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Supplementary Information for

Global warming is causing a more pronounced dip in marine species richness around the equator

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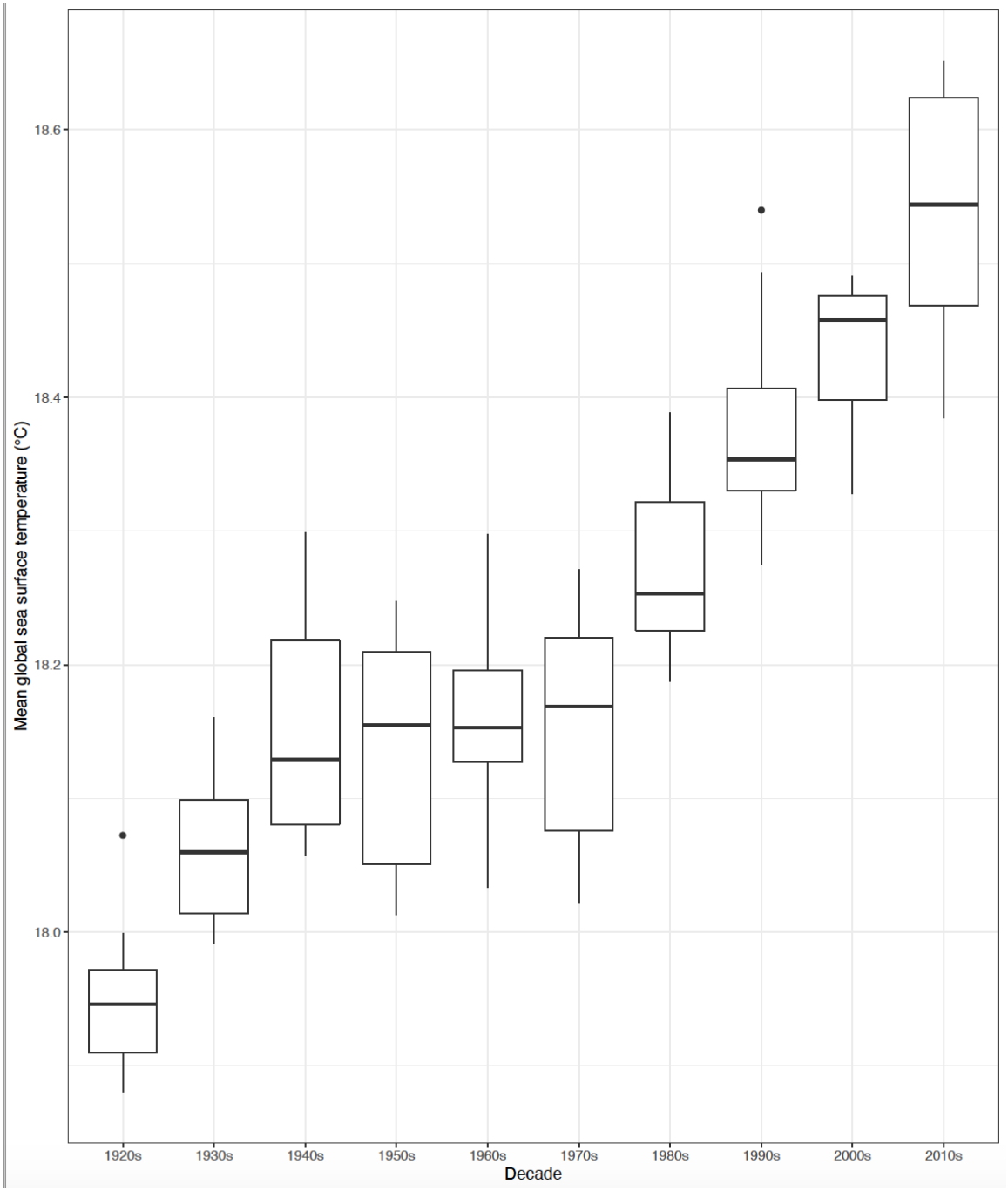


Fig. S1. Time series plot of SST (°C) averaged across 5° latitudinal bands in each decade (n= 34). The 25th and 75th percentiles are indicated by the lower and upper boundaries of the boxes, respectively. The black line inside the boxes represents the medians. The points outside the boxes are outliers.

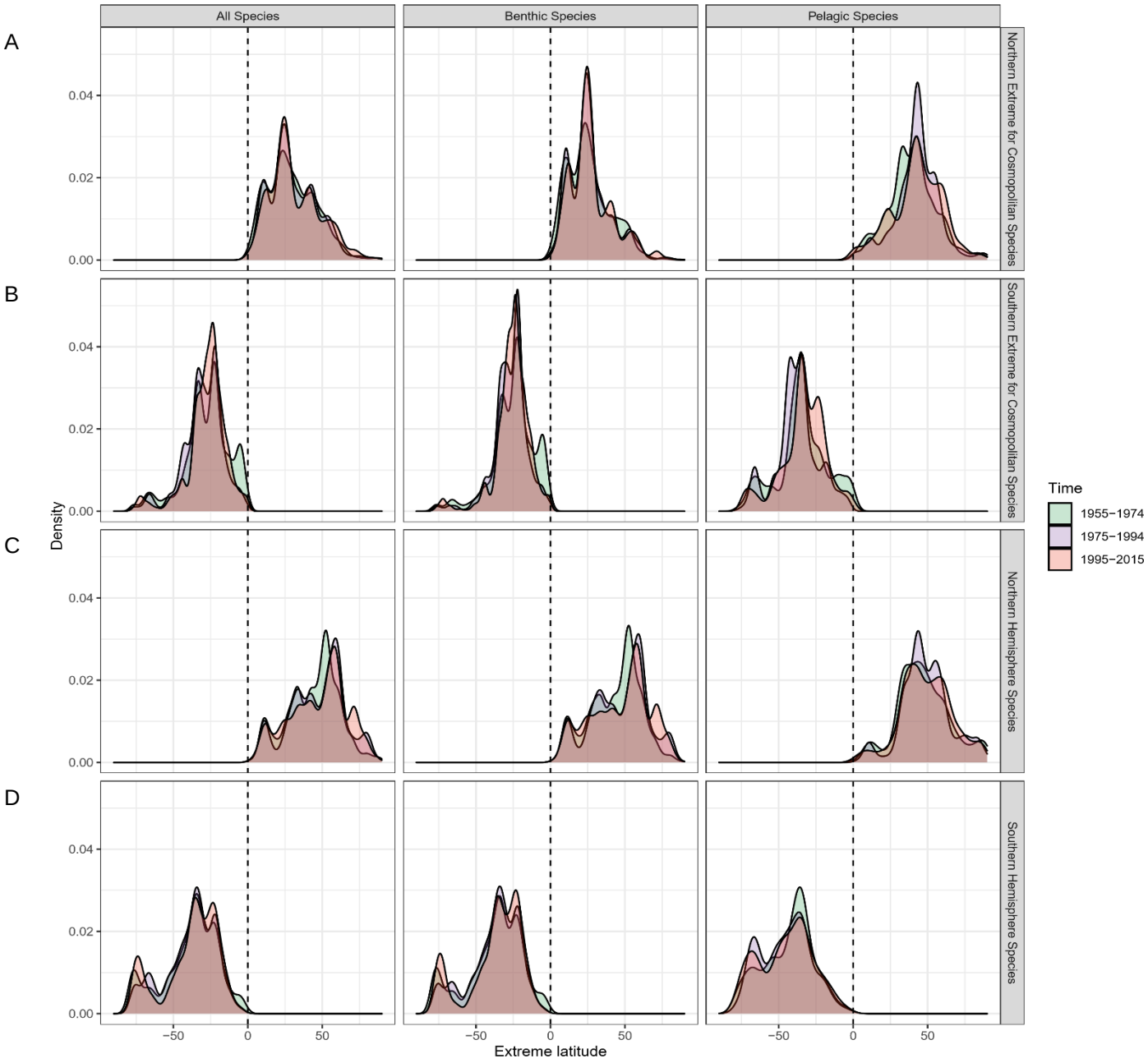
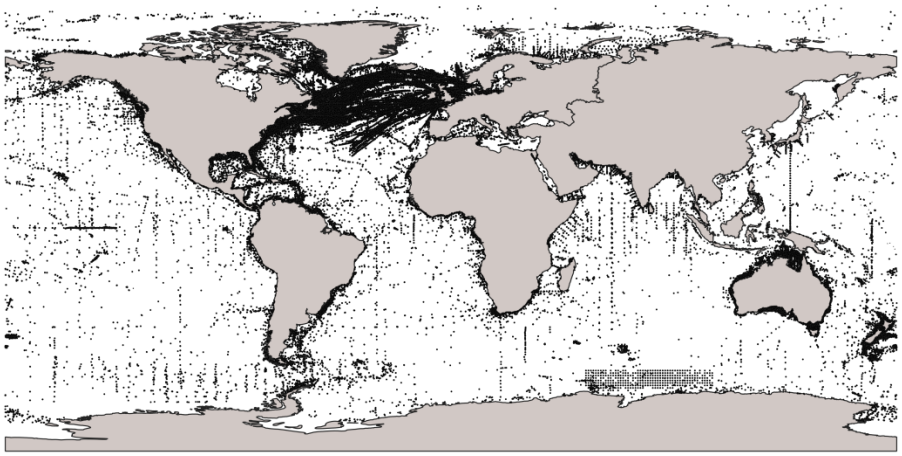
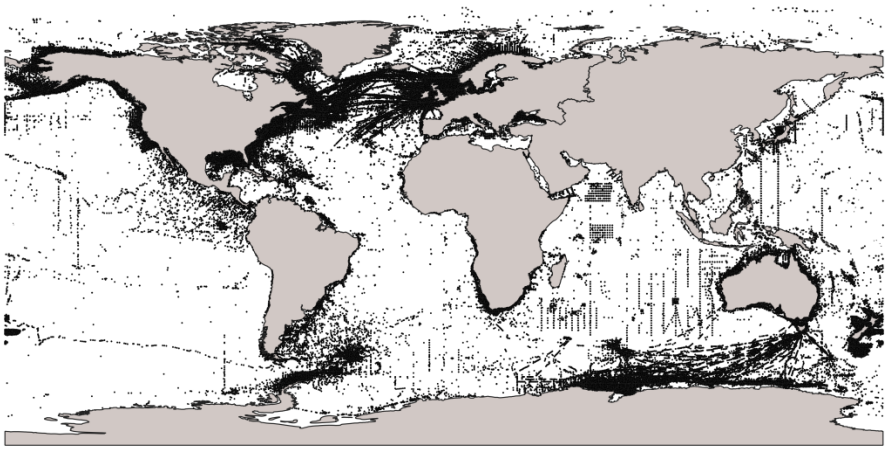


