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Supplementary Materials for

Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss

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This PDF file includes:

Materials and Methods

Figs. S1 to S10

Table S1

Captions for databases S1 and S2

Supplementary References

Other supplementary material for this manuscript includes the following:

Databases S1 and S2 (zipped archives)

Materials and Methods

Data collection

We searched the scientific literature and online biodiversity databases for publicly available time series of species abundance estimates for consistently sampled ecological assemblages *(sensu* (*23*)). Our criteria for inclusion of a dataset were that (i) it included more than 3 years (not necessarily consecutive) of sampling, (ii) the sampling methods were described and relatively consistent through time, (iii) abundance estimates of all species in the sample were reported (i.e. assemblage rather than population data). A full list of the datasets used, their characteristics and sources are included in the table S1. Datasets were checked for duplicates, for species with zero abundance and for non-organismal records, which were deleted prior to any analysis. Because of differences in sampling methodology, taxa, and species richness time series were kept separate in all analysis. Each time series was classified in terms of: realm (marine or terrestrial), taxon (birds, fish, mammals, marine invertebrates, marine plants, terrestrial invertebrates, terrestrial plants and mixed when it involved multiple taxa). The geographical coordinates of the samples were used to calculate the aerial extent of the time series and to classify it into climatic regions (temperate, tropical, polar and combinations), with time series that included samples in the tropics, temperate and polar region being classified as global. The extent of each dataset was calculated using a convex hull (minimum bounding polygon) around the geographical coordinates.
Most diversity metrics are affected by sampling effort (*24*), and sampling effort was often not constant throughout the time series. To prevent variation in sampling effort from obscuring temporal diversity patterns, we employed sample-based rarefaction within each time series. Specifically, we used year as the temporal grain and for each time series we found the minimum number of samples in a year. We bootstrap resampled the data from each other year to obtain a constant number of samples through time. Species abundances were then pooled within each year so that there was one assemblage per year per time series, and the pooled abundances were used to calculate α diversity and temporal β diversity indices. Some time series included years with an unusually low number of samples. To assess if this was causing an excessive loss of information, we individually assessed each time series and removed any years with less than half of the average number of samples prior to performing the sample based rarefaction described above. This process did not affect the results of our analysis (Figure S10) and hence only the first type of rarefaction is reported in the main text.

α diversity

Although a plethora of α diversity indices are available, most indices cluster in four main groups that correspond to measures of: species richness, total abundance, evenness, and dominance (*24*). For each of the clusters we chose metrics that are relatively unaffected by sampling effort. Additionally, we report metrics that are widely used in community ecology, conservation biology, and environmental impact studies. Specifically, for each yearly pooled sample, we calculated 10 different metrics: **(i)** total species richness (S); **(ii)** total abundance (N); **iii)** variance of S among samples; **iv)** variance of N among samples; **v)** $S/\sqrt{N}$; **vi)** PIE evenness $(\frac{N}{N-1})(1-\sum_{i=1}^{S}\pi_i^2)$ (*25*), where π_i is the abundance of species i divided by total abundance; **vii)** McNaughton dominance $\frac{N_1+N_2}{N}$, where N_1 and N_2 are the abundances of the first and second most abundant species (*24*); **viii)** the exponential of Shannon diversity (also known as the Hill Number ^1D (*26*)) $e^{-\sum \pi_i \ln(\pi_i)}$; and two asymptotic species richness estimators **ix)** Chao1, $S + \left(\frac{n-1}{n}\right)\frac{F_1^2}{2F_2}$, and **x)** and the bias corrected Chao1, $S + \left(\frac{n-1}{n}\right)\frac{F_1(F_1-1)}{2(F_2+1)}$, where F_1 and F_2 are the number of species represented by one and two individuals respectively (*27*).

β diversity

In addition to α diversity metrics, we calculated measures of temporal turnover in species composition (temporal β diversity). Specifically, we calculated four metrics of turnover: **(i)** the Jaccard similarity index; **ii)** the Morisita-Horn index; **iii)** the Chao community similarity index, all of which were calculated using the function vegdist in vegan (*28*); and **iv)** the Pearson correlation coefficient between the abundances of each species in the two samples being compared. We report patterns of similarity for pooled abundances between each year and the first year in the time series in the main text (i.e. comparing each year to the time series baseline), and between each year and the last year of the time series (Figure S7) to ensure our results are robust to the year used to detect cumulative changes in composition.

We do not include in our analysis a comparison between the baseline year and itself (which is always equal to the maximum of the similarity metric). Negative trends in the resulting temporal beta diversity series are indicative of accumulating changes associated to diverging community composition. Positive trends are indicative of earlier steps in the time series being more different from the baseline than later time steps. This can occur, for example, as a result of cyclical variation or as a result of recovery from a disturbance immediately after the baseline year. In a stochastic system under pure white noise randomness, the trend from of the time series will be zero. However, noise generates error around zero, and hence we expect the 95% interval to include both positive and negative slopes. As an example both of the neutral model simulations we ran (Figure S8 and S9) showed some positive slopes due to a combination of these reasons. Similarities between pairs of consecutive samples (not included) were constant through time, and do not allow determining whether differences accumulate or merely fluctuate.

Analysis

To estimate the global long-term trends in diversity, to each of the 14 metrics (10 community structure and 4 composition turnover metrics), we first fit a linear model with a single slope but a different intercept and a residual variance for each time series, by using generalized least squares (GLS). Additionally, we fit a linear model to each time series allowing a different slope and an intercept, by using ordinary least squares (OLS). The R squared value and the p-value of each slope coefficient (the OLS estimate) are also calculated. However, the provided p-value may be overly confident due to the unknown correlated structure so a careful interpretation is required. These statistics are included to provide intuitive information of the fitted linear trend of each time series, rather than in a classical hypothesis-testing context. Note that the OLS estimates that we have obtained are unbiased in the presence of undefined autocorrelation structures in the data (*29*). We analyze the frequency distributions of the slope coefficients, focusing specifically on the proportion of its positive and negative values

We assessed if the ability to detect an overall negative trend in α diversity was driven by our focus on long-term linear trends by calculating the log ratio between all consecutive samples ($\ln(S_t/S_{t-1})$, where S_t and S_{t-1} are species richness at time t and the previous time respectively. Positive ratios correspond to increases in S and negative ratios decreases.

We also estimate the effects of time series characteristics on the slope estimates in two different ways. For categorical characteristics (bioclimatic region, realm and taxa) we fit models with different slopes for each class of time-series, and different intercepts for each individual time series. For numerical characteristics (area of geographic extent of the samples, year of start and duration of the time-series) we fit a linear model to the estimates of the slopes as a function of the time series characteristic.

Markov model of temporal change in community similarity

To generate a null expectation for changes in Jaccard's Index through time, we created a species-level stochastic colonization-extinction model, in which each species has unique fixed parameters for the probability of colonization in a single time step when it is absent (C_i), and for the probability of extinction in a single time step when it is present (E_i). This "molecular" colonization and extinction model (*30*) assumes the environment is constant and that species interactions do not affect colonization and extinction probabilities. This model is a species-specific version of the more general MacArthur and Wilson (*31*) equilibrium model of island biogeography (*32*). At equilibrium, the expected species richness $\hat{S}$ is:

$$\hat{S} = \sum_{i=1}^{S} \frac{C_i}{C_i + E_i}$$

To create an isotropic sample space of all possible colonization and extinction values, we assigned at the start of the simulation unique C_i and E_i values to a hypothetical assemblage of 50 species by drawing from a random uniform (0,1) distribution. The C_i and E_i values for each species in the assemblage were drawn independently. Once these values were fixed, the simulation began with an empty assemblage and allowed colonization and extinction to proceed for a burn-in period of 1000 time steps. After the burn-in, we created a time-series of 300 steps. We then calculated the Jaccard Index of similarity between the initial species composition, and the composition present at each subsequent time step. We fit a simple least-squares regression slope of the trend line of Jaccard's values as a measure of how compositional turnover might be expected to change from a baseline measure for a dynamic assemblage that is in a colonization-extinction equilibrium. We replicated this procedure 1000 times to generate a histogram of expected slope values.

