

Supporting Online Material: Impacts of biodiversity loss on ocean ecosystem services

Boris Worm, Edward B. Barbier, Nicola Beaumont, J. Emmett Duffy, Carl Folke, Benjamin S. Halpern, Jeremy B.C. Jackson, Heike K. Lotze, Fiorenza Micheli, Stephen R. Palumbi, Enric Sala, Kimberley A. Selkoe, John J. Stachowicz, Reg Watson

Methods and data sources

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Supporting references

Methods and data sources

Experiments

We systematically searched major science, ecological and marine journals from 1960 to mid-2005 for experiments that (i) involved marine or estuarine organisms, (ii) conducted experiments including at least three species, (iii) measured some aspect of ecosystem functioning in mixed-species and single-species treatments. The following journals were searched: Science journals: *Science, Nature, Proceedings of the National Academy of Sciences USA*; Ecology journals: *Ecology, Ecological Monographs, Ecological Applications, Oecologia, Oikos, Ecology Letters, Journal of Ecology, Journal of Animal Ecology*; Marine journals: *Limnology and Oceanography, Marine Biology, Marine Ecology Progress Series, Journal of Experimental Marine Biology and Ecology, Journal of the Marine Biological Association of the United Kingdom*.

We grouped studies according to trophic level (primary producer or consumer) and response variable (resource use, primary or secondary production, nutrient cycling, and resilience). For each variable, we conducted a meta-analysis comparing the log ratio of responses in the highest-diversity treatment over the average of all single-species treatments. The effect size was weighted by the sample sizes and standard deviations derived from the original study. Response ratios were combined by fixed-effects meta-analysis. Weights for the log-response ratios were estimated based on sample variance and sample size from the individual studies

$$v_{\ln R} = \frac{(S_E)^2}{N_E(\bar{X}_E)^2} + \frac{(S_C)^2}{N_C(\bar{X}_C)^2} \quad , \quad (1)$$

Where S , N , \bar{X} refer to the standard deviation, sample size and mean of the experimental diversity treatment (E), or control treatment (C), respectively. The mean effect size was considered significant if the parametric 95% confidence intervals did not include zero. All data sources for the meta-analysis of experimental data in Fig. 1A-B are detailed in Table S1 and references $S1$ - $S20$. Fig. 1C is based on eelgrass shoot density data from $S3$ and $S17$. Copepod egg production in Fig. 1D was estimated as the product of survival and fecundity data taken from $S16$.

Coastal ecosystems

The regional analysis presented in Fig. 2 focused on 12 estuarine and coastal ecosystems in North America, Europe, and Australia that form a broad temporal and spatial gradients of human impacts (Table S2). We used an existing database that combines >800 individual references on the history of human-induced ecological changes in these ecosystems covering palaeontological, archaeological, historical, fisheries and ecological records for species that have been of economical, structural, or functional significance throughout history ($S21$). Quantitative and qualitative records of abundance were combined to estimate relative abundance over time as pristine (100%), abundant (90%), depleted (50%), collapsed (10%), and extinct (0%) ($S22$). Recovery was defined as an increase of collapsed species to >10% of abundance. The database covers 30-80 species per study system from six taxonomic (marine mammals, birds, reptiles, fish, invertebrates, vegetation) and seven functional groups (large and small carnivores, large and small herbivores, suspension feeders, submerged aquatic vegetation, wetlands). The database also contains time series of water quality (mainly derived from sediment cores and water quality assessments) and species invasions ($S21$) thus reflecting historical changes in an ecosystem context.

To determine changes in biodiversity over historical time scales we extracted the percent of species that have collapsed (<10%) or became extinct (0%) over time (Fig. 2A). We also extracted the percent of fish taxa currently collapsed or extinct and analyzed whether regional species richness buffers against fisheries loss (Fig. 2B). We used the number of fish species per Large Marine Ecosystem (LME, $S22$) as an independent measure for regional species richness.

This measure is independent of changes in local biodiversity over time, as it captures the total recorded richness of the regional ecosystem derived from checklists, museum records, and other sources. Also there is no significant relationship between regional species richness and time since beginning of commercial exploitation (linear regression, $r=0.46$, $P=0.313$). Percent change in biodiversity (Fig. 2C) was determined as the percent of species currently depleted (<50%), rare (<10%), extinct (0%), or recovered (from 0-10% to >10%) compared to the historical baseline.

For changes in ecosystem services (Fig. 2D), we extracted the percent of fisheries, nursery habitats, and filter function collapsed compared to the historical baseline. Fisheries included all fish taxa that have been of commercial importance throughout history. Nursery habitats included all records on oyster beds, seagrass beds, and wetlands. Filter function included three functional groups: suspension feeders (oysters, mussels, polychaetes, hydrozoans, sponges, corals), all submerged vegetation (seagrasses, rockweeds, macroalgae, other macrophytes), and wetlands (saltmarshes, wetlands, mangroves). These groups are part of the estuarine filter that recycles and stores nutrients, traps sediments, and reduces phytoplankton abundance.

