

Supplementary material: Global-scale predictions of community and ecosystem properties from simple ecological theory

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Primary production estimates

Primary production (PP) was computed with a wavelength- and depth-resolved model, building on the approach of Longhurst *et al.* (1995). Primary production estimates were output as $\text{mgC m}^{-2} \text{d}^{-1}$ based on the mean of monthly estimates for 2002. The main biological input to the models was the surface concentration of chlorophyll *a* pigment provided by the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) global time series (McClain *et al.* 2004). At high latitudes the available monthly data were extrapolated to a 12 month period, since there is poor remote sensing coverage of high latitudes in winter and the locations are usually associated with very low primary production or sea ice cover.

Extrapolated data were excluded from this analysis because overestimation of primary production usually occurs in regions where remote sensing coverage is poor (Gregg & Casey 2007). Spectral irradiance at the ocean surface was estimated with the model of Gregg & Carder (1990) combined with a correction for cloud cover. The spectral light field is subsequently propagated into the water column with a bio-optical model. Primary production at each depth was calculated as a function of the concentration of chlorophyll *a* and light through a light-photosynthesis curve, based on parameters that vary with biogeographic provinces and seasons. Primary production was integrated over day length and depth (down to the 0.1% light level). All changes from the implementation of Longhurst *et al.* (1995) are detailed in Mélin (2003). The primary production estimates obtained at global scales with this approach are broadly consistent with those from other models driven by ocean colour data (Behrenfeld *et al.* 2002; Carr *et al.*

2006). All outputs were mapped onto a 36km grid that covered the world's seas and oceans. Sea surface temperature (SST) estimates for each cell were derived from the Moderate-resolution Imaging Spectroradiometer (MODIS) carried by the NASA terra-satellites. Monthly SST averages for 2002 were extracted through the Jet Propulsion Laboratory physical oceanography DAAC web portal (<http://poet.jpl.nasa.gov/>). Depth for each cell was determined from the General Bathymetric Chart of the Oceans (GEBCO) digital atlas, as maintained at the British Oceanographic Data Centre.

P_s (picophytoplankton production) and P_p (total primary production) were converted from g C m^{-3} to g C m^{-2} assuming the productive layer depth to be 75 m or the reported depth if <75 m. Carbon was converted to wet mass and equivalent spherical diameter (ESD) assuming $0.1 \text{ g C} = 1 \text{ g wet mass} = 1 \text{ cm}^3$, and body mass classes in the spectrum were 0.1 \log_{10} units.

Frequency distribution of maximum body mass

The frequency distribution of maximum body mass was estimated for all fish species reported to be present in each of 64 large marine ecosystems (Fishbase, Froese & Pauly 2000). Length was converted to weight using the general relationship $W = 0.01L^3$, where W is weight in g and L is length in mm. Figure S1 shows the mean number of species in log maximum body mass classes (mean \pm S.E.M). Species with maximum body mass smaller than the $10^{0.05}$ g (midpoint 1.1 g) class used in the published analysis accounted for a very small proportion (<2%) of the total number of fish species.

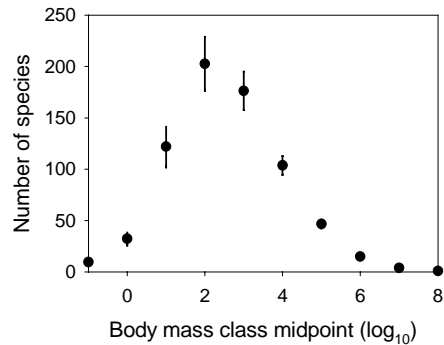


Figure S1. Mean number of species in log maximum body mass classes (mean± S.E.M), based on recorded numbers of species at maximum body mass in 64 large marine ecosystems.

