Morganti T., Ribes M., Moskovich R., Weisz J., Yahel G., Coma R. (2021) In situ pumping rates of 20 marine demosponges is a function of osculum area. Frontiers in Marine Science 8:583188. Doi: 10.3389/fmars.2021.583188

SUPPLEMENTARY MATERIAL

Table S1 Taxonomic groups of the sponge species analyzed in each of the three regions (Mediterranean Sea, Red Sea and Caribbean Sea).

Location	Class	Order	Family	Species
Mediterranean Sea	Demospongiae	Dictyoceratida	Dysideidae	*Dysidea avara*
	Demospongiae	Poecilosclerida	Crambeidae	*Crambe crambe*
	Demospongiae	Haplosclerida	Petrosiidae	*Petrosia ficiformis*
	Demospongiae	Chondrosiida	Chondrosiidae	*Chondrosia reniformis*
	Demospongiae	Agelasida	Agelasidae	*Agelas oroides*
Red Sea	Demospongiae	Tetractinellida	Theonellidae	*Theonella swinhoei*
	Demospongiae	Poecilosclerida	Podospongiidae	*Diacarnus erythraenus*
	Demospongiae	Suberitida	Suberitidae	*Suberites clavatus*
	Demospongiae	Haplosclerida	Callyspongiidae	*Callyspongia siphonella*
	Demospongiae	Poecilosclerida	Mycalidae	*Mycale fistulifera*
	Demospongiae	Haplosclerida	Niphatidae	*Niphates rowi*
	Demospongiae	Poecilosclerida	Crellidae	*Crella cyathophora*
Caribbean Sea	Demospongiae	Agelasida	Agelasidae	*Agelas conifera*
	Demospongiae	Haplosclerida	Callyspongiidae	*Callyspongia vaginalis*
	Demospongiae	Verongiida	Aplysinidae	*Aplysina archeri*
	Demospongiae	Haplosclerida	Callyspongiidae	*Callyspongia plicifera*
	Demospongiae	Dictyoceratida	Irciniidae	*Ircinia strobilina*
	Demospongiae	Haplosclerida	Niphitidae	*Niphates digitalis*
	Demospongiae	Haplosclerida	Petrosiidae	*Xestospongia muta*
	Demospongiae	Clionaida	Clionaidae	*Spheciospongia vesparium*

Table S2. Sponge volume (V, cm^3), number of oscula (#) and osculum cross-sectional area (OSA, mm^2) for sampled species. *n*, number of sampled specimens for each species. Average is expressed as mean ± SE. HMA: High-Microbial-Abundance; LMA: Low-Microbial-Abundance.

Location	Species	n	Host type	V (cm^3)		Osculum		OSA (mm^2)		Growth form
				range	average	#	average	range	average	
Mediterranean Sea	*D. avara*	39	LMA	1.5 - 148	32 ± 5	2 - 45	13 ± 2	0.14 - 25	5.6 ± 0.4	encrusting
	C. crambe	39	LMA	0.8 - 25	8 ± 1	2- 23	7 ± 1	0.2 - 35	4.8 ± 0.4	encrusting
	P. ficiformis	40	HMA	3 - 420	83 ± 15	2- 37	12 ± 2	0.8 - 17	4.3 ± 0.2	massive
	C. reniformis	41	HMA	3 - 180	62 ± 9	2 - 13	4 ± 0.4	0.2 - 64	10.5 ± 1	massive
	A. oroides	40	HMA	3 - 440	117 ± 20	2 - 10	4 ± 0.4	0.3 - 31	7.9 ± 0.7	massive
Red Sea	*T. swinhoei*	6	HMA	48- 196	112 ± 20	1	1 ± 0	24 - 75	57 ± 8	tubular
	D. erythraenus	3	HMA	33 -141	71 ± 35	1 - 3	2 ± 1	19 -68	36 ± 7	branching
	S. clavatus	2	HMA	41 - 117	79 ± 38	3 - 12	8 ± 5	11- 23	17 ± 2	massive
	C. siphonella	6	LMA	1 -23	12 ± 5	1	1 ± 0	27 -290	165 ± 53	tubular
	M. fistulifera	2	LMA	-	-	3	3 ± 0	8 - 42	24 ± 6	encrusting
	C. cyathophora	3	LMA	10 - 20	15 ± 3	1 - 3	2 ± 1	18 - 46	30 ± 5	massive
	N. rowi	2	LMA	6 -21	14 ± 8	2 - 3	3 ± 1	10 -19	14 ± 2	encrusting
Caribbean Sea	*A. conifera*	8	HMA	187 - 8808	2934 ± 3048	1	-	393 – 1891	960 ± 514	tubular
	A. archeri	6	HMA	165 - 353	281 ± 89	1	-	79 – 254	169 ± 72	tubular
	C. vaginalis	5	LMA	60 - 110	88 ± 19	1	-	214 – 726	404 ± 199	tubular
	C. plicifera	6	LMA	50 - 190	105 ± 59	1	-	1037 – 2604	1551 ± 577	tubular/vase
	I. strobilina	2	HMA	2342 - 2544	2443 ± 100	1	-	2248 – 2323	2286 ± 38	massive
	N. digitalis	10	LMA	100 - 505	227 ± 121	1	-	705 – 4418	1973 ± 1188	tubular/vase
	S. vesparium	16	HMA	1226 - 32552	11285 ± 10297	1	-	1555 – 39584	10991 ± 12022	massive
	X. muta	5	HMA	385 - 28253	12389 ± 13110	1	-	415 – 7775	4969 ± 3566	massive

Table S3. The parameters of the allometric function (a) between sponge pumping rate (PR, mL min^{-1} $sponge^{-1}$) and total osculum cross-sectional area (∑OSA, mm^2), and (b) between sponge pumping rate (PR, mL min^{-1} $sponge^{-1}$) and sponge volume (V, cm^3) from the five Mediterranean species. Data are expressed as the regression coefficient ± the 95% CI. *n*, number of sampled specimens. The *b* scaling exponents were statistically different from zero in all equations ($p < 0.001$).

