Scienze per l'Ambiente Marino e Costiero

a.a. 2024-2025

GESTIONE E CONSERVAZIONE ECOSISTEMI MARINI - IMPATTI ANTROPICI E CONSERVAZIONE DELLA FAUNA MARINA

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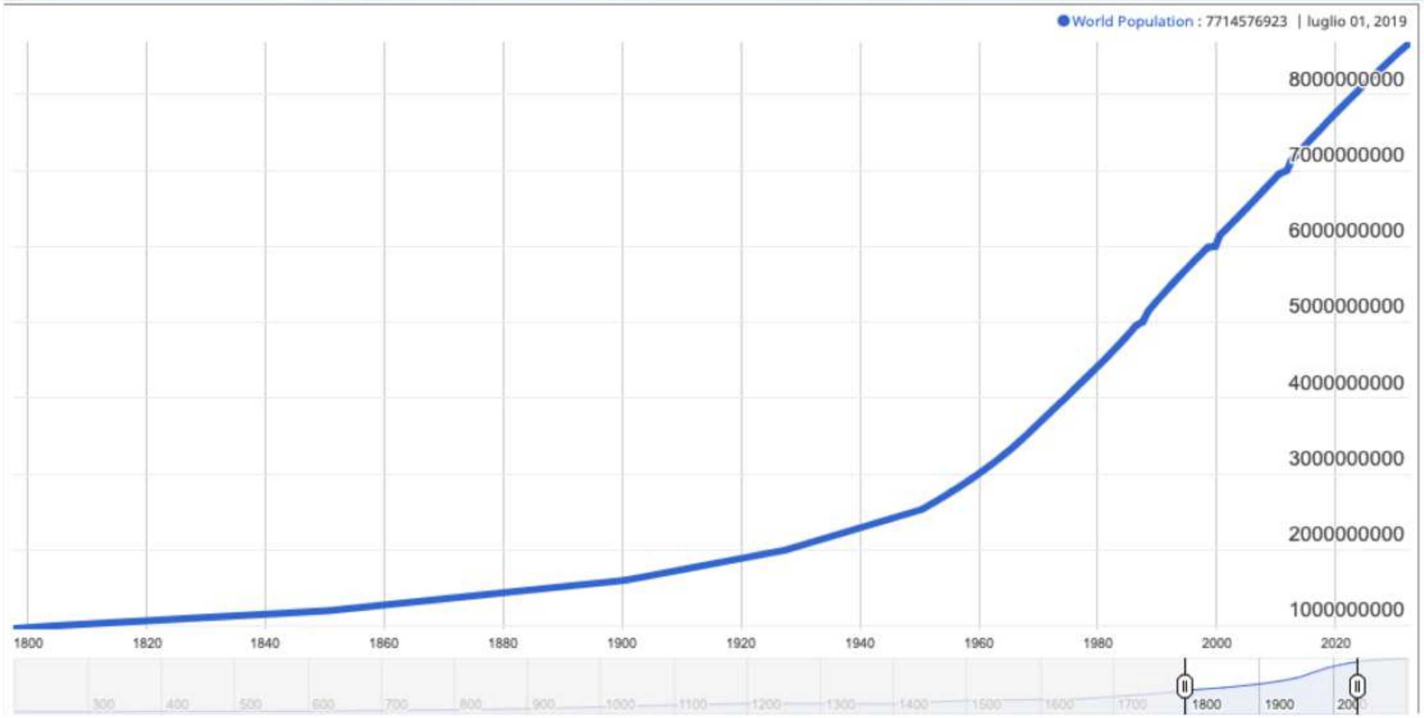
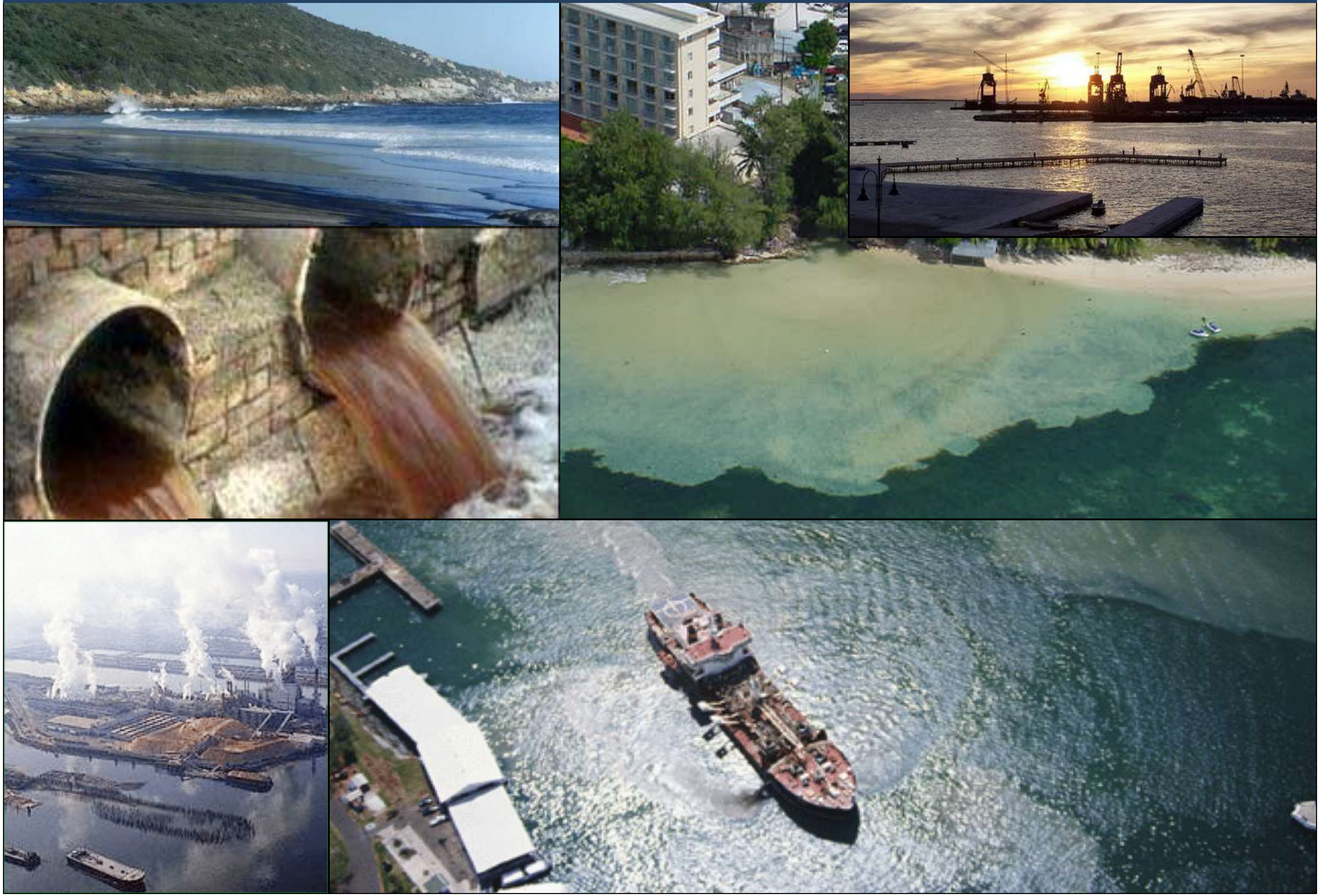
Human threats to marine ecosystems