The mean slope of the 1000 replicates is -1.27×10^{-5} (Figure S8). The distribution of slope values is fairly symmetric (negative slopes = 59% of the distribution) and brackets 0.0. In spite of the wide range of colonization and extinction parameters used in the replicate simulations, the confidence interval is relatively small (-1.39×10^{-4} to 1.01×10^{-4}), and most slopes do not deviate much from 0.

Neutral model

We ran simulations of Hubbell's version of the neutral model (*33*) using software code as described and placed in the public domain by McGill (*34*). Simulations were run for all combinations of population size, J, in 1,000/10,000/100,000, biodiversity parameter, θ, in 5/10/50 representing roughly tree richness in boreal, temperate and tropical forests, and migration rates of 0.01/0.1/0.7 spanning from extremely low to extremely high migration rates and generation times of 1 or 100 years (ranging from, e.g. small mammals to trees). Thus in total 3x3x3x2=54 parameter combinations spanning most of the range or parameters estimated for neutral models across different ecological systems to date. For each parameter combination, 10 separate Monte Carlo replicates were run for a total of 540 simulations of neutral communities. Each simulation was run for 500 years, where a year was defined to correspond to J/LS separate death/birth events (where LS is generation time in years for the organisms and where LS was 1 and 100), and indices were calculated once very 5 years (100 data points).
For each of the 540 simulations, a linear OLS slope of Jaccard similarity vs year was calculated to match the estimates of temporal turnover β diversity in the main text. The regression was estimated with a burn in period (i.e. ignoring the first 25 or 250 years) or without but the results were similar (a burn in-period had slopes slightly closer to zero) so we conservatively report results without a burn-in. Of these 65% or 351/540 were statistically significantly different from zero ($p<0.05$), but the mean decrease in Jaccard similarity per year was -0.000210 (median of 0.000128, Figure S9). These values are two orders of magnitude smaller than the temporal turnover in species composition found in the empirical, real-world datasets (Figure 3b, 4) of -0.01. There is considerable variability around this mean ($\sigma=0.00024$), but only two of the 540 simulated values comes within an order of magnitude of the simulated values. Results for abundance-based measures of similarity were similar. Morisita Horn decayed at mean rate of -0.000039 per year (median (-0.000002 per year). Pearson log-abundance correlation decayed at a mean rate of -0.000079 per year (median rate of -0.000037 per year). In summary, the neutral theory simulations show a consistent pattern of decaying similarity over time (positive β diversity). There is considerable variability in the rates due both to the innate stochasticity of neutral theory and variable combinations. However, the neutral rates of community turnover are much slower than empirically observed. Specifically, on average the neutral model changes composition at a rate two orders of magnitude slower than empirically observed data, and even the extreme 1% of all neutral simulations (across all parameter combinations) closest to empirical data are still an order of magnitude slower than empirical data. Empirically communities show turnover in composition at a rate on average 100x faster than neutral communities across a range of biologically realistic parameters.

Fig. S1.

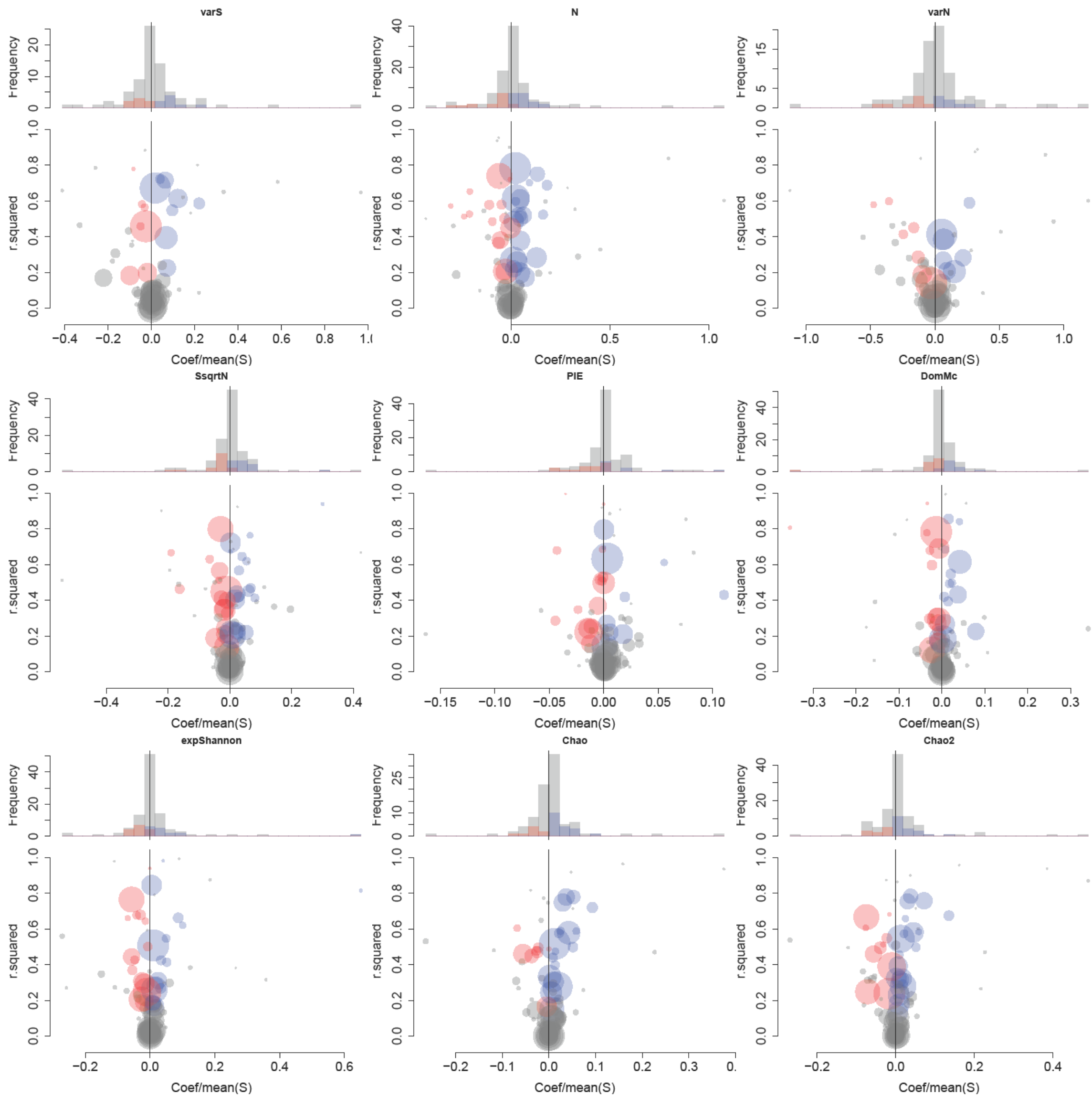

Figure S1 - Slope estimate distributions for 9 α diversity metrics (as per panel titles). Slope estimates (horizontal axis), r^2 (vertical axis) and number of data points in time series (bubble size) for each of the datasets. Bubbles are color coded as blue (positive slope), red (negative slope) and grey (non-significantly different from 0).