Fig. S2. Comparison of density plots of the extreme latitudes of observation records in three time periods (1955—1974, 1975—1994, 1995—2015) of cosmopolitan species found in both the hemispheres, with (A) their extreme northern latitude and (B) their extreme southern latitude illustrated, and species found predominantly in the (C) northern hemisphere and (D) southern hemisphere. Species were classified as northern and southern, when >=75% of observations fell in one hemisphere or the other; the remaining species were classified as cosmopolitan. Note: this comparison was based on species common to all three time periods.

A 1955 to 1974



B 1975 to 1994



C 1995—2015

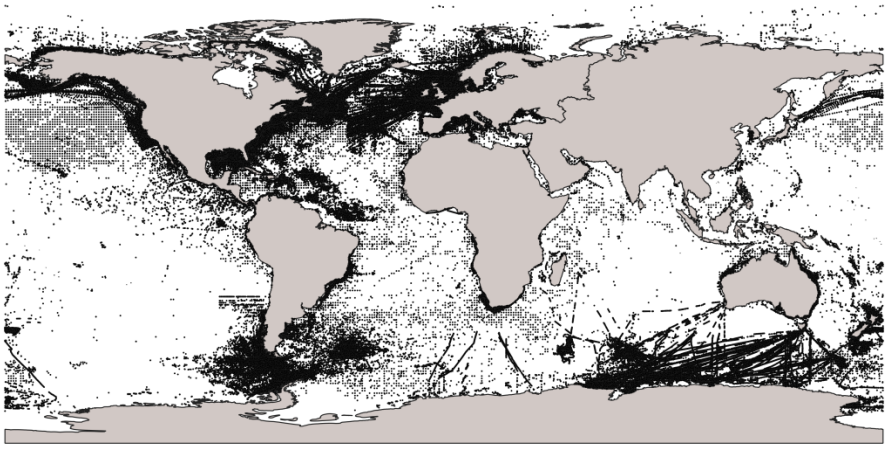


Fig.S3. Sampling coverage (black dots) in the time period: (A) 1955—1974, (B) 1975—1994 and (C) 1995—2015.

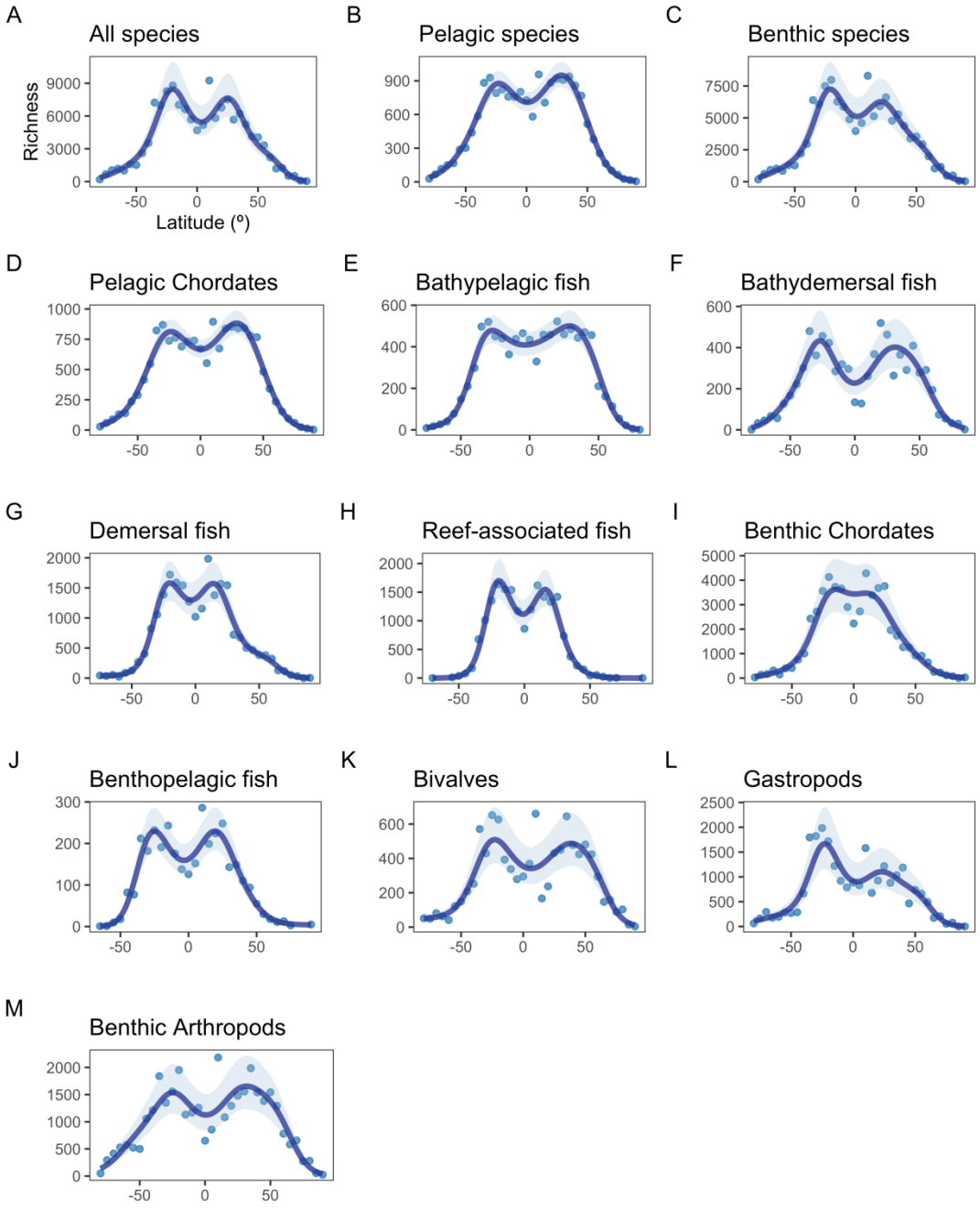


Fig. S4. The latitudinal distribution of species richness in marine taxa at the scale of 5° latitudinal bands based on the GAMs (the effect of Latitude adjusting for shelf area), where the degree of smoothness for each parameter was estimated using generalised cross validation, for (A) All species; (B) Pelagic species; (C) Benthic species; (D-E) organisms in the pelagic environment; and (F-M) organisms living near, on or in the seabed. The shaded region in each graph shows the ±95% confidence envelope for the fit.

