Supplement of Biogeosciences, 15, 6277–6296, 2018
https://doi.org/10.5194/bg-15-6277-2018-supplement

Biogeosciences
Open Access

Supplement of

Coral reef carbonate budgets and ecological drivers in the central Red Sea – a naturally high temperature and high total alkalinity environment

Anna Roik et al.

Correspondence to: Christian R. Voolstra (christian.voolstra@kaust.edu.sa) and Anna Roik (aroik@geomar.de)

Supplementary Materials

Supplementary Text

Text S1 Calculation of carbonate budgets.

The following variables were incorporated in the G_{budget} calculations:

- Census-based calcification rate of the benthic community, $G_{benthos}$ [kg $CaCO_3$ m^{-1} y^{-1}], derived from site-specific benthic calcification rates extrapolated over transect data
- Census-based net-accretion/erosion rates of reef "rock" surface area (endolithic and epileptic), $G_{netbenthos}$ [kg $CaCO_3$ m^{-1} y^{-1}], derived from site-specific bulk net-accretion/erosion rates G_{net} extrapolated over transect data
- Census-based erosion rates (epilithic), E_{echino} [kg $CaCO_3$ m^{-1} y^{-1}] and E_{parrot} [kg $CaCO_3$ m^{-1} y^{-1}], of crucial bioeroder communities such as sea urchins and parrotfishes, respectively, derived from erosion rates reported in literature extrapolated over transect data

First, $\mathbf{G_{benthos}}$ were calculated using *in situ* measured site and genus specific calcification rates of corals and calcareous crusts as reported by Roik et al. (2015) (Table S2). These calcification rates were extrapolated over the percentage cover of respective calcifier communities assessed in six 10 m rugosity transects per site (Equation box S1 (a), Table S3). Next, $\mathbf{G_{netbenthos}}$ rates were calculated for each reef site using G_{net} rates derived from limestone block assays, and the percentage cover of the reef substrate category "rock"/ "recently dead coral" form the same transects (Equation box S1 (b), Table S2 and S3). Benthic transects were performed following Perry et al., (2012) and these data were previously reported in detail in Roik et al. (2015).

Parrotfish abundances per species and fork length were recorded in stationary visual census count surveys (FL size categories: 1 = 5 - 14 cm, 2 = 15 - 24 cm, 3 = 25 - 34 cm, 4 = 35 - 44 cm, 5 = 45 - 70, and 6 > 70 cm). The survey design was based on n = 6 plots of Ø = 15 m (duration = 10 min, 9.30 am - 12.00 pm, distance between plots 20 m, adapted from Bannerot and Bohnsack, 1986). Care was taken not to count any individual parrotfish more than once. Table S4 provides a summary of these data. Species- or genus-specific parrotfish abundance data were normalized to survey time and plot area. Next, data were converted into erosion rates using calculations based on size-specific estimates for bite rate and volume for several Red Sea taxa (Equation box S2 (a)). This integrates the assumption of 10 h of feeding activity per day as shown in Table S5 (Alwany et al., 2009; Hoey et al., 2016)). Specifically, bite rates and volumes were adjusted according to the percentage of bites leaving scars, and to fish size using the relationship between bite volume and average fork length, using Equations S3 (b) and (e) (see Bruggemann et al., 1994, 1996), as recommended in Perry et al. (2012). These specific erosion rates as well as parrotfish abundances were used to calculate parrotfish erosion rates per site, $\mathbf{E_{parrot}}$ (Equation box S2 (f) and Table S6).

To estimate sea urchin erosion rates for the reef sites, $\mathbf{E_{echino}}$, abundances of major sea urchin genera and their size classes were assessed. The sea urchin census was conducted along the benthic rugosity transects between 9.00 and 14.00 h, and included the most common bioerosive genera *Diadema*, *Echinometra*, *Echinostrephus*, and *Eucidaris* in five size classes (1 = 0 - 20, 2 = 21 - 40, 3 = 41 - 60, 4 = 61 - 80, 5 = 81 - 100 mm urchin diameter, Table S7). Genus and size specific erosion rates for sea urchins (Table S8) were employed in equations *sensu* Perry et al., (2012) to estimate erosion rates per individual echinoid genus (Equation box S3 (a) - (d)).