(a) $PR = a\ (\sum OSA)^b$

Location	Species	n	a (mL min^{-1} $sponge^{-1}$)	b	R^2
Mediterranean Sea	*D. avara*	39	13.65 ± 10.71	0.69 ± 0.16	0.78
	C. crambe	39	9.71 ± 3.86	0.73 ± 0.10	0.87
	P. ficiformis	40	4.83 ± 4.75	0.91 ± 0.22	0.79
	C. reniformis	41	12.10 ± 5.94	0.78 ± 0.11	0.86
	A. oroides	40	17.81 ± 9.07	0.62 ± 0.12	0.81
	HMA	121	11.19 ± 4.59	0.75 ± 0.09	0.76
	LMA	78	9.72 ± 4.47	0.76 ± 0.10	0.81
Caribbean and Red Sea	HMA	32	30.07 ± 24.40	0.78 ± 0.09	0.95
	LMA	34	26.48 ± 60.08	0.67 ± 0.30	0.57

(b) $PR = aV^b$

Location	Species	n	a (mL min^{-1} $sponge^{-1}$)	b	R^2
Mediterranean Sea	*D. avara*	39	44.83 ± 32.94	0.50 ± 0.19	0.54
	C. crambe	39	23.88 ± 11.43	0.77 ± 0.19	0.75
	P. ficiformis	40	10.41± 9.06	0.65 ± 0.17	0.74
	C. reniformis	41	18.03 ± 14.99	0.61 ± 0.18	0.69
	A. oroides	40	18.52 ± 14.02	0.46 ± 0.14	0.64
	HMA	121	25.46 ± 12.31	0.46 ± 0.10	0.53
	LMA	78	42.58 ± 15.99	0.52 ± 0.10	0.63
Caribbean and Red Sea	HMA	32	94.64 ± 111.39	0.57 ± 0.12	0.85
	LMA	32	16.31 ± 21.30	1.04 ± 0.23	0.80

Table S4. Backward stepwise multiple regression to estimate the set of allometric variables (sponge volume, V cm^3 and total osculum cross-sectional area, ∑OSA mm^2) to describe the variance observed in pumping rate (PR, mL min^{-1} $sponge^{-1}$) within each of the five Mediterranean sponge species. Values are the standardized coefficients ± standard error for each variables (rows) and each species (columns) over the two steps (Step1: V + ∑OSA; Step 2: ∑OSA). R squared (R^2) is also reported below. Variables were removed from the model when F< 3.90 and p>0.055. The variance inflaction factor (VIF) is reported for the first step model for each specie.

Step 1	*D. avara* (n=39)				*C. crambe* (n=39)				*C. reniformis* (n=41)				*A. oroides* (n=40)				*P. ficiformis* (n=40)			
	std.Coeff	*F*	*p*	VIF	std.Coeff	*F*	*p*	VIF	std.Coeff	*F*	*p*	VIF	std.Coeff	*F*	*p*	VIF	std.Coeff	*F*	*p*	VIF
V	0.04 ± 0.65	0.12	0.729	2.242	0.43 ± 0.96	35.26	<0.001	2.154	0.18 ± 0.30	2.37	0.132	3.442	0.20 ± 0.09	3.30	0.077	2.471	0.22 ± 0.26	1.57	0.219	5.292
∑OSA	0.84 ± 0.36	48.15	<0.001		0.59 ± 0.20	64.92	<0.001		0.77 ± 0.50	43.50	<0.001		0.74 ± 0.34	44.53	<0.001		0.69 ± 0.59	16.27	<0.001	
Step 2																				
∑OSA	0.87 ± 0.24	118.99	<0.001		-	-	-		0.92 ± 0.27	215.11	<0.001		0.89 ± 0.23	151.96	<0.001		0.89 ± 0.26	138.87	<0.001	
R^2	0.76								0.85				0.80				0.79			

Supplementary Figures

Figure S1. Mosaic pictures and growth forms of the study species from Red Sea (**A-G**), Mediterranean Sea (**H-L**) and Caribbean Sea (**M-T**). **A**: *Theonella swinhoei* (tubular); **B**: *Diacarnus erythraenus* (branching); **C**: *Suberites clavatus* (massive, buried in sand); **D**: *Crella cyathophora* (massive); **E**: *Callyspongia siphonella* (tubular); **F**: *Mycale fistulifera* (encrusting); **G**: *Niphates rowi* (encrusting); **H**: *Petrosia ficiformis* (massive); **I**: *Dysidea avara* (encrusting); **J**: *Chondrosia reniformis* (massive); **K**: *Crambe crambe* (encrusting); **L**: *Agelas oroides* (massive)*;* **M:** *Spheciospongia vesparium* (massive); **N:** *Niphates digitalis* (tubular/vase); **O:** *Aplysina archeri* (tubular); **P:** *Agelas conifera* (tubular); **Q:** *Ircinia strobilina* (massive); **R:** *Callyspongia vaginalis* (tubular); **S:** *Callyspongia plicifera* (tubular/vase); **T:** *Xestospongia muta* (massive). Scale bars represent the mean oscula diameter in each species.