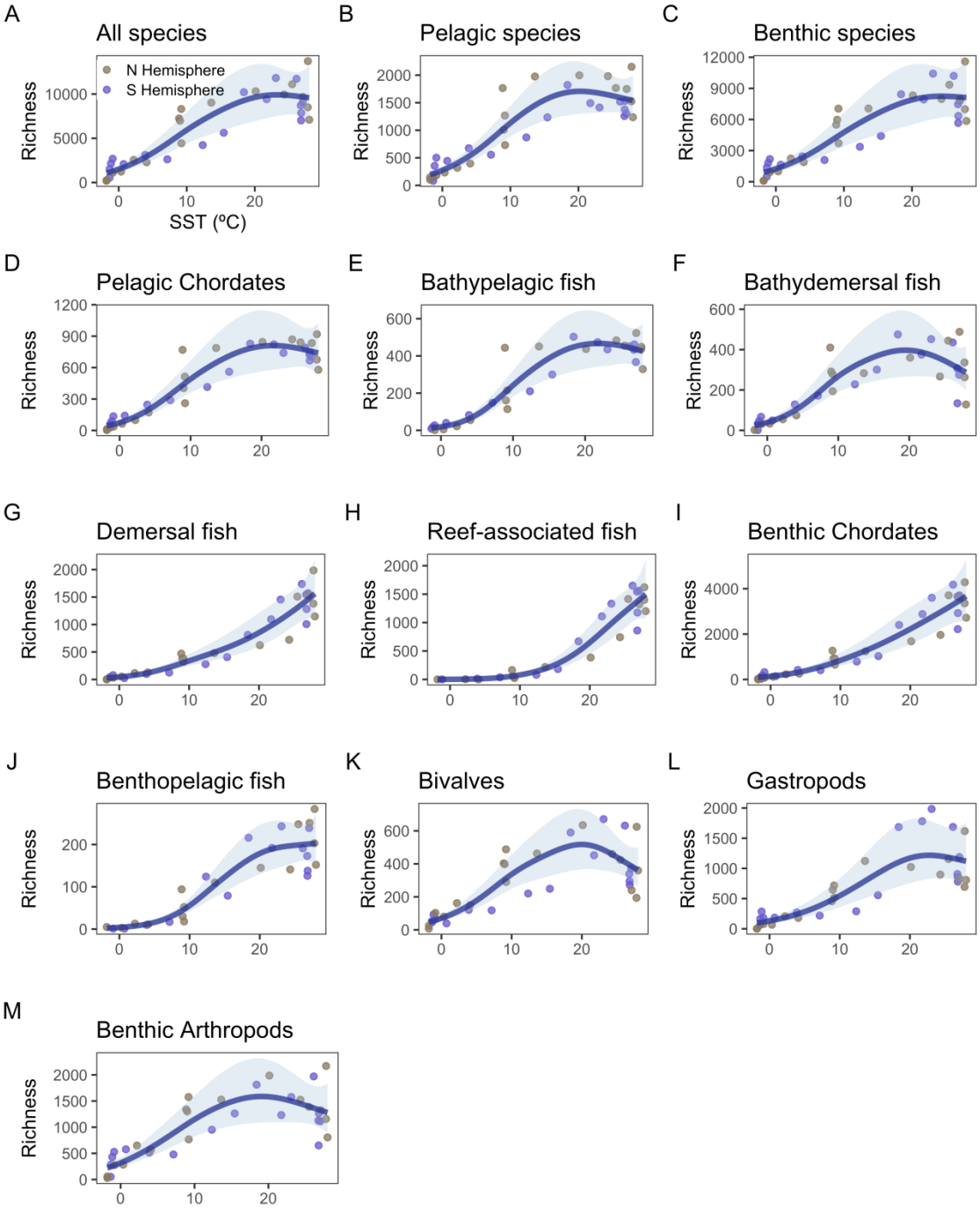


Fig. S5. The relationship between species richness and sea surface temperature (SST) based on the GAMs, where the degree of smoothness for each parameter was estimated using generalised cross validation, for (A) All species; (B) Pelagic species; (C) Benthic species; (D-E) organisms in the pelagic environment; and (F-M) seabed associated organisms. The shaded region in each graph shows the ±95% confidence envelope for the fit.

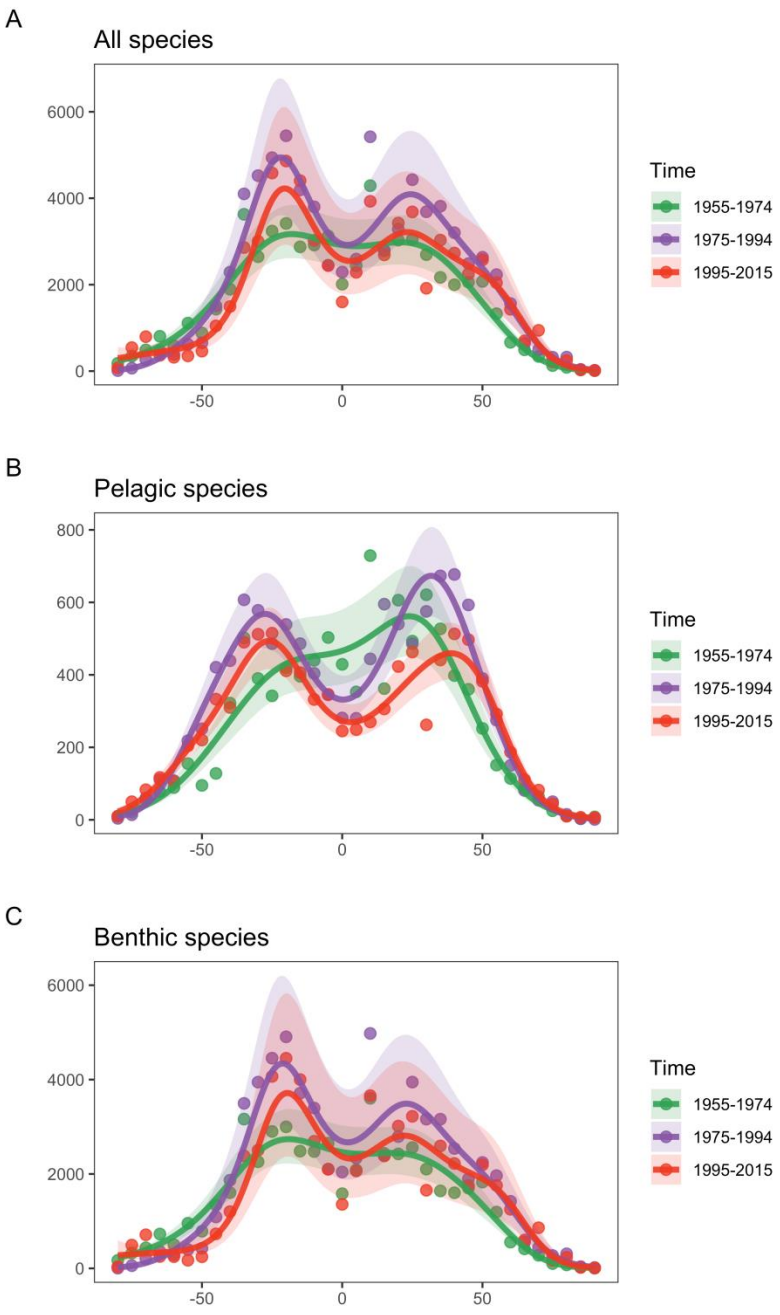


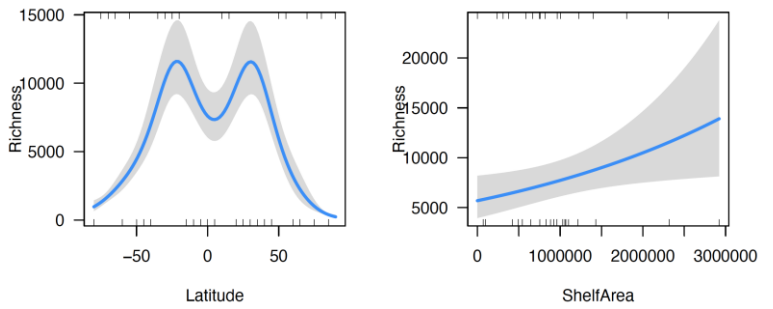
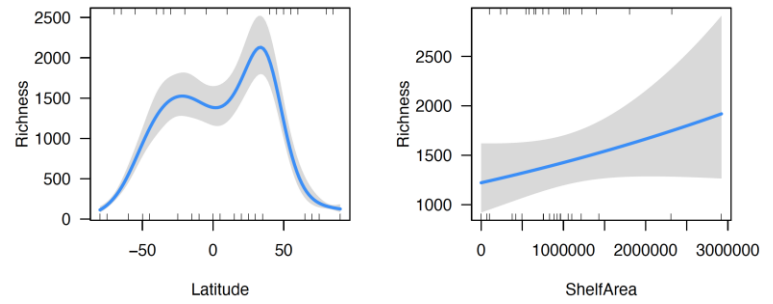
Fig. S6. Latitudinal distribution in species richness using GAMs (the effect of Latitude adjusting for shelf area in each 5° latitudinal band), where the degree of smoothness for each parameter was estimated using generalised cross validation, for (A) All species, (B) Pelagic, and (C) Benthic species in three time periods: 1955—1974 (green), 1975—1994 (purple), and 1995—2015 (red). Shaded regions represent ±95% confidence envelopes for models fit to each of the periods, with shades (from green to red) reflecting progression of time periods from older to more recent.

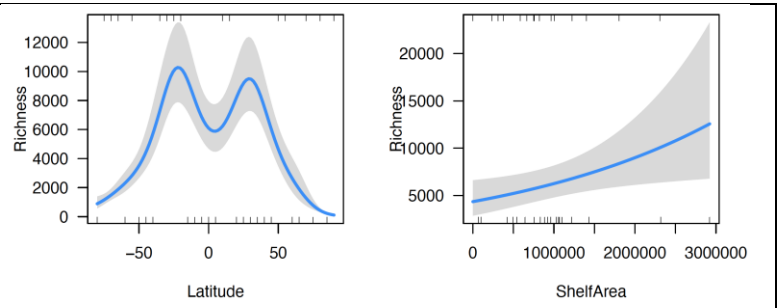
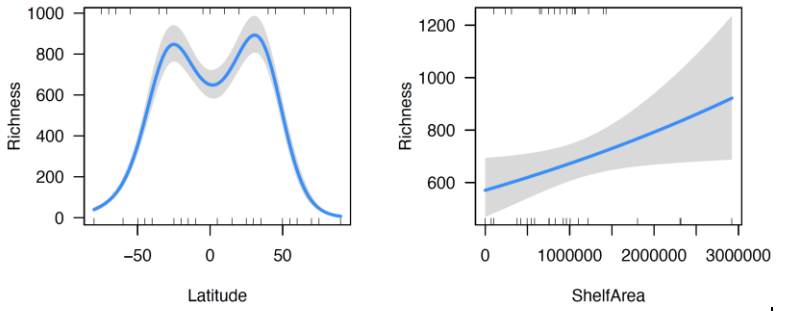
Table S1. Examples of explanations given for the latitudinal gradients in marine species richness in the literature, listed chronologically.