For the risks analysis (Fig. 2E) we extracted time series on oxygen depletion and species invasions from the same database and collected independent time series on beach closures, harmful algal blooms, fish kills, shellfish closures, and coastal flooding from the literature and published databases (Table S3). Depending on the length of the time series, we estimated the percent change between the averages of the most recent and the earliest time interval (Table S3). Because long time series for beach closures were not available, we estimated the average percent of beaches closed in recent years (Table S3). Beach closures were determined as the percent of beaches not meeting standards. For comparability among study systems, we consistently used the European Union threshold levels of elevated bacterial counts as standards with guide levels for total coliforms = 500 and coliform units (CFU) = 100. For oxygen depletion, we included independent data sets from sediment cores and water columns for the Baltic Sea and Chesapeake Bay.

Large Marine Ecosystems

The global analysis presented in Fig. 3 is based on detailed catch records for 64 Large Marine Ecosystems (LME) worldwide (Table S4). We used the spatial database of global fisheries catches of the Sea Around Us Project (SAUP, Fisheries Centre, University of British Columbia, Vancouver, Canada, according to *S53*). This database comprises nearly half a billion records of catch rates for global half-degree latitude and longitude spatial cells, for all reported taxa and countries from 1950 to 2003. The spatial database is based on a consolidation of several major data sources such as the FAO capture fisheries and its regional bodies, the International Council for the Exploration of the Seas (ICES) STATLANT database (www.ices.int/fish/statlant.htm), the Northwest Atlantic Fisheries Organization (NAFO; www.nafo.ca/), as well as data provided from the Canadian, United States, and other governments. We used these data to follow fisheries catch trajectories 1950-2003. Fisheries were defined by catches of unique animal taxa (usually defined by species, or genus or family in some cases) within the spatial confines of individual large marine ecosystems (LMEs, Table S4). The global system of LMEs is widely accepted as a useful way to divide coastal and shelf ecosystems (*S54*). Collectively, these areas comprised 83% of total commercial fisheries yields for 1950-2003. Fish diversity data by LME is available for these areas from FishBase (www.fishbase.org). Catch data were filtered by excluding all taxa that yielded less than 10kt of cumulative catch over the last 52 years. This was done to exclude minor and experimental fisheries that were not pursued over time. However, excluding these fisheries (or using 1, or 100kt filters) did not have a major effect on the results. A fishery was considered to have started when annual catches reached 10% of the annual maximum for the time series. Individual fish species i were classified as collapsed for LME k when total yield C had declined to $C_{ik} < 0.1$ relative to the maximum yield in LME k . Species were considered as recovered when their yield had increased to $C_{ik} > 0.1$ subsequent to a collapse. The terms ‘collapsed’ or ‘recovered’ as used here refer strictly to the delivery of services (fish products), not necessarily to the biological condition of the stock. The starting year of a fishery (average: 1963) did not vary systematically across the diversity gradient (linear regression, $r=0.158$, $P=0.233$), but the year it collapsed (average: 1985) did increase with diversity ($r=0.272$, $P=0.0377$), i.e. fisheries began at the same time but collapsed later, on average, in high-diversity areas. This is consistent with the proposed diversity effect.

Relationships between species richness and fisheries productivity and stability were tested using linear regression models on log-transformed data. Standard linear least squares regression and robust regression techniques gave nearly identical results; therefore we report linear least squares results in Fig. 3. Robust regression models were controlling for potential outliers in the independent variables space and in the response (dependent variable) space using the High Efficiency High Breakpoint method as proposed by Yohai, Stahel, and Zamar (S55) and implemented in the `lmRobMM` procedure in S-Plus vs. 7. Individual LMEs were considered statistically independent, as by definition they represent distinct ecosystems governed by unique biological, hydrographic and climatic conditions (S54). Temporally autocorrelated time series (Fig. 3A) were analyzed using the `AUTOREG` procedure in SAS vs. 8.

Marine reserves and fishery closures

We searched the literature and online databases for data collected on biological diversity and ecosystem services inside and outside or before and after an established marine reserve (n=44) or fishery closure (n=4). Marine reserves are defined here as no-take areas that are fully protected from fishing. We also used data for dive tourism in 138 Caribbean marine protected areas (MPAs). Note that not all of these Caribbean protected areas were no-take reserves, some had limited fishing allowed, and some were not well enforced. Regardless, based on the success stories of no-take reserves, there appears to be an expectation from divers of greater biodiversity inside the protected areas that drives choice of diving locations.