Photo credits: Raz Moskovich for Red sea species, Teresa Morganti for Mediterranean species and Jeremy Weisz (N, P, R, T), Sven Zea (M, Q) and Joseph Pawlik (O, S) for Caribbean species.

Figure S1

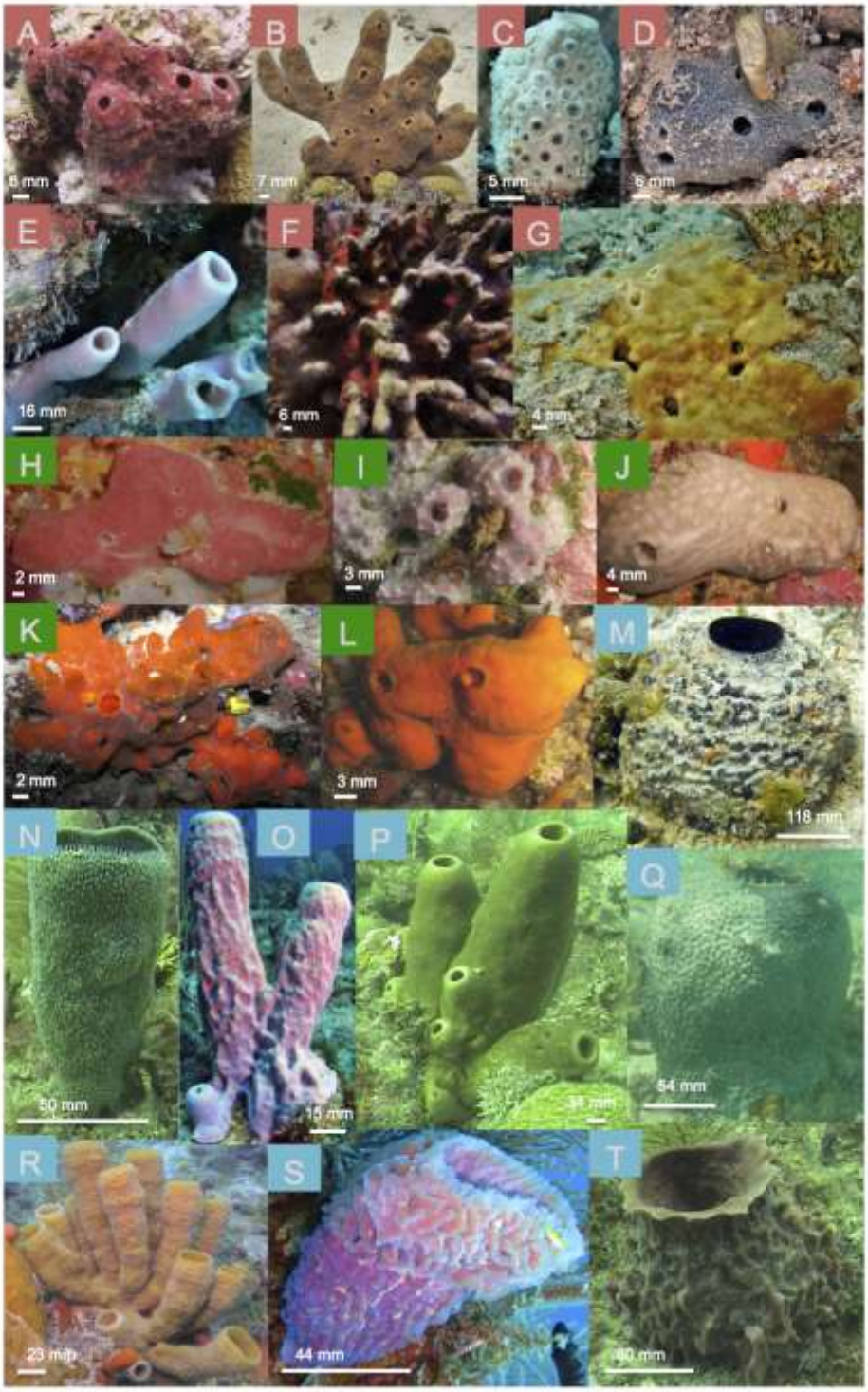
A
6 mm
B
7 mm
C
5 mm
D
6 mm
E
16 mm
F
6 mm
G
4 mm
H
2 mm
I
3 mm
J
4 mm
K
2 mm
L
3 mm
M
118 mm
N
50 mm
O
15 mm
P
34 mm
Q
54 mm
R
23 mm
S
44 mm
T
80 mm

Figure S2.