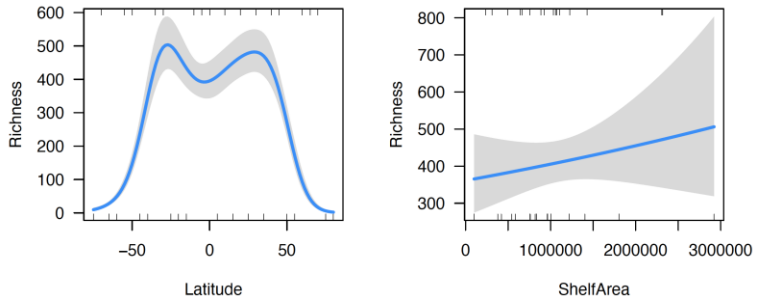
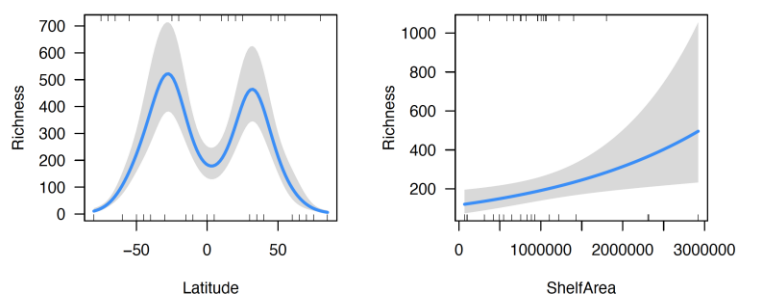
Study	Taxa (species)	Region	Explanation
Rex et al. (1)	Deep-sea benthos (97 epibenthic sled samples)	Atlantic	Seasonal sinking of organic matter (availability of food)
Bolton (2)	Seaweeds (> 1,700)	Global	Climate and historical events
Flessa and Jablonski (3)	Bivalves (600 genera)	Global	Mass extinction
Roy et al (4)	Marine prosobranch gastropods (3,916)	Western Atlantic and eastern Pacific Ocean from the tropics to the Arctic	Sea surface temperature (SST)
Rutherford et al. (5)	Planktonic foraminifers (33)	Global	Temperature variation with depth
Roy et al. (6)	Bivalves (930)	North-eastern Pacific marine shelf	SST
Crame (7)	Marine bivalves (29)	Global (shallow water)	Productivity
Rex et al. (8)	Deep-sea benthos (isopods, gastropods, and bivalves) (93)	North Atlantic	Seasonal sinking of organic matter (availability of food)
Culver and Buzas (9)	Benthic foraminifera (< 25)	Atlantic Ocean (Norwegian Sea to the Weddell Sea)	Ecological and historical factors related to food supply
Willig (10)	Crustaceans, molluscs, corals, brachiopods, foraminifers, vascular plants, mammals, birds, reptiles, amphibians, fish, tunicates (review)	The coastal areas of North and South America	Geographic area, evolutionary speed, Rapoport effect, and geographic constraint
Macpherson (11)	Fish and invertebrates (6,643)	Atlantic Ocean	SST (best predictor for benthic taxa) and nitrate concentration (pelagic taxa)
Woodd-Walker et al. (12)	Copepod diversity (47 genera)	Atlantic Ocean	Temporal patterns of primary and secondary production
Connolly et al. (13)	Reef corals (727) and associated reef fish (1,766)	IWP	Geographic constraints, environmental variables, speciation, and extinction
Mora et al. (14)	Reef fish (1,970)	Indian and Pacific oceans	Dispersal
Valdovinos et al. (15)	Marine molluscs (629)	Pacific South American shelf	Shelf area
Gage et al. (16)	Cumacea (225)	Atlantic	Biogeography
Witman et al. (17)	Marine benthic communities (> 3,000)	Global	Colonisation
Gratwicke and Speight (18)	Caribbean fish (530)	South shore of Tortola	Habitat complexity
Rex et al. (19)	Benthic molluscs (189)	Global	Nutrient input
Worm et al. (20)	Tuna and bill fish (145)	Global	Thermoregulation, dissolved oxygen, and temperature
Brayard et al. (21)	Foraminifers (33)	Atlantic Ocean	SST and sea surface current
Dolan et al. (22)	Tintinnids (30)	Global	Food resources
Kerswell (23)	Benthic marine micro algae and Bryopsidales (191)	Global	Competition among corals and variation in speciation and extinction
Fuhrman et al. (24)	Planktonic marine bacteria (103 samples, 1,129 genotypes)	Global (57 locations, coastal and deep sea)	SST
Rombouts et al. (25)	Marine copepod diversity (~70)	Global	Ocean temperature, salinity,

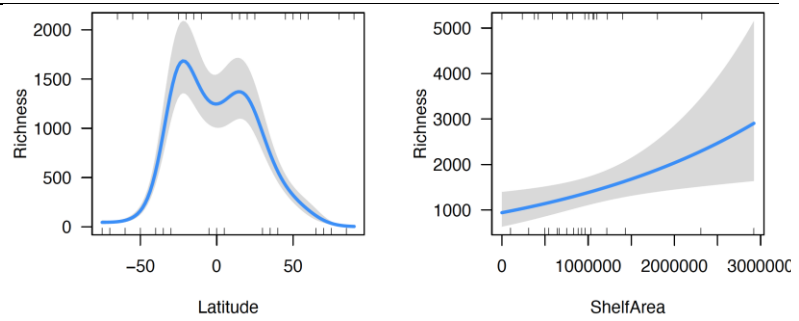
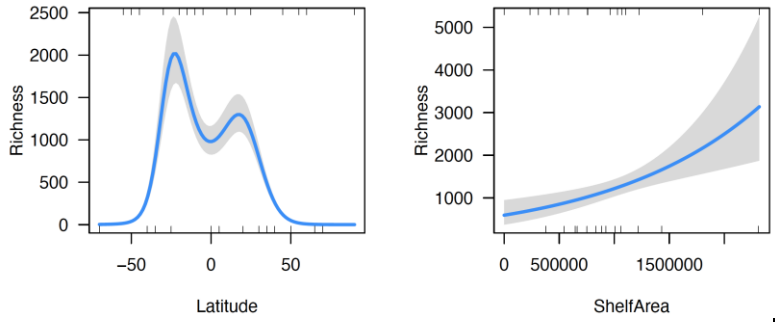
			and energy (Chlorophyll a)
Tittensor et al. (26)	Fish and sharks (coastal and oceanic), cephalopods, corals, pinnipeds, euphausiids, foraminifers, cetaceans, mangroves (11,567)	Global	SST
Kaschner et al. (27)	Marine mammals (115)	Global	Global warming (temperature)
Beaugrand et al. (28)	Foraminifers and copepods (~70)	Global	Thermal tolerance and fluctuation in temperature and season, Mid Domain Effect (MDE), and niche space
Saeedi et al. (29)	Solenidae (~60)	Global	SST

Table S2. Information on the full GAM models for Figure 1.

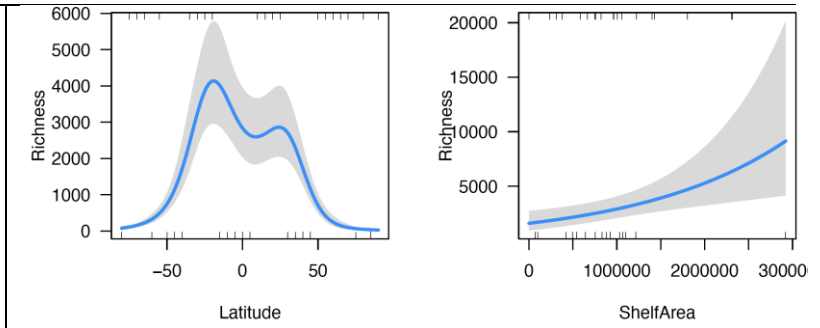
Group	Model summary	Plots
All	Family: Negative Binomial(17.38) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 8.083e+00 1.293e-01 62.488 <2e-16 *** ShelfArea 3.058e-07 1.338e-07 2.284 0.0223 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 639 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.847 Deviance explained = 94.4% -REML = 308.79 Scale est. = 1 n = 35	
Pelagic species	Family: Negative Binomial(30.955) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 6.517e+00 1.012e-01 64.411 <2e-16 *** ShelfArea 1.546e-07 1.047e-07 1.477 0.14 --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 801 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.905 Deviance explained = 96.1% -REML = 242.8 Scale est. = 1 n = 35	