Population growth and human activities

1		China	1,418,893,371
2		India	1,365,306,523
3		U.S.A.	328,550,372
4		Indonesia	268,896,126
5		Brazil	212,036,976
6		Pakistan	203,710,047
7		Nigeria	199,767,139
8		Bangladesh	167,669,368
9		Russia	143,911,639
10		Mexico	131,961,321



Human activities and disturbance



Drivers of pressure

Chemical

Physical

Biological

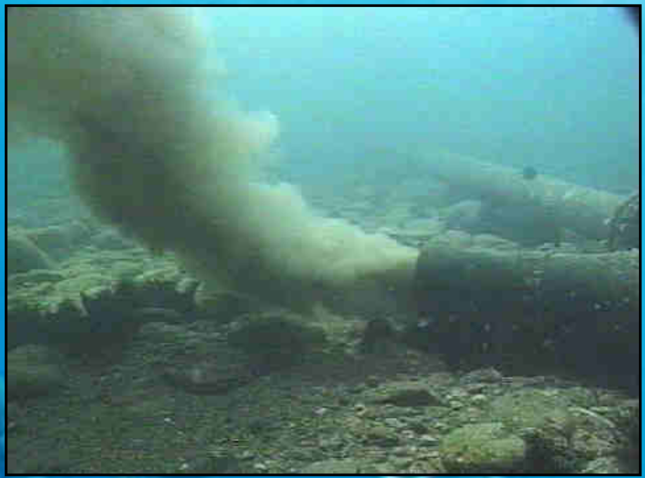
Activity
↓
Drivers
↓
Pressure
↓
Impact

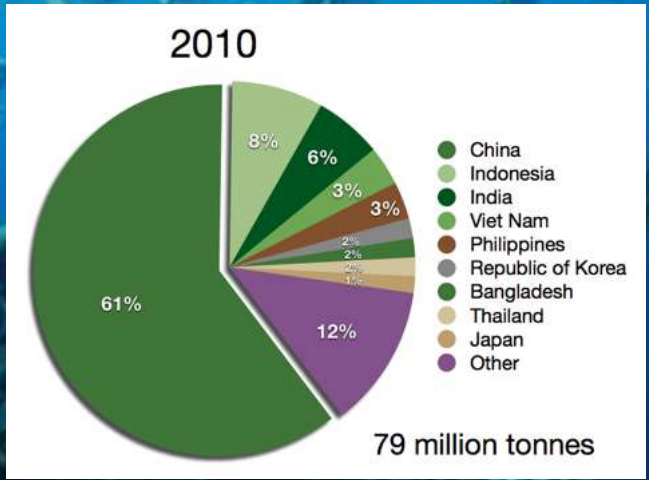
Not all human activities lead necessarily to impact marine systems. Only those generating pressure levels sufficient to affect significantly ecosystem structure (biological and abiotic) and processes, from individual to population, or community and ecosystem level.

Example: drainage agriculture – freshwater inputs – decrease in salinity – change in community structure

Industrial production – carbon dioxide emission – increase in ocean acidification – increased juvenile mortality of marine species with ensuing decreasing populations

