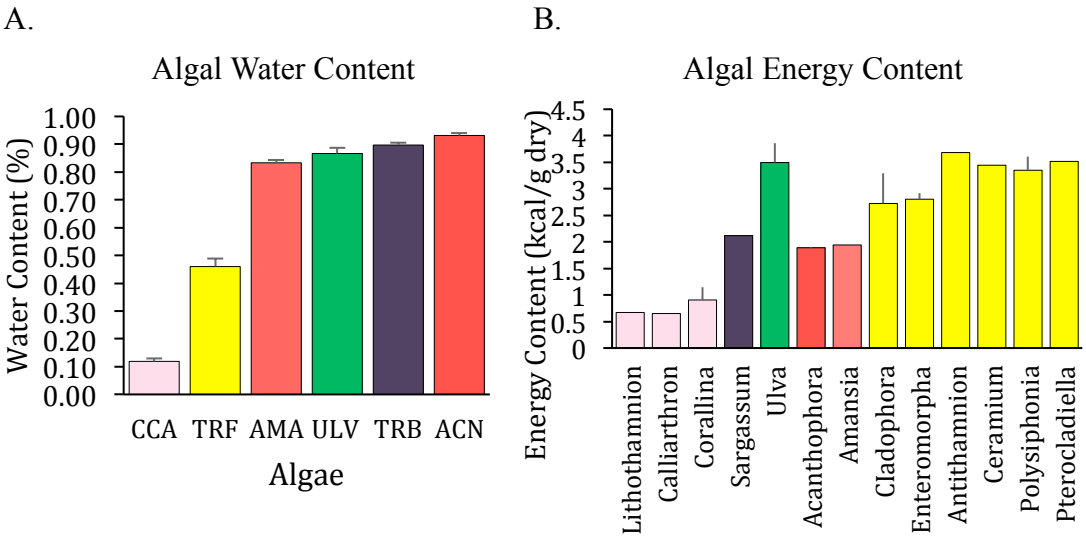

Figure S7. Metrics used to convert daily algal ingestion rates (g wet mass/d) into hourly energy equivalents (J/h). (a) Water content of each alga was measured and used to convert dry energy content values (kcal/g dry) collected from the literature (b) into wet energy content (kcal/g wet). Colors in (b) indicate the grouping of each genus used to estimate energy content of algal taxonomic groups in (a). Values in (b) from sources in Table S3. Error bars are 1 s.e.

Table S2. Summary of estimated water content and energy content per unit dry and wet mass of each algal taxon used in this study.

Alga	Water Content (%)	kcal/g dry	kcal/g wet	J/g wet
CCA	0.119	0.670	0.590	2.469
ACN	0.931	1.888	0.130	0.544
AMA	0.833	1.941	0.324	1.356
TRB	0.897	2.115	0.218	0.912
TRF	0.460	3.270	1.766	7.389
ULV	0.866	3.491	0.466	1.950

Table S3. Sources of algal energy content data in Fig. S8b.

No.	Reference
1	Angel AR, Pirozzi I, de Nys R, Paul NA. 2012. Feeding Preferences and the Nutritional Value of Tropical Algae for the Abalone *Haliotis asinina*. PLoS ONE 7(6): e38857.
2	Bruggemann, J. Henrich, Madeleine J. H. van Oppen, Anneke M. Breeman. 1994. Foraging by the stoplight parrotfish *Sparisoma viride*. I. Food selection in different, socially determined habitats. Mar. Ecol. Prog. Ser. 106: 41-55.
3	Paine and Vadas. 1969. Calorific values of benthic marine algae and their postulated relation to invertebrate food preference. Marine Biology 4: 79-86
4	Lamare M.D. and S.R. Wing. 2001. Calorific content of New Zealand marine macrophytes. New Zealand Journal of Marine and Freshwater Research 35(2): 335-341
5	Marsham et al. 2007. Comparison of nutritive chemistry of a range of temperate seaweeds. Food chemistry 100: 1331-1336
6	Pillans et al. 2004. Food choice in *Siganus fuscescens*: influence of macrophyte nutrient content and availability. Journal of Fish Biology 64: 297-309
7	McDermid, Stuercke, Balazs. 2007. Nutritional composition of marine plants in the diet of the green sea turtle. Bulletin of Marine Science 81(1): 55-71

