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Supplement of

ForamEcoGEnIE 2.0: incorporating symbiosis and spine traits into a trait-based global planktic foraminiferal model

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Table S1 Collected studies in plankton net tow data compilation

Literature	Source	Region
Kuroyanagi and Kawahata, 2004	https://doi.org/10.1016/j.marmicro.2004.06.001	Japan Seas
Sousa et al., 2014	https://doi.org/10.1016/j.csr.2013.11.027	SE Brazilian margin
Bahr et al., 2013	https://doi.org/10.1016/j.epsl.2013.09.036	Caribbean
Schmuker& Schiebel, 2002	https://doi.org/10.1016/S0377-8398(02)00082-8	Caribbean
Ortiz, Mix & Collier (1995)	https://doi.org/10.1029/95PA02088	California Current
Bé et al. (1985)	https://doi.org/10.1016/0377-8398(85)90002-7	Panama Basin
Ufkes et al. (1998)	https://doi.org/10.1016/S0377-8398(97)00032-7	ES Atlantic
Bergami et al., (2009)	https://doi.org/10.1016/j.marmicro.2009.06.007	Ross Sea
Schiebel and Hemleben (2000)	https://doi.org/10.1016/S0967-0645(00)00008-4	eastern North Atlantic (BIOTRANS)
Schiebel et al., 2002	https://doi.org/10.1016/S0967-0645(02)00141-8	Azores Front
Schiebel et al., 2004	https://doi.org/10.1016/j.marmicro.2004.02.001	Arabian Sea
Rebotim et al., 2017	https://doi.org/10.5194/bg-14-827-2017	eastern North Atlantic
Meilland et al., 2020	https://doi.org/10.5194/bg-17-1437-2020	Barents Sea
Lessa et al., 2020	https://doi.org/10.5194/bg-17-4313-2020	subtropical South Atlantic
Taylor et al., 2018	https://doi.org/10.1016/j.quascirev.2018.05.006	North Pacific
Rippert et al., 2016	https://doi.org/10.1016/j.marmicro.2016.08.004	western Pacific warm pool
Tolderlund and Bé, 1971	https://doi.org/10.2307/1485143	western North Atlantic
Meilland, 2015	PhD thesis	Southern Ocean

Table S2 Collected studies in sediment trap data compilation

Literature	Source	Region
Zaric et al., 2005	https://doi.org/10.1016/j.marmicro.2005.01.002	global
Chapman et al., 2010	https://doi.org/10.1029/2008PA001708	NE Atlantic
Mohtadi et al., 2009	https://doi.org/10.1029/2008PA001636	Java sea

Table S3 Model parameter value and units adapted from EcoGEnIE (Ward et al., 2018)

Parameter	Description	Value	Unit	Equation
Cell Quota				
Q_c	Cell carbon content	1.45E-11 x $V^{0.88}$	mmol C $cell^{-1}$	
$Q^P{}_{min}$	Minimum P/C quota ratio	3.3E-3	mmol P (mmol $C)^{-1}$	2
$Q^P{}_{max}$	Maximum P/C quota ratio	1.1E-2	mmol P (mmol $C)^{-1}$	2
$Q^{Fe}{}_{min}$	Minimum Fe/C quota ratio	1.0E-6	mmol Fe (mmol $C)^{-1}$	2
$Q^{Fe}{}_{max}$	Maximum Fe/C quota ratio	4.0E-6	mmol Fe (mmol $C)^{-1}$	2
Nutrient uptake				
$V^m{}_{PO4}$	Maximum PO_4 uptake rate	4.4E-2 x $V^{0.06}$	mmol P (mmol $C)^{-1}$ d^{-1}	12
$V^m{}_{Fe}$	Maximum Fe uptake rate	1.4E-4 x $V^{-0.09}$	mmol Fe (mmol $C)^{-1}$ d^{-1}	12
α_{PO4}	Affinity to PO_4	1.1 x $V^{-0.35}$	m^3 (mmol $C)^{-1}$ d^{-1}	12
α_{Fe}	Affinity to Fe	0.175 x $V^{-0.36}$	m^3 (mmol $C)^{-1}$ d^{-1}	12
Temperature				
A	Temperature dependency	0.05		5
T_{ref}	Reference temperature	20	°	5
Loss terms				
γ_{basal}	Respiration loss		mmol C (mmol $P)^{-1}$	4
m_{basal}	Mortality loss		d^{-1}	6
Photosynthesis				
P_a	Maximum	3.08		13
P_b	photosynthesis	5		13
P_c	rate definition ($P_{a,b,c}$)	-3.08		13
$Q^m{}_{chl}$	maximum Chl *a*/P ratio	48	mg Chl *a* (mmol $P)^{-1}$	16
α	initial P-I curve slope	3.83E-7	mmol C (mg Chl $a)^{-1}$ (μEin $m^{-2})^{-1}$	16
Grazing				
K	Half-saturation concentration	5.0	mmol C m-3	7

