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

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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

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

Where $S, N, \overline{X}$ 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*)

$$v_i = \frac{(N_c + N_E)}{(N_C N_E)} + \frac{\ln(R^2)}{2(N_C + N_E)}\ , \qquad (2)$$

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)**
S1	Primary producers	Nutrient use	total N storage in plant biomass	6	0.439	0.010
S1	Primary producers	Nutrient use	litter N concentration	6	0.154	0.001
S1	Primary producers	Nutrient use	benthic microalgal N concentration	6	0.173	0.007
S2	Primary producers	Nutrient use	porewater NH4, before disturbance	8	0.092	0.052
S2	Primary producers	Nutrient use	porewater NH4, after disturbance	8	0.654	0.020
S1	Primary producers	Primary production	total plant biomass	6	0.698	0.003
S3	Primary producers	Primary production	shoot density at ~4.5 mo	6	0.450	0.037
S4	Primary producers	Primary production	average of all treatments	5	0.491	0.003
S5	Primary producers	Secondary production	survival x growth (urchin)	4	0.643	0.004
S6	Primary producers	Secondary production	survival x growth (*A. marcuzii*)	5	0.543	0.005
S6	Primary producers	Secondary production	survival x growth (*C. compta*)	5	0.804	0.002
S6	Primary producers	Secondary production	survival x growth (*A. valida*)	5	0.227	0.002
S6	Primary producers	Secondary production	survival x growth (*G. mucronatus*)	5	1.173	0.004
S7	Primary producers	Secondary production	survival x growth (*A. longimana*)	12	0.583	0.003
S8	Primary producers	Secondary production	copepod egg production: high food	3	-0.377	0.049
S8	Primary producers	Secondary production	copepod egg production: low food	3	0.118	0.084
S9	Primary producers	Secondary production	gastropod shell growth	3	0.480	0.021
S10	Primary producers	Secondary production	copepod survival x fecundity	4	1.061	0.065
S11	Primary producers	Secondary production	growth (*Amphisorus*)	3	0.674	0.003
S11	Primary producers	Secondary production	growth (*Amphistegina*)	3	0.501	0.002
S12	Primary producers	Secondary production	copepod egg production	4	1.833	0.029
S3	Primary producers	Secondary production	fouling invertebrate density	6	0.341	0.006
S13	Consumers	Resource use	algal biomass (chl *a*)	3	0.257	0.161
S14	Consumers	Resource use	algal biomass	6	1.927	0.249
S15	Consumers	Resource use	algal biomass (predators present)	4	1.255	0.818
S16	Consumers	Resource use	space use (*Botrylloides* experiment)	4	0.369	0.012
S16	Consumers	Resource use	space use (*Ascidiella* experiment)	4	0.176	0.010

