

Supplementary Material

Trophic roles determine coral reef fish community size structure

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Trophic position ~ body size sensitivity analyses

1. Herbivore trophic fractionation

We estimated the trophic position of herbivores using an additive approach (Hussey et al. 2014). Herbivorous fish fractionate differently to carnivores, so we used the mean trophic fractionation ($\Delta N = 4.778\text{‰}$) of herbivorous reef fish from published estimates (Mill et al. 2007). We tested the sensitivity of our results to ΔN by estimating herbivore trophic position for ΔN values ranging from 1 to 8‰, and refitting the optimum mixed effects model for both the species-based and individual-based approaches. The trophic pathway interaction term remained insignificant for all ΔN values, indicating that herbivore slopes were not distinct from carnivore slopes (Table S1).

2. Location of isotope specimen collection

We examined trophic position ~ body size relationships for specimens collected from sites on the northeast coast (n = 5) and those collected from sites in the Bay of Wrecks on the southeast coast (n = 5). Sites on the northeast coast are closer to Kiritimati's population centres than the Bay of Wrecks, and thus may experience light fishing pressure that might influence food web structure. Relationships between trophic position and body size remained positive and significant for the species-based and individual-based analyses at north and south locations, for both herbivores and carnivores (Fig. S1, S2; Table S2). All random effects structures were identical to those selected for the models using the full dataset (see Methods, Results), except for the individual-based model at southern sites that would not converge for species nested within family, and thus was refit with only species as a random effect.

Size spectra sensitivity analyses

Size spectra were fit to visual census data from Kiritimati collected in 2011 and 2013 to examine size structuring and energy pathways in coral reef food webs. Herbivores had shallower slopes than carnivores, and, generally, abundance decreased with increasing body size. Sensitivity analyses were run to examine whether this result was robust to differences in year, in site location, in the size range observed, and in diver identity. We also assessed potential impacts of fishing pressure at sites near the population centres on Kiritimati.

1. Differences in year.

Visual censuses were carried out in 2011 and 2013. Spectra fit to each year separately yield the same qualitative result (Fig. S3). The herbivore spectrum was shallower ($b = 1.18$, 95% CI = 1.16, 1.19) in 2011 than in 2013 ($b = 1.37$, 95% CI = 1.36, 1.39). The carnivore spectrum was slightly steeper in 2011 ($b = 1.66$, 95% CI = 1.65, 1.67) than 2013 ($b = 1.62$, 95% CI = 1.62, 1.63).

2. Differences in site

Visual censuses were carried out at 14 sites on the east coast of Kiritimati. We examined differences between sites on the northeast coast ($n = 7$) and sites in the Bay of Wrecks on the southeast coast ($n = 7$). Sites on the northeast coast are closer to Kiritimati's population centres than the Bay of Wrecks, and thus may experience light fishing pressure that might influence food web structure. However, size spectra exponents were qualitatively similar between these regions, and across years (Fig. S4).

3. Differences in diver

Visual censuses were conducted by 4 divers: Scott Clark, Jonatha Giddens, Sheila Walsh, and Rowan Trebilco. SC took part in every dive ($n = 26$), JG dived every site in 2013 ($n = 14$), and SW ($n = 11$) and RT ($n = 2$) dived in 2011. Size

spectra results were qualitatively similar across divers, dive teams, and across years (for SC) (Fig. S5, Fig. S6, Table S3).

4. Differences across sites sampled in 2011 and 2013 (n = 4)

Visual censuses were conducted at 4 sites in both years (3, 15, 19, 24). Spectra fit to the observed body sizes at each site did not differ qualitatively across years (Fig. S7). Site 25 was also sampled in both years, but the likelihood optimization failed to estimate 95% confidence intervals for the carnivore spectrum in 2013, and so we omitted site 25 from the figure.

5. Differences in the minimum and maximum size cut off (X_{\min} , X_{\max} , Equation 3 main text)

Underwater visual censuses of reef fish are subject to known biases that can strongly influence estimates of abundance, biomass and community structure (Ward-Paige et al. 2010). Bozec et al. (2011) examined fish detection rates on paired-diver transects and found that estimates of small, cryptic species decreased strongly with increasing distance from the transect line, whereas large mobile fish were underestimated due to diver avoidance, though noted that large fish biases can be site- and species-specific. Conversely, Ward-Paige et al. (2010) reported overestimation of large mobile fish in non-instantaneous underwater visual censuses (e.g. line transects) when fish move into the survey area after the survey has started. The extent of this bias decreased substantially for transect widths > 5 m. We attempted to reduce these biases in our sample design where, specifically, we counted small fishes in a 4 m wide

strip and large fishes in an 8 m wide strip. We also conducted sensitivity analyses to test the potential effect of biases in counting small and large fish on our size spectra estimates. We estimated the size spectrum exponent b for different minimum and maximum observed size limits (Fig. S8), thus removing the observations that may be subject to over- or underestimation. Though the estimates of herbivores and carnivores changed slightly for each change in minimum/maximum observed body mass, our results remained qualitatively robust.

6. Omnivorous species contribution to trophic pathways

Omnivorous species derive energy from benthic and pelagic resource bases and, as such, we could not confidently assign each species a trophic pathway (herbivores or carnivores). We removed omnivores from the main size spectra analyses, but their inclusion as either carnivores (Fig. S9, top) or herbivores (Fig. S9, bottom) did not qualitatively affect our results: the herbivore spectra was always shallower than the carnivore spectrum.