Additional sensitivity analyses

We explored the sensitivity of biomass estimates to the scaling of production (P) and weight (W) by applying the same change in scaling to all equations simultaneously. The range of values we used, 0.72 to 0.80, was large in relation to reported 95% CI for fitted W exponents in P to W relationships. These were 0.75 to 0.76 for the exponent in equation 2, for example (Brown et al. 2004). In part, these narrow CI reflect the wide range in body mass over which the relationships have been fitted, but we also apply the values of the exponents over many orders of magnitude in body mass (up to 17) when applying our method. Changes in the scaling of P and W by ± 0.4 from the assumed value of 0.76 change the total global biomass of all animals (and fish) by <3 fold, less than the expected effects of plausible changes in predator-prey mass ratios or transfer efficiency (see main paper). Since sensitivity to the assumed P to W scaling varies with primary production and temperature, and since variation in P and W scaling might be expected to be a local or regional phenomenon depending on community

composition, we also explored the effects of changing the values of exponents in relative terms, where biomass at a primary production of $1000 \text{ mg C m}^{-2} \text{ d}^{-1}$ is given a value of one (figure S2). When expressed in relative terms, changes in biomass with primary production did not depend on temperature (although absolute biomass did). Despite making the conservative assumption that the change in exponents would be of the same magnitude in all relationships, the effects that would be associated with variation around the confidence limits for these empirical relationships were small in relation to those associated with expected uncertainty in estimates of transfer efficiency and the predator-prey body mass ratios.

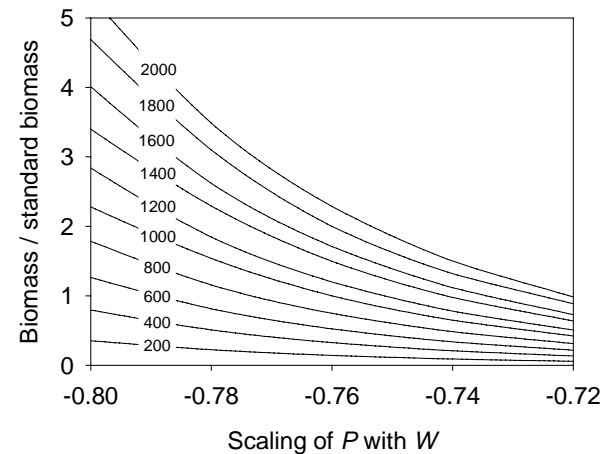


Figure S2. Relationship between the W exponent of the scaling relationship between P and W and the relative total animal biomass estimated by our model as a function of primary production ($\text{mg C m}^{-2} \text{ d}^{-1}$). Biomass is expressed in relative terms, as a proportion of the biomass predicted by the model when primary production is $1000 \text{ mg C m}^{-2} \text{ d}^{-1}$. Values on the lines are primary production in $\text{mg C m}^{-2} \text{ d}^{-1}$.

To supplement the results provided in the main paper, a more comprehensive analyses of the sensitivity of biomass and production by

temperature zones and body mass classes to changes in the assumed transfer efficiency is presented in tables S1 and S2.

Table S1. Sensitivity of estimates of fish biomass and production (10^6 t) to transfer efficiency by temperature zone. Temperature is the mean annual sea surface temperature (SST), ‘all fish’ ‘includes teleosts and elasmobranchs.

SST °C/ TE	All fish biomass			All fish production			Elasmobranch biomass			Elasmobranch production		
	0.1	0.125	0.15	0.1	0.125	0.15	0.1	0.125	0.15	0.1	0.125	0.15
-5-0°	8.87	21.27	44.57	1.86	3.76	6.78	0.69	2.11	5.27	0.01	0.03	0.08
0-5°	70.65	166.11	342.59	20.82	41.37	73.40	5.35	15.98	39.30	0.12	0.34	0.82
5-10°	79.90	186.25	381.70	36.20	71.34	125.88	6.00	17.75	43.36	0.20	0.59	1.41
10-15°	69.16	160.02	325.80	48.97	95.90	168.17	5.16	15.16	36.77	0.27	0.79	1.88
15-20°	52.70	122.16	249.02	58.02	113.69	199.57	4.00	11.77	28.62	0.32	0.93	2.23
20-25°	35.41	82.77	170.15	60.44	119.46	211.36	2.71	8.08	19.83	0.34	0.98	2.37
>25°	68.92	160.12	327.00	175.98	345.39	607.19	5.22	15.41	37.55	0.98	2.84	6.79
Totals	385.62	898.70	1840.83	402.29	790.90	1392.35	29.14	86.26	210.71	2.24	6.49	15.58