All data sources are detailed in Table S5 and references S56-S104. Effect sizes were calculated as the response ratio $\ln R$ of the variable within the protected over the fished area (or before-after reserve establishment). Response ratios from individual studies were combined by standard meta-analysis. Few studies reported measures of variance, and so weights for the log-response ratios were estimated based on sample size (S105). Sampling variances v for each study i were calculated including effect sizes (S105)

$$v_i = \frac{(N_c + N_e)}{(N_c N_e)} + \frac{\ln(R^2)}{2(N_c + N_e)}, \quad (2)$$

where N_C and N_E refer to the sample size in fished and protected areas respectively. Weights were calculated as the inverse of the sampling variance. Because sample sizes varied greatly ($3 < N < 350$), this approach may weight some studies disproportionately. For comparison we present weighted and unweighted averages. The single exception was the dive trip data set (*S105*) which was based on complete operator records rather than samples. Therefore confidence intervals or weights could not be calculated for dive trip data. We regard our estimates of effect size as conservative, because reserve studies that used proper Before–After, Control–Impact (BACI) experimental designs showed that control and reserve sites were equivalent prior to protection and that control sites improved along with the reserves after those were established (*S106*). This implies that any bias in our current perception of reserve impacts introduced by inside-outside comparisons likely underestimates the effect of the reserve.

Table S1. Studies used in the meta-analysis of experimental data.

Reference	Trophic level	Service category	Response variable	Maximum richness	Effect size (lnR)	variance (lnR)
<i>S1</i>	Primary producers	Nutrient use	total N storage in plant biomass	6	0.439	0.010
<i>S1</i>	Primary producers	Nutrient use	litter N concentration	6	0.154	0.001
<i>S1</i>	Primary producers	Nutrient use	benthic microalgal N concentration	6	0.173	0.007
<i>S2</i>	Primary producers	Nutrient use	porewater NH ₄ , before disturbance	8	0.092	0.052
<i>S2</i>	Primary producers	Nutrient use	porewater NH ₄ , after disturbance	8	0.654	0.020
<i>S1</i>	Primary producers	Primary production	total plant biomass	6	0.698	0.003
<i>S3</i>	Primary producers	Primary production	shoot density at ~4.5 mo	6	0.450	0.037
<i>S4</i>	Primary producers	Primary production	average of all treatments	5	0.491	0.003
<i>S5</i>	Primary producers	Secondary production	survival x growth (urchin)	4	0.643	0.004
<i>S6</i>	Primary producers	Secondary production	survival x growth (<i>A. marcuzii</i>)	5	0.543	0.005
<i>S6</i>	Primary producers	Secondary production	survival x growth (<i>C. compta</i>)	5	0.804	0.002
<i>S6</i>	Primary producers	Secondary production	survival x growth (<i>A. valida</i>)	5	0.227	0.002
<i>S6</i>	Primary producers	Secondary production	survival x growth (<i>G. mucronatus</i>)	5	1.173	0.004
<i>S7</i>	Primary producers	Secondary production	survival x growth (<i>A. longimana</i>)	12	0.583	0.003
<i>S8</i>	Primary producers	Secondary production	copepod egg production: high food	3	-0.377	0.049
<i>S8</i>	Primary producers	Secondary production	copepod egg production: low food	3	0.118	0.084
<i>S9</i>	Primary producers	Secondary production	gastropod shell growth	3	0.480	0.021
<i>S10</i>	Primary producers	Secondary production	copepod survival x fecundity	4	1.061	0.065
<i>S11</i>	Primary producers	Secondary production	growth (<i>Amphisorus</i>)	3	0.674	0.003
<i>S11</i>	Primary producers	Secondary production	growth (<i>Amphistegina</i>)	3	0.501	0.002
<i>S12</i>	Primary producers	Secondary production	copepod egg production	4	1.833	0.029
<i>S3</i>	Primary producers	Secondary production	fouling invertebrate density	6	0.341	0.006
<i>S13</i>	Consumers	Resource use	algal biomass (chl <i>a</i>)	3	0.257	0.161
<i>S14</i>	Consumers	Resource use	algal biomass	6	1.927	0.249
<i>S15</i>	Consumers	Resource use	algal biomass (predators present)	4	1.255	0.818
<i>S16</i>	Consumers	Resource use	space use (<i>Botrylloides</i> experiment)	4	0.369	0.012
<i>S16</i>	Consumers	Resource use	space use (<i>Asciodiella</i> experiment)	4	0.176	0.010

