

Ecography

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**Supplementary material**

**Appendix 1:** Justification for the choice of maximum body size and diet as reef fish functional attributes.

### **Body size**

Size has a primary role in defining the ecological niche and ecological role of species, general reviews on this subject can be found in Wilson (1975) and LaBarbera (1986). More specifically the following aspects are important for reef fish:

- Energy needs: the amount of energy for metabolism increases with body size, but the amount of energy per unit of body mass decreases with body size (Munday & Jones, 1998).
- Prey selection or predator escape (Costa *et al.*, 2009): prey selection is linked to mouth gape size, which is itself a function of body size, larger fish being able to eat larger prey. Predators are also limited by the size of their prey. Therefore large fish tend to be less predated than smaller ones, all other factors being equal. In addition larger fish have higher swimming speed, which enables them to flee their predator more efficiently. Large fish have the capacity to swim over longer distances therefore increasing their foraging range compared to smaller species or smaller individuals.
- Reproductive capacity, sex ratio, size at maturity, sex reversal: the size of gonads and therefore the quantity of reproductive products is proportional to body weight, usually according to a power function. This means that larger species or larger fish will produce far more gametes than smaller species or smaller individuals. The sex ratio of many species is a function of body size, for instance small parrotfish are nearly always females, small anemone fish are nearly always males (Wong *et al.*, 2007). The size at maturity is proportional to body size, larger species being mature at relatively larger sizes than small ones. Similarly, sex reversal, which is a frequent process for reef fish, occurs at larger sizes in large species (Wong *et al.*, 2007).
- Diversity services in particular biomass production: fish weight is exponential to its body length, therefore assemblages with large species will tend to have larger biomasses than assemblages with small species, for a given diversity level. As the geographical distribution of species fish size is not random (Luiz *et al.*, 2013) this means that the biomass-diversity relationship for reef fish is not spatially homogeneous (Mora *et al.*, 2011). See also Ackerman *et al.* (2004) on the relationship between density and body size.
- Growth and production: small fish species tend to grow faster and have a higher production rate than larger species (see Paloheimo & Dickie, 1966; for general information) (there are exceptions both ways however). This means that biomass and production may not be related in the same way in reef fish assemblages dominated by small species compared to assemblages dominated by large species

- Mortality rate: small species tend to have a much higher mortality rate than larger ones (Henrique *et al.*, 2013; Munday & Jones, 1998). There are however intrinsic factors to each species. In particular mortality is linked to many other traits such as school size, mobility, level in the water column.
- PLD: large species tend to have wider geographical ranges and also longer Pelagic Larval Durations (PLD) than small species (Luiz *et al.*, 2013)
- Temperature tolerance is related to body size in reef fishes (Ospina & Mora, 2004)

## Diet

Diet, as size, is an essential component of reef fish ecological niche as indicated in general reviews such as Hiatt & Strasburg (1960), Hobson (1974), Sale (1977), Bellwood *et al.* (2006). In particular diet may be important for the following:

- Trophic level and trophic niche width (for general views see Araujo *et al.*, 2011; Bearhop *et al.*, 2004): the trophic level of a species and its trophic niche width is determined by the food type it feeds on as well as the variety of food items (Floeter *et al.*, 2004; Ferreira *et al.*, 2004; Wilson *et al.*, 2008; Frederich *et al.*, 2010; Curtis-Quick *et al.*, 2012; Litsios *et al.*, 2012) For instance a species may be specialized in coral polyps but depending on where it lives it may eat polyps from different species (Lawton & Pratchett, 2012). Within the same trophic guild other species may eat only polyps from a given species or genus of *Acropora* wherever it lives.
- Habitat requirements (prey need to be present): many species having a specialized diet will restrict their habitat to areas where the food they need is present is sufficient in quantity and quality. Coral feeders are typical (Berumen & Pratchett, 2008) but there are many herbivores and plankton feeders (Frederich *et al.*, 2009; Burkepile & Hay, 2008) that live in specific habitats because of their diet.
- Feeding behavior: the way fish feed on a given item may have profound implications on the habitat and community. For instance, herbivorous fishes can be split according to several feeding behaviors such as grazers, browsers, scrapers (Bellwood & Choat, 1990). Each of these behaviors will generate different consequences on the algae/coral relationship and on many other ecological processes. The same could be said of coral feeders, of mobile invertebrate feeders.
- Home range (depending on energy requirements and type of prey and prey availability, home range will be either small or wide). For instance, large carnivorous species will necessarily have a wide home range as the resources needed to sustain their metabolism cannot be found on a restricted part of the reef. On the opposite, some small plankton feeders may stay their entire adult lives on the same spot as plankton drifts by.