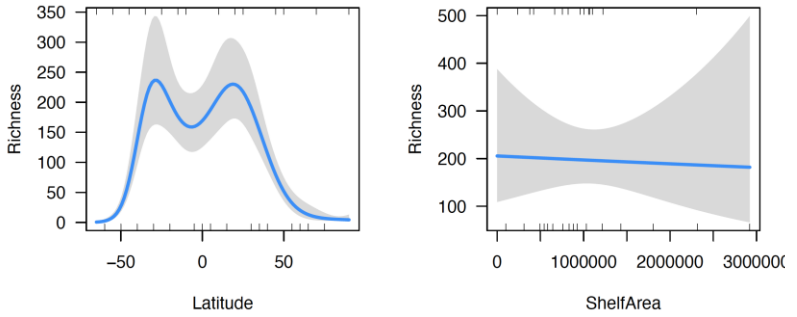
Benthic species	Family: Negative Binomial(13.164) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.812e+00 1.488e-01 52.51 <2e-16 *** ShelfArea 3.633e-07 1.539e-07 2.36 0.0183 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 548.5 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.831 Deviance explained = 93.2% -REML = 304.54 Scale est. = 1 n = 35	
Pelagic chordates	Family: Negative Binomial(102.859) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.505e+00 7.635e-02 72.11 <2e-16 *** ShelfArea 1.642e-07 7.709e-08 2.13 0.0332 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 1817 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.963 Deviance explained = 98.9% -REML = 197.86 Scale est. = 1 n = 35	

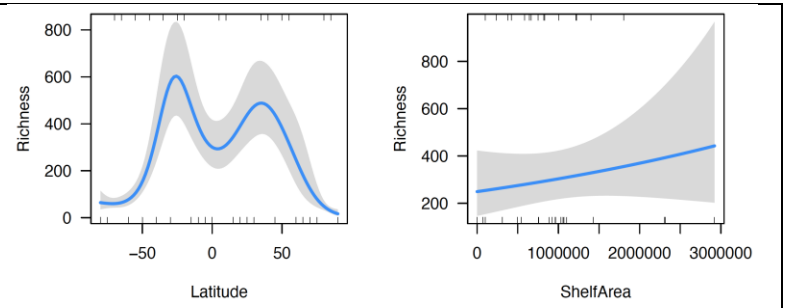
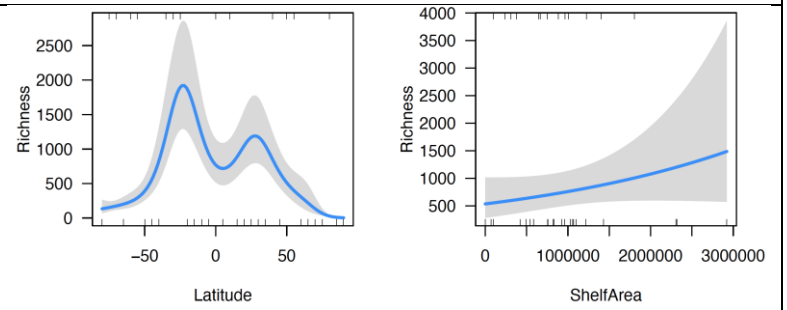
Bathypelagic fish	Family: Negative Binomial(66.802) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 4.920e+00 1.317e-01 37.346 <2e-16 *** ShelfArea 1.154e-07 1.253e-07 0.921 0.357 --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 995.6 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.949 Deviance explained = 98.6% -REML = 166.97 Scale est. = 1 n = 32	
Bathydemersal fish	Family: Negative Binomial(10.303) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 4.533e+00 1.911e-01 23.720 < 2e-16 *** ShelfArea 4.945e-07 1.881e-07 2.629 0.00855 ** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 294.1 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.785 Deviance explained = 89.7% -REML = 195.22 Scale est. = 1 n = 34	

Demersal fish	Family: Negative Binomial(20.49) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.309e+00 1.511e-01 35.139 <2e-16 *** ShelfArea 3.855e-07 1.498e-07 2.573 0.0101 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 1039 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.932 Deviance explained = 97% -REML = 212.09 Scale est. = 1 n = 34	
Reef-associated fish	Family: Negative Binomial(44.303) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 4.533e+00 2.040e-01 22.225 < 2e-16 *** ShelfArea 7.180e-07 2.048e-07 3.506 0.000454 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 1562 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.97 Deviance explained = 99% -REML = 160.1 Scale est. = 1 n = 28	

Benthic chordates	Family: Negative Binomial(8.386) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 6.067e+00 1.918e-01 31.630 < 2e-16 *** ShelfArea 5.950e-07 1.980e-07 3.005 0.00266 ** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 626.9 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.879 Deviance explained = 93.5% -REML = 258.51 Scale est. = 1 n = 35
Benthopelagic fish	Family: Negative Binomial(13.414) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 4.089e+00 2.597e-01 15.744 <2e-16 *** ShelfArea -4.181e-08 2.681e-07 -0.156 0.876 --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 298.9 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.839 Deviance explained = 95.1% -REML = 143.94 Scale est. = 1 n = 30





Bivalves	Family: Negative Binomial(8.783) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.159e+00 1.894e-01 27.238 <2e-16 *** ShelfArea 1.965e-07 1.959e-07 1.003 0.316 --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 230.5 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.748 Deviance explained = 87.9% -REML = 211.88 Scale est. = 1 n = 35	
Gastropods	Family: Negative Binomial(5.844) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.671e+00 2.314e-01 24.506 <2e-16 *** ShelfArea 3.492e-07 2.388e-07 1.462 0.144 --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 267.6 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.737 Deviance explained = 88.5% -REML = 239.23 Scale est. = 1 n = 35	

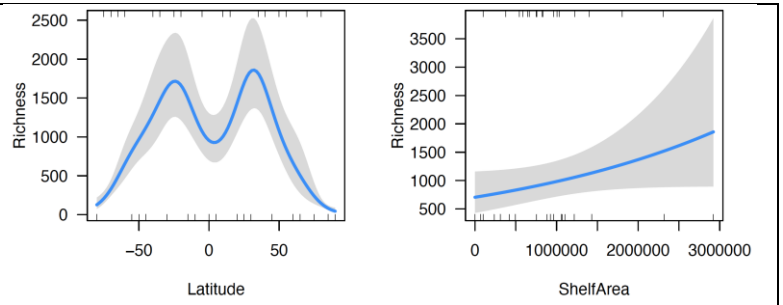
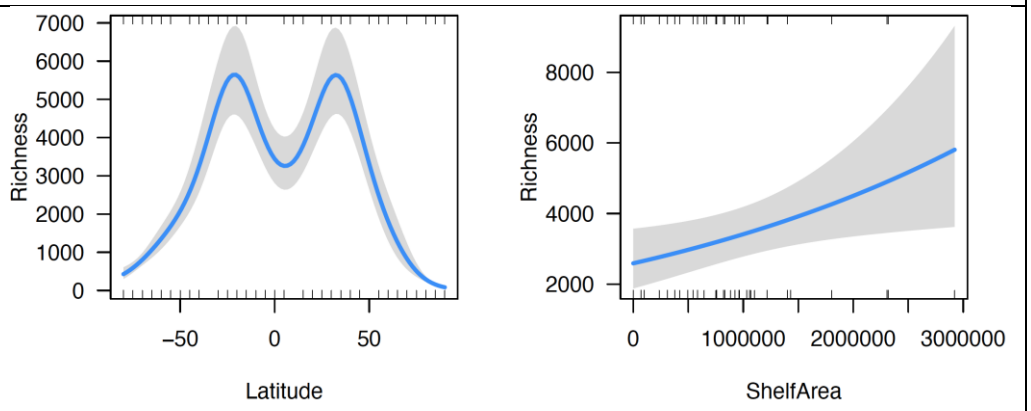
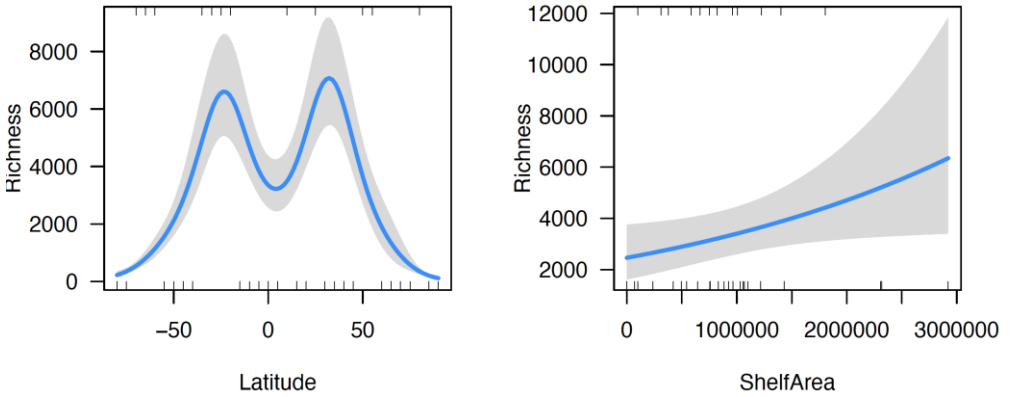
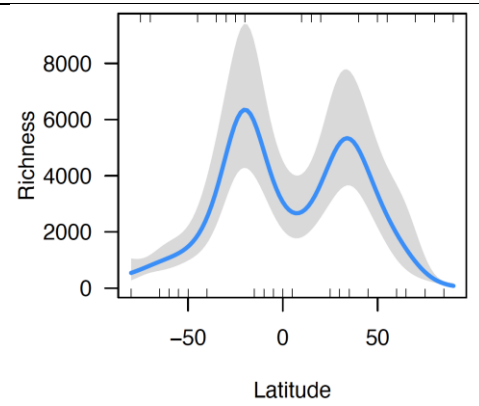
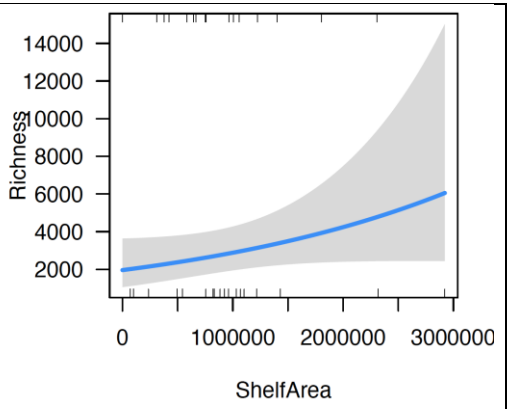
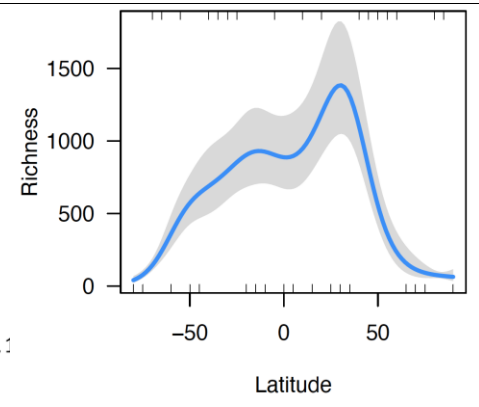
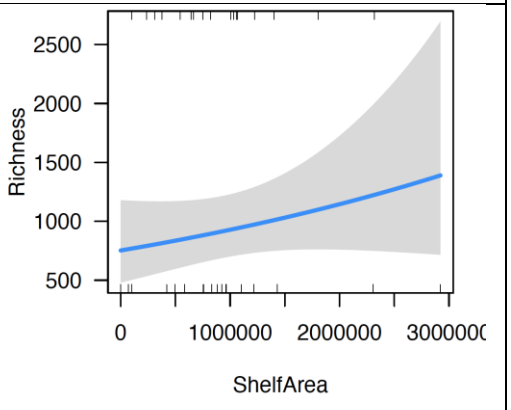
Benthic arthropods	Family: Negative Binomial(9.534) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 6.308e+00 1.766e-01 35.710 <2e-16 *** ShelfArea 3.313e-07 1.827e-07 1.813 0.0698 . --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 268.2 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.685 Deviance explained = 87.8% -REML = 254.76 Scale est. = 1 n = 35	