Fig. S2

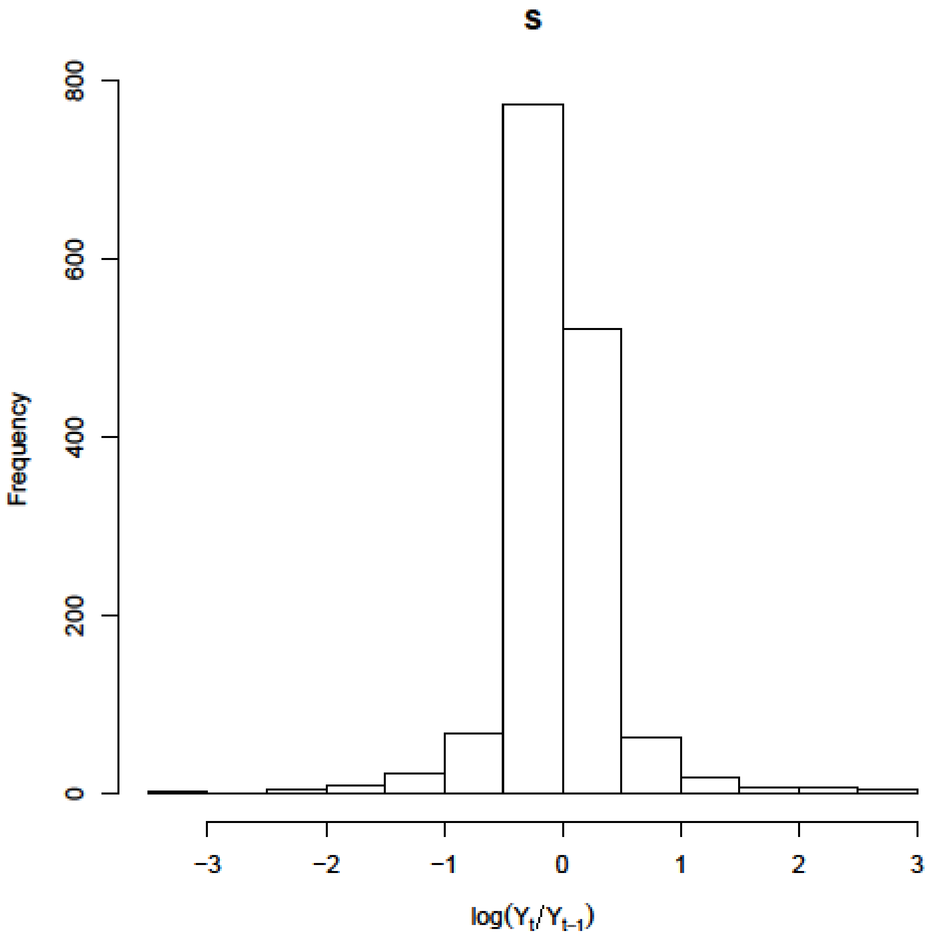

Figure S2 – Histogram of log ratios of consecutive species richness.

Fig. S3

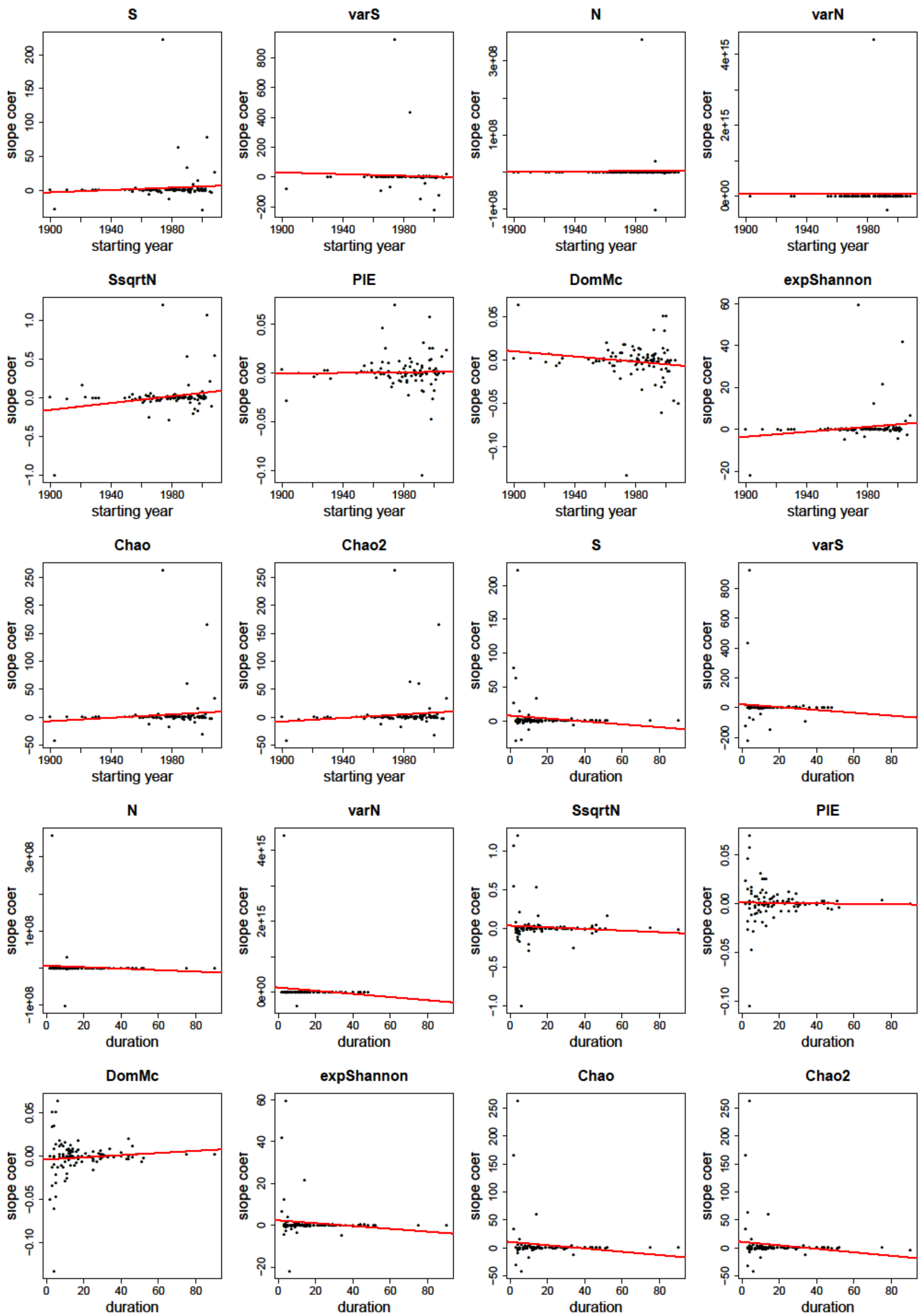

Figure S3 – Linear slopes as a function of time series start year, duration for each of the 10 α diversity metrics.