This approach corresponds to the *ReefBudget* (http://geography.exeter.ac.uk/reefbudget/) methodology described in (Perry et al., 2012) . Adjustments were made according to the availability of data from the Red Sea reef sites:

- All census data used in our study has been collected from a discrete depth (7.5 and 9 m), while *ReefBudget* considers two depth ranges (0 - 5 m and 5 - 10 m)
- In place of estimating microbioerosion and boring sponge erosion from census data and site-specific or literature-reported erosion rates, we employ site-specific G_{net} data (i.e, net-accretion/erosion rates measured in a limestone block assay) which includes the rates of endolithic bioerosion
- We use genus- and site-specific calcification rates (Roik et al. 2015) and species- and size-specific parrotfish erosion rates from the northern Red Sea (Alwany et al. 2009)

Supplementary Equations

Equation box S1 Benthic community calcification and net-accretion/-erosion of the reef "rock" surface area ($G_{benthos}$ and $G_{netbenthos}$)

Legend:

Transect planar length:	d1 [m]
Rugosity length:	d2 [m]
Rugosity:	R = d2 / d1
Percentage cover of a category in a transect:	COV [%]
Calcifier transect category (*i* = number of all categories):	CAT*i*
Sum of *Rock* and *Recently Dead Coral* (transect categories):	RCDC
Accretion/calcification rate per benthos category:	$G_{Calcifier}$ (CAT)# / G_{net} (CAT)#

Equations:

(a) $\mathbf{G_{benthos} = \sum_{CAT1}^{CATi} GCalcifier\ (CAT) * R * COV}$ [kg $CaCO_3$ m^{-1} y^{-1}]

(b) $\mathbf{G_{netbenthos} = G_{net}\ (RCDC) * R * COV}$ [kg $CaCO_3$ m^{-1} y^{-1}]

#see Table S2

Equation box S2 Parrotfish bioerosion (E_{parrot})

Legend:

Bioerosion rate per individual *Cetoscarus bicolor**:	$E_{parrotIndvBIC}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Chlorurus gibbus**:	$E_{parrotIndvGIB}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Chlorurus sordidus**:	$E_{parrotIndvSOR}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus ferrugenius**:	$E_{parrotIndvFER}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus frenatus**:	$E_{parrotIndvFREN}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus ghobban**:	$E_{parrotIndvGHO}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus niger**:	$E_{parrotIndvNIG}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual Other *Scarus**:	$E_{parrotIndvSCAR}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Bioerosion rate per individual *Hipposcarus harid***:	$E_{parrotIndvHAR}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Average fork length averages:	FL [cm] {10, 20, 30, 40, 57, 100}
Species-specific bite volume (from Table S5):	$BVol_{species}$ [cm^3]
Species-specific bite rate (from Table S5):	Brate [b minute^{-1}]
Fork length specific bite volume (Bruggemann et al., 1994):	$BVol_{Bruggemann}$ [cm^3]
Fork size adjustment factor# (Bruggemann et al., 1994):	$factor_{Bruggemann}$
% of bites leaving scars (Bruggemann et al., 1996):	B %
Adjusted species and fork size specific bite volume:	$BVol_{adj}$ [cm^3]
Size adjusted bite rate:	$Brate_{adj}$ [b minute^{-1}]
Reef carbonate density (Alwany et al., 2009):	$\rho = 1.4$ [g cm^{-3}]
Hours of active feeding per day (Alwany et al., 2009):	$h_{Feed} = 10$ [h]
Bioerosion rate per individual:	$E_{parrotIndv}$ [kg $CaCO_3$ individual^{-1} y^{-1}]
Parrot fish abundance (census based):	$Abund_{parrot}$ [individuals m^{-2}]

Equations:

(a) $E_{parrotIndv} = Brate_{Adj} * BVol_{Adj} * \rho * 60 min * h_{Feed} * 365 * 0.001$

(b) $BVol_{Adj} (FL) = BVol_{Species} * factor_{Bruggeman} (FL)$

(c) $Brate_{Adj} (FL) = B \% / 100 * Brate$

(d) $factor_{Bruggeman} (FL) = BVol_{Bruggemann} (FL) / BVolBruggemann (40)$

(e) $B_{VolBruggemann} = 1.362 * 10^{-6} * FL^3$

(f) $E_{parrot} = E_{parrotIndv} * Abund_{parrot}$ [kg $CaCO_3$ m^{-2} y^{-1}]