S13	Consumers	Secondary production	grazer biomass	3	-0.027	0.087
S14	Consumers	Secondary production	grazer biomass	6	0.446	0.006
S15	Consumers	Secondary production	grazer biomass (predators present)	4	0.988	0.076
S17	Consumers	Secondary production	ciliate biovolume (experiment I)	4	0.230	0.112
S17	Consumers	Secondary production	ciliate biovolume (experiment II)	7	1.569	0.050
S17	Consumers	Secondary production	ciliate biovolume (experiment III)	4	0.933	0.046
S14	Consumers	Nutrient regeneration	sediment organic carbon	6	0.426	0.036
S18	Consumers	Nutrient regeneration	NH4 flux	4	0.129	0.024
S18	Consumers	Nutrient regeneration	NH4 flux	3	0.121	0.068
S18	Consumers	Nutrient regeneration	NH4 flux	3	0.171	0.248
S19	Consumers	Nutrient regeneration	NH4 flux (with flow)	5	0.334	0.127
S19	Consumers	Nutrient regeneration	NH4 flux (no flow)	5	0.095	0.090
S20	Consumers	Nutrient regeneration	Oxygen flux	3	0.000	0.003
S20	Consumers	Nutrient regeneration	Phosphate flux	3	-0.359	0.098
S20	Consumers	Nutrient regeneration	depth-integrated pH	3	0.015	0.000
S15	Consumers	Stability	predation effect on grazer biomass	4	0.766	0.111
S15	Consumers	Stability	predation effect on algal biomass	4	0.704	0.568
S15	Consumers	Stability	predation effect on eelgrass biomass	4	1.186	0.685
S17	Consumers	Stability	UVB effect on ciliate biovolume (experiment I)	4	-0.731	0.335
S17	Consumers	Stability	UVB effect on ciliate biovolume (experiment II)	7	0.489	0.174
S16	Consumers	Stability	invader survival (*Botryllus*)	4	0.493	0.052
S16	Consumers	Stability	invader cover (*Botrylloides*)	4	0.080	0.001
S16	Consumers	Stability	invader cover (*Ascidiella*)	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: *Aphanizomenon* and *Nodulari* (100 μm 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 μg 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	*S43*
Adriatic	# positive surge anomalies >208 cm / yr	1940-2001	10 yr	*S44*
Lawrence	# storm surges >1m per decade at Charlottetown, Prince Edward Island	1940-1999	10 yr	*S45*
Massachusetts	# floods / yr	1993-2004	5 yr	*S46*
Delaware	# floods / yr	1993-2004	5 yr	*S46*
Chesapeake	# floods / yr	1993-2004	5 yr	*S46*
Pamlico	# floods / yr	1993-2004	5 yr	*S46*
Galveston	# floods / yr	1993-2004	5 yr	*S46*
San Francisco	# floods / yr	1993-2004	5 yr	*S46*
Species invasions (n=6)				
Baltic	# invasions per decade, aquatic species	1800-2004	50 yr	*S47*
Wadden	# invasions per decade, North Sea, marine estuarine species	1800-1996	50 yr	*S48*
Adriatic	# invasions per decade, Mediterranean, molluscs only	1877-2000	50 yr	*S49*
Bay of Fundy	# invasions per decade, Bay of Fundy to Long Island Sound, marine and estuarine excluding cryptogenic species	1817-1999	50 yr	*S50*
Chesapeake	# invasions per decade, marine and brackish species	1800-2002	50 yr	*S51*
San Francisco	# invasions per decade, marine and tidal fresh species	1850-1995	50 yr	*S52*

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 (ln*R*=Response ratio; N_C=Sample size in fished area; N_E=Sample size in protected area).

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

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

Supporting References

Experiments

S1. Callaway, J. C., G. Sullivan, and J. B. Zedler. 2003. Species-rich plantings increase biomass and nitrogen accumulation in a wetland restoration experiment. Ecological Applications **13**: 1626-1639.

S2. Hughes, A. R., and J. J. Stachowicz. 2004. Genetic diversity enhances the resistance of a seagrass ecosystem to disturbance. Proceedings of the National Academy of Sciences of the United States of America **101**: 8998-9002.

S3. Reusch, T. B. H., A. Ehlers, A. Hämmerli, and B. Worm. 2005. Ecosystem recovery after climatic extremes enhanced by genotypic diversity. Proceedings of the National Academy of Sciences of the United States of America **102**: 2826-2831.

S4. Watermann, F., H. Hillebrand, G. Gerdes, W. E. Krumbein, and U. Sommer. 1999. Competition between benthic cyanobacteria and diatoms as influenced by different grain sizes and temperatures. Marine Ecology Progress Series **187**: 77-87.

S5. Beddingfield, S. D., and J. B. McClintock. 1998. Differential survivorship, reproduction, growth and nutrient allocation in the regular echinoid *Lytechinus variegatus* (Lamarck) fed natural diets. Journal of Experimental Marine Biology and Ecology **226**: 195-215.

S6. Cruz-Rivera, E., and M. E. Hay. 2000. The effects of diet mixing on consumer fitness: macroalgae, epiphytes, and animal matter as food for marine amphipods. Oecologia **123**: 252-264.

S7. Cruz-Rivera, E., and M. E. Hay. 2001. Macroalgal traits and the feeding and fitness of an herbivorous amphipod: the roles of selectivity, mixing, and compensation. Marine Ecology Progress Series **218**: 249-266.

S8. Dam, H. G., and R. M. Lopes. 2003. Omnivory in the calanoid copepod *Temora longicornis*: feeding, egg production and egg, hatching rates. Journal of Experimental Marine Biology and Ecology **292**: 119-137.