<i>S13</i>	Consumers	Secondary production	grazer biomass	3	-0.027	0.087
<i>S14</i>	Consumers	Secondary production	grazer biomass	6	0.446	0.006
<i>S15</i>	Consumers	Secondary production	grazer biomass (predators present)	4	0.988	0.076
<i>S17</i>	Consumers	Secondary production	ciliate biovolume (experiment I)	4	0.230	0.112
<i>S17</i>	Consumers	Secondary production	ciliate biovolume (experiment II)	7	1.569	0.050
<i>S17</i>	Consumers	Secondary production	ciliate biovolume (experiment III)	4	0.933	0.046
<i>S14</i>	Consumers	Nutrient regeneration	sediment organic carbon	6	0.426	0.036
<i>S18</i>	Consumers	Nutrient regeneration	NH4 flux	4	0.129	0.024
<i>S18</i>	Consumers	Nutrient regeneration	NH4 flux	3	0.121	0.068
<i>S18</i>	Consumers	Nutrient regeneration	NH4 flux	3	0.171	0.248
<i>S19</i>	Consumers	Nutrient regeneration	NH4 flux (with flow)	5	0.334	0.127
<i>S19</i>	Consumers	Nutrient regeneration	NH4 flux (no flow)	5	0.095	0.090
<i>S20</i>	Consumers	Nutrient regeneration	Oxygen flux	3	0.000	0.003
<i>S20</i>	Consumers	Nutrient regeneration	Phosphate flux	3	-0.359	0.098
<i>S20</i>	Consumers	Nutrient regeneration	depth-integrated pH	3	0.015	0.000
<i>S15</i>	Consumers	Stability	predation effect on grazer biomass	4	0.766	0.111
<i>S15</i>	Consumers	Stability	predation effect on algal biomass	4	0.704	0.568
<i>S15</i>	Consumers	Stability	predation effect on eelgrass biomass	4	1.186	0.685
<i>S17</i>	Consumers	Stability	UVB effect on ciliate biovolume (experiment I)	4	-0.731	0.335
<i>S17</i>	Consumers	Stability	UVB effect on ciliate biovolume (experiment II)	7	0.489	0.174
<i>S16</i>	Consumers	Stability	invader survival (<i>Botryllus</i>)	4	0.493	0.052
<i>S16</i>	Consumers	Stability	invader cover (<i>Botrylloides</i>)	4	0.080	0.001
<i>S16</i>	Consumers	Stability	invader cover (<i>Ascidella</i>)	4	0.209	0.003

Table S2. Estuarine and coastal study systems.

System	Large Marine Ecosystem	Country
Western Baltic Sea	Baltic Sea	Europe
Wadden Sea	North Sea	Europe
Northern Adriatic Sea	Mediterranean Sea	Europe
Southern Gulf St. Lawrence	Scotian Shelf	Canada
Outer Bay of Fundy	Scotian Shelf	Canada
Massachusetts Bay	Northeast U.S. Shelf	USA
Delaware Bay	Northeast U.S. Shelf	USA
Chesapeake Bay	Northeast U.S. Shelf	USA
Pamlico Sound	Southeast U.S. Shelf	USA
Galveston Bay	Gulf of Mexico	USA
San Francisco Bay	California Current	USA
Moreton Bay	East-central Australian Shelf	Australia

Table S3. Data sources for the analysis of services and risks in coastal and estuarine ecosystems.

System	Detail	Time series	Interval	Ref.
Beach closures (n=10)				
Baltic	% beaches not meeting standards	1999-2002	4 yr	S23
Wadden	% beaches not meeting standards	1999-2002	4 yr	S23
Adriatic	% beaches not meeting standards	1999-2002	4 yr	S23
Massachusetts	% beaches not meeting standards	1999-2002	4 yr	S24
Delaware	% beaches not meeting standards	1999-2002	4 yr	S24
Chesapeake	% beaches not meeting standards	1999-2002	4 yr	S24
Pamlico	% beaches not meeting standards	1999-2002	4 yr	S24
Galveston	% beaches not meeting standards	1999-2002	4 yr	S24
San Francisco	% beaches not meeting standards	1999-2002	4 yr	S24
Moreton	% beaches not meeting standards	2000-2001	2 yr	S25
Harmful blooms (n=6)				
Baltic	Concentration of cyanobacterial blooms: <i>Aphanizomenon</i> and <i>Nodulari</i> ($100 \mu\text{m L}^{-1}$)	1887-1908 vs. 1981-93		S26
Wadden	Surface algal bloom events per year	1979-1995	5 yr	S27
Adriatic	Mucilage events per decade	1729-1991	50 yr	S28
Bay of Fundy	PSP toxins in clams, events per decade exceeding $100 \mu\text{g}$ per 100g tissue	1944-1983	10 yr	S29
Lawrence	Harmful algal species, mean cells L^{-1} per yr	1995-2004	3 yr	S30