** based on Alwany et al. 2009*
*** based on Hoey et al. 2016*
#Relative to FL = 40

Equation box S3 Sea urchin bioerosion (E_{echino})

Legend:

Bioerosion rate per individual *Diadema#*:	$E_{echinoIndvD}$ [kg $CaCO_3$ individuals^{-1} y^{-1}]
Bioerosion rate per individual *Echinometra#*:	$E_{echinoIndvE}$ [kg $CaCO_3$ individuals^{-1} y^{-1}]
Bioerosion rate per individual *Other#*:	$E_{echinoIndvO}$ [kg $CaCO_3$ individuals^{-1} y^{-1}]
Size class averages:	S [mm] {10, 30, 50, 70, 90}
Echinoid abundance per reef site (census based):	$Abund_{echino}$ [individuals m^{-2}]

Equations:

(a) $E_{echino} = E_{echinoIndv} * Abund_{echino}$ [kg $CaCO_3$ m^{-1} y^{-1}]

(b) $E_{echinoIndvD} (S) = 0.0029 * S^{1.6624} * 0.001 * 365$ [kg $CaCO_3$ individuals^{-1} y^{-1}]

(c) $E_{echinoIndvE} (S) = 0.0007 * S^{1.7309} * 0.001 * 365$ [kg $CaCO_3$ individuals^{-1} y^{-1}]

(d) $E_{echinoIndvO} (S) = 0.00008 * S^{2.4537} * 0.001 * 365$ [kg $CaCO_3$ individuals^{-1} y^{-1}]

#from *ReefBudget* (Perry et al., 2012)

Supplementary Tables

Table S1 Sampling schedule for seawater samples

Inorganic nutrients N = 1, 4 L	Total alkalinity N = 3, each 50 ml	Season
08.12.2013	-	winter
05.03.2014	05.03.2014	winter
10.03.2014	10.03.2014	winter
17.03.2014	17.03.2014	winter
26.03.2014	26.03.2014	winter
23.06.2014	23.06.2014	summer
16.07.2014	16.07.2014	summer
20.08.2014	20.08.2014	summer
28.08.2014	28.08.2014	summer
04.09.2014	04.09.2014	summer
10.09.2014	10.09.2014	summer

Dates = dd.mm.yyyy

Table S2 Table of site-specific *in situ* calcification and net-accretion/erosion rates assigned to benthic transect categories.

Transect Code	Benthos category	Main representative genera	Nearshore[#]	Midshore	Offshore
HCB	Other Hard Coral (branching)*	*Acropora* sp. and *Pocillopora* sp.	1.753 (0.021)	3.119 (0.886)	3.598 (1.257)
HCE	Other Hard Coral (encrusting)*	*Acropora* sp., *Pocillopora* sp., and *Porites* sp.	2.842 (1.295)	3.341 (2.339)	4.246 (1.78)
HCM	Other Hard Coral (massive)*	*Pocillopora*	2.732 (0.608)	3.469 (0.901)	4.11 (1.247)
HCP	Other Hard Coral (platy/foliose)*	*Acropora* sp., *Pocillopora* sp., and *Porites* sp.	2.842 (1.295)	3.341 (2.339)	4.246 (1.78)
ACR	Acroporidae*	*Acropora* sp.	1.753 (0.021)	2.699 (0.737)	3.151 (1.156)
POC	Pocilloporidae*	*Pocillopora* sp.	2.732 (0.608)	3.469 (0.901)	4.11 (1.247)
POR	Poritidae*	*Porites* sp.	3.93 (0.537)	3.83 (4.257)	6.673 (1.299)
CC	Calcareous crusts / coralline algae	Calcareous crust community	0.138 (0.042)	0.263 (0.084)	0.411 (0.08)
		Specific accretion/erosion rate (G_{net})[$]			
DC	Recently Dead Coral	G_{net}	-0.787 (0.16)	0.036 (0.201)	0.227 (0.096)
RC	Rock	G_{net}	-0.787 (0.16)	0.036 (0.201)	0.227 (0.096)

*Calcification rates as kg $CaCO_3$ m^{-2} y^{-1} are taken from Roik et al. (2015) and are averaged per genus/community per reef site.

#Since calcification rate for *Pocillopora* sp. was not measured for the nearshore reef, the average from the next closest site, the midshore sheltered reef, is used.