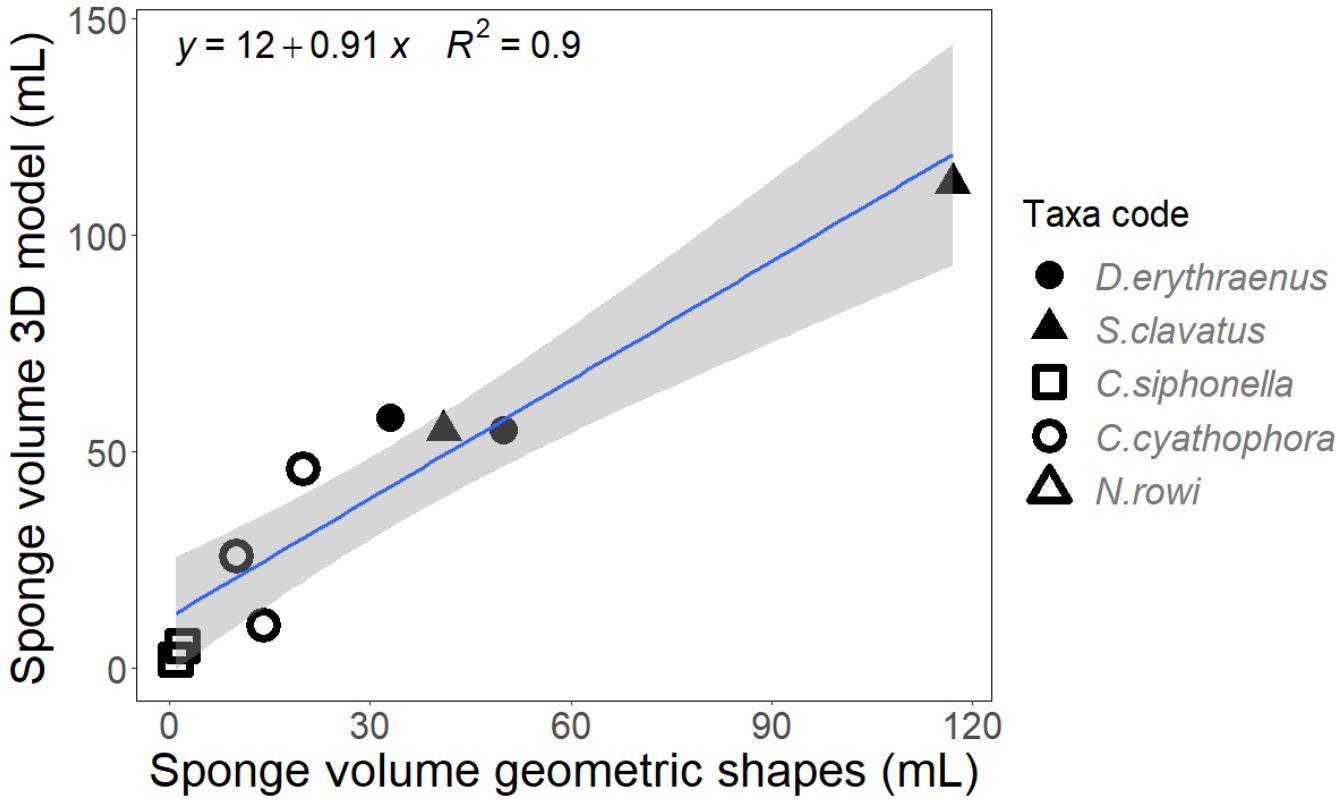

Figure S2. Comparison of the methods used to estimate sponge volume in the Red Sea sponge specimens: 3D model (photogrammetry) and approximation to geometric shape. Grey area represents the 95% confidence interval for the regression line. Due to niche structure, there was no access to take reasonable amount of pictures for building 3D model in *T. swinhoei* specimens.