	of all species at 11 monitoring sites			
US estuaries	Harmful algal bloom events per year	1970-1996	5 yr	S31
Fish kills (n=3)				
Chesapeake	# events / yr	1984-2003	5 yr	S32
Pamlico	# events / yr	1997-2003	3 yr	S33
Galveston	# events / yr	1970-2003	5 yr	S34
Shellfish closures 10 yr (n=7)				
Bay of Fundy	% estuarine shellfish area limited for harvest in Maine	1985-1995	5 yr	S35
Massachusetts	% estuarine shellfish area limited for harvest in Massachusetts	1985-1995	5 yr	S35
Delaware	% estuarine shellfish area limited for harvest in Delaware	1985-1995	5 yr	S35
Chesapeake	% estuarine shellfish area limited for harvest in Maryland and Virginia	1985-1995	5 yr	S35
Pamlico	% estuarine shellfish area limited for harvest in North Carolina	1985-1995	5 yr	S35
Galveston	% estuarine shellfish area limited for harvest in Texas	1985-1995	5 yr	S35
San Francisco	% estuarine shellfish area limited for harvest in California	1985-1995	5 yr	S35
Shellfish closures 35 yr (n=3)				
Bay of Fundy	# of shellfish closures, NB	1960-1995	5 yr	S36
Lawrence	# of shellfish closures, PEI	1960-1995	5 yr	S36
US estuaries	% shellfish area limited for harvest in US	1960-1995	5 yr	S35
Oxygen depletion (n=6)				
Baltic	Aerial extent of laminated sediments (km ²)	1900-2000	10 yr	S37
Baltic	Dissolved oxygen concentration Kiel Bay (mg L ⁻¹)	1950-2000	10 yr	S38
Adriatic	Dissolved oxygen concentration in bottom layer in summer (mg L ⁻¹)	1911-1984	5-10 yr	S39
Chesapeake	Anaerobic bacterial biomarker abundance, sediment core	1900-2000	20 yr	S40
Chesapeake	Water volume with low dissolved oxygen (<0.5 ml L ⁻¹)	1950-1980	4 yr	S41
Pamlico	Degree of pyritization, sediment core	1800-2000	20 yr	S42

Coastal flooding (n=9)

Wadden	# storm tides per decade at Cuxhaven	1850-1995	10 yr	<i>S43</i>
Adriatic	# positive surge anomalies >208 cm / yr	1940-2001	10 yr	<i>S44</i>
Lawrence	# storm surges >1m per decade at Charlottetown, Prince Edward Island	1940-1999	10 yr	<i>S45</i>
Massachusetts	# floods / yr	1993-2004	5 yr	<i>S46</i>
Delaware	# floods / yr	1993-2004	5 yr	<i>S46</i>
Chesapeake	# floods / yr	1993-2004	5 yr	<i>S46</i>
Pamlico	# floods / yr	1993-2004	5 yr	<i>S46</i>
Galveston	# floods / yr	1993-2004	5 yr	<i>S46</i>
San Francisco	# floods / yr	1993-2004	5 yr	<i>S46</i>

Species invasions (n=6)

Baltic	# invasions per decade, aquatic species	1800-2004	50 yr	<i>S47</i>
Wadden	# invasions per decade, North Sea, marine estuarine species	1800-1996	50 yr	<i>S48</i>
Adriatic	# invasions per decade, Mediterranean, molluscs only	1877-2000	50 yr	<i>S49</i>
Bay of Fundy	# invasions per decade, Bay of Fundy to Long Island Sound, marine and estuarine excluding cryptogenic species	1817-1999	50 yr	<i>S50</i>
Chesapeake	# invasions per decade, marine and brackish species	1800-2002	50 yr	<i>S51</i>
San Francisco	# invasions per decade, marine and tidal fresh species	1850-1995	50 yr	<i>S52</i>

Table S4. Large Marine Ecosystems (LME).

LME #	LME Name	Latitude (N)	Longitude (E)	Area (km ²)	Fish species richness
1	East Bering Sea	57.3	-167.5	1355778	184
2	Gulf of Alaska	54.3	-139.9	1464613	309
3	California Current	34.9	-120.4	2227006	803
4	Gulf of California	33.4	-110.4	224031	363
5	Gulf of Mexico	30.2	-92.9	1535015	969
6	Southeast U.S. Continental Shelf	33.0	-81.8	324234	1118
7	Northeast U.S. Continental Shelf	48.2	-75.8	299457	648
8	Scotian Shelf	45.6	-62.1	284128	198
9	Newfoundland-Labrador Shelf	51.5	-60.6	902776	172
10	Insular Pacific-Hawaiian	23.3	-166.6	985971	829
11	Pacific Central-American Coastal	9.1	-90.5	1973475	943
12	Caribbean Sea	12.9	-75.2	3273830	1539
13	Humboldt Current	-29.1	-71.0	2547702	752
14	Patagonian Shelf	-37.6	-61.5	1153589	332
15	South Brazil Shelf	-22.5	-48.6	564789	951
16	East Brazil Shelf	-11.3	-45.6	1086782	896
17	North Brazil Shelf	1.3	-53.0	1052460	935
18	West Greenland Shelf	68.6	-55.3	373991	158
19	East Greenland Shelf	68.6	-30.1	321712	158
20	Barents Sea	66.1	42.1	1698857	201
21	Norwegian Shelf	68.2	3.5	1119675	232
22	North Sea	54.6	10.7	723171	185
23	Baltic Sea	59.6	21.1	369849	169
24	Celtic-Biscay Shelf	51.1	-5.1	759320	317
25	Iberian Coastal	40.4	-6.1	319862	586
26	Mediterranean Sea	36.4	17.7	2524934	599
27	Canary Current	23.9	-1.3	1116366	1267
28	Guinea Current	4.5	3.8	1922365	725
29	Benguela Current	-20.9	17.8	1468081	819
30	Agulhas Current	-22.1	34.9	2646502	1306
31	Somali Coastal Current	0.6	38.7	841283	689
32	Arabian Sea	28.4	51.7	3940642	933
33	Red Sea	18.5	31.9	459408	1189
34	Bay of Bengal	25.0	90.1	3665152	686
35	Gulf of Thailand	8.4	102.2	386967	606
36	South China Sea	17.2	105.5	3193252	3689
37	Sulu-Celebes Sea	7.8	121.4	1009767	1165
38	Indonesian Sea	-3.9	119.9	2286488	2437
39	North Australian Shelf	-17.8	133.8	792874	1839
40	Northeast Australian Shelf	-18.0	149.8	1284723	1733
41	East-Central Australian Shelf	-28.6	149.4	654182	1242
42	Southeast Australian Shelf	-40.5	143.2	1179619	220
43	Southwest Australian Shelf	-31.6	126.0	1063159	473