$Average net-accretion rates G_{net} as kg $CaCO_3$ m^{-2} y^{-1} are based on the measurements of limestone blocks deployed for this study.

Mean and standard deviation in parenthesis

Table S3 Census-based calcification rate of benthic calcifier communities $G_{benthos}$ [kg $CaCO_3$ m^{-2} y^{-1}] per reef site and the census-based net-accretion/-erosion rate in reef "rock" surface area per reef site $G_{netbenthos}$ [kg $CaCO_3$ m^{-2} y^{-1}]

	Site-specific benthic calcification rates by transect category									G_{net}		
Reef	HCB	HCE	HCM	HCP	ACR	POC	POR	CC	**$G_{benthos}$**	DC	RC	**$G_{netbenthos}$**
Nearshore	0.034 (0.038)	0.097 (0.066)	0.139 (0.05)	0 (0)	0.007 (0.018)	0.009 (0.011)	0.138 (0.091)	0.002 (0.002)	0.426 (0.149)	-0.004 (0.007)	-0.311 (0.128)	-0.315 (0.129)
Midshore	0.005 (0.013)	0.181 (0.171)	0.367 (0.321)	0.042 (0.08)	0.385 (0.174)	0.37 (0.234)	0.373 (0.216)	0.039 (0.034)	1.762 (0.242)	0.002 (0.001)	0.007 (0.003)	0.009 (0.003)
Offshore	0.12 (0.198)	0.382 (0.226)	0.408 (0.353)	0.064 (0.136)	0.352 (0.546)	0.315 (0.246)	1.018 (0.76)	0.155 (0.039)	2.812 (0.646)	0.007 (0.007)	0.086 (0.027)	0.094 (0.022)

HCB=Other Hard Coral (branching), HCE=Other Hard Coral (encrusting), HCM=Other Hard Coral (massive), HCP=Other Hard Coral (platy/foliose), ACR= Acroporidae POC= Pocilloporidae, POR= Poritidae, CC= Calcareous crusts (coralline algae), DC=Recently Dead Coral, RC= Rock

Means over six transect replicates; standard deviation in parenthesis

Table S4 Parrotfish abundances, size ranges, and estimated biomasses [m^{-2}].

Site	Abundance (individuals [m^{-2}])	Size range (categories)	Biomass (g parrotfish [m^{-2}])
Nearshore	0.17 (0.60)	1-4	82.18 (46.67)
Midshore	0.13 (0.01)	2-5	67.97 (9.21)
Offshore	0.08 (0.01)	1-4	24.69 (6.044)

Means over six replicates; standard errors in brackets. Size ranges are based on size categories (1 = 5 - 14 cm, 2 = 15 - 24 cm, 3 = 25 - 34 cm, 4 = 35 - 44 cm, 5 = 45 - 70). Biomass conversions are based on observed parrotfish abundance and were converted into biomass estimates based on length-weight relationships for the respective species extracted from fishbase (www.fishbase.org; accessed in December 2015).

Table S5 Parrotfish species-specific bite rates and bite volumes employed for E_{parrot} calculation

Species	Bite rate [b $minute^{-1}$]	Bite volume [cm^3]	Reference
Cetoscarus bicolor	5.88	0.110	Alwany et al. 2009
Chlorurus gibbus	6.38	0.114	Alwany et al. 2009
Chlorurus sordidus	15.30	0.008	Alwany et al. 2009
Scarus ferrugenius	11.88	0.009	Alwany et al. 2009
Scarus frenatus	10.72	0.011	Alwany et al. 2009
Scarus ghobban	10.92	0.063	Alwany et al. 2009
Scarus niger	19.78	0.002	Alwany et al. 2009
Hipposcarus harid	9.00	0.021	Hoey et al. 2016*
Other *Scarus*	11.23	0.040	average of all values used here

* bite volume is an average of "scraper" bite volumes from Alwany et al. (2009)