Fig. S4

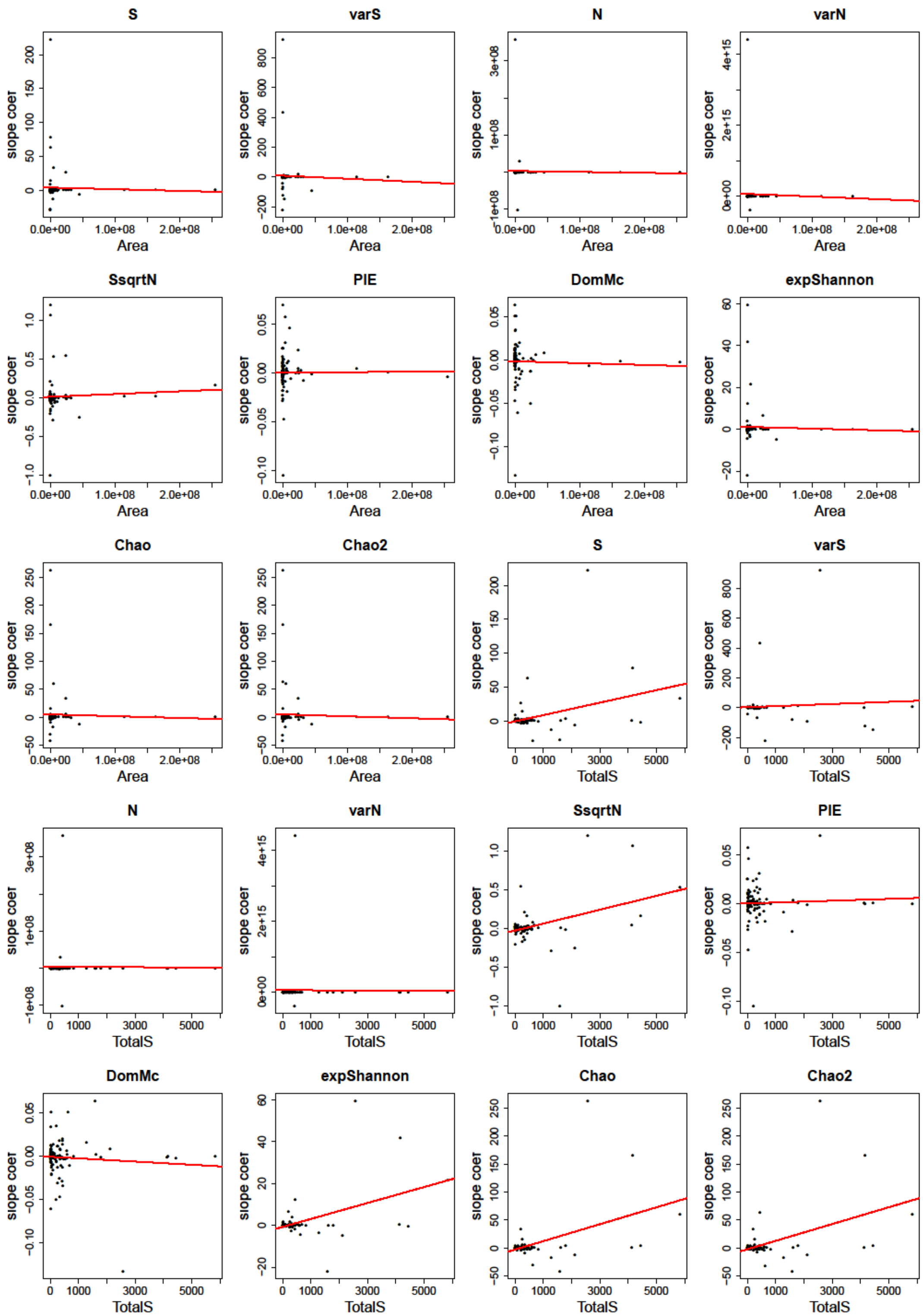

Figure S4 – Linear slopes as a function of time series area of spatial extent of sampling locations and total species richness, for each of the 10 α diversity metrics.

Fig. S5

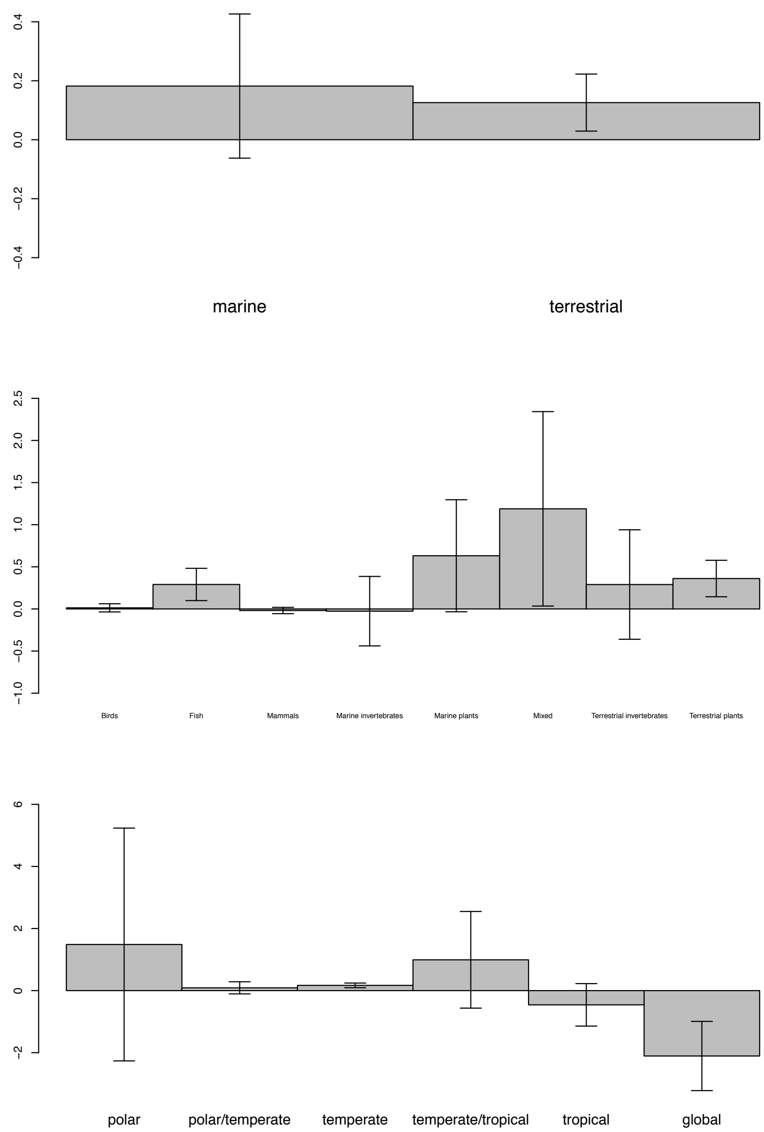

Figure S5 – Estimates of slopes per realm (top), taxon (middle) and climatic region (bottom).

Fig. S6

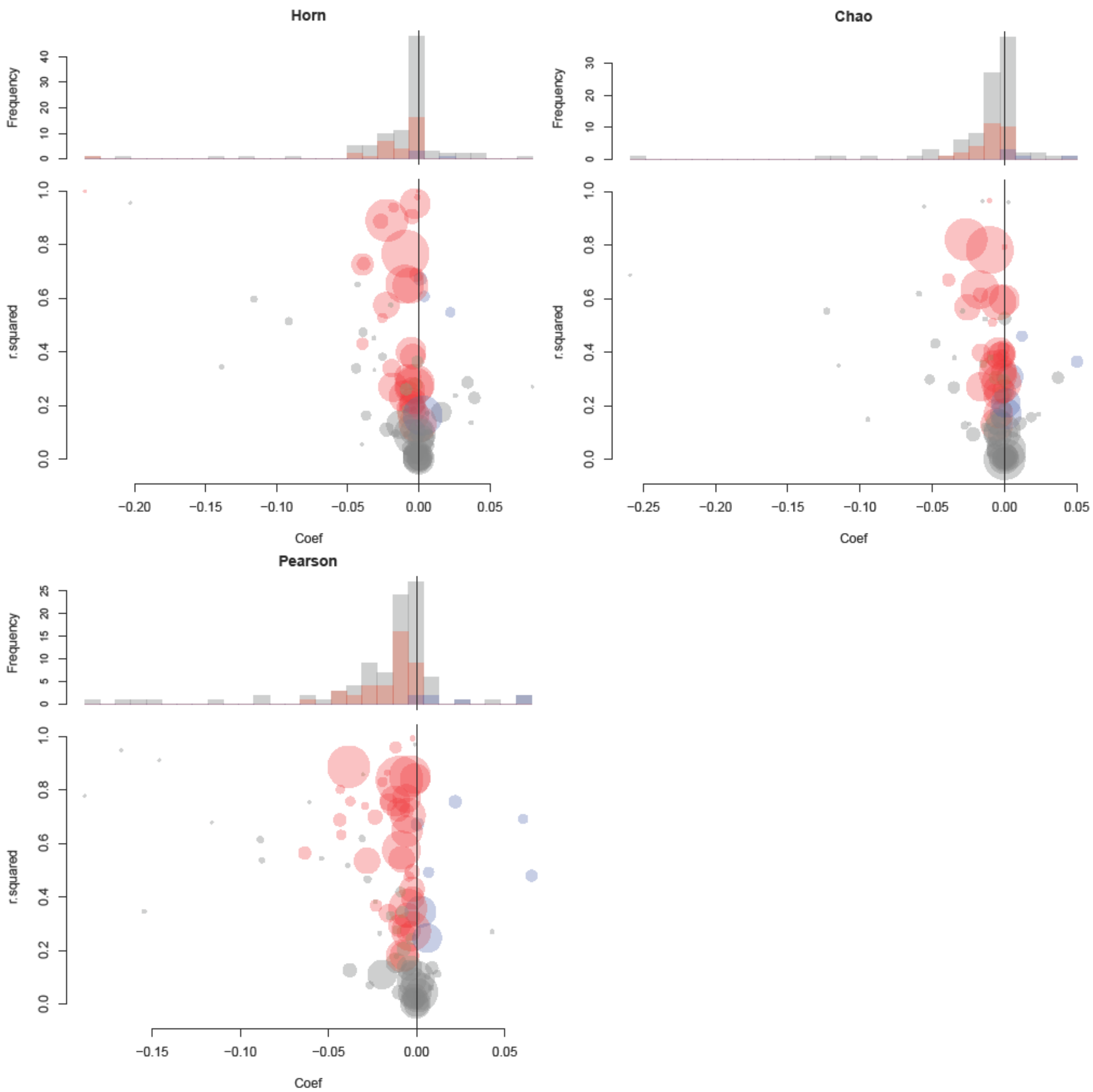

Figure S6 - Slope estimate distributions for the three remaining β diversity metrics (as per panel titles). Slope estimates (horizontal axis), R^2 (vertical axis) and number of data points in time series (bubble size) for each of the datasets. Bubbles are color coded as blue (positive slope), red (negative slope) and grey (non-significantly different from 0).

