Supplementary Materials

Supplementary Text....................2
Supplementary Equations....................3
Supplementary Tables....................5
Supplementary Figures....................16
Supplementary References....................17

Supplementary Text

Text S1 Calculation of carbonate budgets. The following variables were incorporated in the G_{budget} estimates: site specific benthic calcification rates ($G_{benthos}$, kg m^{-1} y^{-1}), net-accretion/erosion rates of hard substrate ($G_{netbenthos}$, kg m^{-1} y^{-1}), and erosion rates of crucial bioeroders such as sea urchins (E_{echino}, kg m^{-1} y^{-1}) and parrotfishes (E_{parrot}, kg m^{-1} y^{-1}). First, $G_{benthos}$ was estimated using *in situ* measured calcification rates of corals and calcareous crusts as reported by Roik et al. (2015) (Table S3). These calcification rates ($G_{calcifier}$) were extrapolated over the percentage cover of respective calcifiers assessed in six 10 m rugosity transects per site (Equation box S1 a, Table S4). Transects were performed following Perry et al., (2012) and transect data were previously reported in detail in Roik et al. (2015). At the sandy bottom dominated, lagoonal midshore site, transect locations were selected based on availability of hard reef substrate.

To account for the carbonate net-accretion/erosion of the hard substrate category "rock"/ "recently dead coral", $G_{netbenthos}$ rates were calculated for each reef site using G_{net} rates derived from limestone block assays (Equation box S1 b, Table S3). To estimate echinoid erosion rates (E_{echino}), abundances of major sea urchin genera and their size classes per reef site 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). Genus and size specific erosion rates for sea urchins were employed in equations *sensu* Perry et al., (2012) to estimate erosion rates per individual echinoid genus (Equation box S2 (a) - (c), Table S5 - 6). Parrotfish abundances per species and fork length (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) were recorded in stationary visual census count surveys (n = 6, plot Ø = 15 m, duration = 10 min, 9.30 am - 12.00 pm, distance between plots 20 m, adapted from Bannerot and Bohnsack, 1986, Table S7). Care was taken not to count any individual parrotfish more than once. Parrotfish species- or genus-specific abundance data were normalized to survey time and plot area, and converted into erosion rates via calculations based on size-specific estimates for bite rate and volume for several Red Sea taxa, under the assumption of 10 h of feeding activity per day; shown in Table S8 (Alwany et al., 2009; Hoey et al., 2015). 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 c and d (Bruggemann et al., 1994, 1996) as recommended in (Perry et al., 2012). These specific erosion rates as well as abundances were used to calculate parrotfish erosion rates (E_{parrot}) per site (Equation box S3 (a) - (b), Table S7 - 9).

Supplementary Equations

Equation box S1 Benthic community calcification and net-accretion/erosion of bare reef substrate ($G_{benthos}$ and $G_{netbenthos}$)

Legend:

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

Equations:

(a) $G_{benthos} = \sum_{k=CAL} G_{Calcifier}(k) * R * COV$

(b) $G_{netbenthos} = G_{net}(RCDC) * R * COV$

(c) $R = d2 / d1$

#see Table S3

Equation box S2 Sea urchin bioerosion (E_{echino})

Legend:

Bioerosion rate per individual *Diadema*#:	$E_{echinoIndvD}$ [kg individuals^{-1} y^{-1}]
Bioerosion rate per individual *Echinometra*#:	$E_{echinoIndvE}$ [kg individuals^{-1} y^{-1}]
Bioerosion rate per individual *Other*#:	$E_{echinoIndvO}$ [kg 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}]
Echinoid bioerosion rate per reef site:	**E_{echino} [kg m^{-2} y^{-1}]**

Equations:

(a) $E_{echino} = E_{echinoIndv} * Abund_{echino}$

(b) $E_{echinoIndvD}(S) = 0.0029 * S^{1.6624} * 0.001 * 365$

(c) $E_{echinoIndvE}(S) = 0.0007 * S^{1.7309} * 0.001 * 365$

(d) $E_{echinoIndvO}(S) = 0.00008 * S^{2.4537} * 0.001 * 365$

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

Equation box S3 Parrotfish bioerosion (E_{parrot})