Supplement 8. Replicate Grazing Assays

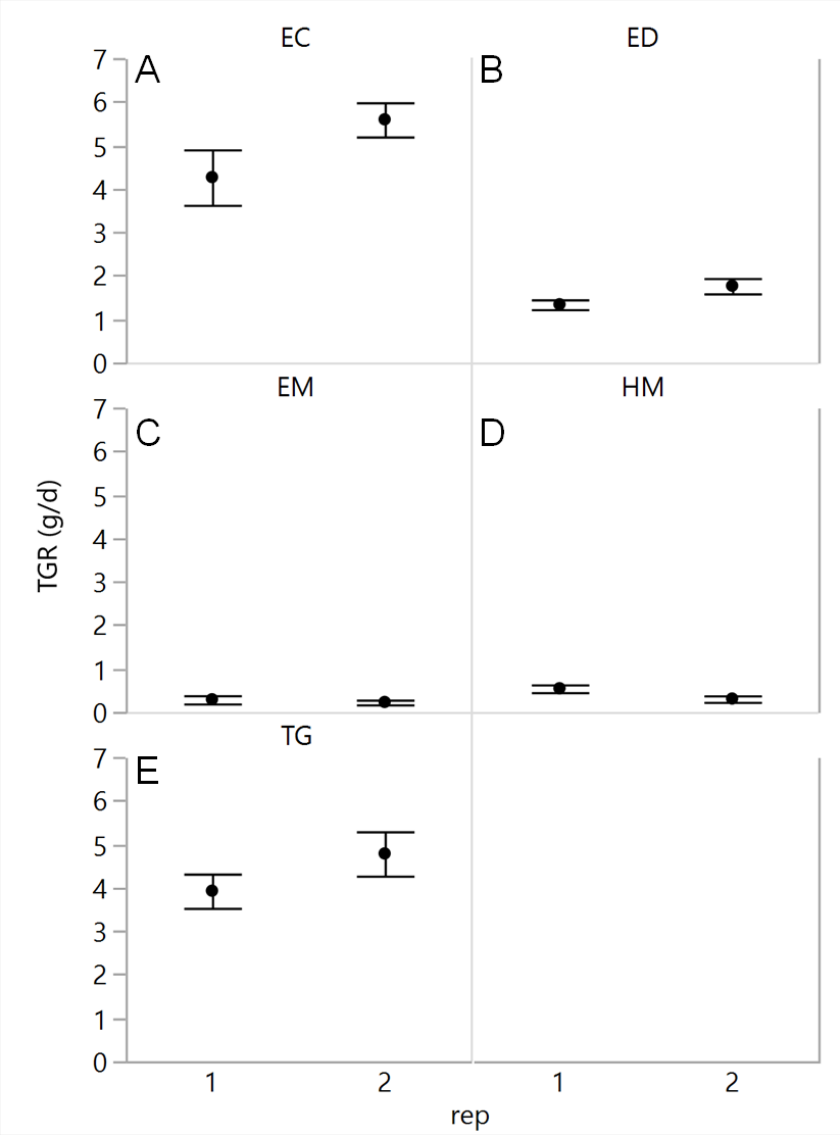

Figure S8. Mean ± SE control-corrected total grazing rates (*TGR*) for each of 2 replicate (n=10) assays for EC (A), ED (B), EM (C), HM (D) and TG (E). No significant differences among replicate assays were observed for any of the 5 echinoid sp.; therefore, grazing data were pooled for species comparisons. Urchin codes as in Fig. 1.

Supplement 9. Replicate Metabolic Assays

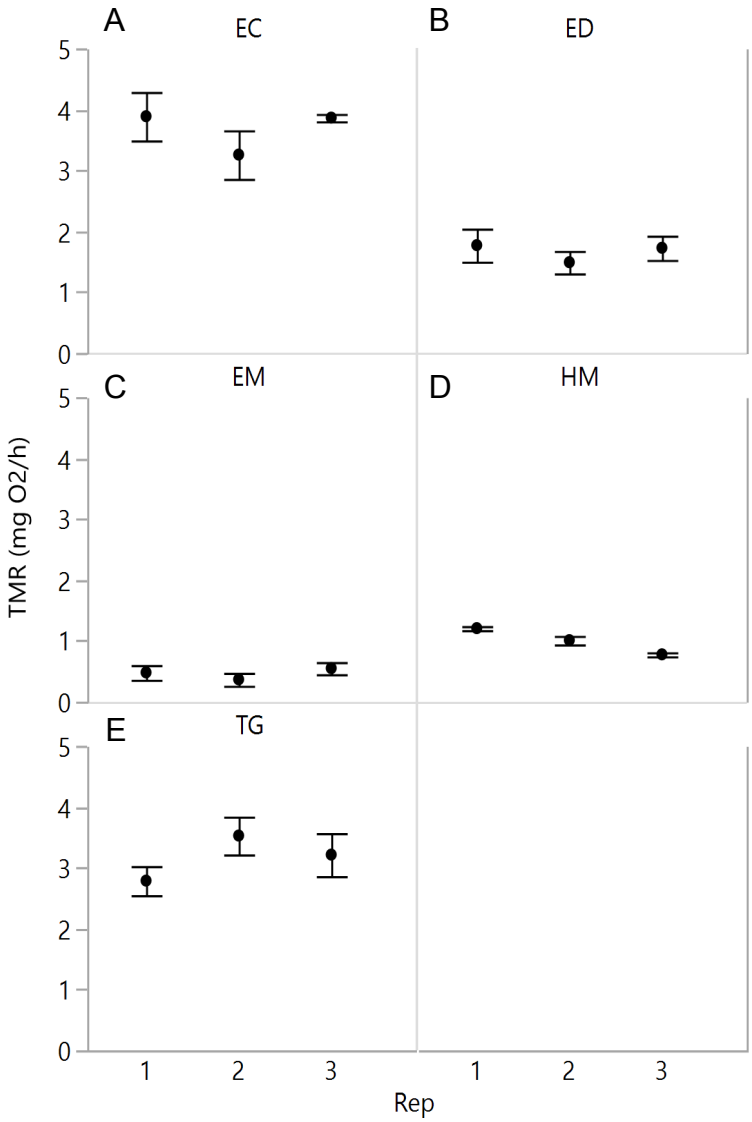

Figure S9. Mean ± SE corrected total metabolic rates (*TMR*) for each of 3 replicate (n=3) assays for EC (A), ED (B), EM (C), HM (D) and TG (E) (Lewis et al. 2018). No significant differences among replicate assays were observed for EC, ED, EM & HM. Low values resulted in small, but detectible differences (0.19-0.43 mg O_2/h) among replicate HM assays ($F_{2,6}$ = 19.5, p = 0.002); however, due to the low magnitude and lack of any difference among other species, metabolic rates were pooled to strengthen species contrasts (Underwood 1997). Urchin codes as in Fig. 1.