Figure S3

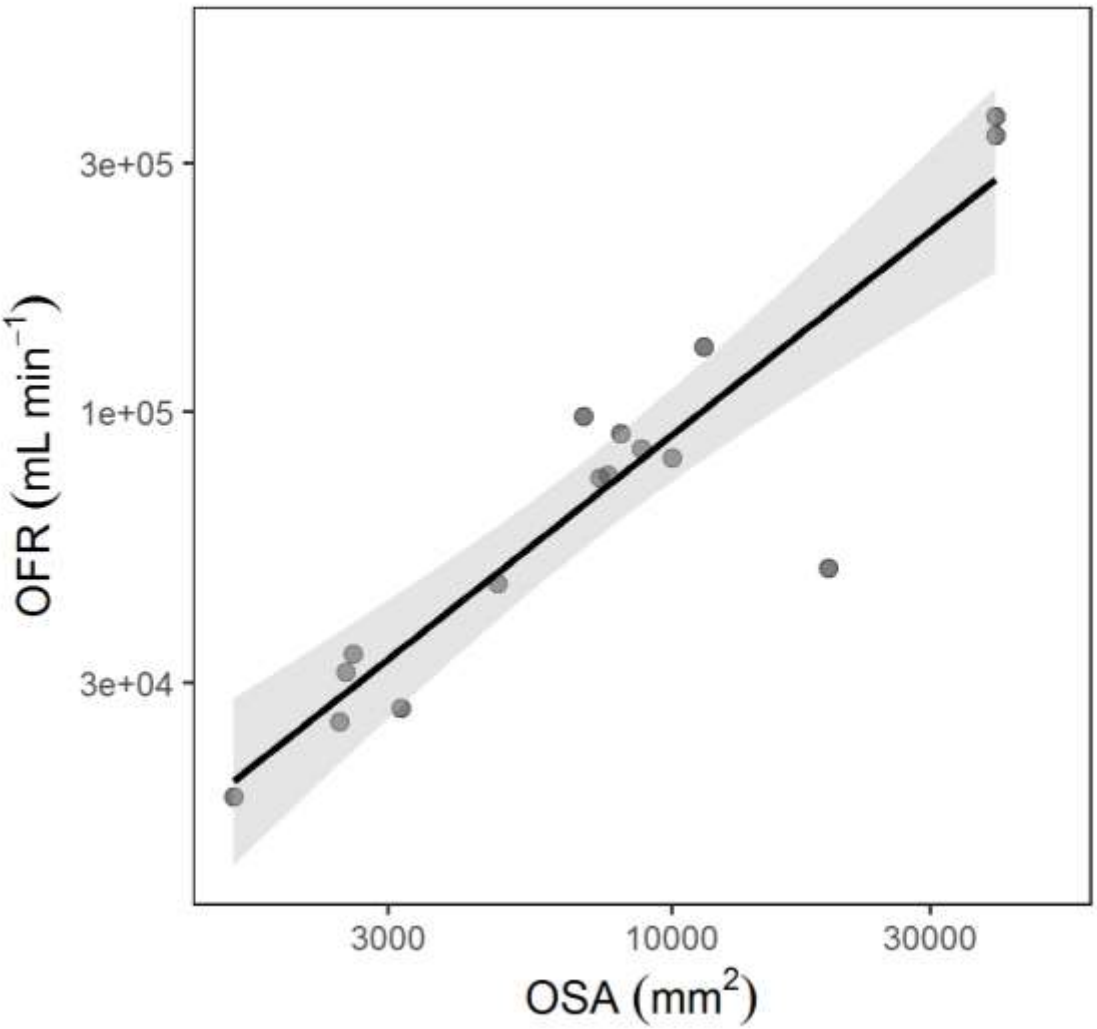

Figure S3. The relationship between osculum flow rate (OFR, mL min^{-1}) and osculum cross-sectional area (OSA, mm^2) on single osculated specimens of *S. vesparium* from the Caribbean Sea. Power regression: $y = 10.53x^{0.98}$, $R^2 = 0.89$, $p<0.001$, n=37. Grey area represents the 95% CI.

Figure S4

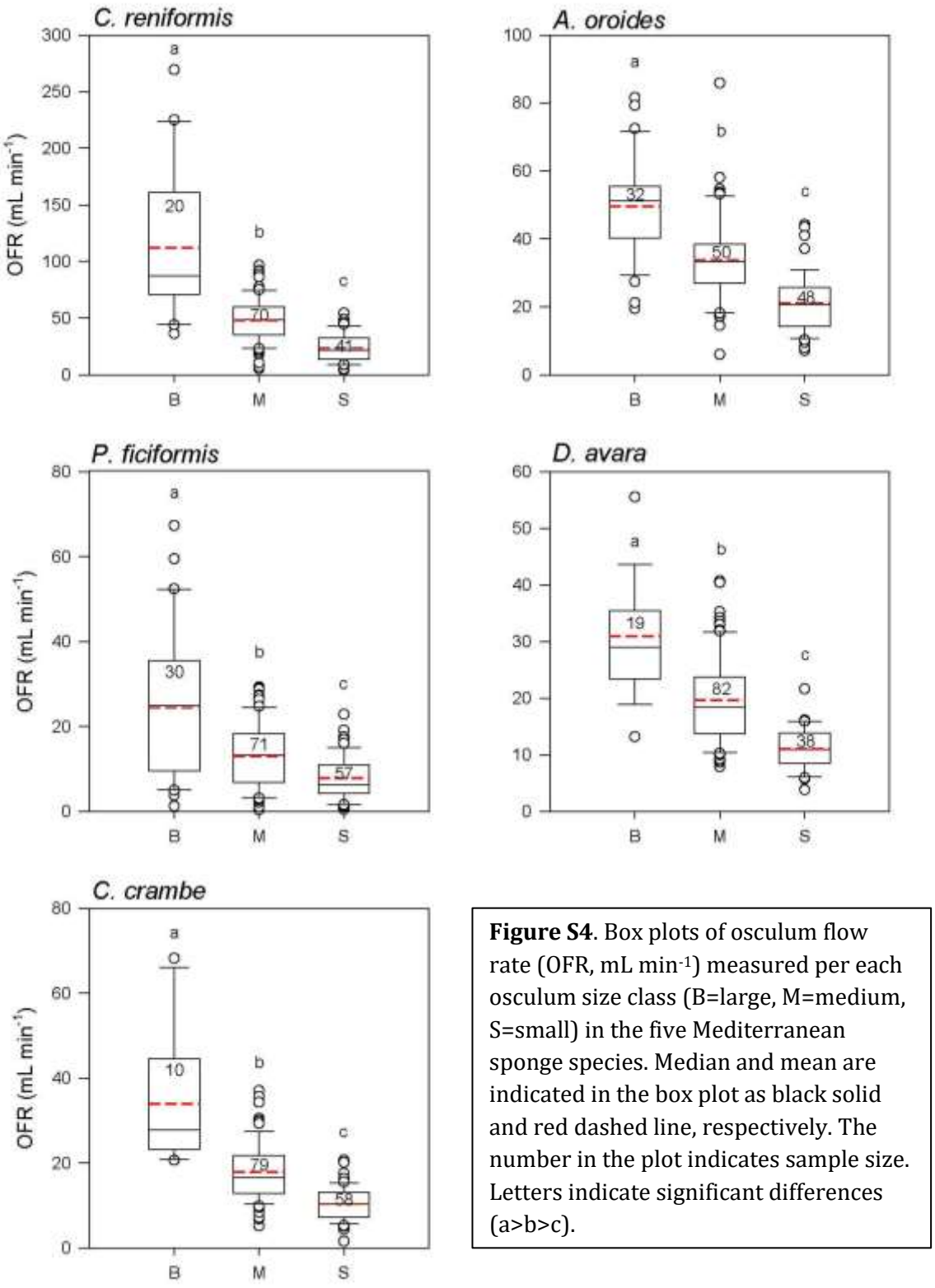

Figure S4. Box plots of osculum flow rate (OFR, mL min^{-1}) measured per each osculum size class (B=large, M=medium, S=small) in the five Mediterranean sponge species. Median and mean are indicated in the box plot as black solid and red dashed line, respectively. The number in the plot indicates sample size. Letters indicate significant differences (a>b>c).