Organic-inorganic compounds

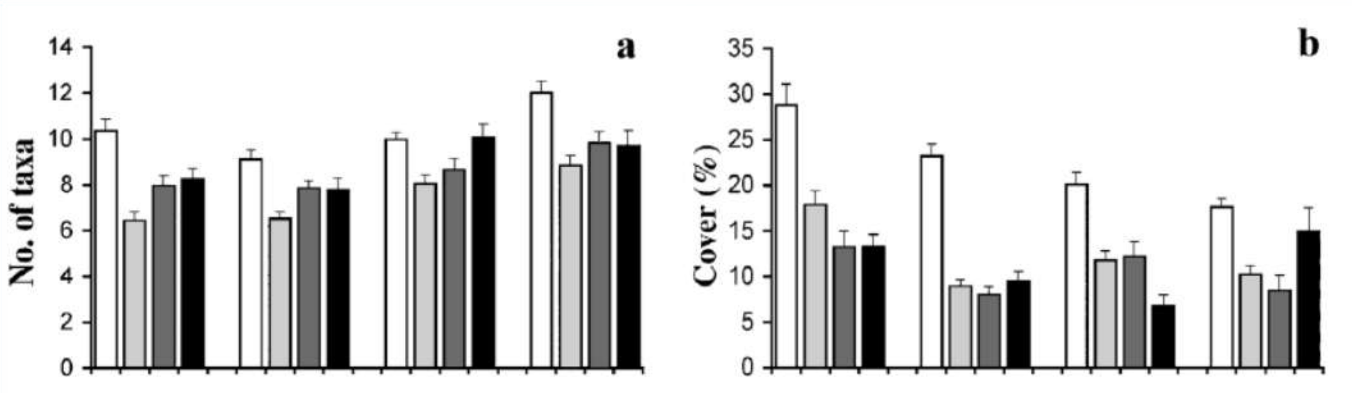


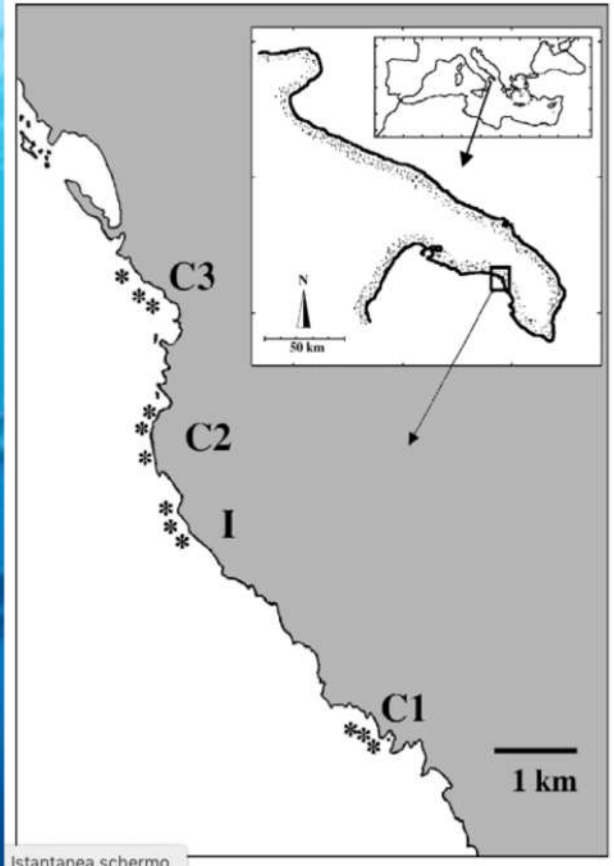


Sewage outfalls
Aquaculture

Direct introduction of nutrients and other substances (soap, hydrocarbons, etc.) in the marine system. Different effects, depending on the substances. Generally, change in community structure around the outfall (depending on the sewage flux) are frequent with increasing abundance of ephemeral opportunistic species.

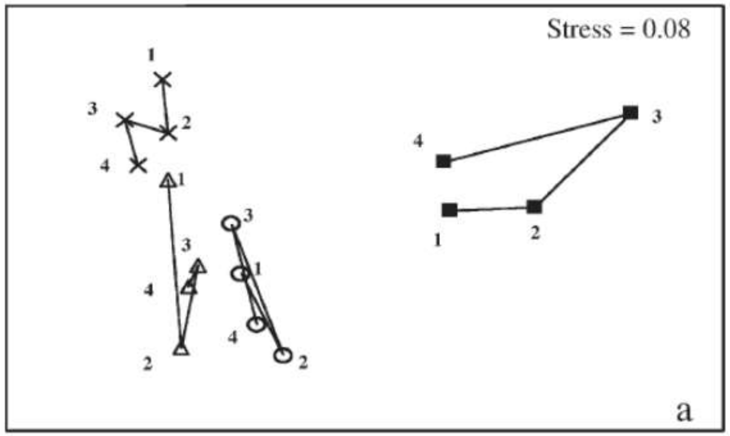
Local effects of sewage discharge





Source of variation	df	Time 1 MS	Time 1 *F*	Time 1 p	Time 2 MS	Time 2 *F*	Time 2 p	Time 3 MS	Time 3 *F*	Time 3 p	Time 4 MS	Time 4 *F*	Time 4 p	MS_{denom}
L	3	2.287	3.877	0.0006	3.127	4.439	0.0010	3.444	3.744	0.0004	2.172	2.190	0.0072	S(L)
I-v-Cs	1	3.750	2.409	*0.0614*	4.587	1.914	*0.1324*	7.044	4.286	*0.0038*	3.809	2.812	*0.0394*	*Cs*
Cs	2	1.556	2.608	0.0052	2.397	2.896	0.0120	1.643	2.033	0.0238	1.354	1.416	0.2086	S(L)
S(L)	8	0.590	3.964	0.0002	0.704	5.511	0.0002	0.920	6.476	0.0002	0.992	7.774	0.0002	Residual
Residual	108	0.149			0.128			0.142			0.128			