σ	Prey range	0.5		10
V	Optimal predator:prey size ratio	10		10
^	Grazing refuge strength	-1	(mmol C m-3)-1	7
G_m	Maximum grazing rate	$21.9 \times V^{-0.16}$	d^{-1}	7
Carbon flux				
β_{max}	maximum DOM fraction	0.8		22
β_{min}	minimum DOM fraction	0.4		22
β_s	Plankton size at which DOM/POM = 1	100	μm	22

Table S4 Functional group classification of planktic foraminifer species. Taxonomy is following mikrotax (Young et al. 2017) and symbiosis follows Takagi et al., (2019) and Schiebel and Hemleben, (2017)

Name	Symbiosis	Spinose	Remark
Dentigloborotalia anfracta	No	No	
Globorotalia cavernula	No	No	
Globorotalia crassaformis	No	No	
Globorotalia hirsuta	No	No	Synonyms: *Hirsutella hirsuta*
Globorotalia menardii	Yes	No	Symbionts facultative
Globorotalia scitula	No	No	Synonyms: *Hirsutella scitula*
Globorotalia truncatulinoides	No	No	Synonyms*: Truncorotalia truncatulinoides*
Globorotalia tumida	No	No	
Globorotalia ungulata	No	No	
Globorotalia theyeri	No	No	
Globoconella inflata	Yes	No	Symbionts facultative. Synonyms: *Globorotalia inflata*;
Neogloboquadrina dutertrei	Yes	No	Symbionts facultative
Neogloboquadrina incompta	No	No	Previously called *Neogloboquadrina pachyderma* (right)
Neogloboquadrina pachyderma	No	No	Previously called *Neogloboquadrina pachyderma* (left)
Pulleniatina obliquiloculata	Yes	No	Symbionts facultative
Globoquadrina conglomerata	No	No	
Globorotaloides hexagonus	No	No	
Berggrenia pumilio	No	No	
Globigerina bulloides	No	Yes	Symbiont-barren spinose
Globigerina falconensis	Yes	Yes	
Globigerinoides conglobatus	Yes	Yes	
Globigerinoides ruber	Yes	Yes	Darling and Wade, (2008). Include two subspecies *G. ruber* pink and *G. ruber* white

Trilobatus sacculifer	Yes	Yes	Synonyms: *Globigerinoides sacculifer*; *Globigerinoides elongatus*
Globigerinoides tenellus	No	Yes	spinose without symbionts (Aze et al., 2011); Synonyms *Globoturborotalita tenellus*
Orbulina universa	Yes	Yes	
Beella digitata	Yes	Yes	unclear as subthermocline dwelling, Coxall et al 2007; Synonyms: *Globigerinella digitata*
Globigerinella siphonifera	Yes	Yes	Synonyms: *Globigerina aequilateralis*
Globigerinella calida	Yes	Yes	Synonyms: *Globigerina calida*
Globigerinella adamsi	Yes	Yes	
Turborotalita quinqueloba	No	No	
Turborotalita humilis	Yes	Yes	
Globoturborotalita rubescens	Yes	Yes	
Sphaeroidinella dehiscens	Yes	Yes	
Candeina nitida	Yes	No	Symbionts facultative
Globigerinita glutinata	Yes	No	Symbionts facultative
Globigerinita uvula	Yes	No	Symbionts facultative; (Takagi et al., 2019, 2020)
Globigerinita minuta	No	No	
Tenuitella iota	No	No	
Hastigerina pelagica	No	Yes	Symbiont-barren spinose
Hastigerinella digitata	No	Yes	sister species of *H.pelagica*; symbiont bearing Takagi et al. (2019)
Streptochilus globigerus	Undetermined	Undetermined	very rare, limited information
Tenuitella compressa	Undetermined	Undetermined	Synonyms: *Tenuitella fleisheri* (synonyms under discussion)
Tenuitella fleisheri	Undetermined	Undetermined	Synonyms: *Tenuitella compressa*
Tenuitella parkerae	Undetermined	Undetermined	limited information
Turborotalita clarkei	Undetermined	Yes	
Globigerinella radians	Yes	Yes	very close to *G.siphonifera*
Orcadia riedeli	Undetermined	Undetermined	Rare species, limited information, (Schiebel et al., 2017)
Globorotalia flexuosa	No	No	synonyms: *Globorotalia tumida flexuosa*

Table S5 Root Mean Square Error (RMSE) of our model with optimal parameters for inter-model comparison