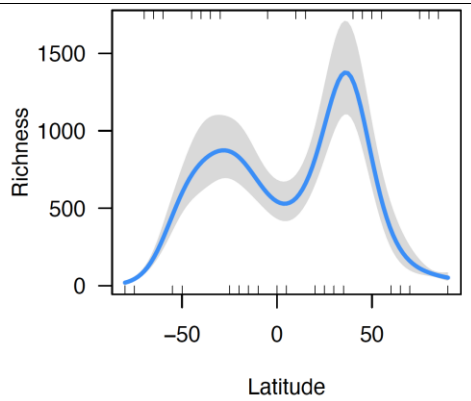
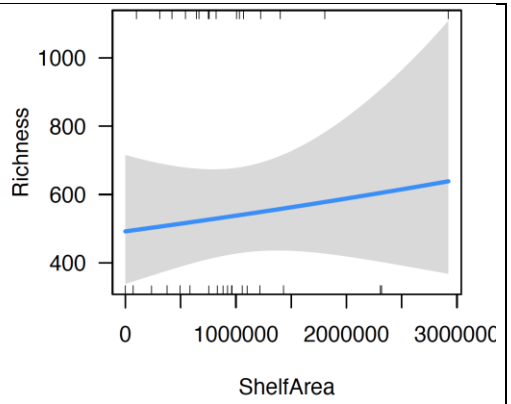
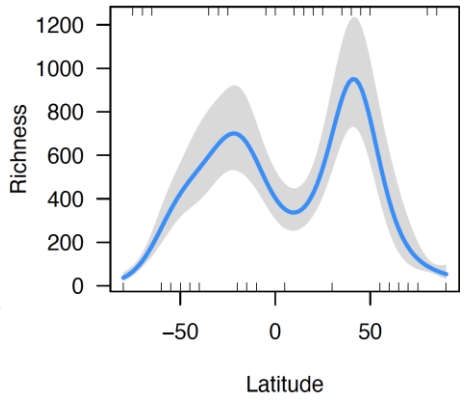
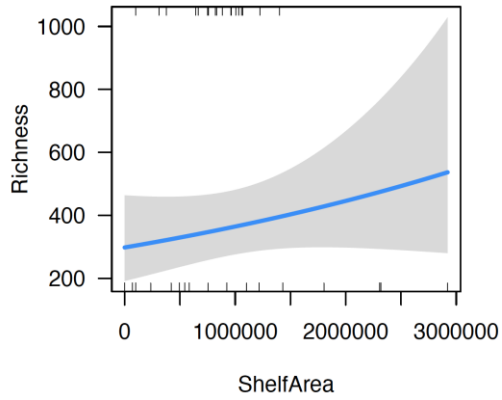
Table S3. Summary of GAM results obtained from the model of species richness as a function of SST (Figure 2). All models were significant with P < 2e-16, edf = 4, Ref.df = 4, scale estimate = 1.

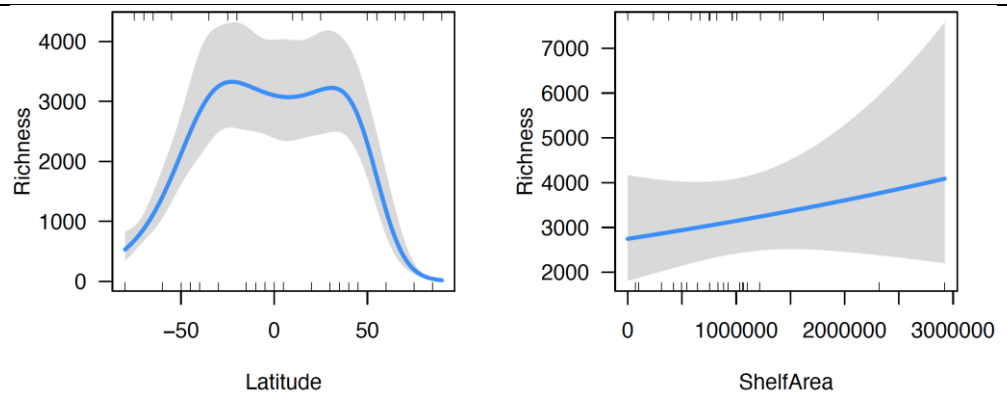
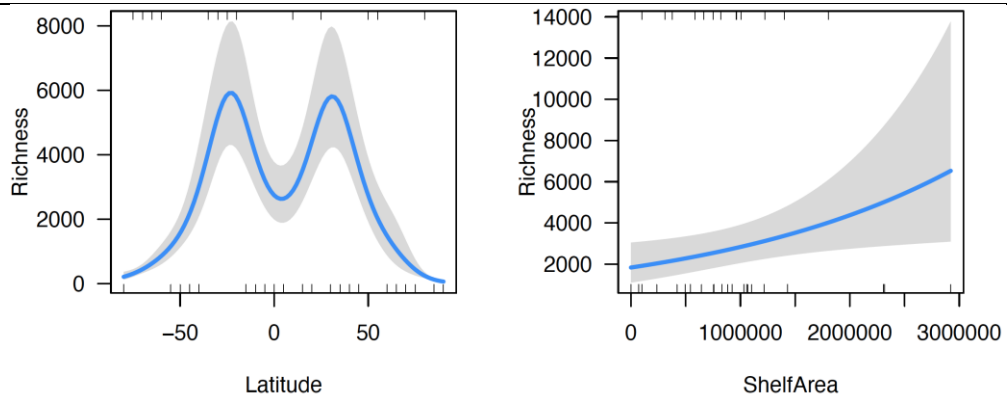
Group	Parametric coefficients				Rsq.(adj)	-REML	Deviance explained	n
	Estimate	Std.Error	Z value	Chi. sq				
All Species	7.87	0.08	92.4	151.0	**0.863**	297.6	77.8%	35
Pelagic species	5.81	0.07	73.1	182.2	**0.889**	224.4	79.7%	35
Benthic species	7.81	0.07	107.5	175.2	**0.839**	175.2	81.6%	34
Bathydemersal fish	5.45	0.06	88.53	119.8	**0.619**	142.6	81.9%	25
Demersal fish	6.22	0.06	95.44	350.8	**0.843**	170.0	91.7%	26
Reef associated fish	6.08	0.09	66.96	221.4	**0.836**	142.9	91.5%	22
Benthic Chordates	7.01	0.05	128.3	362.4	**0.858**	220.5	91.6%	30
Benthopelagic fish	4.73	0.08	56.97	69.4	**0.622**	110.7	84.2%	22
Bivalves	5.51	0.06	81.77	118.4	**0.611**	189.9	77.5%	32
Gastropods	6.31	0.07	85.45	134.4	**0.707**	225.2	79.1%	33
Benthic arthropods	6.76	0.07	88.61	75.0	**0.671**	248.3	66.0%	34
Pelagic Chordates	5.71	0.07	73.26	200.8	**0.887**	221.0	80.8%	35
Bathypelagic fish	5.60	0.04	113.5	260.8	**0.799**	141.7	91.2%	25

Table S4. Information on the full GAM models for Figure 3.