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**Appendix 2:** Sensitivity of nestedness analysis to functional group classification scheme

**Table A2.** Functional nestedness of reef fish assemblages across six biogeographic regions. In order to assess the sensitivity of nestedness analysis to the choice of functional group classification, two distinct functional group schemes were applied. Functional 1 corresponds to the combination of four traits (body size, trophic group, home range and schooling behaviour), while Functional 2 combines six different traits (body size, trophic group, home range, schooling behaviour, activity and level). Obs.: observed WNODF values; 95% CL: WNODF confidence limits from 1000 random matrices obtained from null model “quasiswap” (see methods);  $Z\text{-score} = (X - \mu_{simul}) / \sigma_{simul}$ , where  $X$  is the observed WNODF, and  $\mu_{simul}$  and  $\sigma_{simul}$  are the mean and standard deviation, respectively, of 1000 simulated matrices. Positive  $Z$ -scores indicate higher  $x$  than expected by chance. All matrices were double sorted according to marginal richness and abundance totals.

Matrix	Functional 1			Functional 2		
Site	WNODF			WNODF		
	Obs.	Z-score	95% CL	Obs.	Z-score	95% CL
<b>Western Atlantic</b>	46.9	6.72	40.4–43.7	32.2	6.62	30.9–33.1
<b>Eastern Atlantic</b>	37.7	3.97	30.9–35.8	29.3	4.59	23.5–27.3
<b>Tropical Eastern Pacific</b>	45.5	9.28	34.0–37.3	30.8	8.68	25.3–27.5
<b>Western Indo-Pacific</b>	57.9	18.7	47.5–49.7	44.6	22.6	36.1–37.6
<b>Central Indo-Pacific</b>	61.7	12.7	54.6–56.7	49.7	20.4	42.3–43.7
<b>Central Pacific</b>	58.4	15.7	49.9–52.0	45.5	25.8	37.0–38.4

**Appendix 3:** The hierarchical spatial structure of reef fish assemblages

List of sites within provinces and regions, and map depicting marine biogeographic regions and its provinces (Fig. S1) (*sensu* Kulbicki *et al.*, 2013).

**Table A3.** List of sites embedded in provinces (scale 2) and regions (scale 1). Sites are ordered based on decreasing species richness.

Western Atlantic		Local Richness
	<b>Southwestern Atlantic</b>	
	Hump of Brazil	281
	São Paulo	257
	Espírito Santo	252
	Arraial do Cabo	247
	North Bahia	246
	Ilha Grande	233
	Abrolhos	187
	Santa Catarina	182
	Zumbi	167
	Manuel Luiz	133
	Fernando de Noronha	119
	Rocas' Atoll	103
	Trindade	97
	St. Paul's Rocks	57
	<b>Atlantic Islands</b>	
	Ascension	84
	St. Helena	72
	<b>Caribbean</b>	
	Cuba	452
	Bahamas	442
	Virgin Islands	436
	Florida Keys	419
	Venezuela – Tobago	404
	Pelican Cays, Belize	374
	Mexican Caribbean	360
	Martinique	290
	Guadeloupe	287
	Bonaire Island	273
	Bermuda	272
	Georgia	244
	Saba, Netherland Antilles	223
	Navassa	192
<b>Eastern Atlantic</b>		
	<b>Eastern Atlantic</b>	
	Cabo Verde	251
	São Tome	196
	Senegal	177
	Guinea-Sierra Leone	171
	Canaries	163
	Mauritania	134
	Madeira	121
<b>Tropical Eastern Pacific</b>		
	<b>TEP Islands</b>	
	Galapagos	282
	Cocos	232