	Biomass (mmol C m^{-3})	Carbon Export (mmol C m^{-2} d^{-1})	Relative Abundance	Column Total
symbiont-barren non-spinose	0.03	0.09	0.19	0.31
symbiont-barren spinose	0.02	0.04	0.12	0.18
symbiont-facultative non-spinose	0.01	0	0.34	0.35
symbiont-obligate spinose	0.01	0.02	0.42	0.46
Row Total	0.06	0.16	1.08	1.3

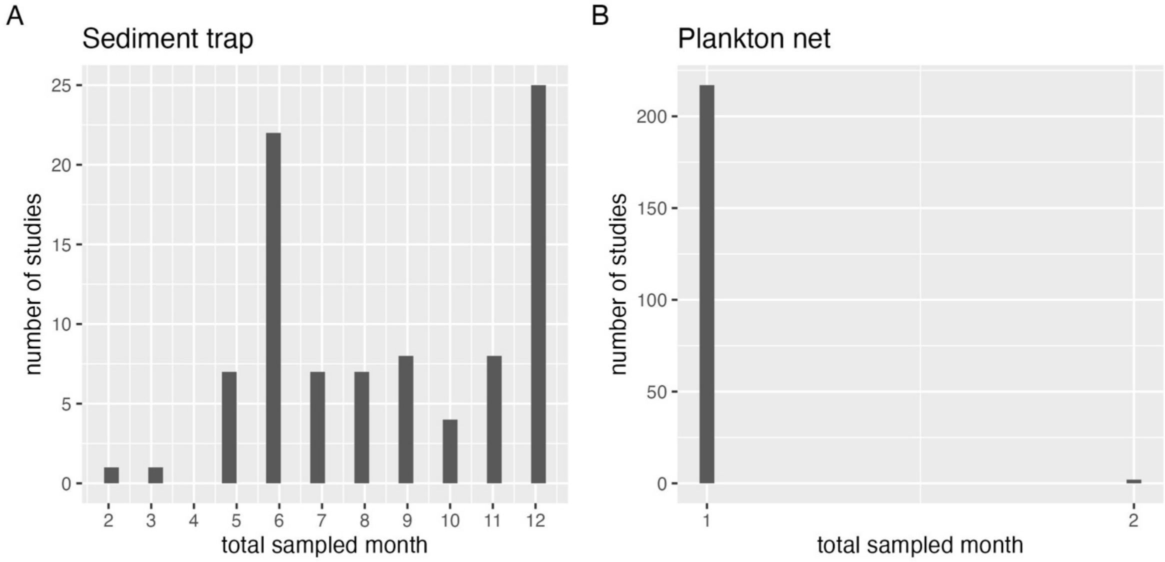

Figure S1. A histogram of sampled duration in collected sediment trap and plankton net data. The sediment traps tend to record seasonal signatures while plankton nets represent sampling of a single record of a few hours (the only two-month sampled data should be a result of sampling at the end of month).