Table S6 Census-based parrotfish bioerosion rates E_{parrot} [kg $CaCO_3$ m^{-2} y^{-1}]

reef	$E_{Cbicolor}$	$E_{Cgibbus}$	$E_{Csordidus}$	E_{Hharid}	E_{Scarus}	$E_{Sferrugineus}$	$E_{Sfrenatus}$	$E_{Sghobban}$	E_{Sniger}	E_{parrot}
Nearshore	0 (0)	0 (0)	-0.256 (0.176)	-0.112 (0.091)	-0.272 (0.138)	-0.067 (0.067)	-0.02 (0.048)	0 (0)	-0.047 (0.024)	**-1.36 (1.886)**
Midshore	0 (0.001)	-0.098 (0.23)	-0.033 (0.038)	-1.07 (1.827)	-0.103 (0.136)	-0.005 (0.011)	0 (0)	-0.05 (0.078)	-0.014 (0.014)	**-0.727 (0.307)**
Offshore	-0.108 (0.203)	-0.098 (0.23)	-0.046 (0.038)	-0.001 (0.002)	-0.078 (0.123)	-0.023 (0.044)	-0.001 (0.001)	-0.09 (0.219)	-0.015 (0.012)	**-0.444 (0.701)**

Means over six replicates; standard deviations in parenthesis. Grey column = sum of bioerosion rates.

Table S7 Overall sea urchin abundances, size ranges, and estimated biomasses.

Site	Abundance (individuals [m^{-2}])	Size range (categories)	Biomass (g sea urchin [m^{-2}])
Nearshore	0.014 (0.006)	1-5	1.43 (0.98)
Midshore	0.002 (0.004)	2-5	0.25 (0.19)
Offshore	0.004 (0.002)	1-2	0.05 (0.04)

Means over six replicates; standard errors in parenthesis. Size ranges are based on size categories (1 ≤ 20 mm; 2 = 21 - 40 mm; 3 = 41 - 60 mm; 4 = 61 - 80 mm; 5 = 81 - 100 mm). Biomass conversions were based on observed parrotfish abundance and extrapolated based on a fitted model by Wahle and Peckham (1999) for *Strongylocentrotus droebachie.*

Table S8 Census-based sea urchin bioerosion rates E_{echino} [kg $CaCO_3$ m^{-2} y^{-1}]

Reef	$E_{Diadema}$	$E_{Echinometra}$	$E_{Echinostrephus}$	$E_{Eucidaris}$	E_{Other}	E_{echino}
Nearshore	-0.217 (0.184)	-0.011 (0.018)	0 (0)	0 (0)	0 (0)	**-0.228 (0.189)**
Midshore	-0.022 (0.038)	-0.002 (0.002)	-0.001 (0.003)	0 (0)	0 (0)	**-0.024 (0.04)**
Offshore	-0.016 (0.001)	-0.002 (0.004)	0 (0)	0 (0)	0 (0)	**-0.019 (0.003)**

Means over six replicates; standard deviations in parenthesis. Grey column = sum of bioerosion rates.

Table S9 G_{net} data were tested for effects of the mixed factors "reef" (fixed: nearshore, midshore, and offshore), and "deployment time" (random: 6, 12, and 30 months) using a univariate 2-factorial PERMANOVA. Significant results in bold (significance level 0.05).

PERMANOVA global results table					
Source	**df**	**SS**	**MS**	**Pseudo-*F***	***p*(PERMANOVA)**
reef	2	0.329	0.164	2.890	*0.168*
deployment time	2	0.095	0.048	5.924	***0.004***
Interaction	4	0.236	0.059	7.336	***0.000***
Residuals	39	0.313	0.008		
Total	47	0.853			

PERMANOVA pair-wise tests				
Groups	***t***	***p*(pair-wise)**	**Unique permutations**	***p*(Monte-Carlo)**
Within 6 months deployment data				
midshore, offshore	0.433	*0.677*	4023	
midshore, nearshore	0.057	*0.957*	5001	
offshore, nearshore	0.719	*0.485*	5030	
Within 12 months deployment data				
midshore, offshore	1.3524	*0.2267*	35	*0.2249*
midshore, nearshore	2.3413	*0.055*	35	*0.0564*
offshore, nearshore	2.5786	*0.025*	35	***0.0395***
Within 30 months deployment data				
midshore, offshore	4.1028	*0.0286*	35	***0.0055***
midshore, nearshore	2.3412	*0.0274*	35	*0.0582*
offshore, nearshore	2.8925	*0.0283*	35	***0.025***

Table S10 G_{budget} and $G_{benthos}$ data were analyzed using a univariate 1-factorial ANOVA to test for the effect of reef site. $G_{netbudget}$, E_{echino}, and E_{parrot} had a non-gaussian distribution and were analyzed using a rank-based method (Kruskal-Wallis). Significant results in bold (significance level 0.05).