7. Potential fishing pressure at north coast sites

We attempted to minimize any confounding influences of exploitation by surveying the fish communities at remote sites on the northwest coast of Kiritimati. Though most of our survey sites are generally inaccessible to subsistence fishers, we acknowledge that the sites on the north coast are nearest Kiritimati's population centres (Figure 1) and so may experience light fishing pressure. We removed observations from the four north coast sites and refitted size spectra to carnivore and herbivore groups (Figure S10). The exponent b increased slightly for both groups,

suggesting that the abundance of large body sizes is depleted at north coast sites. Nevertheless, the carnivore spectrum remains steeper than the herbivore spectrum, consistent with our original predictions.

References

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Ward-Paige, C., Flemming, J.M., and Lotze, H.K. 2010. Overestimating Fish Counts by Non-Instantaneous Visual Censuses: Consequences for Population and Community Descriptions. *PLoS ONE* **5**: e11722. doi:10.1371/journal.pone.0011722.

Trophic pathway interaction term			
	Estimate	P	ΔN
Species-based	-0.042	0.746	1
	-0.051	0.694	2
	-0.057	0.654	3
	-0.063	0.623	4
	-0.068	0.598	5
	-0.071	0.578	6

	-0.075	0.561	7
	-0.078	0.546	8
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	0.031	0.559	1
	0.018	0.728	2
Individual-based	0.009	0.871	3
	0.001	0.989	4
	-0.006	0.913	5
	-0.011	0.834	6
	-0.017	0.765	7
	-0.020	0.710	8

Table S1. Sensitivity of trophic position ~ body size analyses to varying herbivore trophic fractionation (ΔN) values. Significance value and slope of trophic pathway interaction term are reported for the optimum species-based and individual-based mixed effects models reported in the main text. ΔN ranged from 1 to 8%.

	Coefficient	Estimate	Standard error	P value	Marginal R ²	AIC _c	Location
Species-based	Intercept	2.37	0.305	< 0.001	0.17	49.09	North
	log ₂ mass	0.122	0.025	< 0.001			
Species-based with trophic pathway	Intercept	2.76	0.256	< 0.001	0.64	47.53	
	Intercept (herbivore)	-1.09	0.958	0.282			
	log ₂ mass	0.118	0.024	0.001			
	log ₂ mass*herbivore	-0.05	0.117	0.681			
Individual-based	Intercept	2.7	0.251	< 0.001	0.08	57.43	
	log ₂ mass	0.095	0.015	< 0.001			
Individual-based with trophic pathway	Intercept	3.059	0.186	< 0.001	0.65	53.69	
	Intercept (herbivore)	-1.433	0.383	0.004			
	log ₂ mass	0.097	0.017	< 0.001			
	log ₂ mass*herbivore	0.008	0.036	0.817			
Species-based	Intercept	2.173	0.32	< 0.001	0.2	50.39	
	log ₂ mass	0.131	0.026	0.001			
Species-based with trophic pathway	Intercept	2.595	0.274	< 0.001	0.6	49.53	
	Intercept (herbivore)	-1.2	1.033	0.274			
	log ₂ mass	0.122	0.026	0.003			
	log ₂ mass*herbivore	-0.039	0.125	0.766			
Individual-based	Intercept	2.787	0.222	< 0.001	0.04	34.34	
	log ₂ mass	0.067	0.022	0.012			
Individual-based with trophic pathway	Intercept	3.045	0.2	< 0.001	0.4	25.6	
	Intercept (herbivore)	-1.434	0.492	0.009			
	log ₂ mass	0.06	0.023	0.011			
	log ₂ mass*herbivore	0.004	0.059	0.953			

Table S2. Parameter estimates of the best model (as evaluated by AIC_c) for log₂ body mass ~ trophic position relationships in the species-based (linear mixed effects model with family as a random effect) and individual-based (linear mixed effects model random structure of species nested within family as a random effect (north) and species as a random effect (south)) analyses, for sites on the northeast coast (North) and in the Bay of Wrecks (South).

Diver	Year	Energy pathway	<i>b</i>	CI min	CI max
SC	2011	Carnivore	1.60	1.59	1.61
SC	2011	Herbivore	1.20	1.18	1.23
SC	2013	Carnivore	1.52	1.51	1.53
SC	2013	Herbivore	1.37	1.35	1.39
JLG	2013	Carnivore	1.80	1.78	1.81
JLG	2013	Herbivore	1.37	1.35	1.40
RT	2011	Carnivore	1.82	1.79	1.84
RT	2011	Herbivore	1.22	1.09	1.34
SMW	2011	Carnivore	1.70	1.69	1.72
SMW	2011	Herbivore	1.14	1.12	1.17

Table S3. Size spectra exponent estimates with 95% confidence intervals for each diver (SC: Scott Clark; JLG: Jonatha Giddens; RT: Rowan Trebilco; SMW: Sheila Walsh).