Table S2. Sensitivity of calculated global fish biomass and production (10^6 t) by body mass class to transfer efficiency, ‘all fish’ ‘includes teleosts and elasmobranchs.

g / TE	All fish biomass			All fish production			Elasmobranch biomass			Elasmobranch production		
	0.1	0.125	0.15	0.1	0.125	0.15	0.1	0.125	0.15	0.1	0.125	0.15
10^{-5} - 10^{-4}	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-
10^{-4} - 10^{-3}	6.34	11.01	17.31	36.10	62.55	98.18	-	-	-	-	-	-
10^{-3} - 10^{-2}	28.70	51.76	83.96	114.00	203.68	329.14	-	-	-	-	-	-
10^{-2} - 10^{-1}	41.10	78.43	133.38	94.10	178.61	302.55	-	-	-	-	-	-
10^{-1} - 10^0	51.80	104.95	187.70	68.60	138.33	246.36	-	-	-	-	-	-
10^0 - 10^1	57.00	123.31	232.66	43.70	94.11	176.80	-	-	-	-	-	-
10^1 - 10^2	54.90	127.08	253.81	24.40	56.13	111.60	-	-	-	-	-	-
10^2 - 10^3	46.50	115.91	245.81	11.92	29.61	62.50	0.10	0.25	0.54	0.02	0.05	0.10
10^3 - 10^4	39.44	106.26	240.50	5.76	15.46	34.82	4.84	13.31	30.56	0.62	1.71	3.91
10^4 - 10^5	34.64	100.61	242.31	2.95	8.52	20.43	11.94	34.65	83.13	1.00	2.87	6.87
10^5 - 10^6	25.37	79.38	203.37	1.25	3.91	9.97	12.27	38.05	96.47	0.60	1.86	4.70
Totals	385.78	898.70	1840.83	402.78	790.90	1392.35	29.14	86.26	210.71	2.24	6.49	15.58

Additional summaries of biomass and production estimates

The tables and figure in this section provide a more comprehensive analysis of the results presented in the main paper.

Table S3. Primary production (PP) by temperature zones. Temperature is the mean annual sea surface temperature (SST) and PP/FP and PP/EP are the ratios of phytoplankton production to all fish production (teleosts and elasmobranchs) and elasmobranch production respectively.

SST	area	area	PP	PP	PP	PP/FP	PP/EP
°C	10 ⁶ km ²	% of total	10 ¹⁰ t yr ⁻¹	g m ⁻² yr ⁻¹	% of total	ratio	ratio
-5-0°	5.03	1	0.24	485	1	648	78955
0-5°	25.24	7	2.27	900	5	549	66890
5-10°	29.04	8	3.68	1267	9	516	62827
10-15°	28.90	8	4.64	1604	11	483	58863
15-20°	39.15	11	5.57	1423	13	490	59692
20-25°	62.45	18	6.37	1020	15	533	64942
>25°	131.60	38	17.22	1309	42	499	60742
unaccounted	22.75	7	1.47		4		
Totals	344.15	100.	41.46		100		

Table S4. Potential production of fishes and other marine animals of >10⁻⁵ g body mass by temperature zone. Temperature is the mean annual sea surface temperature (SST), AB is all animal biomass, AP all animal production, FB is fish biomass (teleost and elasmobranch), FP is fish production, EB is elasmobranch biomass and EP is elasmobranch production