ANOVA					
G_{budget}	**Df**	**Sum of Squares**	**Mean Squares**	***F*-value**	***p***
reef	2	47.26	23.63	16.69	***< 0.001***
Residuals	15	21.24	1.42		
Tukey HSD multiple comparisons of means					
G_{budget}	**difference in observed means**	**lower limit of 95% conf. interval**	**upper limit of 95% conf. interval**	***p*(adj.)**	
midshore-offshore	-1.42	-3.21	0.36	*0.130*	
nearshore-offshore	-3.92	-5.70	-2.14	***< 0.001***	
nearshore-midshore	-2.50	-4.28	-0.71	***0.006***	
ANOVA					
log10 ($G_{benthos}$)	**Df**	**Sum of Squares**	**Mean Squares**	***F*-value**	***p***
reef	2	17.17	8.585	51.74	**< 0.001**
Residuals	15	2.489	0.166		
Tukey HSD multiple comparisons of means					
log10 ($G_{benthos}$)	**difference in observed means**	**lower limit of 95% conf. interval**	**upper limit of 95% conf. interval**	***p*(adj.)**	
midshore-offshore	-1.05	-1.66	-0.44	***< 0.001***	
nearshore-offshore	-2.39	-3.00	-1.78	***< 0.001***	
nearshore-midshore	-1.34	-1.95	-0.73	***< 0.001***	
Kruskal-Wallis rank sum tests					
$G_{netbenthos}$	**chi-squared**	**df**	***p***		
reef	15.17	2	***0.001***		
Dunn (1964) Kruskal-Wallis multiple comparison					
$G_{netbenthos}$	**Comparison Z**	***p***	***p*(adj. Benjamini-Hochberg)**		
midshore - nearshore	1.95	0.051	*0.051*		
midshore - offshore	-1.95	0.051	*0.077*		
nearshore - offshore	-3.90	0.000	***< 0.001***		
Kruskal-Wallis rank sum tests					
E_{echino}	**chi-squared**	**df**	***p***		
reef	0.56	2	**0.038**		
Dunn (1964) Kruskal-Wallis multiple comparison					
E_{echino}	**Comparison Z**	***p***	***p*(adj. Benjamini-Hochberg)**		
midshore - nearshore	2.50	0.012	***0.037***		
midshore - offshore	0.76	0.447	*0.447*		
nearshore - offshore	-1.74	0.082	*0.123*		
Kruskal-Wallis rank sum tests					
E_{parrot}	**chi-squared**	**df**	***p***		
reef	2.77	2	*0.250*		
Dunn (1964) Kruskal-Wallis multiple comparison					
E_{parrot}	**Comparison Z**	***p***	***p*(adj. Benjamini-Hochberg)**		
midshore - nearshore	-0.49	0.626	*0.626*		
midshore - offshore	-1.62	0.105	*0.314*		
nearshore - offshore	-1.14	0.256	*0.384*		

Table S11 Statistical tests characterizing the spatio-seasonal dynamics in abiotic parameters

	Reef	**Season**	**Season x Reef**
	p	***p***	***p***
Temperature	< 0.001	< 0.001	< 0.001
Salinity	< 0.001	< 0.001	< 0.001
Diurnal pH variation	< 0.001	< 0.001	< 0.001
sqrt(NO_3^-&NO_2^-)	n.s.	n.s.	n.s.
sqrt(NH4+)	n.s.	n.s.	n.s.
sqrt(PO_4^{3-})	n.s.	< 0.001	n.s.
sqrt(TA)*	< 0.001	< 0.001	0.008

All data was analyzed using 2-factorial ANOVA (fixed factors), in one case* univariate PERMANOVA was employed; n.s. = not significant (p < 0.05)

Table S12 Tukey HSD multiple comparisons of means and PERMANOVA pairwise tests* for abiotic data

	Both Seasons			Summer			Winter		
	near,mid	near,off	mid,off	near,mid	near,off	mid,off	near,mid	near,off	mid,off
Temperature	< 0.001	< 0.001	0.003	< 0.001	< 0.001	< 0.001	n.s.	< 0.001	< 0.001
Salinity	< 0.001	< 0.001	n.s.	< 0.001	< 0.001	n.s.	< 0.001	0.003	n.s.
Diurnal pH variation	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
NO_3^-&NO_2^-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
NH_4^+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
sqrt(PO_4^{3-})	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TA*	< 0.001	< 0.001	0.162	0.001	< 0.001	0.036	0.011	0.041	n.s.