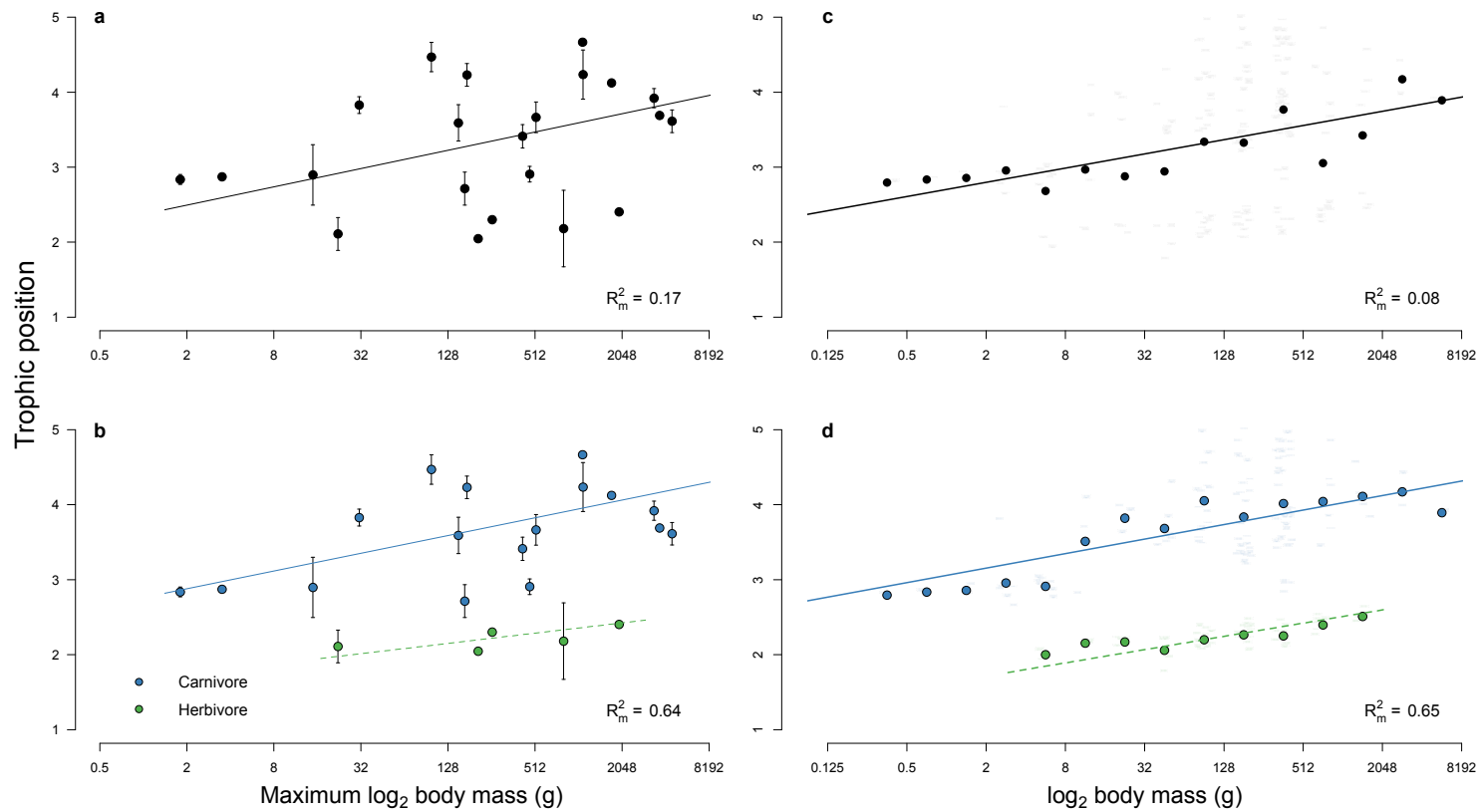


Fig. S1. Trophic position ~ body size relationships at sites on the Northwest coast ($n = 5$). **a, b:** Species-based analyses. Linear mixed effects models of trophic position and \log_2 body mass (g) in the coral reef fish community (a) across all species ($n = 22$), (b) for the two trophic pathways, carnivores (blue, $n = 17$ species) and herbivores (green, $n = 5$ species). For each species, the mean trophic position and 95% confidence intervals are plotted against its maximum mass. **c, d:** Individual-based analyses. Linear mixed effects models individual trophic position and of individual \log_2 body mass (g) in the coral reef fish community (c) across all individuals ($n = 184$) and (d) for the two trophic pathways, carnivores (blue, $n = 129$) and herbivores (green, $n = 55$). Individual trophic position estimates (with jitter, transparent colour) are plotted against body mass class, and overlaid with mean trophic position (solid colour) of each body mass class.