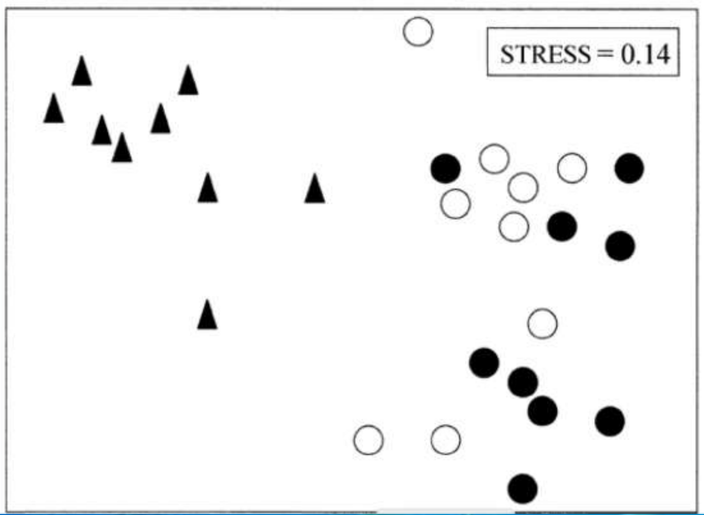
	Time 1 C1	Time 1 C2	Time 1 C3	Time 2 C1	Time 2 C2	Time 2 C3	Time 3 C1	Time 3 C2	Time 3 C3	Time 4 C1	Time 4 C2	Time 4 C3
C2	0.586			0.634			0.639			0.554		
C3	0.686	0.642		0.736	0.670		0.661	0.708		0.659	0.658	
I	0.740	0.740	0.731	0.739	0.714	0.793	0.825	0.856	0.871	0.692	0.740	0.808