	Malpelo	197
	Revillagigedos	165
	Clipperton	111
<b>Continental TEP</b>		
	Panama	297
	Costa Rica	277
	Colombia	267
	Nicaragua	248
	Gulf of California	246
	Honduras	236
	El Salvador	235
	Ecuador	231
	Sinaloa	216
	Tresmarías	193
	Gorgona	182
	Isla la Plata	163
	Guatemala	96
<b>Western Indian</b>		
	Western Indo-Pacific	1617
	Red Sea	1043
	Somali/Arabian	995
	West India and South Indian Shelf	1062
	Central Indian Ocean Islands	439
	Eastern India	431
	Andaman	
<b>Somali/Arabian</b>		
	Red Sea	766
	Gulf of Aqaba	681
	Gulf of Aden	629
	Oman South	527
	Gulf of Oman	441
	Arabian Gulf	319
	Erythrea-Djibouti	312
<b>Western Indo-Pacific</b>		
	Seychelles	1009
	Mozambique	983
	Mauritius	941
	Kenya	933
	Tanzania	928
	Maldives	896
	Comores	854
	Aldabra	821
	Madagascar	775
	Chagos	753
	La Reunion	709
	Somalia	699
	Rodrigues Island	451
	Laccadives	432
	Socotra	422
	Europa	360
	Carajos	312
<b>Central Indo-Pacific</b>		
	Philippines	1951
	China Sea	1728
	Solomon Islands	1688
	Sulawesi	1616
	Bali	1566
	Flores	1550
	Birds Head Peninsula	1538





<b>Polynesia</b>		
	Society Islands	708
	Tuamotu Islands	594
	Cook Islands	585
	Gambier	509
	Marquesas	485
	Rapa Island	393
	Pitcairn	379
	Australes Islands	351
<b>Hawaii</b>		
	Hawaii	512
	Jonston Attol	292
	Midway and Northwestern Hawaii	293
<b>Southwestern Pacific</b>		
	New Caledonia	1324
	Capricorn bunker	1017
	Chesterfield	743
	Loyalty Islands	683
	Lord Howe	427
	Middleton-Elizabeth	415
	Norfolk	255
	Kermadec	145

**Figure A1.** Map of six marine biogeographic regions and its provinces (modified from Kulbicki *et al.*, 2013). Nestedness was assessed at both scales.

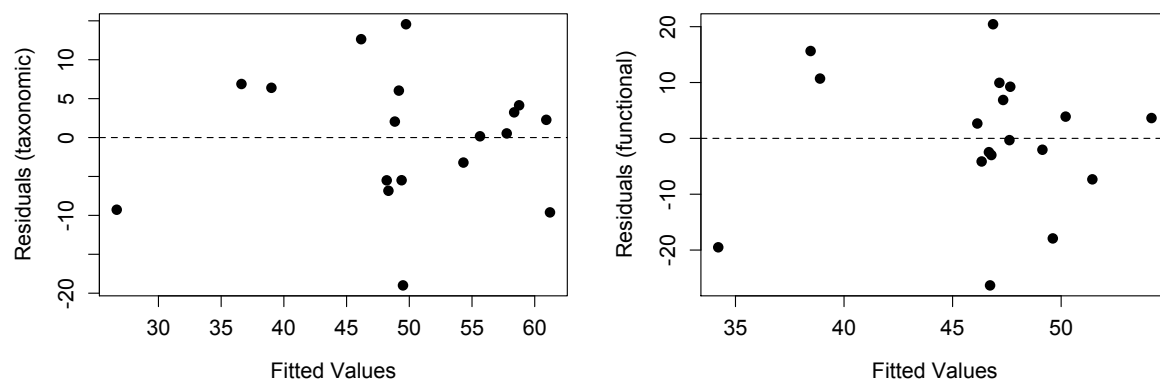
**Appendix 4:** Model selection for the relation between taxonomic and functional nestedness with isolation gradients and plots of the model residuals vs. area gradients.

SCALE 1: Regions and Provinces (n=18)

**Table A4.** Model selection through analysis of variance (ANOVA) for the relation between taxonomic and functional nestedness across reef fish assemblages with isolation gradients. Nestedness (y) was estimated for regions and provinces, and its corresponding isolation value (x) refers to the mean distance from the site to the 10 nearest patches within each biogeographic region and province.