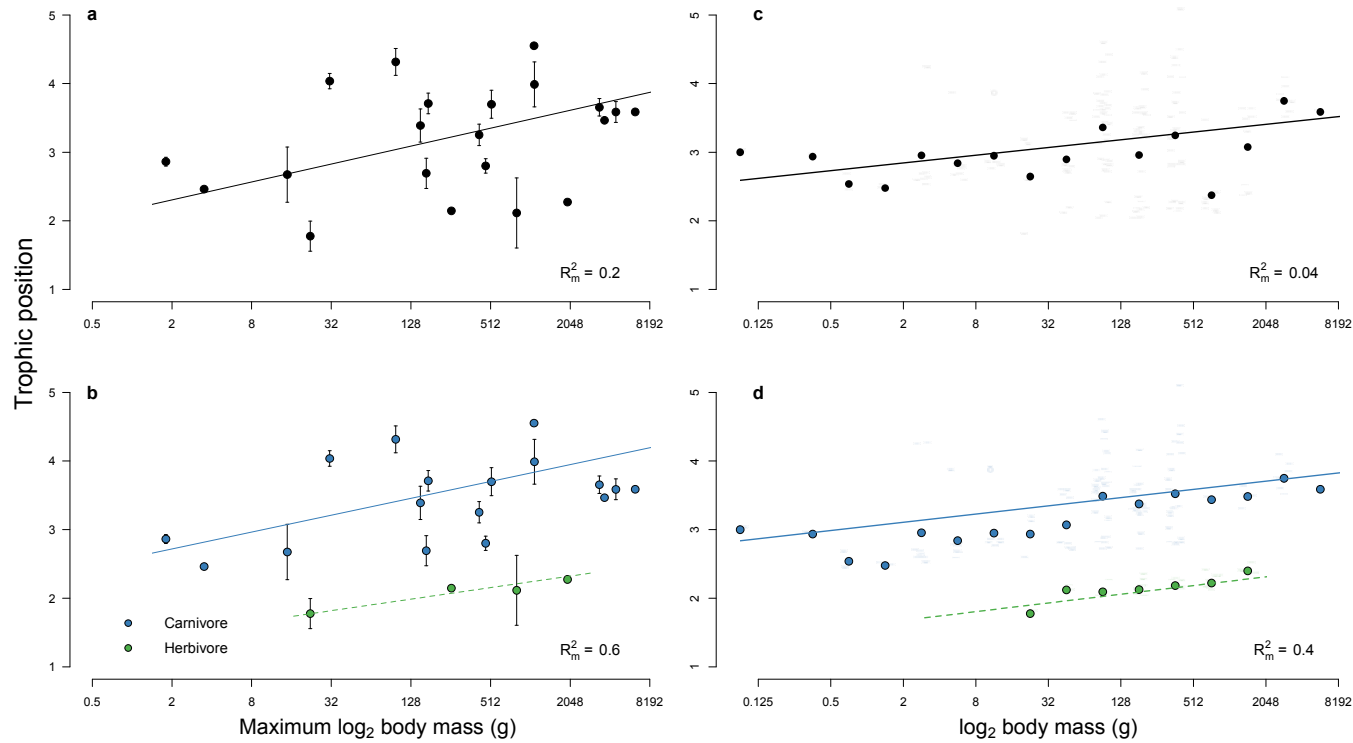


Fig. S2. Trophic position ~ body size relationships at sites in the Bay of Wrecks (Southwest coast (n = 5)). **a, b:** Species-based analyses. Linear mixed effects models of trophic position and log₂ body mass (g) in the coral reef fish community (a) across all species (n = 21), (b) for the two trophic pathways, carnivores (blue, n = 17 species) and herbivores (green, n = 4 species). For each species, the mean trophic position and 95% confidence intervals are plotted against its maximum mass. **c, d:** Individual-based analyses. Linear mixed effects models individual trophic position and of individual log₂ body mass (g) in the coral reef fish community (c) across all individuals (n = 160) and (d) for the two trophic pathways, carnivores (blue, n = 129) and herbivores (green, n = 31). Individual trophic position estimates (with jitter, transparent colour) are plotted against body mass class, and overlaid with mean trophic position (solid colour) of each body mass class.

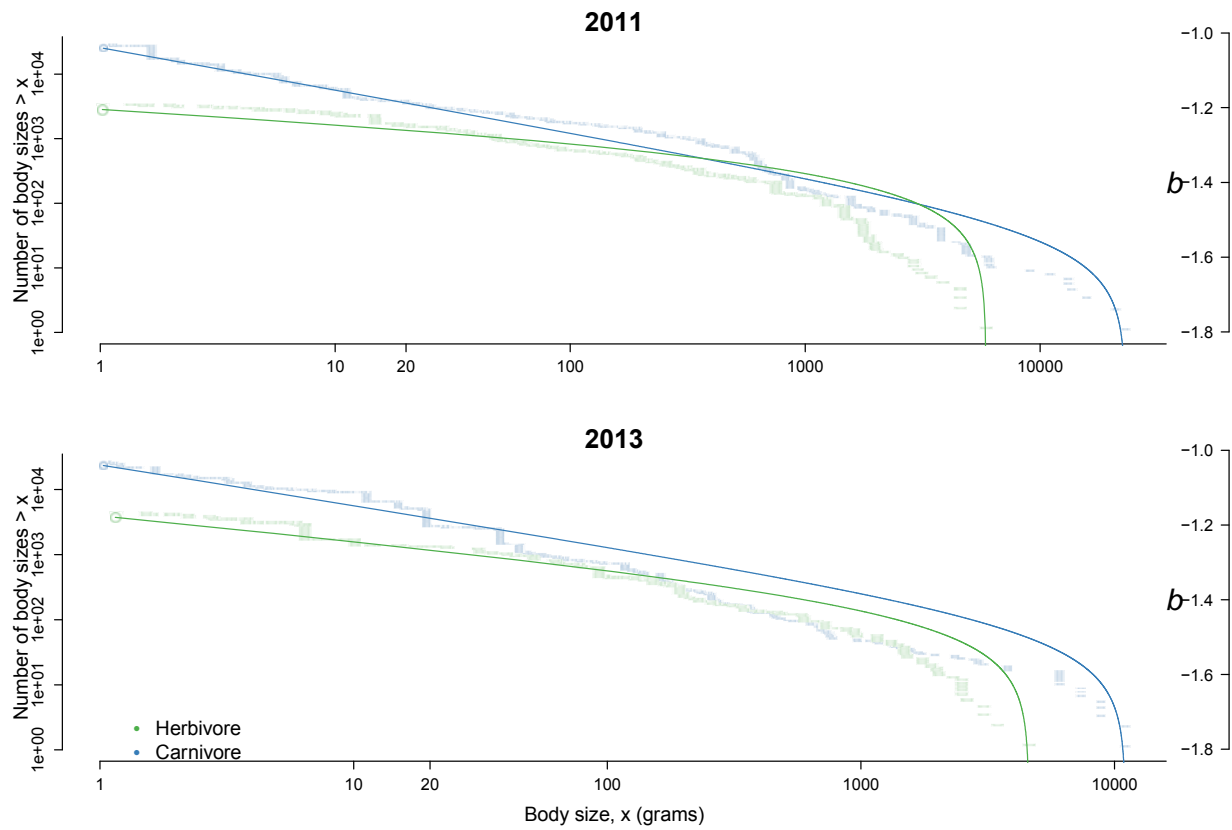


Fig. S3. Rank-frequency plot of reef fish body masses in 2011 (top) and 2013 (bottom), with associated size spectra exponent estimates and 95% confidence intervals (right panel). Carnivore trophic pathway in blue; herbivore trophic pathway in green.