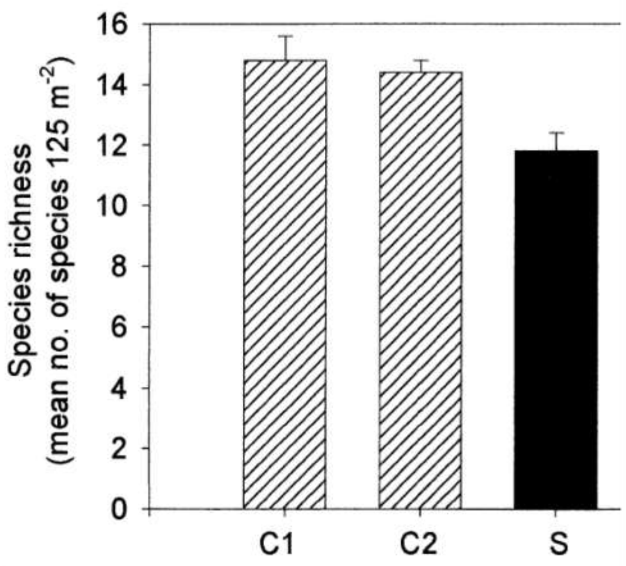


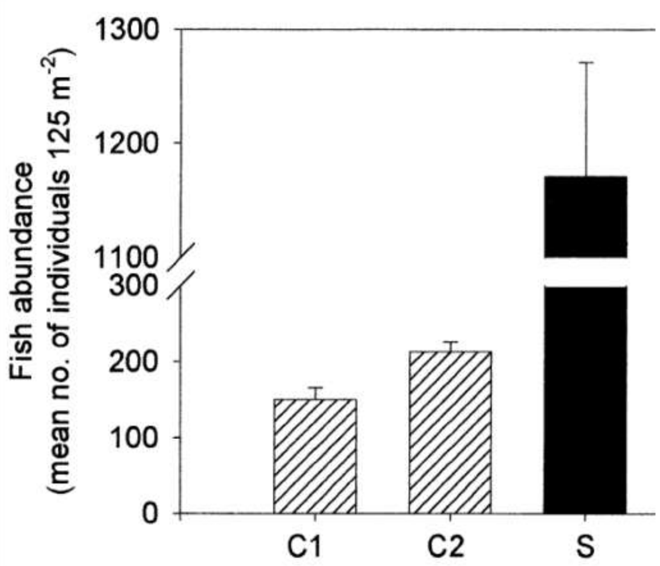
No significant effects on total cover and diversity of benthic assemblages. However, significant changes in assemblage structure, so composition and relative abundances were altered. Increased abundance of ephemeral algal species, with opportunistic algae present only at the impacted location.

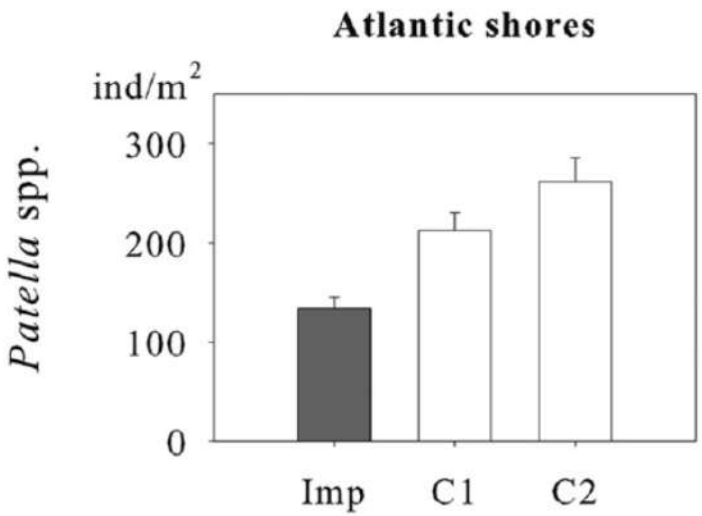
Local effects of sewage discharge

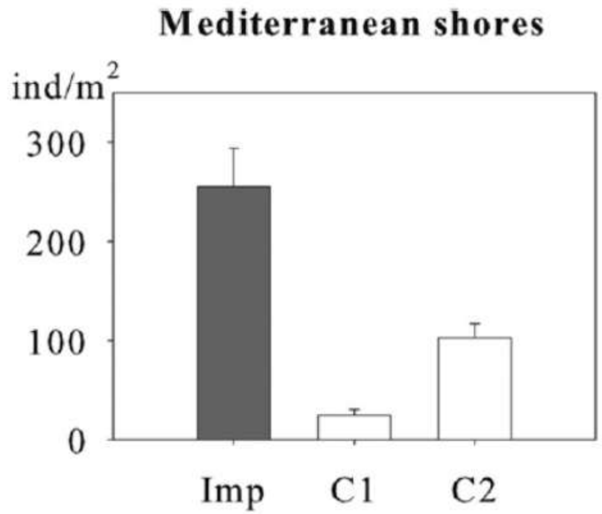
P. Guidetti et al. / Marine Environmental Research 53 (2002) 77–94











Different effects depending on the ecological compartment. For example, the same source of disturbance affected diversity and density of fish assemblages, along with the whole multivariate structure. Increased planktivore fish at the impacted location and decrease carnivore.

Local factors could lead to different response different species of the same genus due to differences in tolerating enrichment or pollution, and different environmental features.