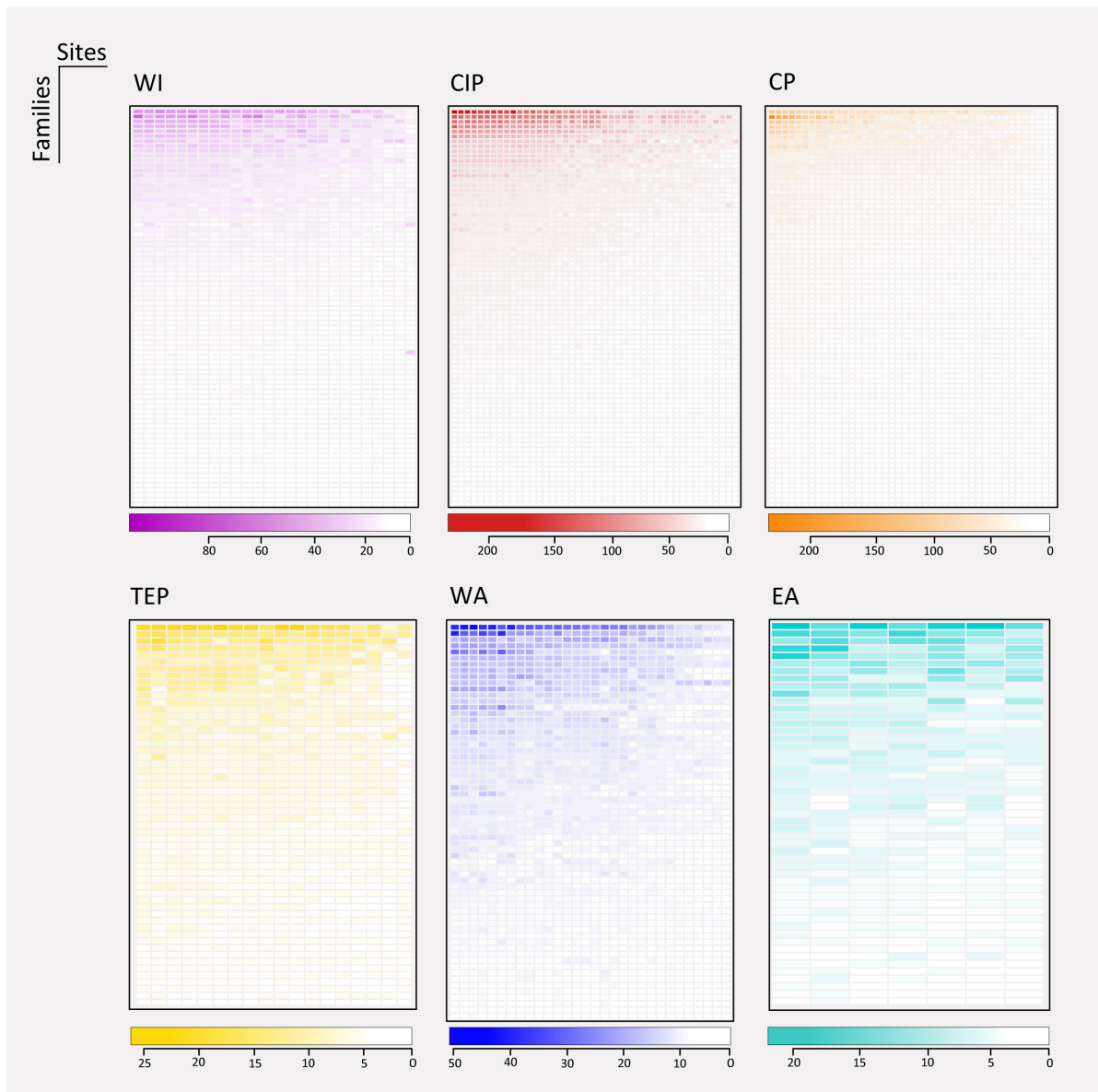
			ANOVA (model comparison)					
			F-statistic	adj R <sup>2</sup>	p-value	Sum of squares	F-value	p-value
Taxonomic	Model 1	$y \sim x$	3.78	0.14	0.06			
	Model 2	$y \sim x + x^2$	4.99	0.49	0.02*	534.01	5.21	0.037*
Functional	Model 1	$y \sim x$	1.60	0.03	0.22			
	Model 2	$y \sim x + x^2$	0.88	0.10	0.63	41.167	0.23	0.633