SST	AB	AB	AP	AP	FB	FB	FP	FP	F P:B	EB	EB	EP	EP	E P:B
°C	10 ⁶ t	g m ⁻²	10 ⁶ t yr ⁻¹	g m ⁻² yr ⁻¹	10 ⁶ t	g m ⁻²	10 ⁶ t yr ⁻¹	g m ⁻² yr ⁻¹		10 ⁶ t	g m ⁻²	10 ⁶ t yr ⁻¹	g m ⁻² yr ⁻¹	ratio
-5-0°	61.84	12.30	47.61	9.47	21.27	4.23	3.76	0.75	0.18	2.11	0.42	0.03	0.01	0.01
0-5°	484.48	19.19	523.74	20.75	166.11	6.58	41.37	1.64	0.25	15.98	0.63	0.34	0.01	0.02
5-10°	543.75	18.73	903.15	31.10	186.25	6.41	71.34	2.46	0.38	17.75	0.61	0.59	0.02	0.03
10-15°	467.49	16.17	1214.19	42.01	160.02	5.54	95.90	3.32	0.60	15.16	0.52	0.79	0.03	0.05
15-20°	356.23	9.10	1439.40	36.76	122.16	3.12	113.69	2.90	0.93	11.77	0.30	0.93	0.02	0.08
20-25°	241.03	3.86	1512.40	24.22	82.77	1.33	119.46	1.91	1.44	8.08	0.13	0.98	0.02	0.12
>25°	467.00	3.55	4372.92	33.23	160.12	1.22	345.39	2.62	2.16	15.41	0.12	2.84	0.02	0.18
Totals	2621.81		10013.40		898.70		790.90		0.88	86.26		6.49		0.08
Means		8.16		31.15		2.80		2.46			0.27		0.02	

Table S5. Estimated production and biomass by FAO areas. ‘Area’ is the total area of the FAO area, while ‘Area with output’ is the area for which valid ocean colour and temperature data were available (to allow estimation of biomass and production). Column codes are PP: primary production, FB: fish biomass, FP: fish production, EB: elasmobranch biomass, EP: elasmobranch production, all expressed as wet weight. There are slight discrepancies in the area of FAO areas reported here and by the FAO (e.g. Garibaldi & Limongelli 2007) that we attribute to differences in the coastline files used in the analyses.