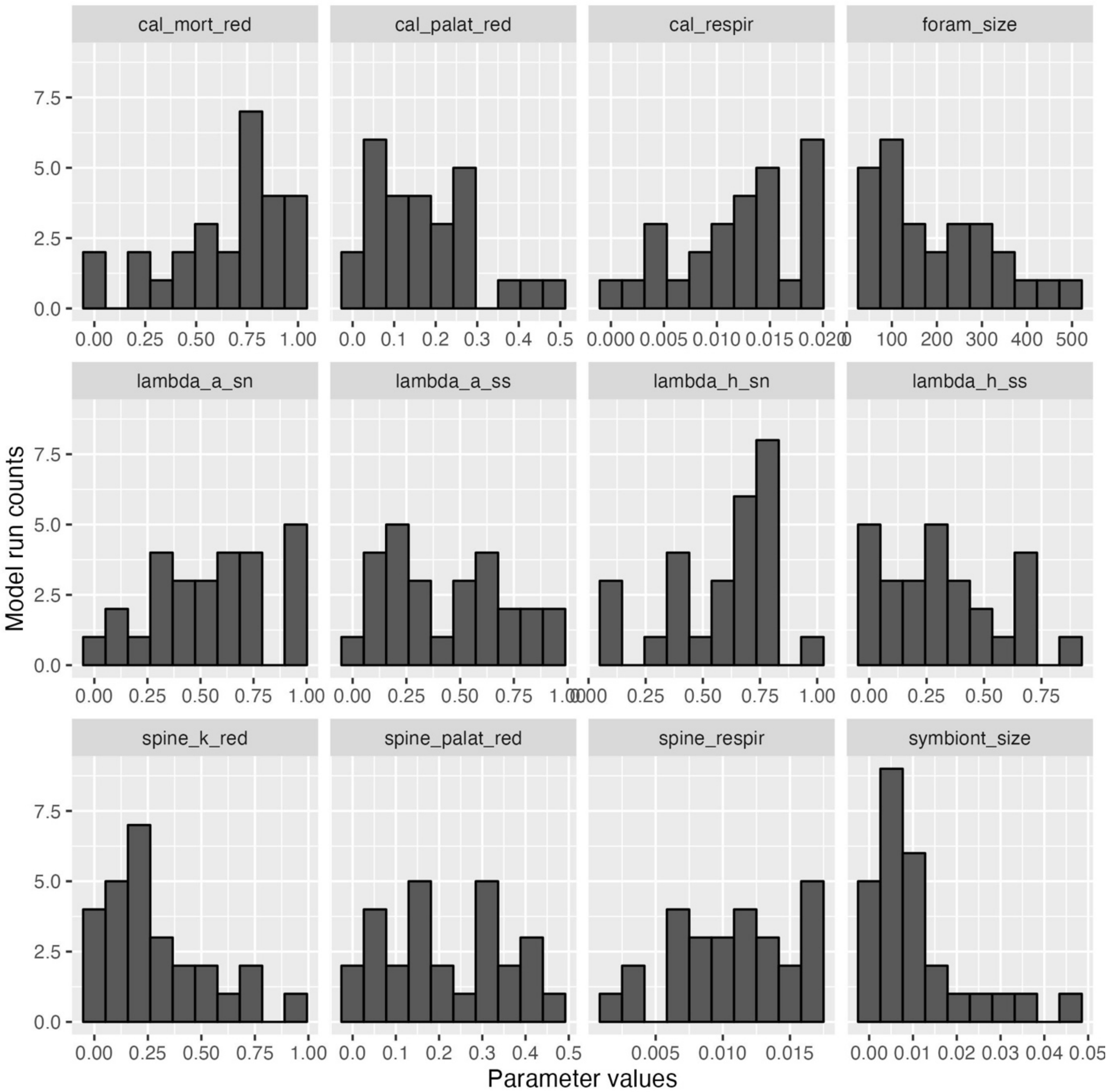

Figure S2. Number of runs for each parameters (linking to Cluster "A" in Figure 2) associated with low annual mean export production of foraminifers (< 1 mmol C m^{-2} d^{-1}) and relatively high relative abundance M-score (>= 0.45). Cluster A achieves the highest (i.e., the best) relative-abundance M-score with good biomass and POC export predictions. Cluster A is also the only cluster with low foraminifer export, suggesting that low export is required to have a high total M-score. Parameter abbreviations are as follows: cal, calcification; mort, mortality; red, reduction strength; palat: palatability; respir, respiration; a, autotroph; h, heterotroph. ss, symbiont-obligate spinose foram, sn, symbiont-facultative non-spinose foram