Legend:

Bioerosion rate per individual *Cetoscarus bicolor**:	$E_{parrotIndvBIC}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Chlorurus gibbus**:	$E_{parrotIndvGIB}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Chlorurus sordidus**:	$E_{parrotIndvSOR}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus ferrugenius**:	$E_{parrotIndvFER}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus frenatus**:	$E_{parrotIndvFREN}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus ghobban**:	$E_{parrotIndvGHO}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Scarus niger**:	$E_{parrotIndvNIG}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual Other Scaridae*:	$E_{parrotIndvSCAR}$ [kg individual^{-1} y^{-1}]
Bioerosion rate per individual *Hipposcarus harid***:	$E_{parrotIndvHAR}$ [kg individual^{-1} y^{-1}]
Average fork length averages:	FL [cm] {10, 20, 30, 40, 57, 100}
Species specific bite volume (from Table S8):	$BVol_{species}$ [cm^3]
Species specific bite rate (from Table S8):	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}]
Hour of active feeding y per day (Alwany et al., 2009):	$h_{Feed} = 10$ [h]
Bioerosion rate per individual:	$E_{parrotIndv}$ [kg individual^{-1} y^{-1}]
Parrot fish abundance (census based):	$Abund_{parrot}$ [individuals m^{-2}]
Parrot fish bioerosion rate per reef site:	**E_{parrot} [kg m^{-2} y^{-1}]**

Equations:

(a) $E_{parrot} = E_{parrotIndv} * Abund_{parrot}$

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

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

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

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

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

** based on Alwany et al. 2009*

*** based on Hoey et al. 2015*

#Relative to FL = 40

Supplementary Tables

Table S1 Sampling schedule for seawater samples

Inorganic nutrients	Total alkalinity and $pH_{(discrete)}$	Season
08.12.2013, n = 1	-	winter
05.03.2014, n = 1	05.03.2014, n = 3	winter
10.03.2014, n = 1	10.03.2014, n = 3	winter
17.03.2014, n = 1	17.03.2014, n = 3	winter
26.03.2014, n = 1	26.03.2014, n = 3	winter
23.06.2014, n = 1	23.06.2014, n = 3	summer
16.07.2014, n = 1	16.07.2014, n = 3	summer
20.08.2014, n = 1	20.08.2014, n = 3	summer
28.08.2014, n = 1	28.08.2014, n = 3	summer
04.09.2014, n = 1	04.09.2014, n = 3	summer
10.09.2014, n = 1	10.09.2014, n = 3	summer

Dates = dd.mm.yyyy

Table S2 Linear drift corrections were applied on data collected by CTD integrated pH sensors (SBE 18/27, Sea-Bird)

Reef site	Deployment season	Linear drift at pH 7
nearshore_exposed	winter	y = -0.0143x + 7.0278
nearshore_exposed	summer	y = 1.1318x + 5.8272
midshore_sheltered	winter	y = 0.0085x + 6.9915
midshore_sheltered	summer	y = 0.691x + 6.2733
midshore_exposed	winter	y = -0.0136x + 7.0329
midshore_exposed	summer	y = 0.5059x + 6.5208
offshore_exposed	winter	y = -0.0845x + 7.1095
offshore_exposed	summer	y = 0.5596x + 6.4256

Table S3 Table of site specific calcification and net-accretion/erosion rates *in situ* assigned to benthic transect categories.