Fig. S7

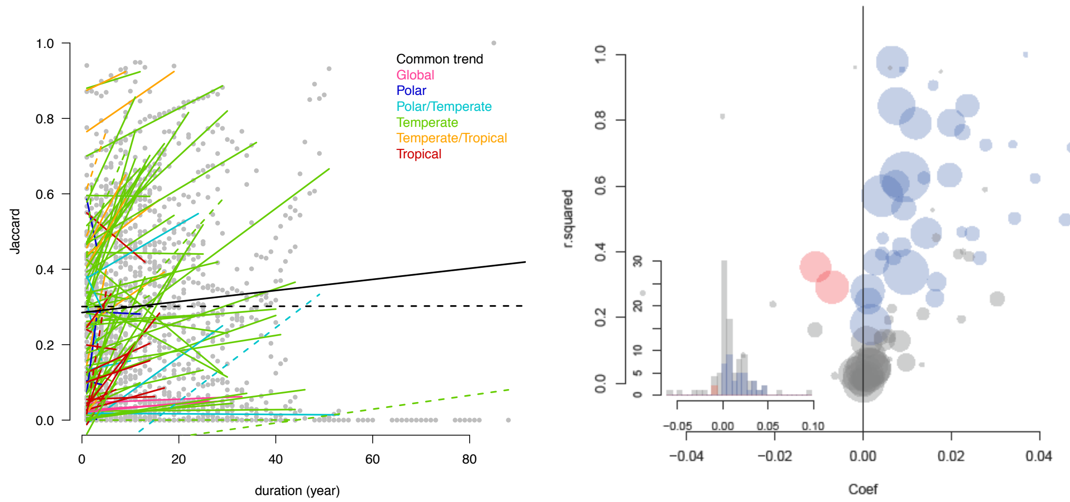

Figure S7 – Left panel: Temporal change in species composition as measured by Jaccard similarity between each sample and the last sample in the time series. Data points are represented by grey circles and models fitted by solid lines. The black line corresponds to a model where a single slope, but different intercepts were fitted to all the time series, and is represented here with the mean intercept. We performed this analysis with all 100 datasets (black dashed line), and excluding 12 time series that either had only two years (as the a comparison with the baseline with itself is not included) or after rarefaction included years when only one species was observed (which makes beta diversity calculations unreasonable) (black solid line). Both analyses have positive slopes. The colored lines correspond to a model where each time series had a different slope and intercept. Color-coding corresponds to climatic regions as per in figure legend. **Right panel:** Slope estimate distributions for cumulative β diversity (as measured by Jaccard similarity) change relative to the last year in the time series. Slope estimates (horizontal axis), r^2 (vertical axis) and number of data points in time series (bubble size) for each of the datasets. Bubbles are color coded as blue (positive slope), red (negative slope) and grey (non-significantly different from 0).

Fig. S8

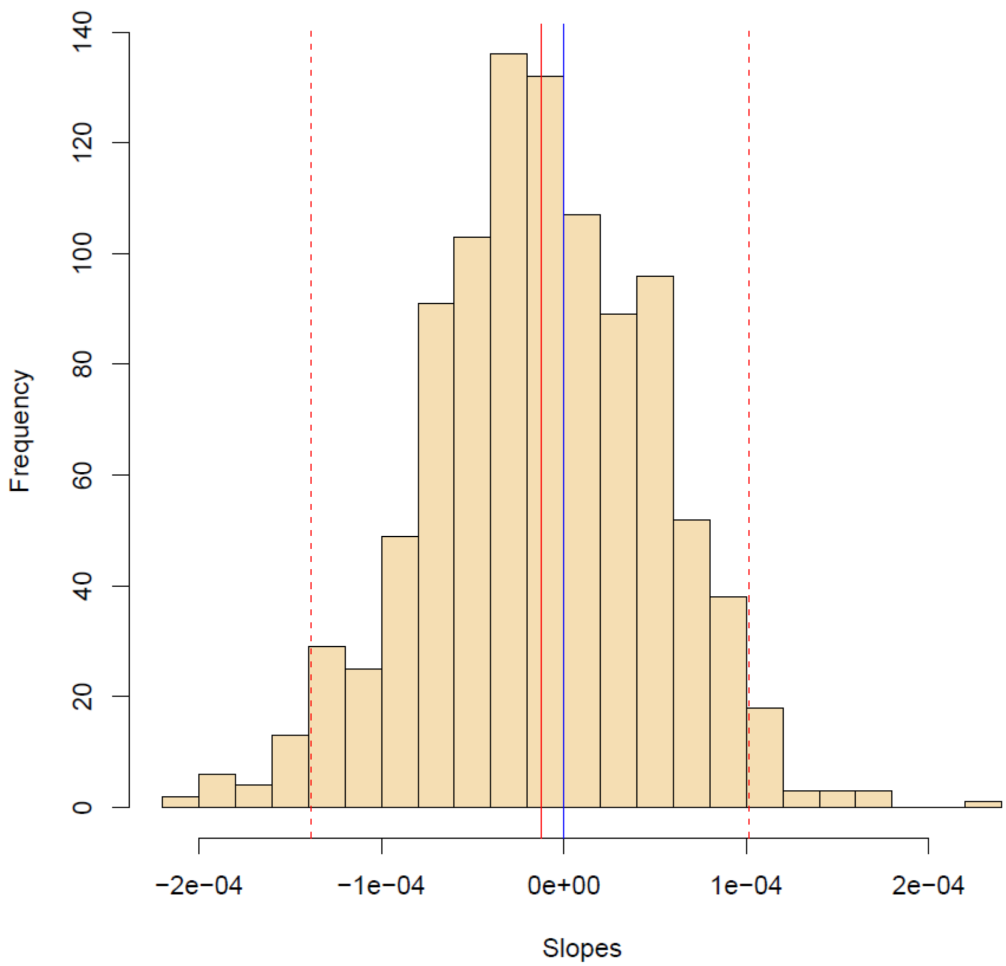

Figure S8 – Histogram of 1000 slope values for an MCMC model of stochastic colonization and extinction. The model assemblage consists of 50 species, each with a unique colonization and extinction probability drawn from a (0,1) random uniform distribution. For each replicate, a burn-in sequence of 1000 transitions was used, and the next 300 time steps were used to generate the temporal series of assemblage composition. Jaccard's similarity index was calculated for each of the time steps $t = 2$ to 300, compared to the baseline assemblage at $t = 1$. The solid red line is the mean slope of the 1000 replicates (mean = -1.27×10^{-5}) , the blue line is a slope value of 0.0, and the dashed red lines bracket the 95% confidence interval. The distribution of slope values is fairly symmetric (negative slopes = 59% of the distribution) and brackets 0.0. In spite of the wide range of colonization and extinction parameters used in the replicate simulations, the confidence interval is relatively small (-1.39×10^{-4} to 1.01×10^{-4}), and most slopes do not deviate much from 0.