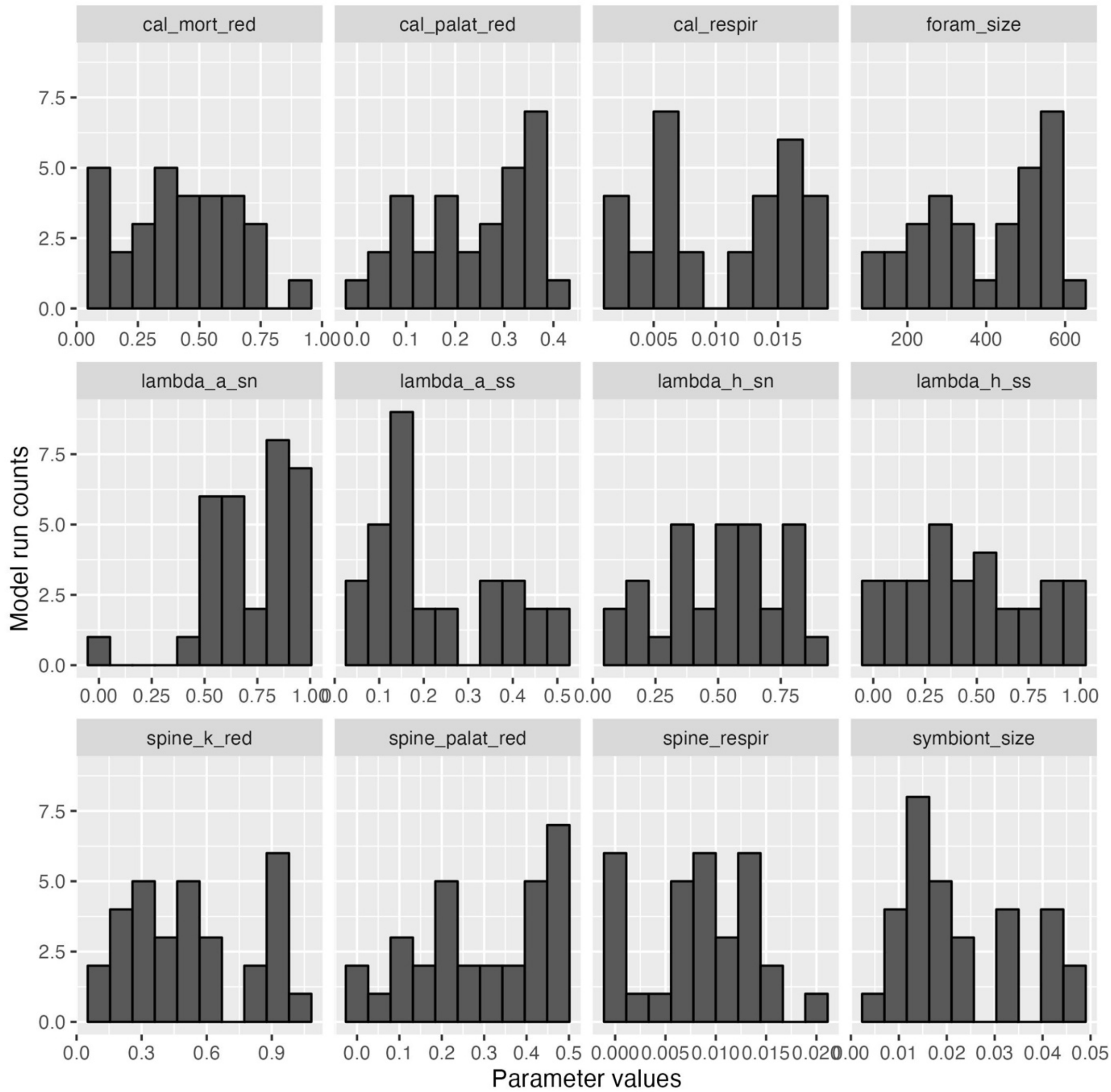

Figure S3. Same histogram as Figure S3 but associated with negative relative abundance M-score (<=-0.3, proxy of Cluster "D" in Figure2). The runs with negative scoring (Cluster D) have large foraminifer size (peaking in 500-600 µm), over protection from grazing. These results suggest the crucial role of foraminifer body size and calcification trait in matching observed data.

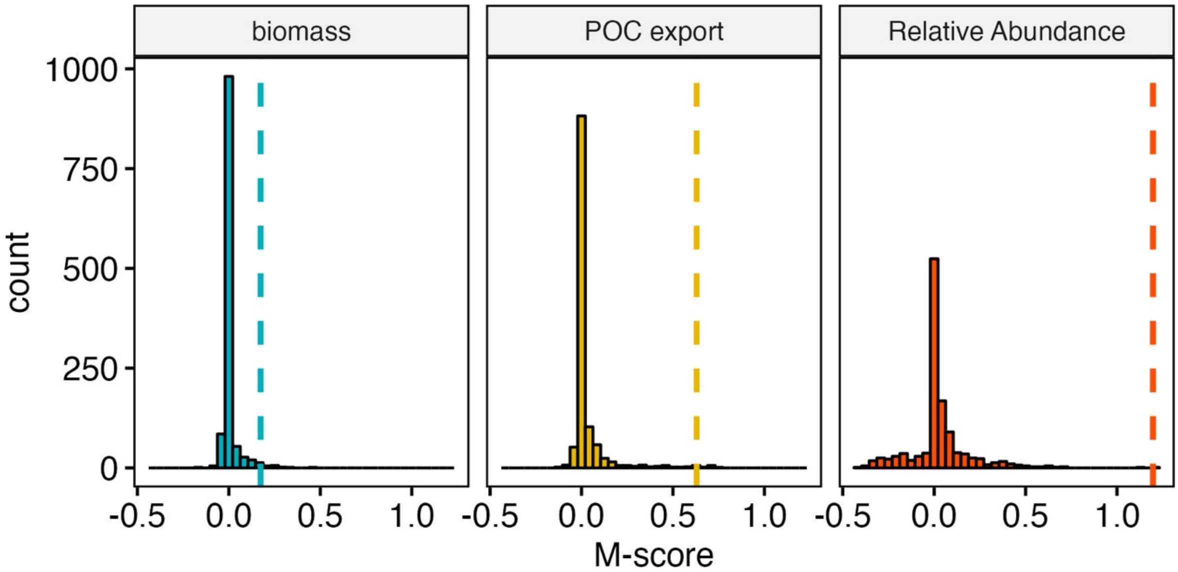

Figure S4. Variable-based M-score distribution histogram of global sensitivity analysis. Dashed line is the M-score of the run with best fit with plankton net (biomass), sediment trap (POC export) and sediment core-top (relative abundance).