S9. Foster, G. G., A. N. Hodgson, and M. Balarin. 1999. Effect of diet on growth rate and reproductive fitness of *Turbo sarmaticus* (Mollusca : Vetigastropoda : Turbinidae). Marine Biology **134**: 307-315.

S10. Lee, W. Y., X. K. Zhang, C. Van Baalen, and C. R. Arnold. 1985. Feeding and reproductive performance of the harpacticoid copepod *Tisbe carolinensis* (Copepods, Crustacea) in four algal cultures. Marine Ecology Progress Series **24**: 273-279.

S11. Lee, J. J., K. Sang, B. ter Kuile, E. Strauss, P. J. Lee, and W. W. Faber, Jr. 1991. Nutritional and related experiments on laboratory maintenance of three species of symbiont-bearing, large foraminifera. Marine Biology **109**: 417-425.

S12. Murray, M. M., and N. H. Marcus. 2002. Survival and diapause egg production of the copepod *Centropages hamatu*s raised on dinoflagellate diets. Journal of Experimental Marine Biology and Ecology **270**: 39-56.

S13. Duffy, J. E., K. S. Macdonald, J. M. Rhode, and J. D. Parker. 2001. Grazer diversity, functional redundancy, and productivity in seagrass beds: An experimental test. Ecology **82**: 2417-2434.

S14. Duffy, J. E., J. P. Richardson, and E. A. Canuel. 2003. Grazer diversity effects on ecosystem functioning in seagrass beds. Ecology Letters **6**: 637-645.

S15. Duffy, J. E., J. P. Richardson, and K. E. France. 2005. Ecosystem consequences of diversity depend on food chain length in estuarine vegetation. Ecology Letters **8**: 301-309.

S16. Stachowicz, J. J., H. Fried, R. W. Osman, and R. B. Whitlatch. 2002. Biodiversity, invasion resistance, and marine ecosystem function: Reconciling pattern and process. Ecology **83**: 2575-2590.

S17. Moorthi, S. 2000. The relationship between diversity and stability in benthic protist communities. Thesis. Leibniz Institute for Marine Science, University of Kiel, Germany.

S18. Emmerson, M. C., M. Solan, C. Emes, D. M. Paterson, and D. Raffaelli. 2001. Consistent patterns and the idiosyncratic effects of biodiversity in marine ecosystems. Nature **411**: 73-77.

S19. Biles, C. L., M. Solan, I. Isaksson, D. M. Paterson, C. Emes, and D. G. Raffaelli. 2003. Flow modifies the effect of biodiversity on ecosystem functioning: an in situ study of estuarine sediments. Journal of Experimental Marine Biology and Ecology **285**: 165-177.

S20. Waldbusser, G. G., R. L. Marinelli, R. B. Whitlatch, and P. T. Visscher. 2004. The effects of infaunal biodiversity on biogeochemistry of coastal marine sediments. Limnology and Oceanography **49**: 1482-1492.

Estuarine and coastal biodiversity

S21. Lotze, H. K., H. S. Lenihan, B. J. Bourque, R. Bradbury, R. G. Cooke, M. C. Kay, S. M. Kidwell, M. X. Kirby, C. H. Peterson, and J. B. C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science **312:** 1806-1809.

S22. Sea Around Us. 2006. A global database on marine fisheries and ecosystems. Fisheries Centre, University British Columbia, Vancouver, BC, Canada. Web Products: Large Marine Ecosystems, http://www.seaaroundus.org/lme/lme.aspx.

Beach closures

S23. Bathing Water Quality Atlas, 2003. European Commission, European Union. http://www.europa.eu.int/water/cgi-bin/bw.pl.

S24. BEACON - Beach Advisory and Closing On-line Notification U.S. Environmental Protection Agency. http://oaspub.epa.gov/beacon/beacon_national_page.main.

S25. Recreational water quality monitoring at popular beaches lakes and rivers in southeast Queensland 2000-2001. Queensland Environmental Protection Agency. http://www.epa.qld.gov.au/publications/p00340aa.pdf/Recreational_water_quality_monitoring_at_popular_beaches_lakes_and_rivers_in_southeast_Queensland_2000__2001.

Harmful blooms

S26. Finni, T., K. Kononen, R. Olsonen, and K. Wallstrom. 2001. The history of cyanobacterial blooms in the Baltic Sea. Ambio **30**: 172-178.