Fig. S9

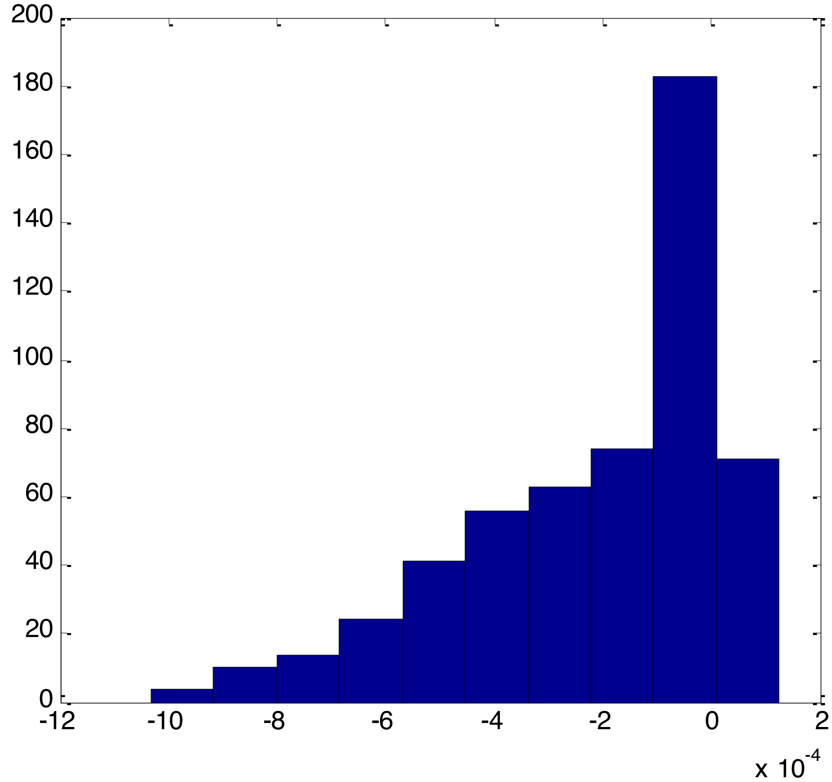

Figure S9 - Histogram of simulated neutral theory temporal β diversity (decay of similarity of composition regression slopes). Mean slope is -0.00021.

Fig. S10

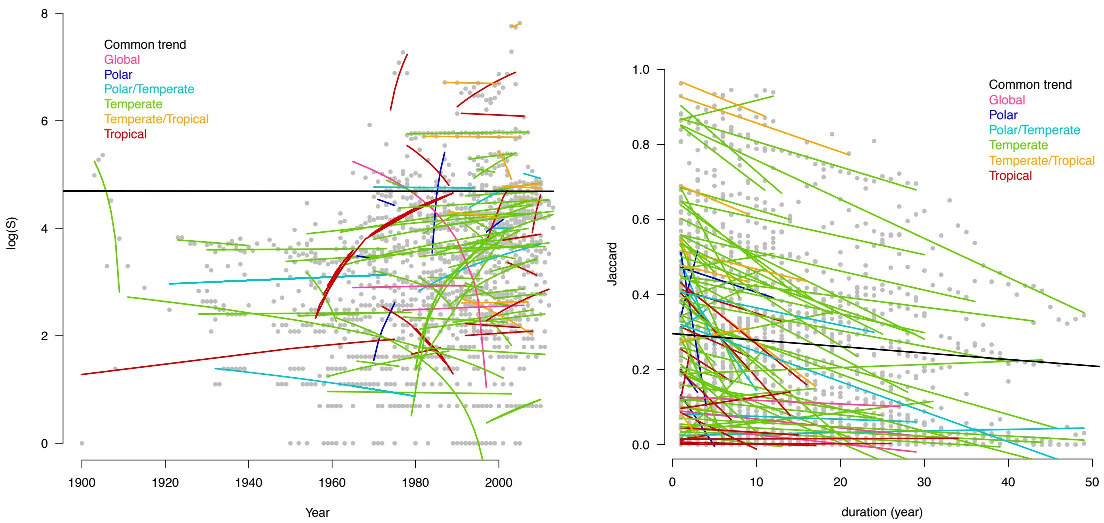

Figure S10 - Temporal change in species richness (left panel) and species composition (right panel) as measured by Jaccard similarity between each sample and the first sample in the time series. This figure is identical to Figure 2, except rarefaction was performed after years with unusually low sample sizes were removed (see methods). Data points are represented by grey circles and models fitted by solid lines. The black line corresponds to a model where a single slope, but different intercepts were fitted the all the time series, and is represented here with the mean intercept. The colored lines correspond to a model where each time series had a different slope and intercept. Color-coding corresponds to climatic regions as per in figure legend

Table S1. Dataset sources and characteristics

Ref	Source	Taxa	Organism	Spatial Grain	Sample Size (sq. m)	Central Latitude	Central Longitude	No of Data Pts (Years)	Start Year	End Year	Species Richness	Area (sq. km)	No of Records
Marine													
Global													
(35)	Australian Antarctic Data Centre	Birds	Birds			-15.715	-0.590004	30	1977	2006	126	162,783,730	116230
(36, 37, 38, 39, 40, 41)	OBIS (Ocean Biogeographic Information System) - OBIS SEAMAP	Birds	Pelagic seabirds			27.316651	-65.499998	26	1965	1992	215	114,454,343	155611
(42)	Southampton Oceanography Center - Discovery Collections	Marine invertebrates	Marine invertebrates and some fish			-4.1129227	-22.458727	26	1965	1999	2112	45,119,448	90036
	Polar												
(43, 44)	ArcOD - Arctic Ocean Diversity	Benthos	Zoobenthos	0.23 - 0.39 m sq grabs	0.23	70.166668	-134.41583	4	1971	1975	343	246,090	2193
(45, 46)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Copepods	1 m and 2 m net samples		79.673351	-143.18335	4	1966	1969	43	10,682,491	16086
(47, 48)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Copepods	2 m closing net		79.571003	-113.4005	4	1970	1975	38	7,111,875	6672
(49, 50, 51)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Zooplankton			70.234165	-133.01335	5	1984	1987	447	180,454	23065
(52, 53)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Zooplankton	0.1 - 0.25 - 0.44 m sq nets	0.25	79.599998	85.80835	4	1997	2001	101	4,206,159	2665
	Polar/Temperate												
(54)	EMODnet (European Marine Observation and Data Network)	Benthos	Macrobenthos	0.25 m sq grab	0.25	38.055	65.614998	23	1981	2010	526	387,745	7452
(55)	OBIS (Ocean Biogeographic Information System) - Canada	Fish	Groundfish			37.434999	-46.375	26	1970	1995	273	7,229,693	410789
(56)	OBIS (Ocean Biogeographic Information System) - OBIS Australia	Mammals	Whales			-62.5	80	42	1932	1980	6	12,743,839	7122
(57)	OBIS (Ocean Biogeographic Information System) - Canada	Marine invertebrates	Marine invertebrates and some fish			67.408991	-67.826576	5	2006	2010	306	3,561,893	16976
(58)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Zooplankton			65.633301	36.225	5	1998	2003	108	260,835	12471
(59)	ArcOD - Arctic Ocean Diversity	Marine invertebrates	Zooplankton	37 cm diameter net		69.974998	0.0166473	22	1921	1973	419	254,866,15	15016
(60)	ArcOD - Arctic Ocean Diversity	Marine plants	Phytoplankton			77.004997	72.396996	10	1993	2003	423	4,092,385	37240
	Temperate												
(41, 61, 62, 63, 64)	OBIS (Ocean Biogeographic Information System) - OBIS SEAMAP	All	Cetaceans, seabirds and turtles			35.309266	-24.079175	12	1988	2008	47	1,579,112	52291
(65)	OBIS (Ocean Biogeographic Information System) - Canada	All	Chromista, fish and marine invertebrates			47.389734	-62.87117	22	1988	2009	33	167,455	35005
(66, 67)	EMODnet (European Marine Observation and Data Network	Benthos	Benthic animals	0.1 m sq day grab used in 100m range ring	0.10	54.014999	0.9050002	5	1992	1996	212	832,035	1347