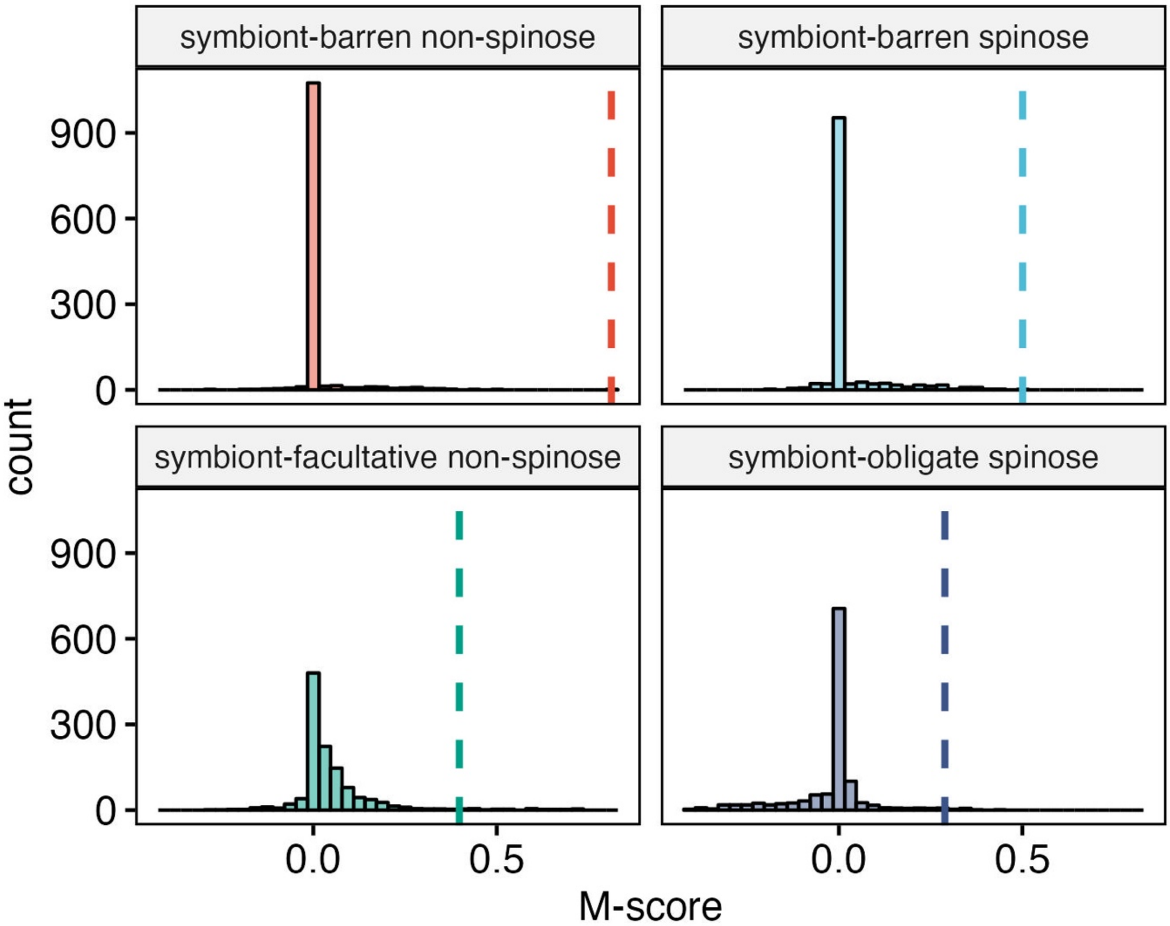

Figure S5. Foraminiferal group-based M-score distribution histogram of global sensitivity analysis. Dashed line is the M-score of optimal parameters.