FAO code	Area	Area 10 ⁶ km ²	Area with output 10 ⁶ km ²	Area with output % area	PP 10 ¹⁰ t yr ⁻¹	PP g m ⁻² yr ⁻¹	FB 10 ⁶ t	FB g m ⁻²	FP 10 ⁶ t yr ⁻¹	FP g m ⁻² yr ⁻¹	EB 10 ⁶ t	EB g m ⁻²	EP 10 ⁶ t yr ⁻¹	EP g m ⁻² yr ⁻¹	F P:B ratio
18	Arctic	7.49	0.98	13	0.11	1117.2	7.46	7.63	2.01	2.06	0.70	0.72	0.02	0.02	0.27
21	Northwest Atlantic	7.29	5.93	81	1.00	1680.8	42.54	7.17	21.07	3.55	3.89	0.66	0.17	0.03	0.50
27	Northeast Atlantic	14.22	9.26	65	1.48	1594.5	72.01	7.78	30.54	3.30	6.65	0.72	0.25	0.03	0.42
31	Western Central Atlantic	14.23	13.97	98	1.73	1241.1	20.54	1.47	34.84	2.49	1.95	0.14	0.29	0.02	1.70
34	Eastern Central Atlantic	14.06	13.77	98	1.90	1382.6	20.94	1.52	38.60	2.80	2.01	0.15	0.32	0.02	1.84
37	Mediterranean & Black Sea	2.71	2.61	96	0.44	1674.7	13.00	4.98	9.25	3.54	1.22	0.47	0.08	0.03	0.71
41	Southwest Atlantic	17.07	16.82	99	1.94	1154.8	43.98	2.62	37.19	2.21	4.29	0.26	0.31	0.02	0.85
47	Southeast Atlantic	18.36	18.16	99	2.12	1166.2	45.97	2.53	40.79	2.25	4.48	0.25	0.33	0.02	0.89
48	Atlantic, Antarctic	12.19	7.11	58	0.51	711.8	33.60	4.73	8.59	1.21	3.31	0.47	0.07	0.01	0.26
51	Western Indian Ocean	28.70	28.28	99	3.42	1208.7	49.45	1.75	67.06	2.37	4.79	0.17	0.55	0.02	1.36
57	Eastern Indian Ocean	30.97	30.57	99	3.76	1231.0	82.24	2.69	73.47	2.40	8.00	0.26	0.60	0.02	0.89
58	Indian Ocean, Antarctic & Southern	13.10	9.79	75	0.77	790.8	46.43	4.74	13.44	1.37	4.57	0.47	0.11	0.01	0.29
61	Northwest Pacific	20.81	19.75	95	2.81	1422.9	77.17	3.91	57.74	2.92	7.25	0.37	0.47	0.02	0.75
67	Northeast Pacific	7.77	7.04	91	1.22	1738.1	53.90	7.65	25.87	3.67	5.04	0.72	0.21	0.03	0.48
71	Western Central Pacific	32.14	31.51	98	4.31	1367.9	41.87	1.33	87.12	2.77	4.05	0.13	0.72	0.02	2.08
77	Eastern Central Pacific	48.17	47.17	98	6.05	1282.0	67.13	1.42	120.76	2.56	6.47	0.14	0.99	0.02	1.80
81	Southwest Pacific	27.29	26.65	98	2.89	1085.9	100.63	3.78	54.67	2.05	9.80	0.37	0.45	0.02	0.54
87	Southeast Pacific	30.52	29.92	98	3.43	1145.6	71.53	2.39	66.33	2.22	6.97	0.23	0.54	0.02	0.93
88	Pacific, Antarctic	9.48	2.14	23	0.10	477.9	8.29	3.87	1.56	0.73	0.82	0.38	0.01	0.01	0.19
-	(not assigned)	(4.41)	(3.69)	(84)	(0.56)	(1517.4)	(13.6)	(3.68)	(11.51)	(3.12)	(1.27)	(0.35)	(0.09)	(0.03)	(0.85)
	Totals	356.58	321.41	90	39.99		898.70		790.90		86.26		6.49		