(68)	OBIS (Ocean Biogeographic Information System) - EurOBIS	Benthos	Benthos			55.336491	-3.2542415	38	1954	2000	4129	1,335,133	398501
(69)	SOTEAG	Benthos	Benthos and marine invertebrates			60.47139	-1.35133	35	1976	2012	252	582	91491
(70)	OBIS (Ocean Biogeographic Information System) - EurOBIS	Benthos	Macro-zoobenthos	0.1 m sq grab	0.10	56.974998	18.33	25	1980	2005	212	148,740	3587
(71)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Benthos	Mainly benthos	20 x 20 km sq grids	20000.00	30.860001	0	12	1993	2004	357	6,794,596	419999
(41, 72)	EMODnet (European Marine Observation and Data Network)	Birds	Birds	300 m transects		56.855001	21.025001	8	1992	1999	68	153,286	6318
(41, 73, 74, 75, 76)	OBIS (Ocean Biogeographic Information System) - OBIS SEAMAP	Birds	Mostly seabirds and some marine mammals	3 km bins		34.931726	-121.85437	20	1987	2006	185	784,953	61730
(77)	OBIS (Ocean Biogeographic Information System) - EurOBIS	Birds	Seabirds			55.65135	-4.4680754	10	1994	2003	27	1,673,443	23363
(41, 78)	EMODnet (European Marine Observation and Data Network	Birds	Seabirds			39.17045	-0.80485	3	1999	2002	16	197,847	1072
(79)	LTER (Long Term Ecological Research)	Fish	Fish			43.992802	-89.494598	32	1981	2012	103		10892
(80)	Peter Henderson	Fish	Fish	2 filter screens mesh 10mm		51.139999	-3.0799999	31	1981	2011	83	<1	5199
(81)	OBIS (Ocean Biogeographic Information System) - Canada	Fish	Fish			43.952541	-63.223873	41	1970	2010	262	595,377	141330
(82)	OBIS (Ocean Biogeographic Information System) - OBIS USA (MARMAP)	Fish	Fish	chevron traps 1.5 m x 1.7 m x 0.6 m		30.940001	-78.5	12	1988	2000	101	101,680	15097
(83)	OBIS (Ocean Biogeographic Information System) - OBIS USA (MARMAP)	Fish	Fish			31.315	-78.215	8	1973	1980	438	167,424	7614
(84)	OBIS (Ocean Biogeographic Information System) - OBIS USA (MARMAP)	Fish	Fish	0.59 m 3 traps		32.400001	-78.580002	10	1980	1989	48	61,329	4546
(85)	DATRAS - online database of trawl surveys	Fish	Fish			56.75225	-6.9619	28	1985	2013	152	520,796	279726
(86)	DATRAS - online database of trawl surveys	Fish	Fish			56.349	17.045	23	1991	2013	143	648,610	751021
(87)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Fish	Fish and marine invertebrates			43.814001	-68.864651	10	2000	2009	147	37,572	38646
(88)	OBIS (Ocean Biogeographic Information System) - Canada	Fish	Mostly fish and some marine invertebrates			53.125599	-141.4296	39	1963	2007	476	652,347	128311

(89)	EMODnet (European Marine Observation and Data Network)	Mammals	Cetaceans			56.94348	-2.6734665	14	1997	2010	9	4,258	1613
(90)	OBIS (Ocean Biogeographic Information System) - South Western Pacific OBIS	Marine invertebrates	Bryozoa			-9.6165009	0.0680008	51	1874	2003	599	24,816,747	6329
(91)	OBIS (Ocean Biogeographic Information System) - AfrOBIS	Marine invertebrates	Copepods			-31.844999	20.89735	12	1988	2000	15	429,677	38535
(92)	EMODnet (European Marine Observation and Data Network)	Marine invertebrates	Marine invertebrates			53.5443	4.627365	12	1992	2003	356	171,011	9984
(80)	Peter Henderson	Marine invertebrates	Marine invertebrates	2 filter screens mesh 10mm		51.139999	-3.0799999	31	1981	2011	15	<1	2210
(93)	OBIS (Ocean Biogeographic Information System) - Canada	Marine invertebrates	Marine invertebrates			43.662792	-63.244329	13	1999	2011	16	621,101	14906
(94)	OBIS - OBIS USA - NEFSC (Northeast Fisheries Science Center)	Marine invertebrates	Marine invertebrates			36.667	-65.533501	41	1956	1989	1791	1,789,437	82621
(94)	OBIS - OBIS USA - NEFSC (Northeast Fisheries Science Center)	Marine invertebrates	Marine invertebrates			36.667	-65.533501	28	1900	1978	1617	1,789,437	51457
(95, 96)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine invertebrates	Marine invertebrates and marine plants			41.504999	-70.555	8	1903	1909	1581	2,171	45313
(80)	Peter Henderson	Marine invertebrates	Plankton	2 filter screens mesh 10mm		51.139999	-3.0799999	28	1982	2010	582	<1	775
(97)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine invertebrates	Sessile marine invertebrates			43.276317	-106.99213	6	2000	2005	100	5,790,445	1401
(98)	OBIS (Ocean Biogeographic Information System) - South Western Pacific OBIS	Marine invertebrates	Starfish			-40.114999	0.0049438	44	1956	2003	156	28,138,739	2258
(99)	EMODnet (European Marine Observation and Data Network	Marine invertebrates	Zooplankton	stations 3 nautical miles apart		44.724501	-2.7983999	6	1995	2004	66	116,189	9059
(100)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine invertebrates	Zooplankton	10 m sq nets	10.00	41.375	-67.418999	5	1995	1999	342	76,893	15246
(101)	OBIS - SCAR-MarBIN (Scientific Committee on Antarctic Research - Marine Biodiversity Information Network	Marine invertebrates	Zooplankton	60 cm closing net		44.200001	0	15	1977	2002	164	8,834,130	2493
(102)	OBIS (Ocean Biogeographic Information System) - Canada	Marine invertebrates/plants	Phytoplankton and zooplankton			44.555	-60.424999	13	1998	2010	320	945,329	56938

(103)	EMODnet (European Marine Observation and Data Network)	Marine plants	Macroalgae	1 m sq stations	1.00	44.957899	33.8528	11	1967	2007	106	1,366	5070
(104)	Journal of Plankton Research	Marine plants	Phytoplankton	200ml sampling from stations		50.150002	-4.1300001	18	1992	2009	168		17838
(105)	EMODnet (European Marine Observation and Data Network)	Marine plants	Phytoplankton			44.5	35.40835	9	1985	1998	379	446,518	9998
(106, 107)	EMODnet (European Marine Observation and Data Network)	Marine plants	Phytoplankton			51.54925	3.91205	9	1982	1990	106		5945
	Tropical/Temperate												
(108)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Benthos	Benthos	0.04 m sq or 0.1 m sq grabs	0.10	39.436501	-113.877	13	1990	2004	5832	4,871,568	173070
(109)	OBIS - NOAA-NBI (National Oceanic and Atmospheric Administration - National Benthos Inventory)	Benthos	Benthos			36.02781	-123.53286	14	1991	2006	4439	2,468,879	111354
(110)	OBIS (Ocean Biogeographic Information System) - OBIS Australia	Benthos	Benthos			-17.595	147.905	4	2003	2006	4157	391,807	93707
(111)	OBIS (Ocean Biogeographic Information System) - OBIS Australia	Fish	Fish			-26.212501	134.525	16	1978	1997	1286	4,301,846	106342
(112, 113, 114)	OBIS (Ocean Biogeographic Information System) - Tropical and Subtropical Western South Pacific OBIS	Fish	Fish			-28.469	-44.826742	3	1997	2002	189	414,849	4125
(115)	OBIS (Ocean Biogeographic Information System) - South Western Pacific OBIS	Fish	Fish			-27.071849	0	43	1961	2005	437	6,824,130	377041
(116)	OBIS (Ocean Biogeographic Information System) - Tropical and Subtropical Western South Pacific OBIS	Fish	Mostly fish and a few invertebrates			-15.437249	-42.09455	18	1972	1989	327	1,852,596	16078
(117)	OBIS - SEFSC-POP (Southeast Fishery Science Center - Pelagic Observer Program)	Fish	Pelagic fish			26.264999	-54.260002	14	1992	2005	19	31,877,769	450905
(118)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Fish	Reef fish			6.7725105	-5.8577728	11	2000	2010	148	24,095,725	21577
(41, 119)	OBIS (Ocean Biogeographic Information System) - SEAMAP (Bahamas Marine Mammal Research Organisation)	Mammals	Marine mammals and a few turtles			24.571583	-75.936535	20	1988	2000	28	106,190	2436