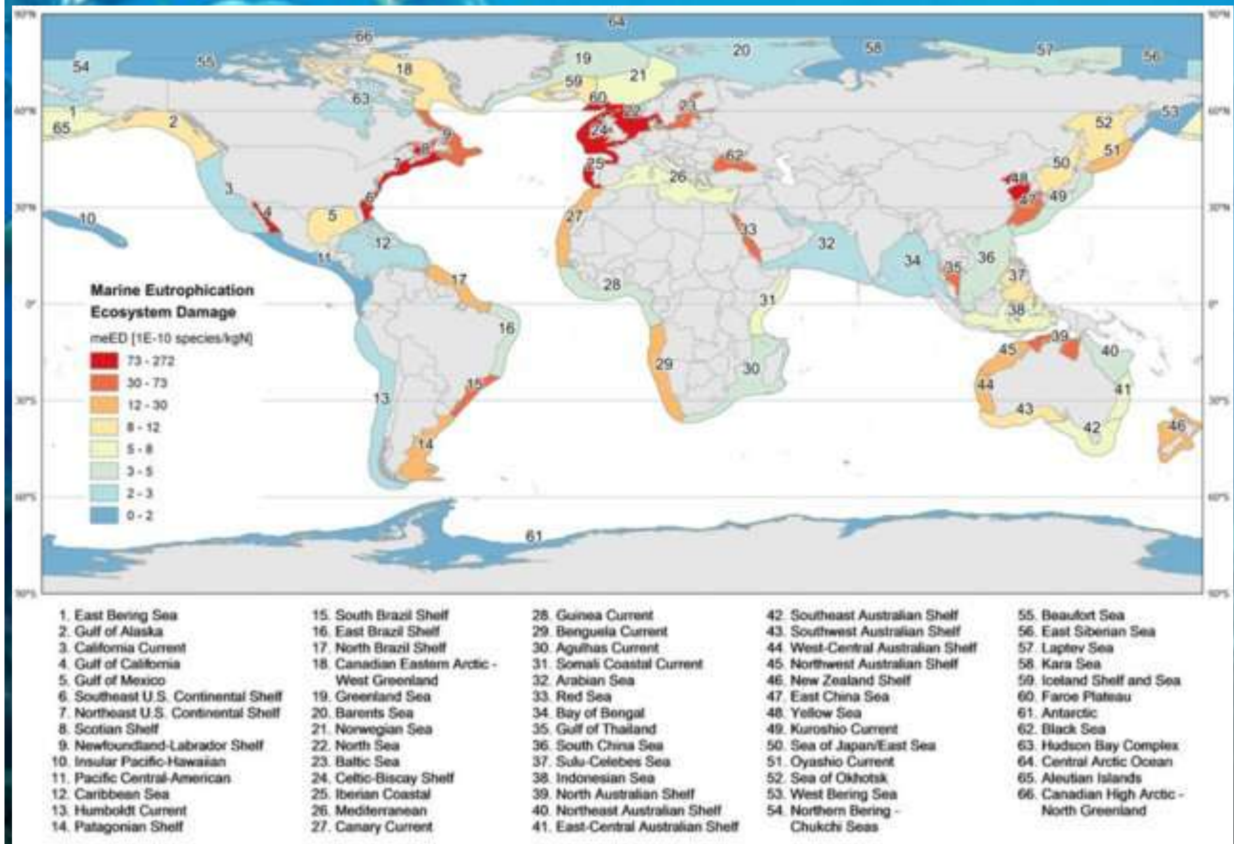
Eutrophication

Abnormal nutrient/organic supply

Oxygen depletion, Hypoxia, anoxia, CH_4 production, H_2S production, changes in community structure