44	West-Central Australian Shelf	-26.9	118.6	547049	472
45	Northwest Australian Shelf	-18.0	118.9	896663	1066
46	New Zealand Shelf	-40.7	172.8	959623	916
47	East China Sea	37.4	105.3	779632	1014
48	Yellow Sea	41.7	110.1	439590	1906
49	Kuroshio Current	32.4	133.5	1312887	1442
50	Sea of Japan	43.6	134.0	984353	490
51	Oyashio Current	46.0	150.4	535269	37
52	Sea of Okhotsk	54.5	146.4	1556089	216
53	West Bering Sea	58.2	174.4	2005272	272
54	Chukchi Sea	70.0	-167.6	569932	81
55	Beaufort Sea	71.0	-140.9	773322	102
56	East Siberian Sea	71.8	160.6	925514	41
57	Laptev Sea	65.0	110.5	504994	42
58	Kara Sea	66.3	81.1	806101	18
59	Iceland Shelf	65.4	-20.0	312287	152
60	Faroe Plateau	60.4	-11.5	150049	174
61	Antarctica	-75.1	90.0	4385933	247
62	Black Sea	43.8	39.8	463322	148
63	Hudson Bay	53.9	-97.9	3911123	18
64	Arctic Ocean	76.5	90.0	6854419	123

Table S5. Data sources for marine reserves and fishery closures (lnR=Response ratio; N_C =Sample size in fished area; N_E =Sample size in protected area).

Variable	Location	Ecosystem type	lnR	Time (yr)	N_C	N_E	Reference
Spp. richness	Amedee, New Caledonia	coral reef	0.742	5.0	3	3	S56
Spp. richness	Apo, Philippines	coral reef	0.336	1.0	5	5	S57
Spp. richness	Bailly, New Caledonia	coral reef	0.236	5.0	3	3	S56
Spp. richness	Balicasag, Philippines	coral reef	0.149	14.0	3	3	S58
Spp. richness	Balicasag, Philippines	coral reef	0.336	1.0	5	5	S57
Spp. richness	Banyuls, France	rocky reef	0.154	1.0	8	8	S62
Spp. richness	Barbados	coral reef	0.063	12.0	21	13	S59
Spp. richness	Carry-le-Rouet, France	rocky reef	0.151	14.0	24	24	S63
Spp. richness	Castellamare, Sicily	groundfish	0.266	4.0	21	30	S60
Spp. richness	English Channel	soft sediment	0.724	23.0	9	6	S61
Spp. richness	English Channel	soft sediment	0.983	2.0	9	6	S61
Spp. richness	French Reef, Florida, USA	coral reef	-0.132	21.0	130	40	S65
Spp. richness	Georges Bank, New England, USA	groundfish	0.104	9.0	350	350	S66
Spp. richness	Goat Island, New Zealand	kelp forest	0.336	13.0	50	85	S67
Spp. richness	Governor Island, Tasmania	kelp forest	0.155	28.0	23	23	S68
Spp. richness	Haunama, Hawaii	coral reef	0.042	18.0	3	3	S69
Spp. richness	Hol Chan, Belize	coral reef	0.091	2.0	24	25	S70
Spp. richness	Honolua, Hawaii	coral reef	0.200	16.0	3	3	S69
Spp. richness	Kealalakua, Hawaii	coral reef	0.020	16.0	3	3	S69
Spp. richness	Kenya	coral reef	0.652	2.0	28	28	S71
Spp. richness	Laregnere, New Caledonia	coral reef	0.626	5.0	3	3	S56
Spp. richness	Maitre, New Caledonia	coral reef	0.370	5.0	4	4	S56
Spp. richness	Manele, Hawaii	coral reef	-0.036	17.0	3	3	S69
Spp. richness	Maria Island, Tasmania	kelp forest	0.155	28.0	23	23	S68
Spp. richness	Mayotte Island, Comoros	coral reef	0.006	3.0	3	3	S72
Spp. richness	Molasses Reef, Florida	coral reef	-0.029	21.0	130	63	S65
Spp. richness	Molokini, Hawaii	coral reef	0.133	17.0	3	3	S69
Spp. richness	Ninepin Pt, Tasmania	kelp forest	0.179	9.0	23	23	S68
Spp. richness	Pamilican, Philippines	coral reef	-0.036	14.0	3	3	S58
Spp. richness	Pamilican, Philippines	coral reef	0.223	1.0	5	5	S57
Spp. richness	Red Sea	coral reef	-0.078	11.0	9	9	S73
Spp. richness	Scandola, France	rocky reef	0.214	17.0	10	10	S64
Spp. richness	Scotian Shelf, Canada	groundfish	0.540	14.0	350	350	S74
Spp. richness	Signal, New Caledonia	coral reef	0.280	5.0	3	3	S56
Spp. richness	South Africa	intertidal	-0.306	10.0	42	28	S75
Spp. richness	South Africa	intertidal	-0.187	10.0	29	28	S75
Spp. richness	South Africa	intertidal	-0.461	2.0	28	34	S75
Spp. richness	St. Lucia, Caribbean	coral reef	0.080	6.0	12	12	S76
Spp. richness	Sumilon, Philippines	coral reef	0.265	10.0	6	6	S77
Spp. richness	Sumilon, Philippines	coral reef	0.377	4.0	6	6	S77
Spp. richness	Tinderbox, Tasmania	kelp forest	-0.018	9.0	23	23	S68
Spp. richness	Transkei, South Africa	rocky shore	1.034	13.0	4	4	S78
Spp. richness	Transkei, South Africa	rocky shore	0.528	13.0	4	4	S78
Fishable species	Apo, Philippines	coral reef	-0.095	1.0	5	6	S77
Fishable species	Apo, Philippines	coral reef	0.620	1.0	5	5	S57
Fishable species	Balicasag, Philippines	coral reef	0.484	1.0	5	5	S57