Transect Code	Benthos category	Assigned calcification rate ($G_{calcifier}$)	Nearshore exposed*	Midshore Sheltered (lagoon)	Midshore exposed	Offshore exposed
HCB	Other Hard Coral (branching)	G_{HCB} = avg ACR POC	1.753 (0.021)	2.514 (0.928)	3.119 (0.886)	3.598 (1.257)
HCE	Other Hard Coral (encrusting)	G_{HCE} = avg ACR POC POR	2.842 (1.295)	2.888 (1.39)	3.341 (2.339)	4.246 (1.78)
HCM	Other Hard Coral (massive)	G_{HCM} = avg POC	2.732 (0.608)	2.732 (0.608)	3.469 (0.901)	4.11 (1.247)
HCP	Other Hard Coral (platy/foliose)	G_{HCP} = avg ACR POC POR	2.842 (1.295)	2.888 (1.39)	3.341 (2.339)	4.246 (1.78)
ACR	Acroporidae	G_{ACR} = avg ACR	1.753 (0.021)	2.362 (1.105)	2.699 (0.737)	3.151 (1.156)
POC	Pocilloporidae	G_{POC} = avg POC	2.732 (0.608)	2.732 (0.608)	3.469 (0.901)	4.11 (1.247)
POR	Poritidae	G_{POR} = avg POR	3.93 (0.537)	4.16 (2.021)	3.83 (4.257)	6.673 (1.299)
CC	Calcareous crusts (coralline algae)	G_{CC} = avg CC	0.138 (0.042)	0.151 (0.042)	0.263 (0.084)	0.411 (0.08)
		Assigned accretion/erosion rate (G_{net})				
DC	Recently Dead Coral	G_{DC} = avg G_{net}	-0.787 (-0.16)	-0.116 (0.615)	0.036 (0.201)	0.227 (0.096)
RC	Rock	G_{RC} = avg G_{net}	-0.787 (-0.16)	-0.116 (0.615)	0.036 (0.201)	0.227 (0.096)

Calcification rates $G_{calcifier}$ (kg m^{-2} y^{-1}) are averaged per reef site from Roik et al. (2015).
Average net-accretion rates G_{net} (kg m^{-2} y^{-1}) are based on the deployment of limestone blocks in this study.
*Since calcification rate for Pocilloporidae (POC) was not measured for the nearshore exposed reef, the average from the midshore sheltered site is used.
Avg = average; standard deviation in parenthesis

Table S4 Census-based benthos community calcification ($G_{benthos}$) and benthos net-accretion/erosion rates ($G_{netbenthos}$ kg m^{-2} y^{-1})

Reef	G_{HCB}	G_{HCE}	G_{HCM}	G_{HCP}	G_{ACR}	G_{POC}	G_{POR}	G_{CC}	$G_{benthos}$	G_{DC}	G_{RC}	$G_{netbenthos}$
Nearshore exposed	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 sheltered	0.136 (0.115)	0.094 (0.092)	0.531 (0.178)	0.116 (0.283)	0.11 (0.217)	0.039 (0.033)	0.125 (0.078)	0.001 (0.001)	1.15 (0.222)	0 (0.001)	-0.027 (0.014)	-0.027 (0.014)
Midshore exposed	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 exposed	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)

Means over six replicates; standard deviation in parenthesis

Table S5 Overall sea urchin abundances, size ranges, and estimated biomasses m^{-2}.

Site	Abundance (individuals m^{-2})	Size range (categories)	Biomass (g sea urchin m^{-2})
inshore_exposed	0.014 (0.006)	1-5	1.43 (0.98)
inshore_sheltered	0.005 (0.003)	2-5	0.98 (0.81)
midshore_exposed	0.002 (0.004)	2-5	0.25 (0.19)
midshore_sheltered	0.005 (0.003)	3-5	1.36 (1.07)
offshore_exposed	0.004 (0.002)	1-2	0.05 (0.04)
offshore_sheltered	0.007 (0.006)	1-2	0.15 (0.11)

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 S6 Census-based sea urchin bioerosion rates E_{echino} (kg m^{-2} y^{-1})

Reef	$E_{Diadema}$	$E_{Echinometra}$	$E_{Echinostrephus}$	$E_{Eucidaris}$	E_{Other}	E_{echino}
nearshore_exposed	0.217 (0.184)	0.011 (0.018)	0 (0)	0 (0)	0 (0)	**0.228 (0.189)**
midshore_sheltered	0.168 (0.185)	0 (0)	0.015 (0.037)	0.004 (0.009)	0 (0)	**0.187 (0.193)**
midshore_exposed	0.022 (0.038)	0.002 (0.002)	0.001 (0.003)	0 (0)	0 (0)	**0.024 (0.04)**
offshore_exposed	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 S7 Parrotfish abundances, size ranges, and estimated biomasses m^{-2}.