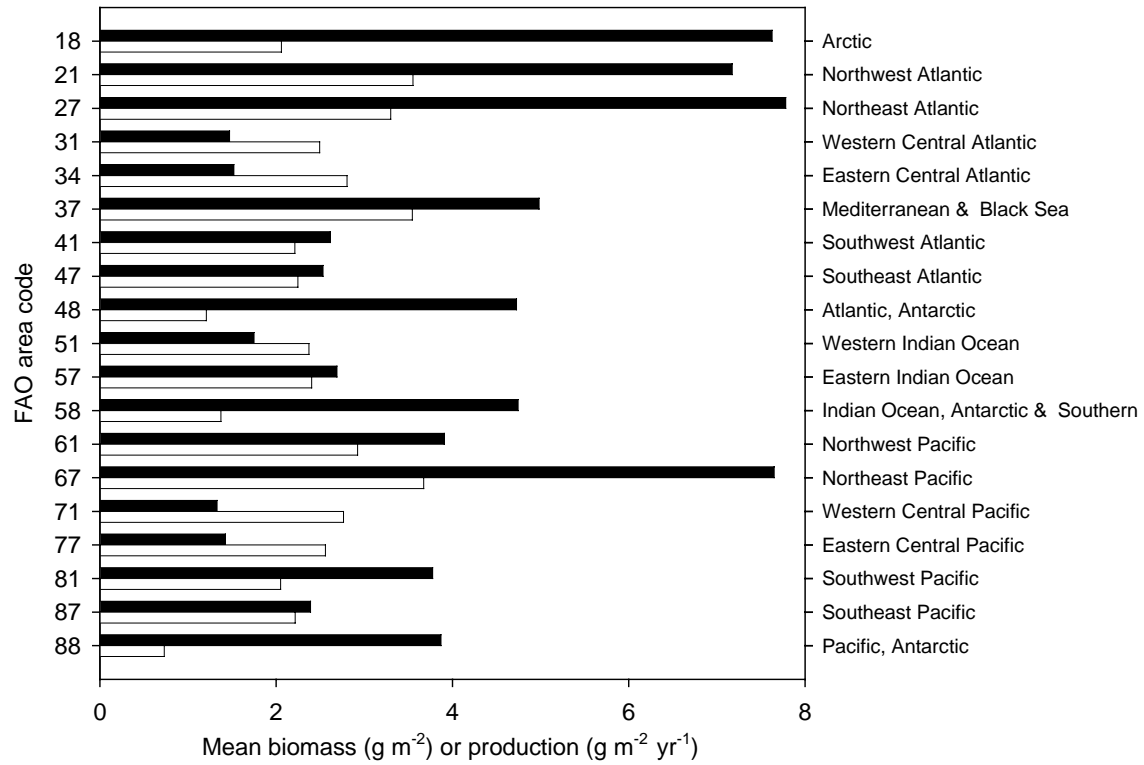


Figure S3. Potential biomass (black bars) and production (white bars) of fishes in FAO fishing areas (see also Supplementary table S5)

Assumptions of our analyses

The paper identified a number of assumptions that were required to complete this analysis. These were (1) that phytoplankton production supports all other production, (2) that phytoplankton production supports production at higher trophic levels in the same grid cell, (3) that surface temperatures reflect the temperature experience of the biota in the water column, (4) that all predation and energy transfer is size-based, (5) that the proportion of fish and elasmobranchs in at least one (unfished) size class is known, (6) that all teleosts and elasmobranchs enter the size spectrum in a single body mass class and (7) that a simple relationship between growth rate and mortality adequately captures changes in abundance of teleosts and elasmobranchs with size. The acceptability of these assumptions and their effects on the analysis are described below.

1. Phytoplankton are the main contributors to total marine primary production. Duarte & Cebrián (1996), for example, estimated that oceanic phytoplankton accounted for 88% of total marine primary production and coastal phytoplankton for 6.5%. The other 5.5% of primary production is contributed by microphytobenthos, coral reef algae, macroalgae, seagrasses, marsh plants and mangroves. These contributions support coastal and coral reef food webs and were all ignored in our analysis, suggesting that we will have underestimated animal biomass and production in these areas. It is also likely that highly-localised sources of non-phytoplankton production, coupled with the transport of zooplankton production from large areas of ocean over reef areas (Hamner *et al.* 1988), account for the very high rates of fish production that have been recorded on small areas of reef (Polunin 1996).

2. The calculation of fish production at the scale of 36×36 km is clearly unrealistic, both because the primary production in this small area is insufficient to sustain viable populations of the largest fishes

and because animals of different sizes move on different scales (Jetz *et al.* 2004). For these reasons, it is preferable to sum or average potential production for the larger size classes of animals over the scales on which they move. This is best achieved at the scale of ecologically defined areas such as the temperature zones or FAO areas, although it is desirable to process the data at smaller scales to account for small scale spatial variation in the size distribution of primary producers and hence in food chain length.