Fishable species	Barbados	coral reef	0.000	11.0	48	30	<i>S59</i>
Fishable species	California (BC)	kelp forest	-0.105	1.0	11	12	<i>S79</i>
Fishable species	California (HMS)	kelp forest	0.154	11.0	12	31	<i>S79</i>
Fishable species	California (PL)	kelp forest	0.251	22.0	15	6	<i>S79</i>
Fishable species	Florida Cays, USA	coral reef	0.000	20.0	130	40	<i>S65</i>
Fishable species	Florida Cays, USA	coral reef	0.054	20.0	130	63	<i>S65</i>
Fishable species	Cape Canaveral, Florida, USA	coral reef	0.000	25.0	402	251	<i>S80</i>
Fishable species	Hol Chan, Belize	coral reef	-0.087	2.0	24	25	<i>S70</i>
Fishable species	Kenya	coral reef	0.654	20.0	20	14	<i>S71</i>
Fishable species	Kenya	coral reef	0.379	1.0	20	19	<i>S71</i>
Fishable species	Kenya	coral reef	0.174	6.0	20	10	<i>S81</i>
Fishable species	Mayotte Island (Comoros)	coral reef	0.000	3.0	9	9	<i>S72</i>
Fishable species	Mediterranean, France	rocky reef	0.080	1.0	8	8	<i>S62</i>
Fishable species	Mediterranean, France	rocky reef	0.041	13.0	8	8	<i>S82</i>
Fishable species	Mediterranean, France	rocky reef	0.000	13.0	63	63	<i>S83</i>
Fishable species	Mediterranean, France	rocky reef	1.386	1.0	8	8	<i>S62</i>
Fishable species	Mediterranean, Italy	rocky reef	0.000	5.0	72	72	<i>S84</i>
Fishable species	Mediterranean, Italy	rocky reef	0.000	5.0	72	72	<i>S84</i>
Fishable species	Mediterranean, Italy	rocky reef	0.000	10.0	24	24	<i>S85</i>
Fishable species	Mediterranean, Spain	rocky reef	0.031	6.0	25	15	<i>S86</i>
Fishable species	New Caledonia	coral reef	0.000	5.0	56	32	<i>S56</i>
Fishable species	New Zealand	kelp forest	0.118	13.0	17	30	<i>S67</i>
Fishable species	Pamilican, Philippines	coral reef	0.464	1.0	5	5	<i>S57</i>
Fishable species	Red Sea	coral reef	0.018	11.0	9	9	<i>S73</i>
Fishable species	Red Sea	coral reef	-0.154	15.0	27	27	<i>S87</i>
Fishable species	St. Vincent-Grenadines, St. Lucia	coral reef	0.049	4.0	40	37	<i>S87</i>
Fishable species	St. Vincent-Grenadines, St. Lucia	coral reef	0.095	6.0	40	38	<i>S87</i>
Fishable species	Sumilon, Philippines	coral reef	0.241	10.0	6	6	<i>S77</i>
CPUE	Apo, Philippines	coral reef	2.303	10.0	NA	NA	<i>S88</i>
CPUE	Castellammare del Golfo, Italy	ground fish	3.194	10.0	NA	NA	<i>S89</i>
CPUE	Georges Bank, New England, USA	ground fish	1.003	6.0	NA	NA	<i>S90</i>
CPUE	Mombasa, Kenya	coral reef	0.748	2.0	NA	NA	<i>S91</i>
CPUE	Mombasa, Kenya	coral reef	0.942	2.0	NA	NA	<i>S91</i>
CPUE	Red Sea	coral reef	0.509	5.0	80	80	<i>S92</i>
CPUE	Scotian Shelf, Canada	ground fish	0.493	14.0	NA	NA	<i>S74</i>
CPUE	St. Lucia, Caribbean	coral reef	0.588	5.0	33	51	<i>S93</i>
CPUE	St. Lucia, Caribbean	coral reef	0.305	5.0	59	133	<i>S93</i>
Catch	Apo, Philippines	coral reef	1.863	10.0	NA	NA	<i>S88</i>
Catch	Georges Bank, New England, USA	ground fish	-0.643	6.0	NA	NA	<i>S90</i>
Catch	Mombasa, Kenya	coral reef	-0.427	2.0	NA	NA	<i>S91</i>
Catch	Scotian Shelf, Canada	groundfish	-0.491	14.0	NA	NA	<i>S94</i>
Catch	St. Lucia, Caribbean	coral reef	0.428	5.0	NA	NA	<i>S93</i>
Catch	St. Lucia, Caribbean	coral reef	0.160	5.0	NA	NA	<i>S93</i>
Resistance	Kenya, 4 reserves	coral reef	-0.313	0.5	7	9	<i>S95</i>
Resistance	Kenya, 4 reserves	coral reef	0.000	0.5	7	9	<i>S95</i>
Resistance	Kenya, 4 reserves	coral reef	1.161	3.0	3	3	<i>S96</i>
Resistance	St. Lucia, Caribbean	coral reef	-0.473	5.0	12	12	<i>S97</i>
Resistance	St. Lucia, Caribbean	coral reef	1.036	1.0	12	12	<i>S97</i>
Recovery	Balicasag, Philippines	coral reef	1.224	14.0	3	3	<i>S58</i>
Recovery	Mayotte Island, Comoros	coral reef	1.018	1.5	4	4	<i>S98</i>