P-values are presented; n.s. = not significant (p < 0.05); near = nearshore, mid = midshore, off = offshore

Table S13 Spearman rank order correlations for abiotic and biotic predictor variables vs. G_{net}.

Dependent variable: G_{net}	**rho**	**t**	***p*(adj. Benjamini-Hochberg)**
Parrot fish abundance	-0.95	-9.24	0.000
Sea urchin abundance	-0.47	-1.70	0.120
% cover CCA	0.95	9.24	0.000
% cover Algae/Sponge	0.47	1.70	0.120
Temperature	-0.47	-1.70	0.120
Salinity	-0.82	-4.52	0.006
Diurnal pH variation	-0.95	-9.24	0.000
NO_3^-&NO_2^-	0.95	9.24	0.000
NH_4^+	0.47	1.70	0.120
PO_4^{3-}	0.82	4.52	0.006
TA	0.95	9.24	0.000

Table S14 Spearman rank order correlations for abiotic and biotic predictor variables vs. G_{budget}.

Dependent variable: G_{budget}	**rho**	**t**	***p*(adj. Benjamini-Hochberg)**
Parrot fish abundance	-0.49	-2.26	0.268
Echinoid abundance	-0.54	-2.58	0.241
% cover branching hard corals	-0.25	-1.01	0.327
% cover encrusting hard corals	0.26	1.09	0.327
% cover massive hard corals	0.34	1.44	0.327
% cover foliose hard corals	0.50	2.30	0.268
% cover Acroporidae	0.27	1.14	0.327
% cover Pocilloporidae	0.51	2.34	0.268
% cover Poritidae	0.45	2.04	0.327
% cover hard coral	0.63	3.23	0.068
% cover CCA/CC*	0.78	4.94	0.002
% cover Algae/Soft coral/Sponge	0.26	1.09	0.327
Rugosity	0.75	4.59	0.004
Temperature	-0.52	-2.46	0.254
Salinity	-0.82	-5.68	0.001
Diurnal pH variation	-0.89	-7.88	0.000
NO_3^-&NO_2^-	0.89	7.88	0.000
NH_4^+	0.52	2.46	0.254
PO_4^{3-}	0.82	5.68	0.001
TA	0.89	7.88	0.000