Site	Abundance (individuals m^{-2})	Size range (categories)	Biomass (g parrotfish m^{-2})
inshore_exposed	0.17 (0.60)	1-4	82.18 (46.67)
inshore_sheltered	0.15 (0.01)	1-4	50.85 (5.44)
midshore_exposed	0.13 (0.01)	2-5	67.97 (9.21)
midshore_sheltered	0.05 (0.01)	1-5	19.54 (5.56)
offshore_exposed	0.08 (0.01)	1-4	24.69 (6.044)
offshore_sheltered	0.10 (0.02)	1-5	36.62 (8.54)

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 - 69 cm). 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 S8 Parrotfish species specific bite rates and bite volumes employed in E_{parrot} estimation

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. 2015*
Other Scaridae	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 S9 Census-based parrotfish bioerosion rates E_{parrot} (kg m^{-2} y^{-1})

reef	$E_{Cbicolor}$	$E_{Cgibbus}$	$E_{Csordidus}$	E_{Hharid}	$E_{Scaridae}$	$E_{Sferrugineus}$	$E_{Sfrenatus}$	$E_{Sghobban}$	E_{Sniger}	E_{parrot}
nearshore_exposed	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_sheltered	0 (0)	0 (0)	0 (0)	-0.229 (0.254)	-0.1 (0.144)	-0.01 (0.014)	0 (0)	0 (0)	-0.005 (0.009)	**-0.338 (0.271)**
midshore_exposed	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_exposed	-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 S10 Ranges and cross-shelf differences of continuously measured seawater temperature and pH$_{(continuous)}$, including carbonate chemistry parameters on coral reefs in the central Red Sea.

	Temperature				**pH$_{(continuous)}$**				**A_T**	**Ω_a**
	avg. daily mean	avg. daily SD	avg. daily min-max	absolute daily min-max	avg. daily mean	avg. daily SD	avg. daily min-max	absolute daily min-max	mean	mean
winter	26	0.1	25.8-26.2	23.8-27.4	8.13	0.12	8.00-8.35	7.60-9.08	2422	3.77
summer	30.9	0.2	30.6-31.3	28.2-32.7	8.15	0.08	8.05-8.30	7.52-9.02	2369	4.00
nearshore	29.4	0.2	29.2-29.7	23.8-32.7	8.27	0.19	8.06-8.60	7.53-9.08	2414[a]/2346[b]	3.72[a]/3.93[b]
offshore	29	0.2	28.7-29.2	25.2-32.2	8.12	0.04	8.06-8.20	7.86-8.61	2429[a]/2393[b]	3.87[a]/4.20[b]
cross-shelf Δ	~0.4	-	-	-	~0.15	-	-	-	15[a] - 47[b]	0.15[a] - 0.27[b]

Temperature (°C), A_T (µmol kg^{-1}), avg. = average, SD = standard deviation, min. = minimum, max. = maximum, Δ = cross-shelf difference between avg. daily means in nearshore and offshore, a = winter, b = summer

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

	Reef *p*	Season *p*	Season x Reef *p*	Test
Continuous data				
Temp daily means	**0.001**	**0.001**	**0.001**	Univariate PERMANOVA: log(x+1) data
Temp daily SDs	**0.003**	**0.001**	**0.001**	
Temp daily min.	**0.001**	**0.001**	**0.001**	
Temp daily max	**0.001**	**0.001**	**0.001**	
$pH_{(continuous)}$ daily means	**0.001**	**0.001**	**0.001**	
$pH_{(continuous)}$ daily SDs	**0.001**	**0.002**	**0.001**	
$pH_{(continuous)}$ daily min.	**0.001**	**0.001**	**0.001**	
$pH_{(continuous)}$ daily max.	**0.001**	**0.932**	**0.002**	
Seawater sampling				
Inorganic nutrients	0.578	**< 0.001**	0.990	Multivariate PERMANOVA (non-transformed, normalized data)
NO_3^-&NO_2^-	0.825	**0.003**	0.973	Univariate 2-way ANOVA (boxcox (x+1) transformed)
NH_4^+	0.478	**0.024**	0.775	Univariate 2-way ANOVA (non-transformed)
PO_4^{3-}	0.208	**< 0.001**	0.853	Univariate 2-way ANOVA (log2 (x+1) transformed)

Table S12 Statistical tests for the site and time effect on cumulative net accretion rates (G_{net}) measured using limestone blocks.