Recovery	Mayotte Island, Comoros	coral reef	1.346	1.5	4	4	<i>S98</i>
Recovery	Pamilican, Philippines	coral reef	-0.206	14.0	3	3	<i>S58</i>
Recovery	St. Lucia, Caribbean	coral reef	0.277	5.0	12	12	<i>S97</i>
Variability	Apo, Philippines	coral reef	-0.153	6.0	5	5	<i>S99</i>
Variability	Apo, Philippines	coral reef	-0.091	6.0	5	5	<i>S99</i>
Variability	Apo, Philippines	coral reef	-0.282	6.0	5	5	<i>S99</i>
Variability	Apo, Philippines	coral reef	-0.503	6.0	6	6	<i>S100</i>
Variability	Channel Islands, California	kelp forest	-0.547	18.0	NA	NA	<i>S101</i>
Variability	Channel Islands, California	kelp forest	-0.123	18.0	NA	NA	<i>S101</i>
Variability	Channel Islands, California	kelp forest	-0.153	18.0	NA	NA	<i>S101</i>
Variability	Channel Islands, California	kelp forest	-0.114	18.0	NA	NA	<i>S101</i>
Variability	Channel Islands, California	kelp forest	0.299	18.0	NA	NA	<i>S101</i>
Variability	Georges Bank, New England, USA	groundfish	-1.135	9.0	5	5	<i>S66</i>
Variability	Georges Bank, New England, USA	groundfish	0.873	9.0	5	5	<i>S90</i>
Variability	NA	seagrass	-0.463	11.0	10	10	<i>S102</i>
Variability	NA	seagrass	0.049	7.0	6	6	<i>S102</i>
Variability	Scotian Shelf, Canada)	groundfish	-0.515	14.0	5	5	<i>S74</i>
Variability	Transkei, South Africa	rocky shore	0.175	13.0	10	10	<i>S78</i>
Variability	Transkei, South Africa	rocky shore	-0.095	13.0	10	10	<i>S78</i>
Variability	Transkei, South Africa	rocky shore	0.116	13.0	10	10	<i>S78</i>
Variability	Transkei, South Africa	rocky shore	-0.025	13.0	10	10	<i>S78</i>
Variability	Glovers Reef, Belize	coral reef	0.526	6.0	4	4	<i>S103</i>
Variability	Glovers Reef, Belize	coral reef	-0.199	6.0	4	4	<i>S103</i>
Variability	Glovers Reef, Belize	coral reef	-0.421	6.0	4	4	<i>S103</i>
Variability	St. Lucia, Caribbean	coral reef	-0.376	3.0	83	114	<i>S76</i>
Dive trips	Caribbean (138 sites)	coral reef	1.386	NA	138	138	<i>S104</i>

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