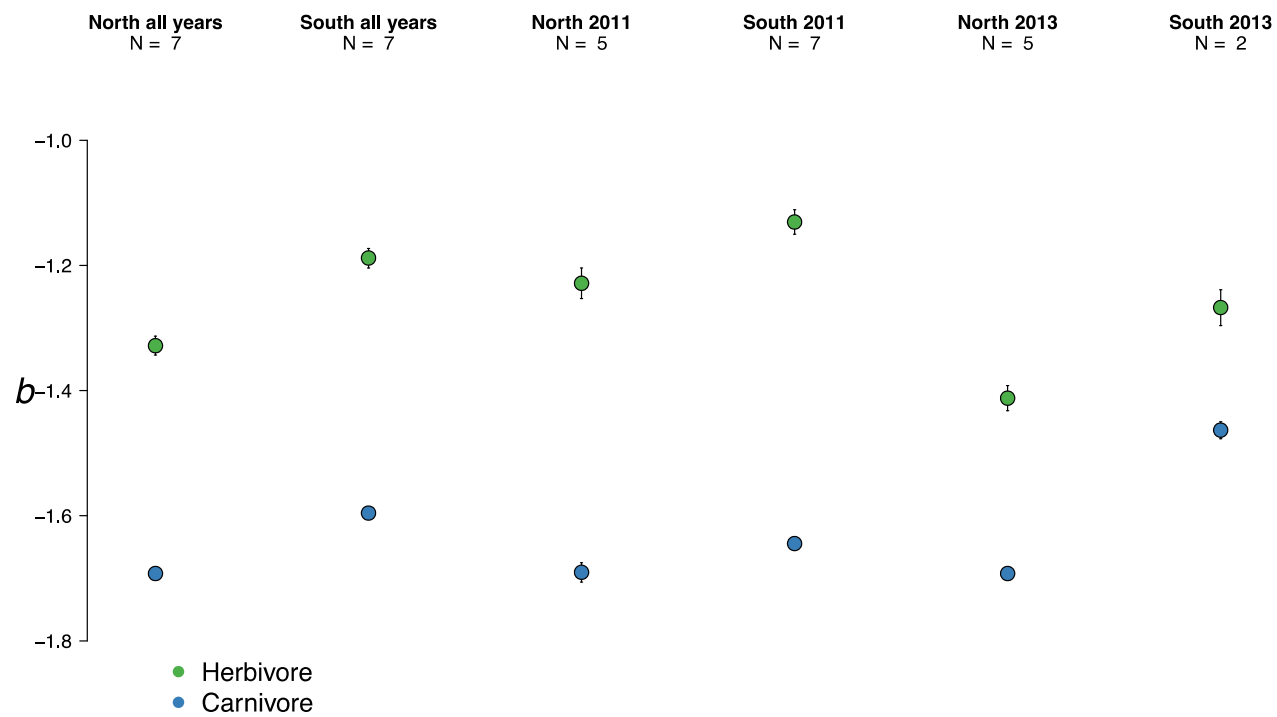


Fig. S4. Size spectra exponent estimates with 95% confidence intervals for northeast coast sites (North, $n = 7$) and Bay of Wrecks sites (South, $n = 7$) across years. Carnivore trophic pathway in blue; herbivore trophic pathway in green.

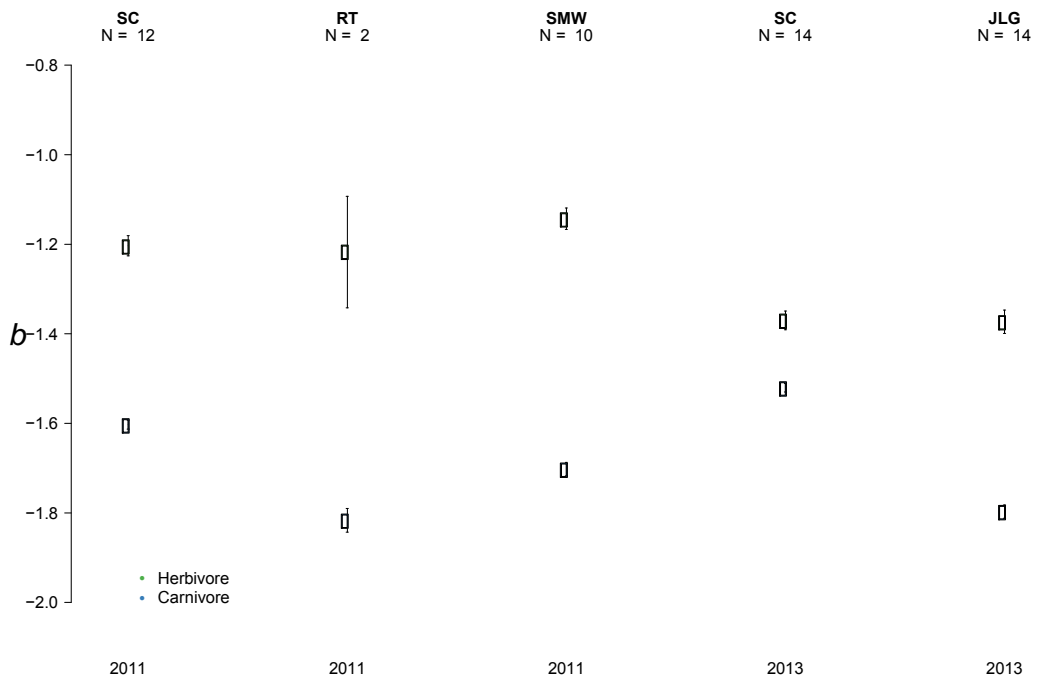


Fig. S5. Size spectra exponent estimates with 95% confidence intervals for each diver across years. Carnivore trophic pathway in blue; herbivore trophic pathway in green.