Group	Period	Model summary	Plots
All species	1955-1974	Family: Negative Binomial(17.398) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.480e+00 1.309e-01 57.162 <2e-16 *** ShelfArea 6.535e-08 1.355e-07 0.482 0.63 --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 688.8 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.79 Deviance explained = 94.6% -REML = 280.08 Scale est. = 1 n = 35	
All species	1975-1994	Family: Negative Binomial(12.922) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.370e+00 1.506e-01 48.92 <2e-16 *** ShelfArea 3.242e-07 1.559e-07 2.08 0.0375 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 568.8 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.842 Deviance explained = 93.8% -REML = 288.03 Scale est. = 1 n = 35	

All species	1995-2015	Family: Negative Binomial(6.043) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.227e+00 2.190e-01 32.993 <2e-16 *** ShelfArea 3.860e-07 2.267e-07 1.703 0.0886 . --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 224.8 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.746 Deviance explained = 85.7% -REML = 293.59 Scale est. = 1 n = 35	 
Pelagic species	1955-1974	Family: Negative Binomial(12.064) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.875e+00 1.610e-01 36.497 <2e-16 *** ShelfArea 2.099e-07 1.664e-07 1.261 0.207 --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 398 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 R-sq.(adj) = 0.834 Deviance explained = 92.1% -REML = 233.42 Scale est. = 1 n = 35	 

Pelagic species	1975-1994	Family: Negative Binomial(18.16) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.893e+00 1.346e-01 43.770 <2e-16 *** ShelfArea 8.915e-08 1.391e-07 0.641 0.522 --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 574.1 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.896 Deviance explained = 94.6% -REML = 225.83 Scale est. = 1 n = 35		
Pelagic species	1995-2015	Family: Negative Binomial(12.523) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 5.627e+00 1.579e-01 35.643 <2e-16 *** ShelfArea 2.014e-07 1.631e-07 1.235 0.217 --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 282.6 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.824 Deviance explained = 89.1% -REML = 224.82 Scale est. = 1 n = 35		

Benthic species	1955-1974	Family: Negative Binomial(13.623) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.111e+00 1.493e-01 47.625 <2e-16 *** ShelfArea 1.361e-07 1.545e-07 0.881 0.378 --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 607.3 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.755 Deviance explained = 93.6% -REML = 273.04 Scale est. = 1 n = 35	
Benthic species	1975-1994	Family: Negative Binomial(9.041) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 7.046e+00 1.801e-01 39.115 <2e-16 *** ShelfArea 4.343e-07 1.864e-07 2.331 0.0198 * --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 435.3 <2e-16 *** --- Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 R-sq.(adj) = 0.808 Deviance explained = 91.9% -REML = 284.46 Scale est. = 1 n = 35	

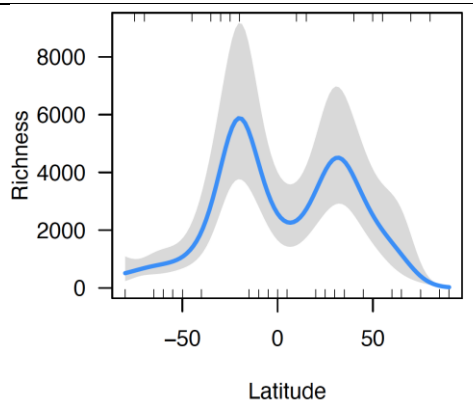
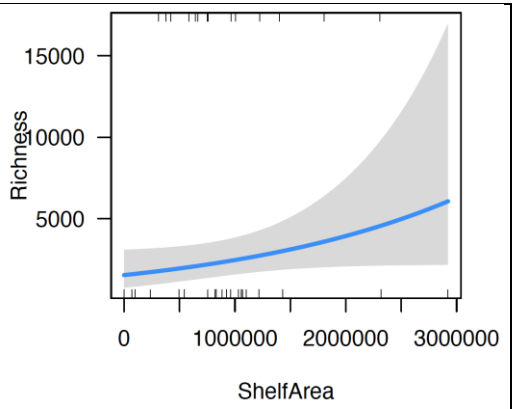
Benthic species	1995-2015	Family: Negative Binomial(4.733) Link function: log Formula: Richness ~ s(Latitude, k = 9, fx = T) + ShelfArea Parametric coefficients: Estimate Std. Error z value Pr(>|z|) (Intercept) 6.924e+00 2.481e-01 27.912 <2e-16 *** ShelfArea 4.691e-07 2.567e-07 1.827 0.0677 . --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 Approximate significance of smooth terms: edf Ref.df Chi.sq p-value s(Latitude) 8 8 217.2 <2e-16 *** --- Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 R-sq.(adj) = 0.722 Deviance explained = 84.4% -REML = 288.28 Scale est. = 1 n = 35	 

Table S5. Summary of the number of species and records in each phylum grouped as Benthic and Pelagic. The words in italics represent classes of Chordates. For detailed information, metadata are available at https://figshare.com/s/befed3d16821d8bf1c11.

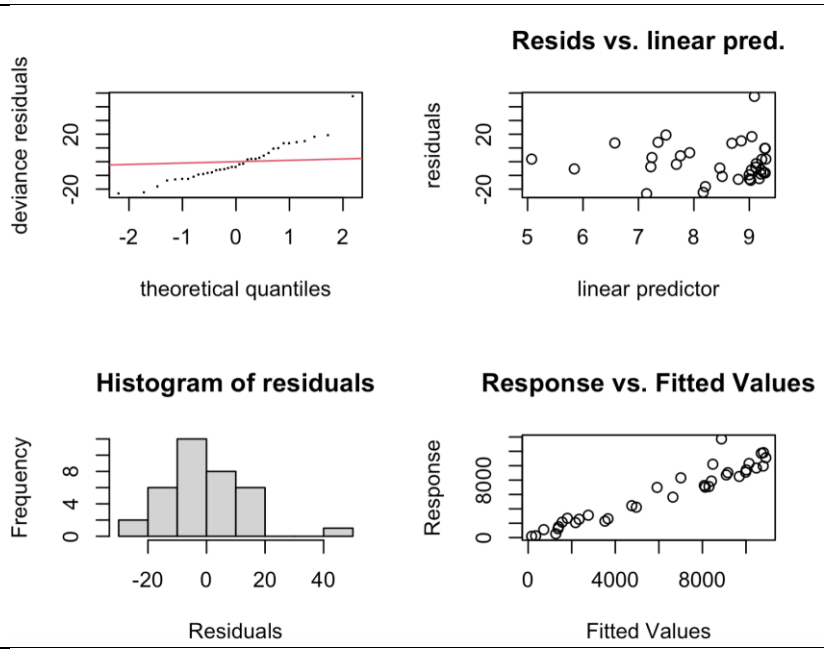
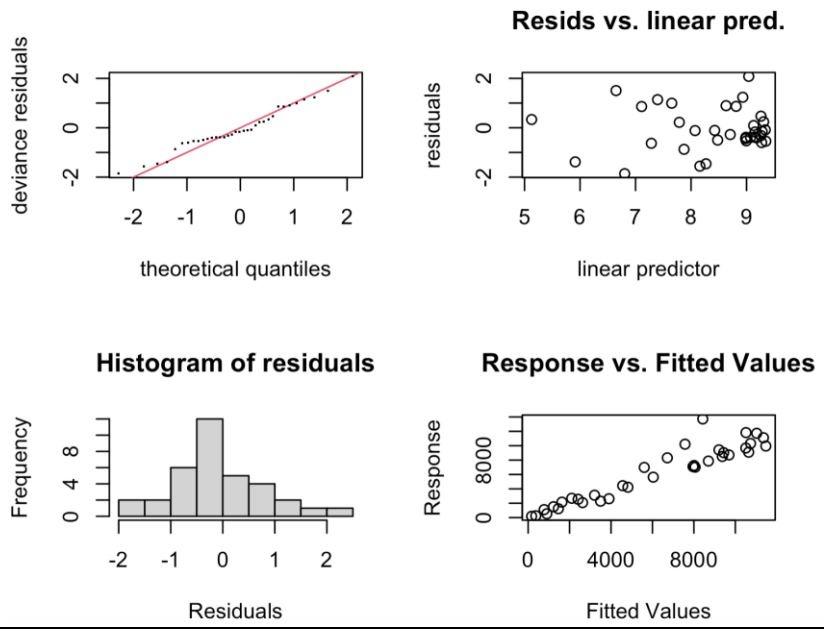
Group	Phylum	Number of species	Number of records
Benthic species	Annelida	3,811	320,119
	Arthropoda	9,070	556,465
	Brachiopoda	30	1,330
	Bryozoa	676	32,466
	Cephalorhyncha	43	75
	Chaetognatha	6	9
	Chordata	11,046	2,830,730
	Actinopteri	9,299	2,502,226
	Ascidiacea	864	34,256
	Coelacanthi	1	20
	Elasmobranchii	786	268,787
	Holocephali	39	22,672
	Mammalia	2	2,001
	Myxini	38	563
	Petromyzonti	4	119
	Reptilia	13	86
	Cnidaria	3,262	116,104
	Ctenophora	6	37
	Echinodermata	2,950	132,509
	Entoprocta	13	129
	Gastrotricha	36	51
	Gnathostomulida	5	5
	Hemichordata	28	260
	Mollusca	9,810	323,838
	Nematoda	889	12,136
	Nemertea	63	1,941
	Platyhelminthes	37	655
	Porifera	1,393	51,726
	Rotifera	9	259
	Sipuncula	30	5,907
	Tardigrada	22	37
	Xenacoelomorpha	14	14
Pelagic species	Annelida	107	10,009
	Arthropoda	2,163	570,658
	Chaetognatha	56	50,777