Figure S5

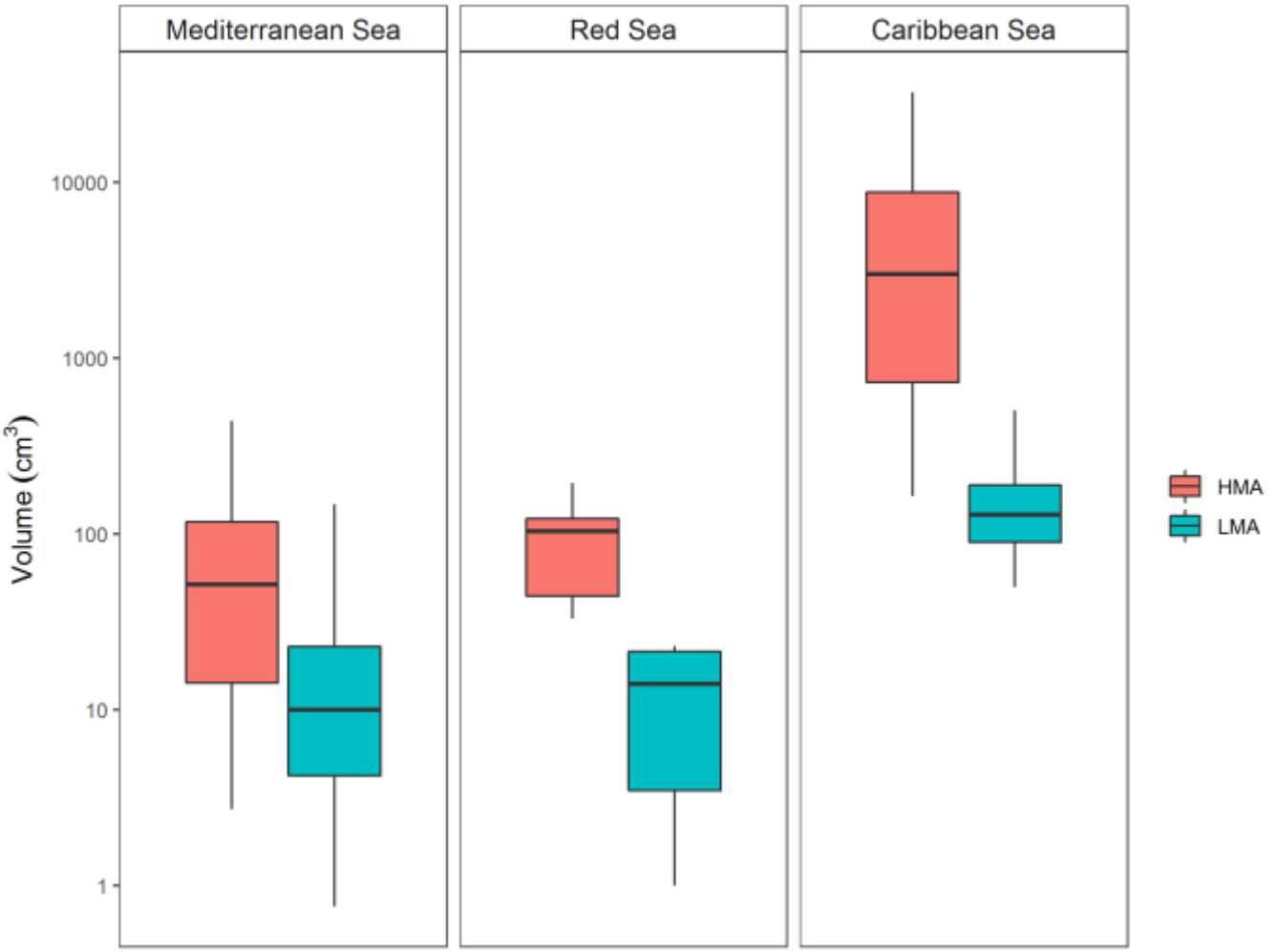

Figure S5. Box plots of the volume (cm^3) of the analyzed sponge species from the three geographic areas (Mediterranean Sea, Red Sea and Caribbean Sea) sorted by host type: High-Microbial-Abundance (HMA, red), and Low-Microbial-Abundance (LMA, cyan) species.