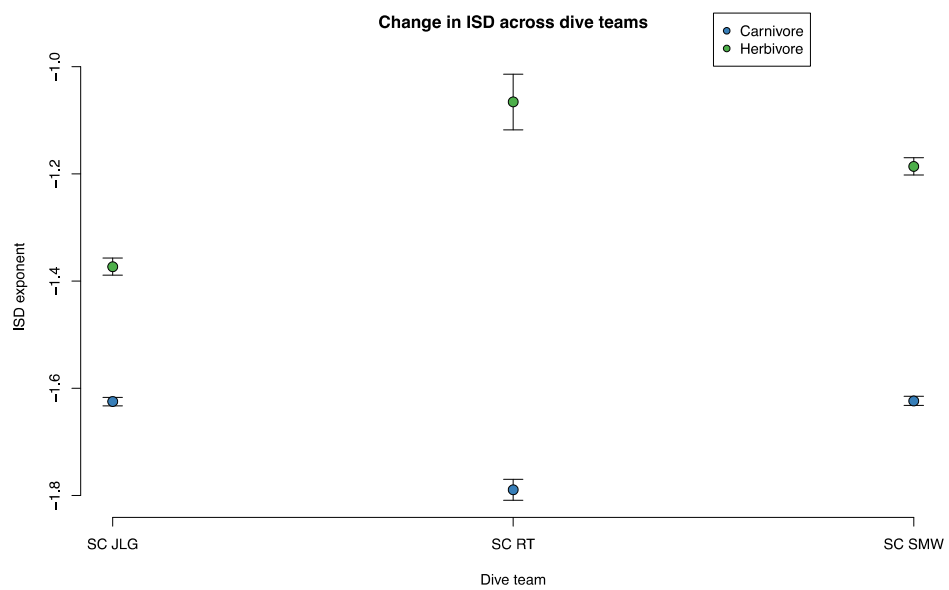


Fig. S6. Size spectra exponent estimates with 95% confidence intervals for each dive team. Carnivore trophic pathway in blue; herbivore trophic pathway in green.

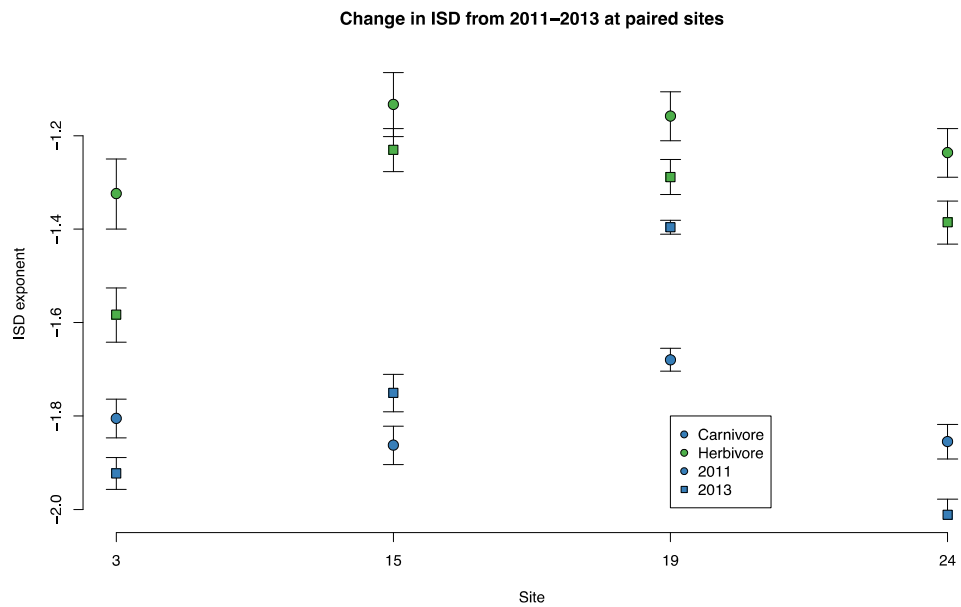


Fig. S7. Size spectra exponent estimates with 95% confidence intervals for sites ($n = 4$) sampled in both 2011 (circles) and 2013 (squares). Carnivore trophic pathway in blue; herbivore trophic pathway in green.