S27. de Jonge, V. N., M. Elliott, and E. Orive. 2002. Causes, historical development, effects and future challenges of a common environmental problem: eutrophication. Hydrobiologia **475/476**: 1-19.

S28. Vollenweider, R.A., G. Montanari, and A. Rinaldi. 1995. Statistical inferences about the mucilage events in the Adriatic Sea, with special reference to recurrence patterns and claimed relationship to sun activity cycles. Science of the Total Environment, **165**: 213-224.

S29. Hallegraef, G. M. 1993. A review of harmful algal blooms and their apparent global increase. Phycological Reviews **13**: 79-99.

S30. Toxic phytoplankton and PSP toxins: Annual records of the abundance of phytoplankton species and physical-chemical parameters of seawater. St. Lawrence Observatory, Department of Fisheries and Oceans, Canada. http://www.osl.gc.ca/en/info/publications/monitorage.html.

S31. HEED. 1998. Marine ecosystems: emerging diseases as indicators of change. Year of the Ocean Special Report, Health Ecological and Economic Dimensions (HEED) of Global Change Program, Center for Health and the Global Environment, Harvard Medical School, Boston, MA, USA.

Fish kills

S32. Maryland Department of the Environment, Fish Kill Investigation Section Database, C. Luckett (pers. comm.), Annapolis, MD, USA.

S33. Fish Kill Event database. North Carolina Division of Water Quality. http://www.esb.enr.state.nc.us/Fishkill/fishkillmain.htm.

S34. Pollution Response and Inventory of Species Mortality (PRISM) database. 2004. C. Contreras (pers. comm.), Texas Parks and Wildlife Department, Austin, Texas.

Shellfish closures

S35. National Shellfish Register. Office of Ocean Resources Conservation and Assessment, NOAA. http://spo.nos.noaa.gov/projects/95register/state_summary.html.

S36. Canadian Shellfish Sanitation Program (CSSP), Environment Canada, Atlantic Region. http://www.atl.ec.gc.ca/epb/sfish/cssp.html.

Oxygen depletion

S37. Jonsson, P., R. Carman, and F. Wulff. 1990. Laminated sediments in the Baltic - a tool for evaluating nutrient mass balances. Ambio **19**: 152-158.

S38. Cloern, J. E. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series **210**: 223-253.

S39. Justic, D., T. Legovic, and L. Rottini-Sandrini. 1987. Trends in oxygen content 1911-1984 and occurrence of benthic mortality in the northern Adriatic Sea. Estuarine, Coastal and Shelf Science **25**: 435-445.

S40. Zimmerman, A. R. 2000. Organic matter composition of sediments and the history of eutrophication and anoxia in the mesohaline Chesapeake Bay. Ph.D. dissertation, Virginia Institute of Marine Sciences, College of William and Mary, Gloucester Point, VA, USA.

S41. Officer, C. B., R. B. Biggs, J. L. Taft, L. E. Cronin, M. A. Taylor, and W. R. Boynton. 1984. Chesapeake Bay anoxia: origin, development, and significance. Science **223**: 22-27.

S42. Cooper, S. R. 2000. The history of water quality in North Carolina estuarine waters as documented in the stratigraphic record. Water Resources Research Institute of the University of North Carolina, Report 327.

Coastal flooding

S43. Gönnert, G. 1999. The analysis of storm surge climate change along the German coast during the 20th century. Quaternary International **56**: 115–121.

S44. Raicich, F. 2003. Recent evolution of sea-level extremes at Trieste (Northern Adriatic). Continental Shelf Research **23**: 225–235.

S45. Forbes, D. L., G. S. Parkes, G. K. Manson, and L. A. Ketch. 2004. Storms and shoreline retreat in the southern Gulf of St. Lawrence. Marine Geology **210**: 169-204.

S46. National Climatic Data Center Storm Event database, NOAA. http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms.

Species invasions

S47. Baltic Sea Alien Species Database. Klaipeda University, Coastal Research and Planning Institute. http://www.ku.lt/nemo/alien_species_search.html.

S48. Reise, K., S. Gollasch, and W. J. Wolff. 1999. Introduced marine species of the North Sea coasts. Helgoländer Meeresuntersuchungen **52**: 219-234.