Figure S6

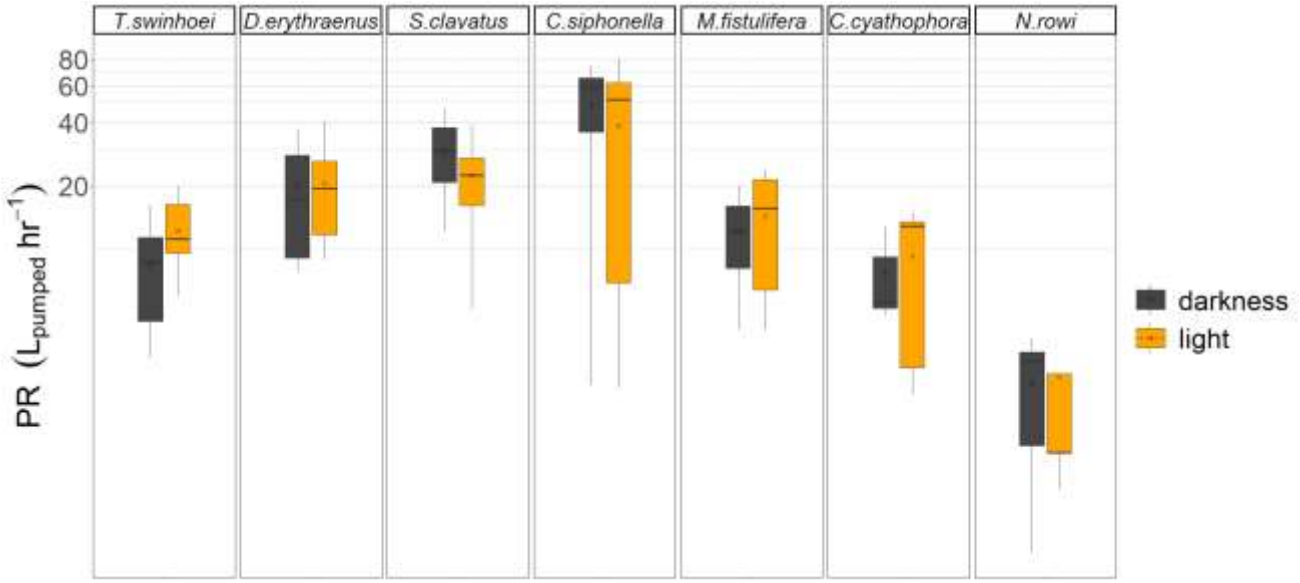

Figure S6. Pumping rate (PR, L hr^{-1} $sponge^{-1}$) measured during the day (light, yellow box plot) and night (darkness, grey box plot) in the seven Red Sea species we studied. Media and mean are indicated in the box plot as black line and *x*, respectively. No significant difference was found between day and night PR measurements in all species (Permutation Test ,n=10000, p>0.05).