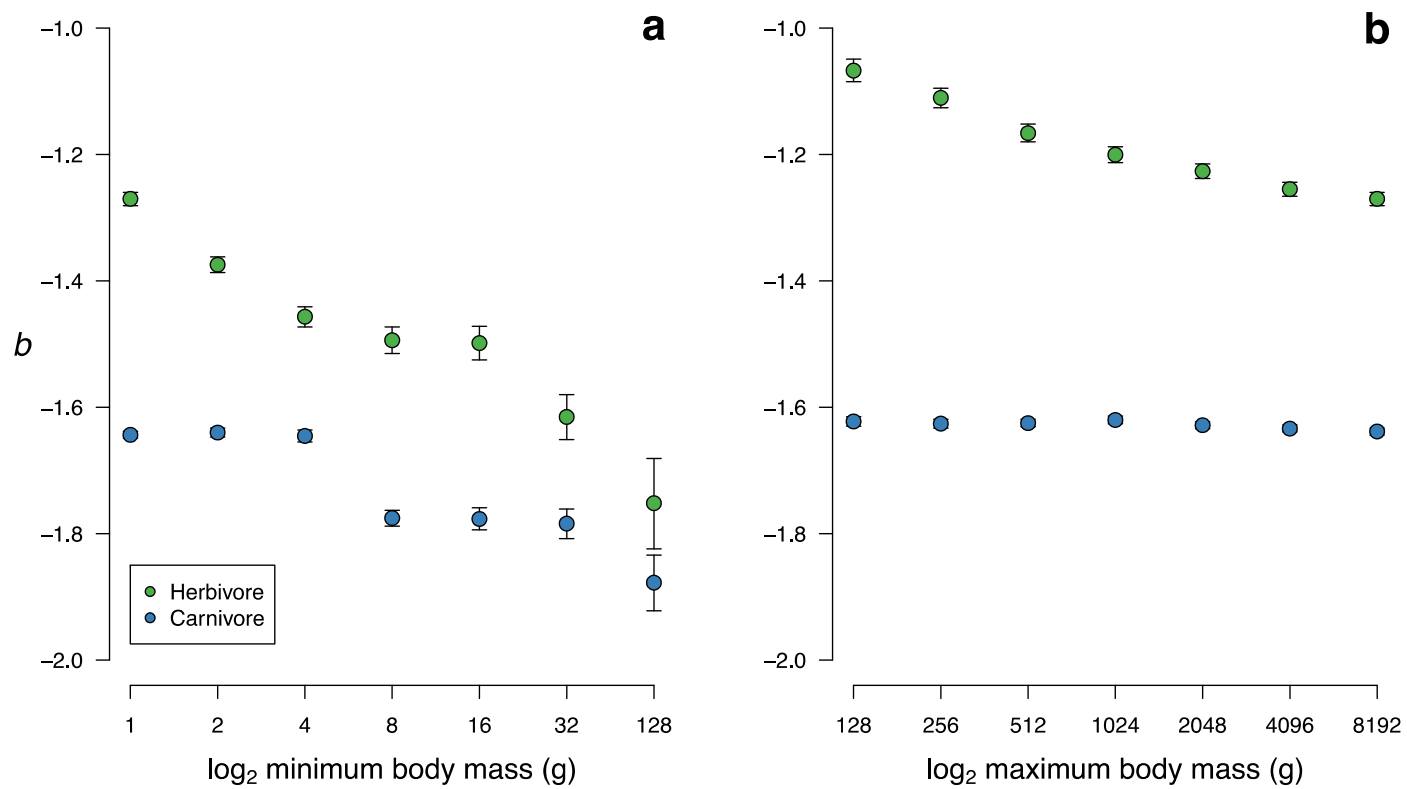


Fig. S8. Size spectra exponent estimates with 95% confidence intervals for different minimum and maximum observed body masses. **a:** We estimated the exponent b separately for herbivores (green) and carnivores (blue) after removing the observations in the smallest \log_2 size categories (2, 4, 8, 16, 32, 128 g). **b:** We estimated the exponent b separately for herbivores (green) and carnivores (blue) after removing the observations in the largest \log_2 size categories (128, 256, 512, 1024, 2048, 4096, 8192 g).