3. Surface temperatures were used as a proxy for the temperatures at which production occurred because global records of subsurface temperatures were not available at the appropriate scales and the distribution of production in relation to subsurface temperatures was not known. A large proportion of primary production does occur in the mixed layer above the thermocline, or on the boundary between mixed and stratified waters, but production at higher trophic levels can take place in both areas and many of the animals responsible will move between distinct temperature zones on a daily basis (e.g. McLaren 1963; Musyl *et al.* 2003). Even in apparently mixed waters fish show complex behaviour in relation to localised gradients in temperature and ‘mean’ temperatures do not reflect the temperatures to which they are exposed (Neat & Righton 2007). Our assumption of continuous exposure to sea surface temperatures will lead to overestimates of individual biomass production and mortality, as surface waters are almost always warmer than the deeper waters. However, temperature gradients are strong and variable in the upper 200- 300m of the water column and we did not consider that a generic correction could be applied. Biomass and production by species that remain permanently in deeper waters, where temperatures are relatively uniform (2-2.5°C for high latitudes and for mid and low latitudes below approximately 2000m depth; Knauss 1997), are expected to make a small contribution to global biomass and production. For example, the biomass of many pelagic and benthic groups decreases rapidly with depth, typically falling 5 fold or more within 1000m (Angel & Baker 1982; Lampitt *et*

al. 1986). Merrett & Haedrich (1997) report biomass estimates for bottom dwelling fishes at depths of 1000-5000m in the eastern North Atlantic of only 10^{-4} to 3×10^{-3} g m⁻² and elasmobranchs are believed to be absent from areas deeper than 3000m (Priode *et al.* 2006), even though the average depth of the oceans is 3700m. Refinements to our approach could involve estimation of fluxes from surface waters to deeper areas, to predict the relative abundance and production of pelagic and bottom-dwelling species at different depths.

4. Our models assume that all transfers of energy are size-based and that a mean PPMR describes predator-prey interactions. More sophisticated treatments could account for any interplay between PPMR and TE across the size spectrum, although existing understanding suggests that this would be compensatory given the stability of the slopes of size spectra in many different systems (Boudreau & Dickie 1992). Transfer efficiency provides a convenient summary of feeding and growth related processes that have also been explicitly modelled (Dickie *et al.* 1987; Moloney *et al.* 1991; Shin & Cury 2001; Pope *et al.* 2006; Hall *et al.* 2006; Anderson & Beyer 2006; Maury *et al.* 2007) and TE is relatively constant in diverse food webs (Christensen & Pauly 1993; Ware 2000). Temperature increases have a small or undetectable effect on PPMR or TE, and hence on the slope of the size spectrum, but they increase rates of energy flux because individuals of any given size will have higher rates of metabolism and thus increased rates of production, mortality and consumption. The mean PPMR also ignores large predators such as marine mammals, basking sharks (*Cetorhinus maximus*) and whale sharks (*Rhincodon typus*) that feed directly on zooplankton ($\mu=8-10$) and effectively remove production that would otherwise enter the longer size-based food chain. The whales, especially, have been greatly depleted by fishing (Allen 1980), but in unexploited ecosystems they may have diverted a considerable proportion of the energy from other parts of the food web. Seabirds are also significant consumers of small pelagic fishes and krill that might otherwise be

available to larger fish predators. Brooke (2004) estimated their consumption as 6.98×10^7 t yr⁻¹, similar to the 2002 global fish catch of 8.45×10^7 t. In the context of the theory we have used, birds and marine mammals could reasonably fill other parts of the size spectrum not occupied by fishes. It would be valuable to understand why birds and mammals dominate some parts of the size spectrum and the advantages or disadvantages conferred by their life histories.

5. One of the greatest sources of uncertainty in the analysis was the prediction of ratios between fish biomass and total biomass in size class $10^{0.05}$ g and between epipelagic or coastal elasmobranch biomass and total biomass in size classes $10^{4.05}$ and $10^{2.95}$ respectively. The data to predict fish biomass as a proportion of total biomass in a given small size class are limited by the lack of studies that have systematically measured the biomass of all animals in a given size window. Data to predict elasmobranch biomass as a proportion of total biomass are available but, with a few notable exceptions (e.g. Friedlander & DeMartini 2002), reflect abundances in disturbed (fished) food webs. The values used in this analysis are principally used to indicate how the method might be applied, but the errors introduced by wrongly specifying the values are smaller than those associated with plausible changes in the values of parameters which we can estimate more reliably (e.g. see sensitivity analyses for predator-prey body size ratios). For example, if a range of values from 0.3 to 0.7 is considered realistic for the contribution of fish to total biomass in size class $10^{0.05}$ g, this would result in fish biomass (summed across the range of body mass classes in which fish are found) varying from 25-58% of total biomass and fish production varying from 15-34%. One remarkable aspect of trying to uncover data for this analysis was the rarity with which the faunal composition of complete sampled is described. Thus scientists with different taxonomic affiliations tend to sort 'their' taxon from the samples and disregard the remaining animals.