S49. Zenetos, A., S. Gofas, G. Russo, and J. Templado. 2004. CIESM Atlas of Exotic Species in the Mediterranean - Vol. 3. Molluscs. CIESM, Monaco.

S50. Carlton, J.T. 2003. A Checklist of the introduced and cryptogenic marine and estuarine organismsfrom Nova Scotia to Long Island Sound. Second Edition, Maritime Studies Program, Williams College - Mystic Seaport, Mystic, CT, USA.

S51. Fofonoff, P. W., G. M. Ruiz, B. Steves, A. H. Hines, and J. T. Carlton. 2006. National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/.

S52. Cohen, A. N., and J. T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science **279**: 555-558.

Large marine ecosystems

S53. Watson, R., A. Kitchingman, A. Gelchu, and D. Pauly. 2004. Mapping global fisheries: sharpening our focus. Fish and Fisheries **5**:168-177.

S54. Sherman, K., L. M. Alexander, and B. D. Gold, editors. 1990. Large Marine Ecosystems: Patterns, processes, and yields. AAAS Publications, Washington, DC.

S55. Yohai, V., W. A. Stahel, and R. H. Zamar. 1991. A procedure for robust estimation and inference in linear regression. in W. A. Stahel and S. W. Weisberg, editors. Directions in Robust Statistics and Diagnostics, Part II. Springer-Verlag, New York, NY.

Marine reserves and fishery closures

S56. Wantiez, L., P. Thollot, and M. Kulbicki. 1997. Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. Coral Reefs **16**: 215-224.

S57. White, A. T. 1988. The effect of community-managed marine reserves in the Philippines on their associated coral reef fish populations. Asian Fisheries Science **2**: 27-41.

S58. Christie, P., A. White, and E. Deguit. 2002. Starting point or solution? Community-based marine protected areas in the Philippines **66**: 441-454.

S59. Rakitin, A., and D. L. Kramer. 1996. Effect of a marine reserve on the distribution of coral reef fishes in Barbados. Marine Ecology Progress Series **131**: 97-113.

S60. Pipitone, C., F. Badalamenti, G. D'Anna, and B. Patti. 2000. Fish biomass increase after a four-year trawl ban in the Gulf of Castellammare (NW Sicily, Mediterranean Sea). Fisheries research **48**: 23-30.

S61. Blyth, R. E., M. J. Kaiser, G. Edward-Jones, and P. J. B. Hart. 2004. Implications of a zoned fishery management system for marine benthic communities. Journal of Applied Ecology **41**: 951-961.

S62. Bell, J. D. 1983. Effects of depth and marine reserve fishing restrictions on the structure of a rocky reef fish assemblage in the north-western Mediterranean Sea. Journal of Applied Ecology **20**: 357-369.

S63. Harmelin, J.-G., F. Bachet, and F. Garcia. 1995. Mediterranean marine reserves: fish indices as tests of protection efficiency. Marine Ecology - Pubblicazioni Della Stazione Zoologica Di Napoli **16**: 233-250.

S64. Francour, P. 1996. L'Ichthofaune de l'herbier a *Posidonia oceanica* dans la reserve marine de Scandola (Corse, Mediterranee Nord-Occidentale): influence des mesures de protection. Journal de Recherche Oceanographique **21**: 29-34.

S65. Bohnsack, J. A. 1981. Effects of piscivorous predators removal on coral reef fish community structure. Pages 258-267 in G. M. Cailliet and C. A. Simenstad, editors. Fish food habits studies. WA Sea Grant Publications, Seattle, WA, USA.

S66. Link, J. S., and J. K. T. Brodziak, editors. 2002. Status of the Northeast U.S. Continental Shelf Ecosystem: A Report of the Northeast Fisheries Science Center's Ecosystem Status Working Group. Northeast Fisheries Science Center Reference Document 02-11. NOAA-NMFS Northeast Fisheries Science Center, Woods Hole, MA, USA. Web products: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0211/.

S67. Cole, R. G., T. M. Ayling, and R. G. Creese. 1990. Effects of marine reserve protection at Goat Island, northern New Zealand. New Zealand Journal of Marine and Freshwater Research **24**: 197-210.

S68. Edgar, G. J., and N. S. Barrett. 1999. Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates, and plants. Journal of Experimental Marine Biology and Ecology **242**: 107-144.