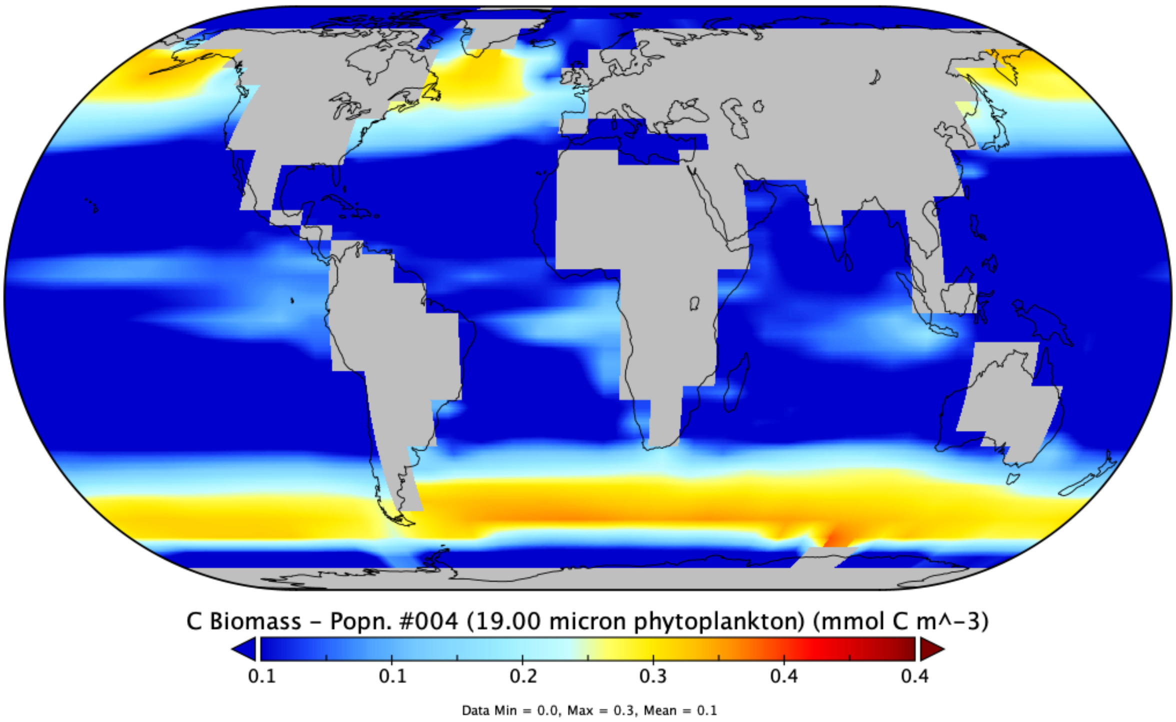

Figure S6 The biomass distribution of the 19 µm phytoplankton which is the "favourite" food of foraminifer given optimal predator: prey size ratio of 10. The biogeographical similarity between this group and non-symbiont foraminifer indicates that foraminifer distribution mostly resembles their food.