6. We ‘introduced’ teleosts and elasmobranchs to the size spectrum at mean sizes of eggs or offspring. This approach could be refined to allow for the introduction of groups defined by a distribution of egg or offspring sizes or to allow for changes in egg sizes with environmental parameters (Chambers 1997).

7. The biomass of animals predicted by the size spectrum will include zooplankton, cephalopods, marine mammals and other groups. The theory to identify the contribution of these groups to the overall spectrum is not well developed. For fish, we explored an approach based on assumptions about the role of life history where we used an approximation to describe reduced mortality at size in animals with larger maximum size. While larger species must have lower mortality rates than smaller species to achieve 1:1 replacement, our approximation summarises two processes that could be partitioned in future work. First, the reduced rate of mortality for larger species; as would be assessed at the level of the population. Second, the reduction and reversal in the relative growth advantage in larger size classes as other groups with larger asymptotic size (in this case elasmobranchs taking over from teleosts) become more abundant; a community level process that depends on the distribution of life histories of component populations with body size. The shape of the function we used to capture these two processes has no rigorous ecological basis, since we could not have parameterised anything that accounted for both within and among species processes at a global scale, but the principle of the approach would allow the contribution to any subset of animals to the size spectrum to be assessed. Our treatment of the size-spectrum does not discriminate population and community level processes. This simplifies parameterisation, but does mean that scalings among populations have to be assumed to apply among individuals and populations. This is a widely accepted, and in some cases validated (Schwinghamer *et al.* 1986), approach, but biases are introduced and need to be quantified (Jennings *et al.*, 2007). Further research could also quantify the absolute rate of change in the composition of life

histories (measured as asymptotic size) of component groups with size and explore the relationships between asymptotic size and rates of mortality for all species that might contribute to the spectrum.

Predicted and known fish production

Current global catches are $\approx 0.3 \text{ g m}^{-2} \text{ yr}^{-1}$ (calculated from FAO landings data at <http://www.fao.org/fishery/statistics> and areas given in table S5). We estimated average global unexploited fish biomass for fishes heavier than 10g as 1.65 g m^{-2} . If maximum sustained yield could be attained at 60% of this biomass, with production amounting to 30% of the reduced biomass, then this equates to a sustainable catch of $\approx 0.3 \text{ g m}^{-2} \text{ yr}^{-1}$. Of course, sustainable exploitation of the entire fish community relies on cropping production in proportion to productivity. This is not observed in practice. Thus large resources of widely dispersed small fish are often almost unfished while more accessible species are often overexploited.

While the generality of our approach is valuable for making global predictions, the approach will need to be developed to provide consistent and reliable predictions at regional scales. In the Eastern Boundary Currents for example, and especially in the Humboldt current, the model underestimates cell sizes in the phytoplankton community, overestimates mean food chain length and underestimates potential fish biomass. Catches from the Humboldt current can average around $30 \text{ g m}^{-2} \text{ yr}^{-1}$ (depending on the measurement of productive area, e.g. Carr 2002, Carr & Kearns 2003), but the fish biomass we calculated would not sustain these. To address regional inconsistencies such as this, we need to reconsider the whether the factors affecting the size distribution of phytoplankton cells are adequately captured by this model in all regions and/ or account for any regional variation in predator-prey mass ratios and transfer efficiency.

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