S69. Grigg, R. W. 1994. Effects of sewage discharge, fishing pressure and habitat complexity on coral ecosystems and reef fishes in Hawaii. Marine Ecology Progress Series **103**: 25-34.

S70. Carter, J., and G. R. Sedberry. 1997. The design, function, and use of marine fishery reserves as tools for the management and conservation of the Belize barrier reef. Proceedings of the Eighth International Coral Reef Symposium 2: 1911-1916.

S71. McClanahan, T. R. 1994. Kenyan coral reef lagoon fish: effects of fishing, substrate complexity, and sea urchins. Coral Reefs **13**: 231-241.

S72. Letourneur, Y. 1996. Réponses des peuplements et populations de poisons aux réserves marines: le cas de l'ile de Mayotte, Ocean Indien occidental. Ecoscience **3**: 442-450.

S73. Roberts, C. M., and N. V. C. Polunin. 1992. Effects of Marine reserve protection on Northern Red Sea fish populations. Proceedings of the Seventh International Coral Reef Symposium **2**: 969-977.

S74. Fisher, J. A. D, and K. T. Frank. 2002. Changes in finfish community structure associated with an offshore fishery closed area on the Scotian Shelf. Marine Ecology Progress Series **240**: 249-265.

S75. Hockey, P. A. R., and A. L. Bosman. 1986. Man as an intertidal predator in Transkei: disturbance, community convergence and management of a natural food resource. Oikos **46**: 3–14.

S76. Hawkins, J. P., C. M. Roberts, C. Dythamb, C. Scheltenc, and M. M. Nuguesd. 2006. Effects of habitat characteristics and sedimentation on performance of marine reserves in St. Lucia. Biological Conservation **127**:487-499.

S77. Russ, G., and A. Alcala. 1989. Effects of intense fishing pressure on an assemblage of coral reef fishes. Marine Ecology Progress Series **56**: 13-27.

S78. Dye, A. H. 1992. Experimental studies of succession and stability in rocky intertidal communities subject to artisanal shellfish gathering. Netherlands Journal of Sea Research **30**: 209-217.

S79. Paddack, M. J., and J. A. Estes. 2000. Kelp forest fish populations in marine reserves and adjacent exploited areas of central California. Ecological Applications **10**: 855-870.

S80. Johnson, D. R., N. A. Funicelli, and J. A. Bohnsack. 1999. Effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Center, Florida. North American Journal of Fisheries Management **19**: 436-453.

S81. McClanahan, T. R., N. A. Muthiga, A. T. Kamukuru, H. Machano, and R. W. Kiambo. 1999. The effects of marine parks and fishing on coral reefs of northern Tanzania. Biological Conservation **89**: 161-182.

S82. Dufour, V., J. –Y. Jouvenal, and R. Galzin. 1995. Study of a Mediterranean reef fish assemblage: comparisons of population distributions between depths in protected and unprotected areas over a decade. Aquatic Living Resources **8**: 17-25.

S83. Francour, P. 1991. The effect of protection level on a coastal fish community at Scandola, Corsica. Revue Ecologie (Terre Vie) **46**: 65-81.

S84. Micheli, F., L. Benedetti-Cecchi, S. Gambaccini, I. Bertocci, C. Borsini, G. C. Osio, and F. Romano. 2005. Cascading human impacts, marine protected areas, and the structure of Mediterranean reef assemblages. Ecological Monographs **75**:81-102.

S85. Vacchi, M., S. Bussotti, P. Guidetti, and G. La Mesa. 1998. Study of the coastal fish assemblage in the marine reserve of the Ustica Island (southern Tyrrhenian Sea). Italian Journal of Zoology **65**: 281-286.

S86. Garcia-Rubies, A., and M. Zabala. 1990. Effects of total fishing prohibition on the rocky fish assemblages of Medes Islands marine reserves (NW Mediterranean). Scientia Marina **54**: 317-328.

S87. Roberts, C. M. 1995. Rapid build-up of fish biomass in a Caribbean marine reserve. Conservation Biology **9**: 815-826.

S88. Maypa, A. P., G. R. Russ, A. C. Alcala, and H. P. Calumpong. 2002. Long-term trends in yield and catch rates of the coral reef fishery at Apo Island, central Philippines. Marine and Freshwater Research **53**: 207-213.