**CCA = crustose coralline algae, CC = calcifying crusts*

Supplementary Figures

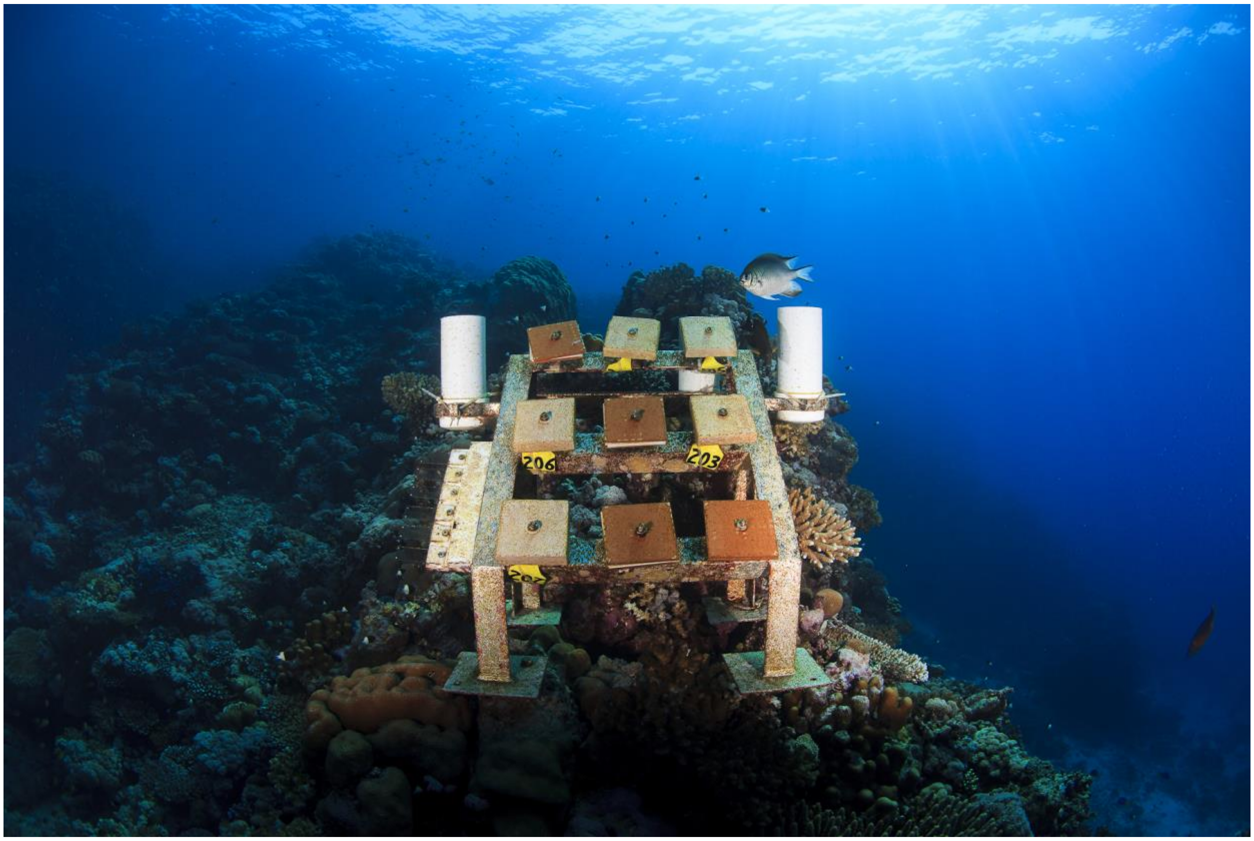

Figure S1 Limestone blocks (= light color blocks in the picture) were used for the measurement of $G_{net.}$ Each block was fixed on a screw to aluminum racks that were permanently attached to the reef. The photo shows such a rack in the midshore reef "Al Fahal" (Photo credit: Tane Sinclair Taylor).

Supplementary References

Alwany, M. A., Thaler, E. and Stachowitsch, M.: Parrotfish bioerosion on Egyptian Red Sea reefs, J. Exp. Mar. Biol. Ecol., 371(2), 170–176, doi:10.1016/j.jembe.2009.01.019, 2009.

Bannerot, S. P. and Bohnsack, J. A.: A stationary visual census technique for quantitatively assessing community structure of coral reef fishes, NOAA. [online] Available from: http://core.kmi.open.ac.uk/download/pdf/11018492.pdf (Accessed 1 September 2014), 1986.

Bruggemann, J., van Oppen, M. and Breeman, A.: Foraging by the stoplight parrotfish *Sparisoma viride*. I. Food selection in different, socially determined habitats, Mar. Ecol. Prog. Ser., 106, 41–55, doi:10.3354/meps106041, 1994.

Bruggemann, J., van Kessel, A., van Rooij, J. and Breeman, A.: Bioerosion and sediment ingestion by the Caribbean parrotfish *Scarus vetula* and *Sparisoma viride*: implications of fish size, feeding mode and habitat use, Mar. Ecol. Prog. Ser., 134, 59–71, doi:10.3354/meps134059, 1996.

Hoey, A. S., Feary, D. A., Burt, J. A., Vaughan, G., Pratchett, M. S. and Berumen, M. L.: Regional variation in the structure and function of parrotfishes on Arabian reefs, Mar. Pollut. Bull., doi:10.1016/j.marpolbul.2015.11.035, 2016.

Perry, C., Edinger, E., Kench, P., Murphy, G., Smithers, S., Steneck, R. and Mumby, P.: Estimating rates of biologically driven coral reef framework production and erosion: a new census-based carbonate budget methodology and applications to the reefs of Bonaire, Coral Reefs, 31(3), 853–868, doi:10.1007/s00338-012-0901-4, 2012.

Roik, A., Roder, C., Röthig, T. and Voolstra, C. R.: Spatial and seasonal reef calcification in corals and calcareous crusts in the central Red Sea, Coral Reefs, 1–13, doi:10.1007/s00338-015-1383-y, 2015.

Wahle, R. A. and Peckham, S. H.: Density-related reproductive trade-offs in the green sea urchin, *Strongylocentrotus droebachiensis*, Mar. Biol., 134(1), 127–137, doi:10.1007/s002270050531, 1999.