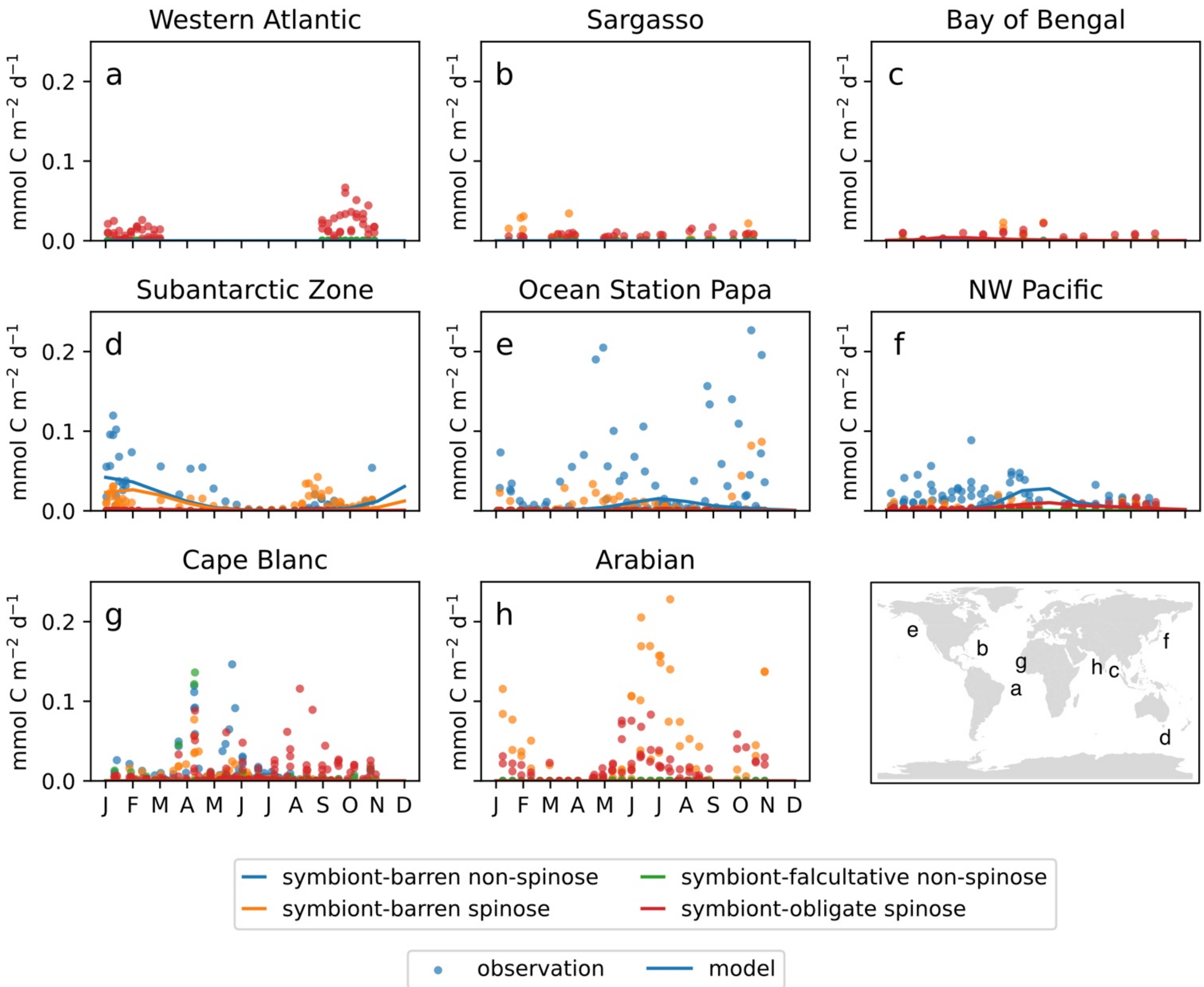

Figure S7. POC export seasonal comparison between the model (lines) and sediment trap data (dots) (mmol C m^{-2} d^{-1}) for the selected locations (shown in the map with corresponding letter). We selected the locations with the most data points. Note that model foraminifera export underestimates observations at most locations and the line is therefore not visible in some panels (a, b, c, g, and h). We ignored interannual variability and focussed on the observed monthly average.

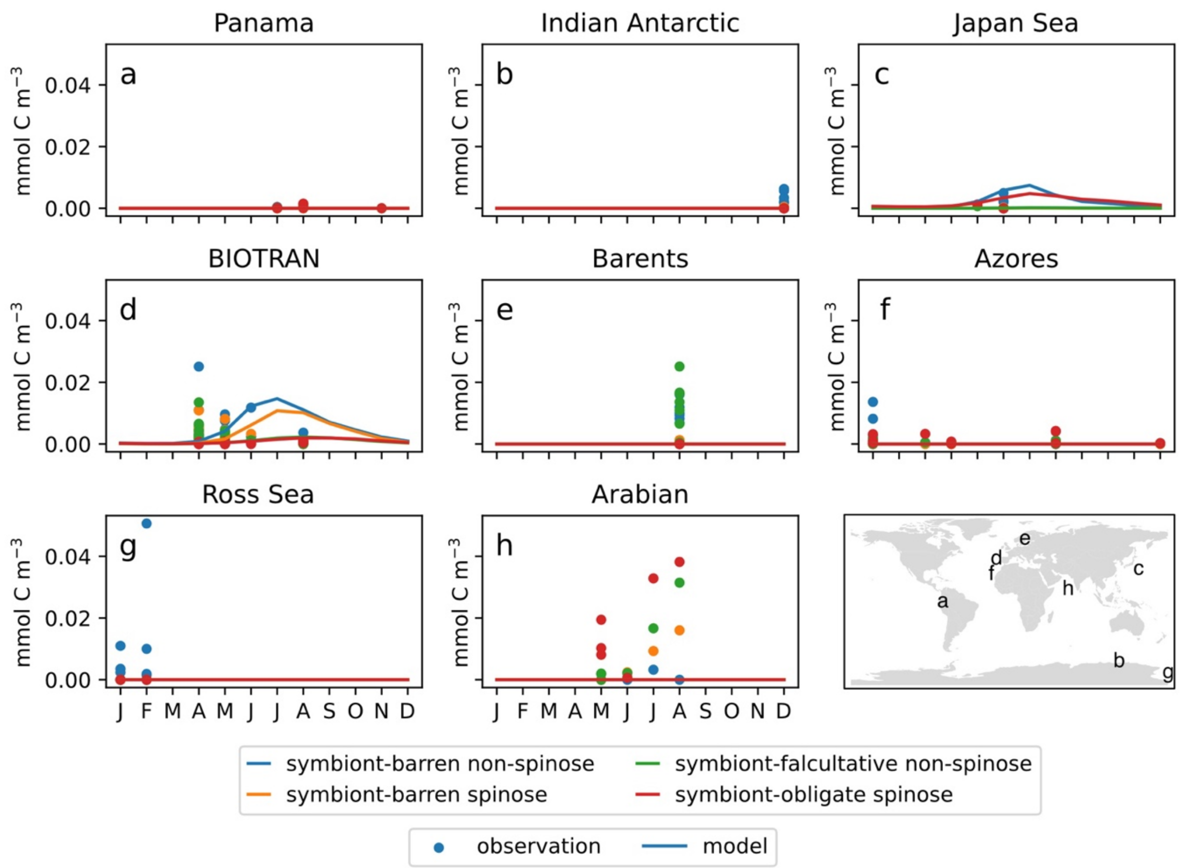

Figure S8. Biomass seasonal comparison between the model (lines) and plankton net data (dots) (mmol C m^{-3}) in selected locations (shown in the map with corresponding letter). We selected the locations with the most data points

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