(120)	OBIS (Ocean Biogeographic Information System) - Tropical and Subtropical Western South Pacific OBIS	Marine invertebrates	Copepods			-14.875	-40.935801	8	1954	1961	119	2,833,607	2300
(121, 122)	OBIS (Ocean Biogeographic Information System) - Tropical and Subtropical Eastern South Pacific OBIS	Marine invertebrates	Copepods			-28.257999	-71.922649	8	2002	2009	106	81,903	1313
(123)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine invertebrates	Corals	0.5 m sq	0.50	6.9476414	-5.8605347	4	2007	2010	209	24,033,496	18535
(124)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine invertebrates	Marine invertebrates			27.97635	-89.790798	5	1974	1978	2573	292,035	59429
(125, 126, 127, 128)	OBIS - SCAR-MarBIN (Scientific Committee on Antarctic Research - Marine Biodiversity Information Network)	Marine invertebrates	Marine invertebrates			-0.0109653	-58.471785	5	1979	1986	44	234	428
(129)	OBIS (Ocean Biogeographic Information System) - Japan	Marine invertebrates	Marine invertebrates			5.0028992	124.3343	16	1996	2012	678	6,059,632	4523
(130)	OBIS (Ocean Biogeographic Information System) - OBIS USA	Marine plants	Tropical algae	0.18 m sq quadrats	0.18	6.9471664	-5.8605347	7	2002	2008	258	24,033,496	10198
	Tropical												
(131)	OBIS - NOAA-CCMA (National Oceanic and Atmospheric Administration - Center for Coastal Monitoring and Assessment)	Fish	Fish			18.308015	-64.746758	10	2001	2010	254	182	28123
(132)	OBIS - NOAA-CCMA (National Oceanic and Atmospheric Administration - Center for Coastal Monitoring and Assessment)	Fish	Fish			17.755365	-64.592091	10	2001	2010	247	126	28017
(133)	OBIS (Ocean Biogeographic Information System) - OBIS Fishbase	Fish	Fish			23.795	120.815	4	2000	2003	632	20,164	3513
(134, 135)	LTER (Long Term Ecological Research)	Fish	Tropical reef fish	5 x 50 m transects		-17.5	-149	6	2005	2010	339	<1	19213
	Terrestrial												
	Polar												
(136, 137)	GPDD - The Global Population Dynamics Database	Mammals	Small land carnivores	100 m transects		67.75	29.5	13	1968	1980	3	<1	144
	Temperate												
(138)	ESA - Ecological Publications (Ecological Monographs)	Birds	Birds	50m interval plots from 500 x 100 m		43.91	-71.75	15	1970	1984	29	50	321

				area									
(139)	ESA - Ecological Publications (Ecology)	Birds	Birds	counts from 28 ha	280000.00	39.5	-82.480003	10	1923	1940	56	<1	418
(140, 141, 142, 143, 144, 145, 146)	Ecological Data Wiki	Birds	Birds	counts from 16 ha	160000.00	51.296459	-0.38352	30	1949	1979	45	<1	954
(147)	Ecological Data Wiki	Birds	Birds	counts from 1 km sq	1000.00	51.41634	-5.1721802	47	1928	1979	29	1	528
(148)	USGS Patuxent Wildlife Research Center	Birds	Breeding birds	50 point counts on a 25 mile transect		40.19165	-93.11685	30	1978	2007	389	13,104,786	699449
(149)	ESA - Ecological Publications (Ecology)	Birds	Ducks	0.2 km wide transects		50.845457	-107.4463	26	1952	1977	13	<1	392
(150, 151)	GPDD - The Global Population Dynamics Database	Birds	Tetraonid birds			61.92411	25.748152	14	1964	1977	4		56
(152)	OBIS (Ocean Biogeographic Information System) - AfrOBIS	Birds	Waterbirds			-28.47	24.675	24	1983	2006	68	1,586,205	15675
(153)	ESA - Ecological Archives	Mammals	Rodents	24 x 0.25 ha plots	2500.00	30.322599	-103.5014	26	1977	2002	45	<1	4470
(154, 155)	GPDD - The Global Population Dynamics Database	Mammals	Small mammals	46 grids from 10 km sq	217.00	45.564041	-73.179016	10	1966	1976	5	10	44
(156)	LTER (Long Term Ecological Research)	Mammals	Small mammals	24 x 3.14 ha webs	31400.00	34.200001	-106.43	21	1989	2008	28	<1	16657
(157, 158)	GPDD - The Global Population Dynamics Database	Terrestrial invertebrates	Butterflies			51	4	14	1983	1996	25		303
(159, 160)	GPDD - The Global Population Dynamics Database	Terrestrial invertebrates	Dragonflies	counts within 20 ponds (208 ha)	2080000.00	52.42205	-0.180928	29	1959	1988	5	2.08	132
(161)	LTER (Long Term Ecological Research)	Terrestrial invertebrates	Moths	taken from 6400 ha		44.243995	-122.158	6	1994	2004	8	64	17663
(162, 163, 164)	LTER (Long Term Ecological Research)	Terrestrial plants	Forest plants	194 x 250 m sq plots	250.00	44.330002	-122.33	26	1962	2008	267	48.5	56455
(165)	ESA - Ecological Archives	Terrestrial plants	Sagebrush steppe plants	26 x 1m squared quadrats	1	44.330002	-112.33	29	1923	1973	98	<1	8034
(166)	ESA - Ecological Publications (Ecology)	Terrestrial plants	Woody plants	2 x 2 m plots (16 ha)	2	47.400002	-95.120003	3	1984	1996	23	<1	1406
		Tropical											
(167)	LTER (Long Term Ecological Research)	Birds	Birds	counts within 25m circular plots		18.190001	-65.43	18	1991	2008	31	<1	1171
(168)	LTER (Long Term Ecological Research)	Terrestrial invertebrates	Land snails	circular (3m radius) quadrats in 16 ha		8.1000004	-65.300003	17	1991	2007	19	<1	16208
(169)	Smithsonian Tropical	Terrestrial plants	Tropical forest trees	50 ha plot	500000.00	2.982	102.313	4	1987	2000	823	<1	3292

	Research Institute												
(170)	Smithsonian Tropical Research Institute	Terrestrial plants	Tropical forest trees	50 ha plot	500000.00	11.5989	76.5338	3	1988	2000	75	<1	225
(171, 172, 173, 174)	Smithsonian Tropical Research Institute	Terrestrial plants	Tropical woody plants	50 ha plot	500000.00	9.1521025	-79.846481	6	1982	2005	314	<1	1798

Additional Data table S1 (separate file)

α diversity indices: All indices were calculated for pooled samples after sample-based rarefaction. We report the mean value out of 100 rarefaction bootstraps. Variable definition: ID, numerical variable identifying a survey; Year, year samples were collected; S species richness; varS variance in species richness among samples; N summed abundances for all species in pooled samples; varN variance among samples in summed abundances for all species; SsqrtN, species richness divided by the square root of total summed abundances; PIE probability of interspecific encounter; DomMc McNaughton dominance; expShannon exponential of Shannon diversity (also known as the Hill Number ^{1}D; Chao, Chao1 asymptotic species richness estimator; Chao2 bias corrected Chao1.

Additional Data table S2 (separate file)

β diversity indices: All indices were calculated for pooled samples after sample-based rarefaction. We report the mean value out of 100 rarefaction bootstraps. Variable definition: ID, numerical variable identifying a survey; Year, year samples were collected; Jaccard_B is the Jaccard similarity between the year's pooled samples and the pooled sample of the first year in the time series (the time series baseline); Horn_B similar to Jaccard_B but using Morisita-Horn distance; Chao_B, as before but using Chao distance; Pearson_B as before but using Pearson correlation

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