Pelagic species	**Chordata**	**2,392**	**1,777,118**
	Actinopteri	1,905	619,610
	Appendicularia	21	8,395
	Ascidiacea	1	1
	Aves	317	872,822
	Elasmobranchii	12	10,055
	Leptocardii	7	1,064
	Mammalia	77	243,098
	Reptilia	6	19,635
	Thaliacea	46	2,438
	Cnidaria	194	25,753
	Ctenophora	28	3,905
	Mollusca	466	92,445
	Rotifera	6	189

Table S6. The number of species, and observation records in All species, Pelagic species, and Benthic species) in the three time periods.

Group	1955-1974	1975-1994	1995-2015
All Species			
Number of species	23,817	29,738	26,943
Number of records	568,554	2,736,154	3,534,959
Pelagic species			
Number of species	3,615	3,561	3,100
Number of records	233,711	947,201	1,319,885
Benthic species			
Number of species	20,202	26,177	23,843
Number of records	334,843	1,788,953	2,215,074

Table S7. Summary of models with Poisson and binomial error structures for Richness as the response and Latitude as the predictor for All species (*Number of species ~ s(Latitude, k = 9); n = 35).*

Error structure	R^2(adj.)	Deviance explained (%)	AIC	Residual plots
Family: Poisson Link function: log	0.89	93.5	7021.04 (edf = 8)	
Family: Negative binomial Link function: log	0.86	93.5	618.44 (edf = 8)	

References

1. Rex, M. A., Stuart, C. T., Hessler, R. R., Allen, J. A., Sanders, H. L., & Wilson, G. D. (1993). Global-scale latitudinal patterns of species diversity in the deep-sea benthos. *Nature*, *365*(6447), 636.
2. Bolton, J. (1994). Global seaweed diversity: Patterns and anomalies. *Botanica Marina*, *37*(3), 241-246.
3. Flessa, K. W., & Jablonski, D. (1995). Biogeography of recent marine bivalve molluscs and its implications for paleobiogeography and the geography of extinction: A progress report. *Historical Biology: An International Journal of Paleobiology*, *10*(1), 25-47.
4. Roy, K., Jablonski, D., Valentine, J. W., & Rosenberg, G. (1998). Marine latitudinal diversity gradients: Tests of causal hypotheses. *Proceedings of the National Academy of Sciences*, *95*(7), 3699-3702.
5. Rutherford, S., D'Hondt, S., & Prell, W. (1999). Environmental controls on the geographic distribution of zooplankton diversity. *Nature*, *400*(6746), 749-753.
6. Roy, K., Jablonski, D., & Valentine, J. W. (2000). Dissecting latitudinal diversity gradients: Functional groups and clades of marine bivalves. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *267*(1440), 293-299.
7. Crame, J. A. (2000). The nature and origin of taxonomic diversity gradients in marine bivalves. *Geological Society*, *London*, *Special Publications*, *177*(1), 347-360.
8. Rex, M. A., Stuart, C. T., & Coyne, G. (2000). Latitudinal gradients of species richness in the deep-sea benthos of the North Atlantic. *Proceedings of the National Academy of Sciences*, *97*(8), 4082-4085.
9. Culver, S. J., & Buzas, M. A. (2000). Global latitudinal species diversity gradient in deep-sea benthic foraminifera. *Deep Sea Research Part I: Oceanographic Research Papers*, *47*(2), 259-275.
10. Willig, M. R. (2001). Latitude, common trends within. *Encyclopedia of Biodiversity* (3), 701-714.
11. Macpherson, E. (2002). Large–scale species–richness gradients in the Atlantic Ocean. *Proceedings of the Royal Society of London B: Biological Sciences*, *269*(1501), 1715-1720.
12. Woodd-Walker, R. S., Ward, P., & Clarke, A. (2002). Large-scale patterns in diversity and community structure of surface water copepods from the Atlantic Ocean. *Marine Ecology Progress Series*, 236, 189-203.
13. Connolly, S. R., Bellwood, D. R., & Hughes, T. P. (2003). Indo-Pacific biodiversity of coral reefs: Deviations from a mid-domain model. *Ecology*, *84*(8), 2178-2190.
14. Mora, C., Chittaro, P. M., Sale, P. F., Kritzer, J. P., & Ludsin, S. A. (2003). Patterns and processes in reef fish diversity. *Nature*, *421*(6926), 933-936.
15. Valdovinos, C., Navarrete, S. A., & Marquet, P. A. (2003). Mollusk species diversity in the Southeastern Pacific: Why are there more species towards the pole? *Ecography*, *26*(2), 139-144.
16. Gage, J. D., Lambshead, P. J. D., Bishop, J. D., Stuart, C. T., & Jones, N. S. (2004). Large-scale biodiversity pattern of Cumacea (Peracarida: Crustacea) in the deep Atlantic. *Marine Ecology Progress Series*, *277*, 181-196.
17. Witman, J. D., Etter, R. J., & Smith, F. (2004). The relationship between regional and local species diversity in marine benthic communities: A global perspective. *Proceedings of the National Academy of Sciences*, *101*(44), 15664-15669.
18. Gratwicke, B., & Speight, M. R. (2005). Effects of habitat complexity on Caribbean marine fish assemblages. *Marine Ecology Progress Series*, *292*, 301-310.
19. Rex, M. A., Crame, J. A., Stuart, C. T., & Clarke, A. (2005). Large-scale biogeographic patterns in marine mollusks: A confluence of history and productivity? *Ecology*, *86*(9), 2288-2297.
20. Worm, B., Sandow, M., Oschlies, A., Lotze, H. K., & Myers, R. A. (2005). Global patterns of predator diversity in the open oceans. *Science*, *309*(5739), 1365-1369.
21. Brayard, A., Escarguel, G., & Bucher, H. (2005). Latitudinal gradient of taxonomic richness: Combined outcome of temperature and geographic mid-domains effects? *Journal of Zoological Systematics and Evolutionary Research*, *43*(3), 178-188.
22. Dolan, J. R., Lemee, R., Gasparini, S., Mousseau, L., & Heyndrickx, C. (2006). Probing diversity in the plankton: Using patterns in Tintinnids (planktonic marine ciliates) to identify mechanisms. *Hydrobiologia*, *555*(1), 143-157.
23. Kerswell, A. P. (2006). Global biodiversity patterns of benthic marine algae. *Ecology*, *87*(10), 2479-2488.
24. Fuhrman, J. A., Steele, J. A., Hewson, I., Schwalbach, M. S., Brown, M. V., Green, J. L., & Brown, J. H. (2008). A latitudinal diversity gradient in planktonic marine bacteria. *Proceedings of the National Academy of Sciences*, *105*(22), 7774-7778.
25. Rombouts, I., Beaugrand, G., Ibaňez, F., Gasparini, S., Chiba, S., & Legendre, L. (2009). Global latitudinal variations in marine copepod diversity and environmental factors. *Proceedings of the Royal Society of London B: Biological Sciences*, *276*, 3053–3062.

26. Tittensor, D. P., Mora, C., Jetz, W., Lotze, H. K., Ricard, D., Berghe, E. V., & Worm, B. (2010). Global patterns and predictors of marine biodiversity across taxa. *Nature*, *466*(7310), 1098-1101.
27. Kaschner, K., Tittensor, D. P., Ready, J., Gerrodette, T., & Worm, B. (2011). Current and future patterns of global marine mammal biodiversity. *PLOS ONE*, *6*(5), e19653.
28. Beaugrand, G., Rombouts, I., & Kirby, R. R. (2013). Towards an understanding of the pattern of biodiversity in the oceans. *Global Ecology and Biogeography*, *22*(4), 440-449.
29. Saeedi, H., Dennis, T. E., & Costello, M. J. (2017a). Bimodal latitudinal species richness and high endemicity of razor clams (Mollusca). *Journal of Biogeography*, *44*(3), 592-604.