3-factorial PERMANOVA	Pseudo-*F*	Unique permutations	*p*
Reef	19.21	9940	**< 0.001**
Exposure	2.02	9841	0.166
Deployment time	19.32	9947	**< 0.001**
Reef x Exposure	2.82	9955	0.066
Reef x Deployment time	11.54	9944	**< 0.001**
Exposure x Deployment time	4.29	9942	**0.021**
Reef x Exposure x Deployment time	1.90	9851	0.172
Pair-wise tests	***t***	**Unique permutations**	***p***
midshore, offshore	1.28	9940	0.205
midshore, nearshore	4.21	9833	**< 0.001**
offshore, nearshore	5.72	9819	**< 0.001**
6-months, 30-months	5.47	9838	**< 0.001**
6-months, 12-months	4.36	9837	**< 0.001**
30-months, 12-months#	no test over all reef sites		

no pair-wise comparison due to missing data

Supplementary Figures

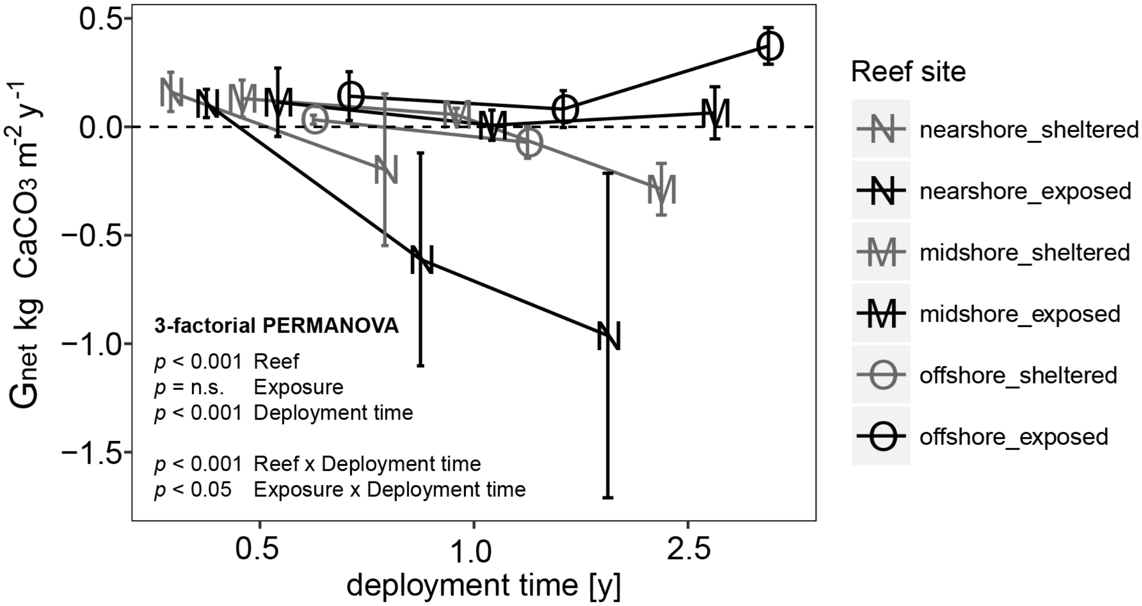

Figure S1. Net-accretion/erosion rates (G_{net}) of limestone blocks after 6-30 deployment months in the study sites. The plot lines show the cumulative G_{net} measured in limestone blocks after 6, 12 and 30 months (0.5, 1, 2.5 years) of deployment. Significant effects are indicated by PERMANOVA *p*-values. Only significant interactions are shown. (EXP = exposed, SHELT = sheltered). (Also see Figure 4 of the article.)

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