\*  $p < 0.01$



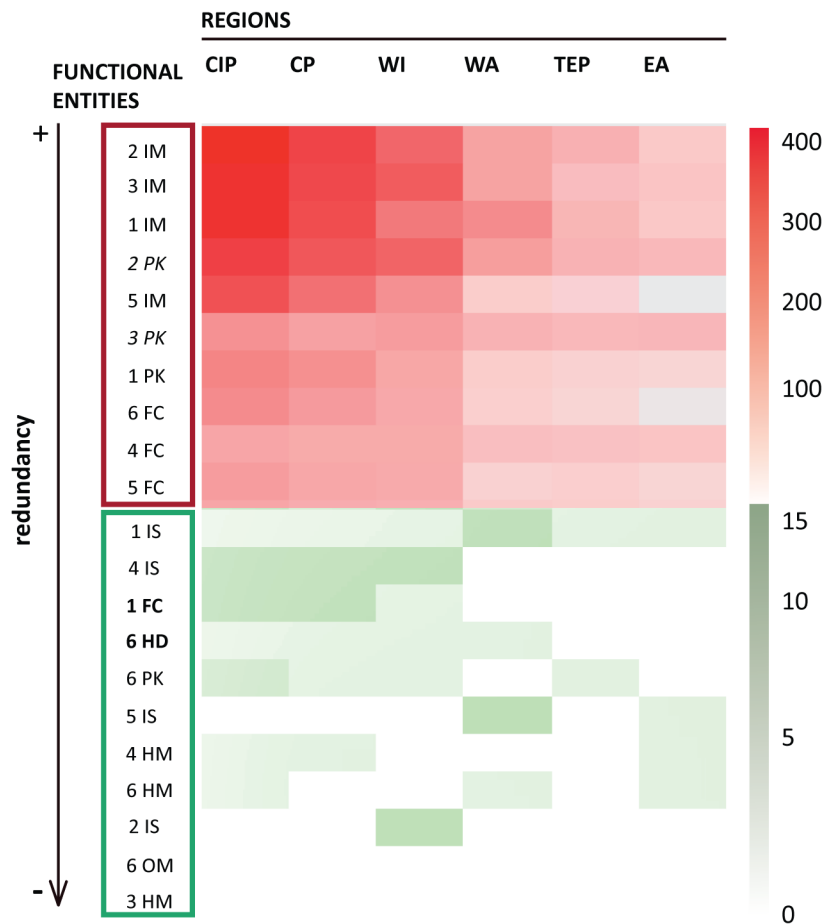
**Figure A2.** Residual plots of the quadratic models for taxonomic and functional nestedness contrasted against area gradients.

## Appendix 5



**Figure A5.** The taxonomic structure of global reef fish assemblages. Maximally packed matrices representing the number of species within families across sites in six biogeographic regions. From left to right, top row: Western Indian (purple), Central Indo-Pacific (red), Central Pacific (orange). Bottom row: Tropical Eastern Pacific (yellow), Western Atlantic (blue) and Eastern Atlantic (light-blue).

## Appendix 6



**Figure A6.** The nested functional structure of global reef fish assemblages. Reef fish FE that occupy the top ten positions (red portion), as well as those in the bottom ten positions (green portion) of a maximally nested matrix. FE in the red rectangle are the ten most widespread and redundant FE across the six biogeographical regions, whereas FE inside the green rectangle are those absent from certain sites and/or represented by a smaller number of species, *i.e.*, less-redundant FE. The gradients from dark-red/ dark-green to pale-red/ pale-green represent decreasing values in matrix cells. Inside the red rectangle, functional entities in italic (2 *PK*, 3 *PK* = planktivores <15 cm) appear as very redundant FE in assemblages of the Indo-Pacific. Inside the green rectangle, functional entities in bold (6 HD = herbivore-detritivores > 80 cm; and 1 FC = piscivores < 7 cm) are those with low redundancy across all 6 regions. CIP = Central Indo-Pacific, CP = Central Pacific, WI = Western Indian, WA = Western Atlantic, TEP = Tropical Eastern Pacific, EA = Eastern Atlantic.