Figure S7

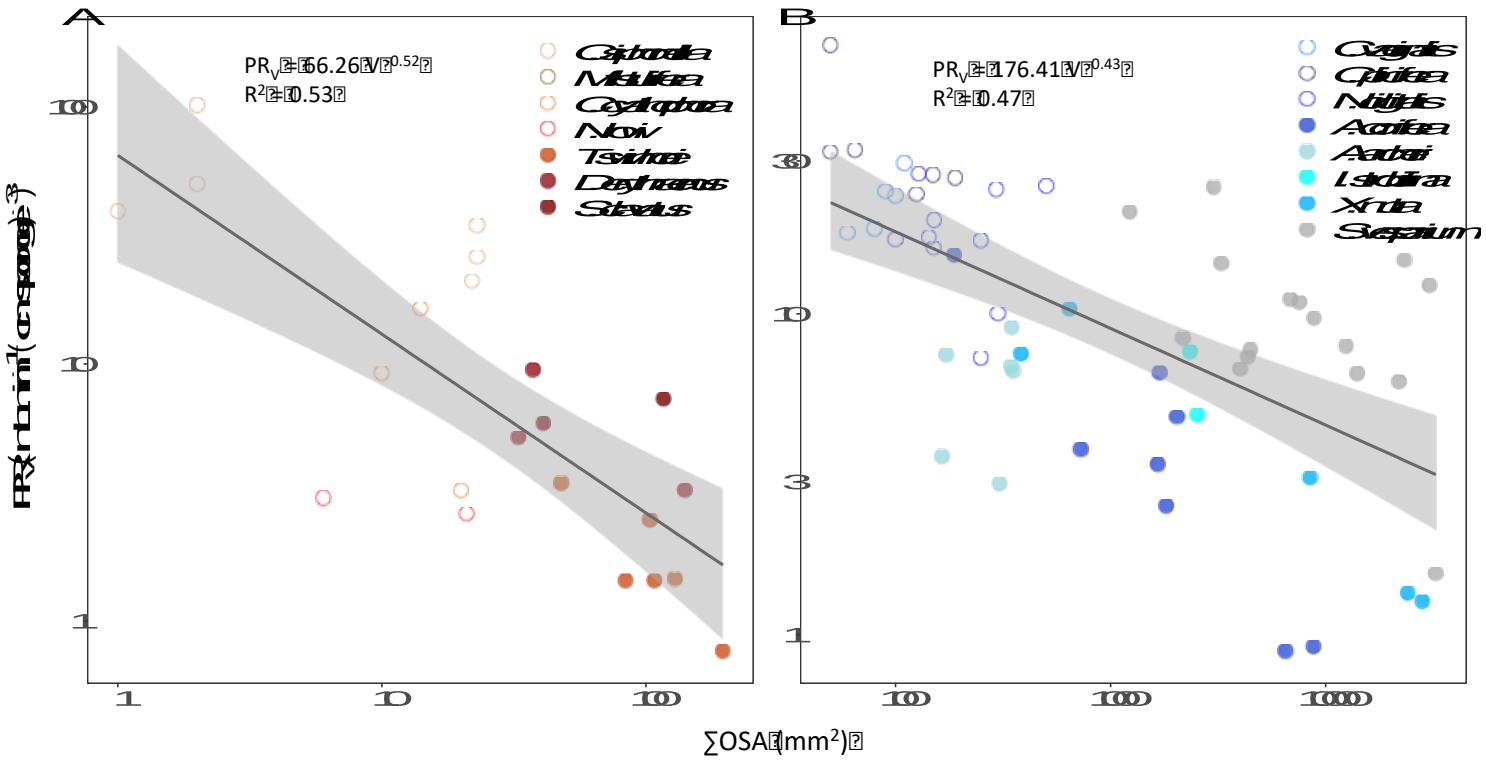

Figure S7. Allometric relationship ($Y = aX^b$) between volume-specific pumping rate (PRv, mL min^{-1} (cm sponge)$^{-3}$) and sponge volume (V, cm^3) in the tropical species from (A) the and (B) Sea. The scaling exponents and coefficients are shown in each panel and the shade areas represent the 95% confidence interval for the regression line. The *b* scaling exponents were statistically different from zero for all species ($p < 0.001$). Note the log-log scale.

Figure S8

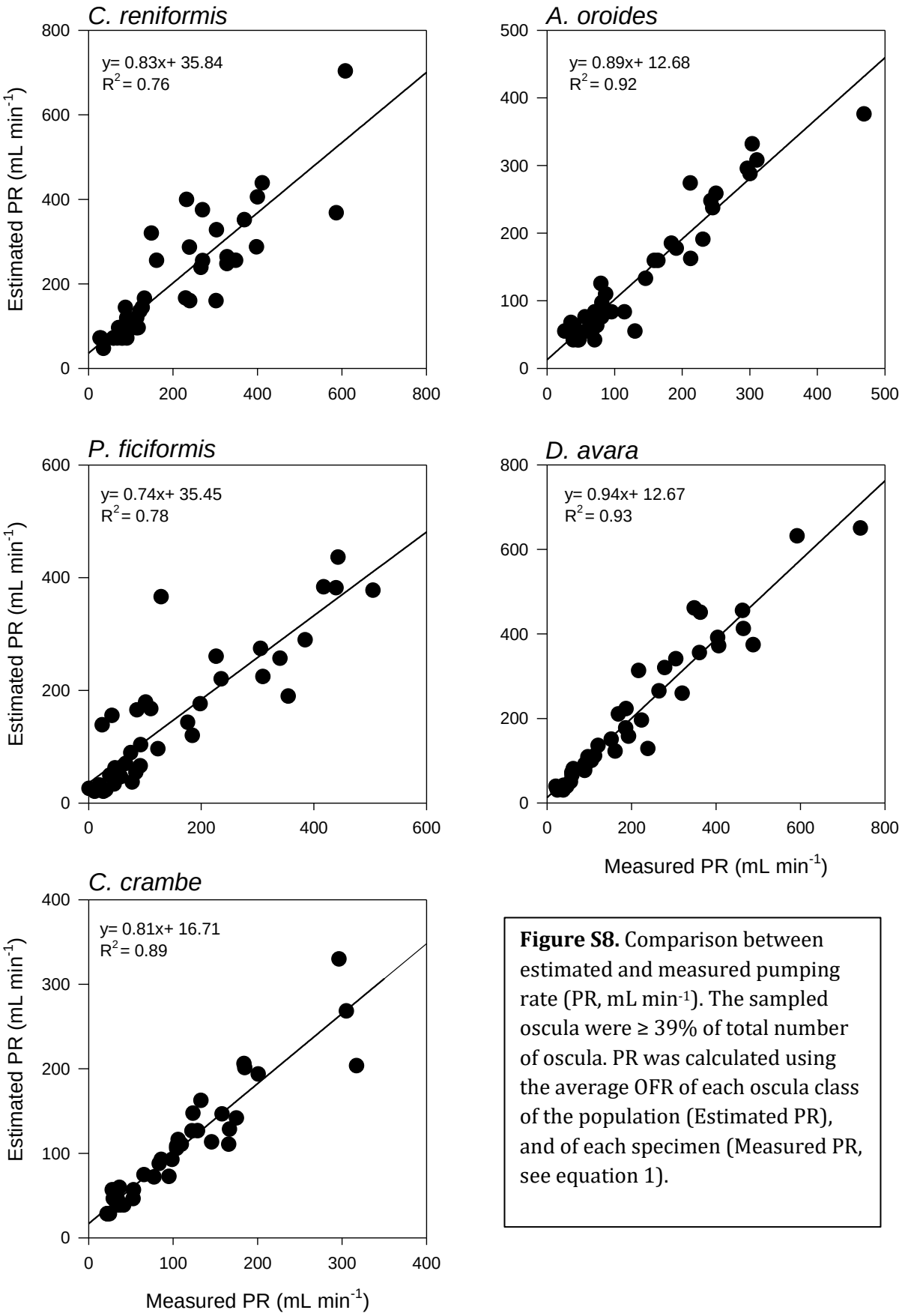

Figure S8. Comparison between estimated and measured pumping rate (PR, mL min^{-1}). The sampled oscula were ≥ 39% of total number of oscula. PR was calculated using the average OFR of each oscula class of the population (Estimated PR), and of each specimen (Measured PR, see equation 1).