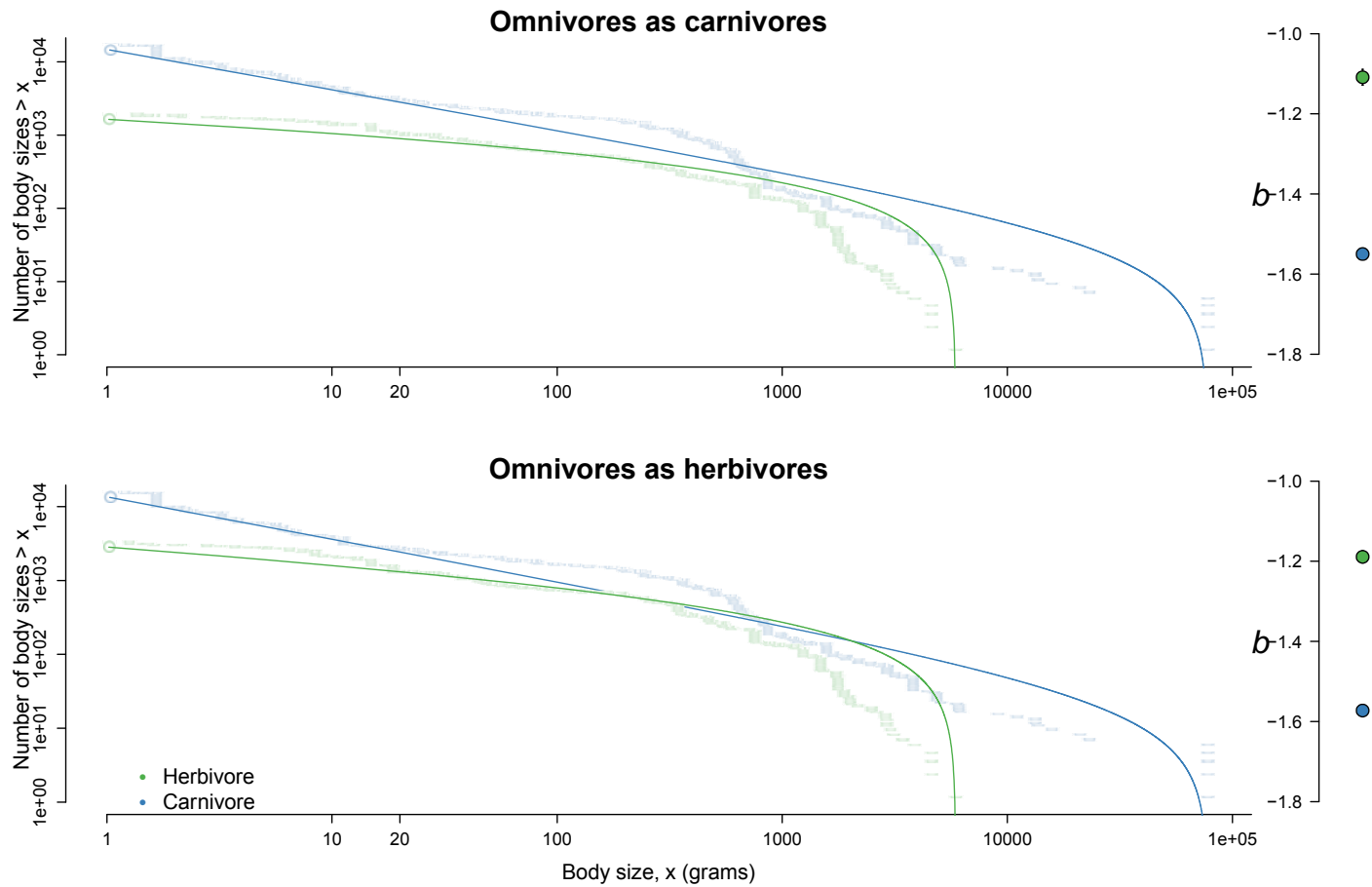


Fig. S9. Rank-frequency plot of observed masses for carnivores (blue) and herbivores (green), and associated size spectra exponent estimates with 95% confidence intervals when omnivorous species were classed as carnivores (top) or herbivores (bottom).

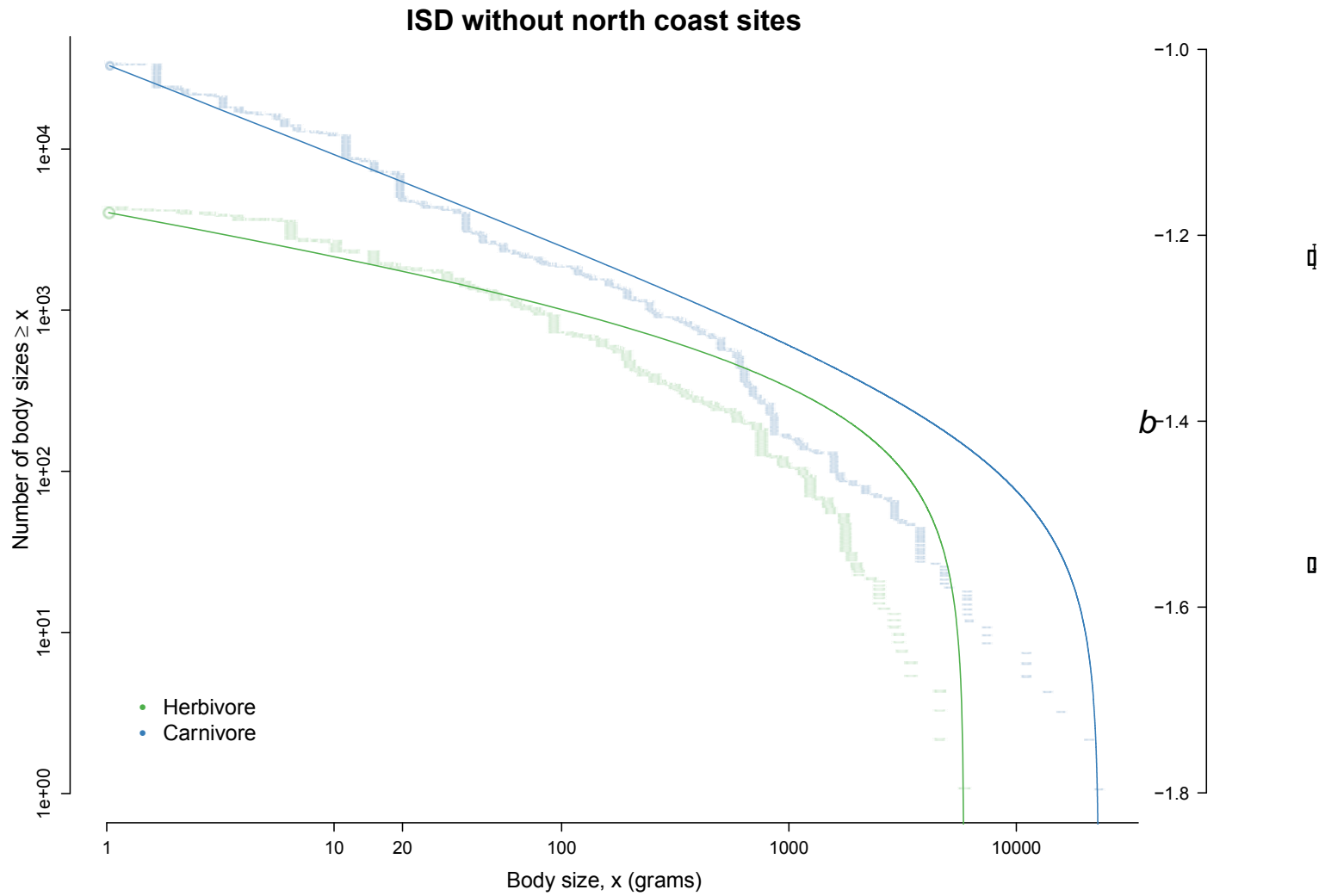


Fig. S10. Rank-frequency plot of observed masses for carnivores (blue) and herbivores (green), and associated size spectra exponent estimates with 95% confidence intervals, with the potentially exploited north coast sites ($n = 4$) removed.