S89. Badalamenti, F., A. A. Ramos, E. Voultsiadou, J. L. Sanchez Lizaso G. D'Anna, C. Pipitone, J. Mas, J. A. Ruiz Fernandez, D. Whitmarsh, and S. Riggio. 2000. Cultural and socio-economic impacts of Mediterranean marine protected areas. Environmental Conservation **27**: 110-125.

S90. Northern Demersal and Southern Demersal Working Groups. 2001. Assessment of 19 Northeast Groundfish Stocks through 2000. Northeast Fisheries Science Center Reference Document 01-20. NOAA-NMFS Northeast Fisheries Science Center, Woods Hole, MA. Web products: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0120/

S91. McClanahan, T. R., and B. Kaunda-Arara. 1996. Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology **10**: 1187-1199.

S92. Galal N., R. F. G. Ormond, and O. Hassan. 2002. Effect of a network of no-take reserves in increasing catch per unit effort and stocks of exploited reef fish at Nabq, South Sinai, Egypt. Marine and Freshwater Research **53**: 199-205.

S93. Roberts, C. M., J. A. Bohnsack, F. Gell, J. P. Hawkins, and R. Goodridge. 2001. Effects of marine reserves on adjacent fisheries. Science **294**: 1920-1923.

S94. Watson, R, A. Kitchingman., A. Gelchu, and D. Pauly. 2004. Mapping global fisheries: sharpening our focus. Fish and Fisheries **5**: 168-177.

S95. McClanahan, T. R., N. A. Muthiga, and S. Mangi. 2001. Coral and algal changes after the 1998 coral bleaching: interaction with reef management and herbivores on Kenyan reefs. Coral Reefs **19**: 380-391.

S96. McClanahan, T., J. Maina, and L. Pet-Soede. 2002. Effects of the 1998 coral morality event on Kenyan coral reefs and fisheries. Ambio **31**: 543–550.

S97. Roberts, C. M., N. L. H. Barker, A. J. Clarke, F. R. Gell, J. P. Hawkins, M. M. Nugues, and C. K. Schelten. 2004. Impact and amelioration of sediment pollution on coral reefs of St. Lucia, West Indies. DFID NRSP Project Report **R7668**, Environment Department, University of York, York, YO10 5DD, UK.

S98. Letourneur, Y., M. Harmelin-Vivien, and R. Galzin. 1993. Impact of hurricane Firinga on fish community structure on fringing reefs of Reunion Island, S.W. Indian Ocean. Environmental Biology of Fishes **37**: 109-120.

S99. Russ, G. R. and A. C. Alcala. 1998. Natural fishing experiments in marine reserves 1983-1993: community and trophic responses. Coral Reefs **17**: 383-397.

S100. Russ, G. R., A. C. Alcala, and C. Angel. 2003: Marine reserves: rates and patterns of recovery and decline of predatory fish, 1983-2000. Ecological Applications **13**: 1553-1565.

S101. Halpern, B.S., and K. Cottenie. 2006. Marine reserve effects on kelp forest community structure and stability. Ecological Applications: in review**.**

S102. Francour, P. 2000. Évolution spatio-temporelle à long terme des peuplements de poissons des herbiers à *Posidonia oceanica* de la réserve naturelle de Scandola (Corse, Méditerranée nord-occidentale). Cybium **24**: 85-95.

S103. McClanahan, T., M. McField, M. Huitric, K. Bergman, E. Sala, M. Nyström, I. Nordemar, T. Elfwing, and N. Muthiga 2001. Responses of algae, corals and fish to the reduction of macroalgae in fished and unfished patch reefs of Glovers Reef Atoll, Belize. Coral Reefs **19**: 367-379.

S104. Green, E., and R. Donnelly. 2003. Recreational scuba diving in Caribbean marine protected areas: do the users pay? Ambio **32**: 140-144.

S 105. Hedges, L. V., and I. Olkin. 1985. Statistical methods for meta-analysis. Academic Press, New York.

S106. Halpern, B. S., S. D. Gaines, and R. R. Warner. 2004. Confounding effects of the export of production and the displacement of fishing effort from marine reserves. Ecological Applications **14**: 1248-1256.