Eutrophication

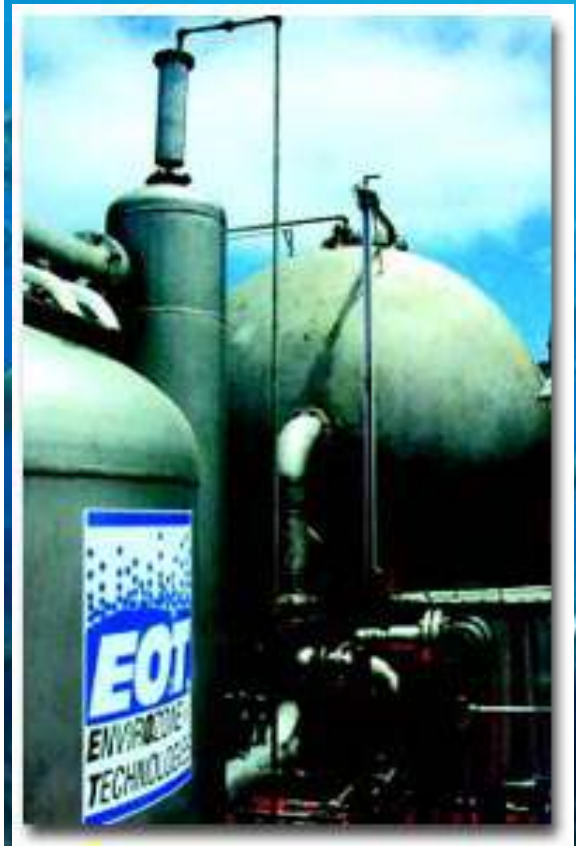
Increase of nutrient, at the beginning, has a positive effect enhancing phytoplankton production, and therefore also secondary production. The excess of nutrient, however, leads to over-proliferation of phytoplankton. This increases turbidity and affect benthic macroalgal stands. Also, toxic microalgae can bloom causing death of organisms (fish and benthos). If the production of biomass from phytoplankton and opportunistic macroalgae is very high, oxidation processes could consume the large port of dissolved oxygen, leading to anoxia, and bacterial anaerobic decomposition of organic matter, which produce hydrogen sulphide.



Cosme et al. 2017

Synthetic compounds

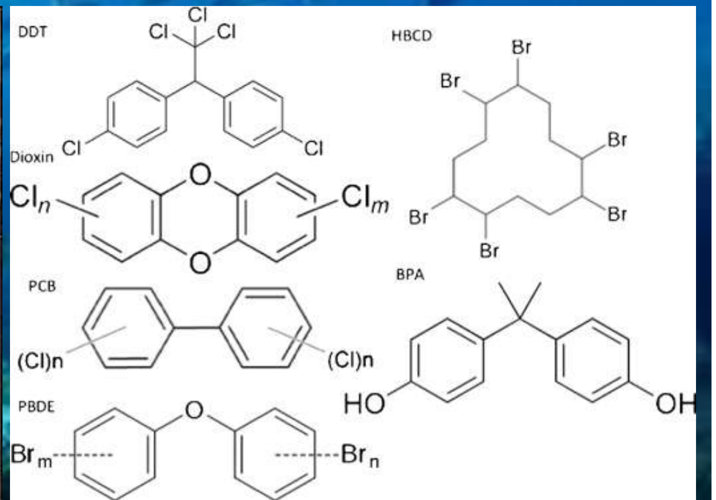
Thousands of new compounds are produced each year. Organisms have not enough time to evolve physiological or biochemical defences



POP

(persistent organic pollutants)

Persistence and interactions



Pollutants

Persistent organic pollutants: The "dirty dozen" TABLE 4.3	
Persistent organic pollutant	*Use*
Aldrin	Insecticide
Chlordane	Insecticide
DDT (dichlorodiphenyl-trichloroethane)	Insecticide
Dieldrin	Insecticide
Endrin	Rodenticide and insecticide
Heptachlor	Fungicide
Hexachlorobenzene	Insecticide; fire retardant
Mirex™	Insecticide
Toxaphene™	Insecticide
PCBs (polychlorinated biphenyls)	Industrial chemicals
Dioxins	By-products of certain manufacturing processes
Furans (dibenzofurans)	By-products of certain manufacturing processes

Most of them have low solubility in seawater, increasing their persistence in the environment and accumulation in sediments. In most cases, endocrine disruptors, genotoxic or mutagen, teratogenic, carcinogenic.

1082 substances…2018
>1400 …2020

Mandatory monitoring for water bodies and sediment characterization in Italy and EU (DLgs 152/2006 receiving the EU WFD - 2000/60/EC)

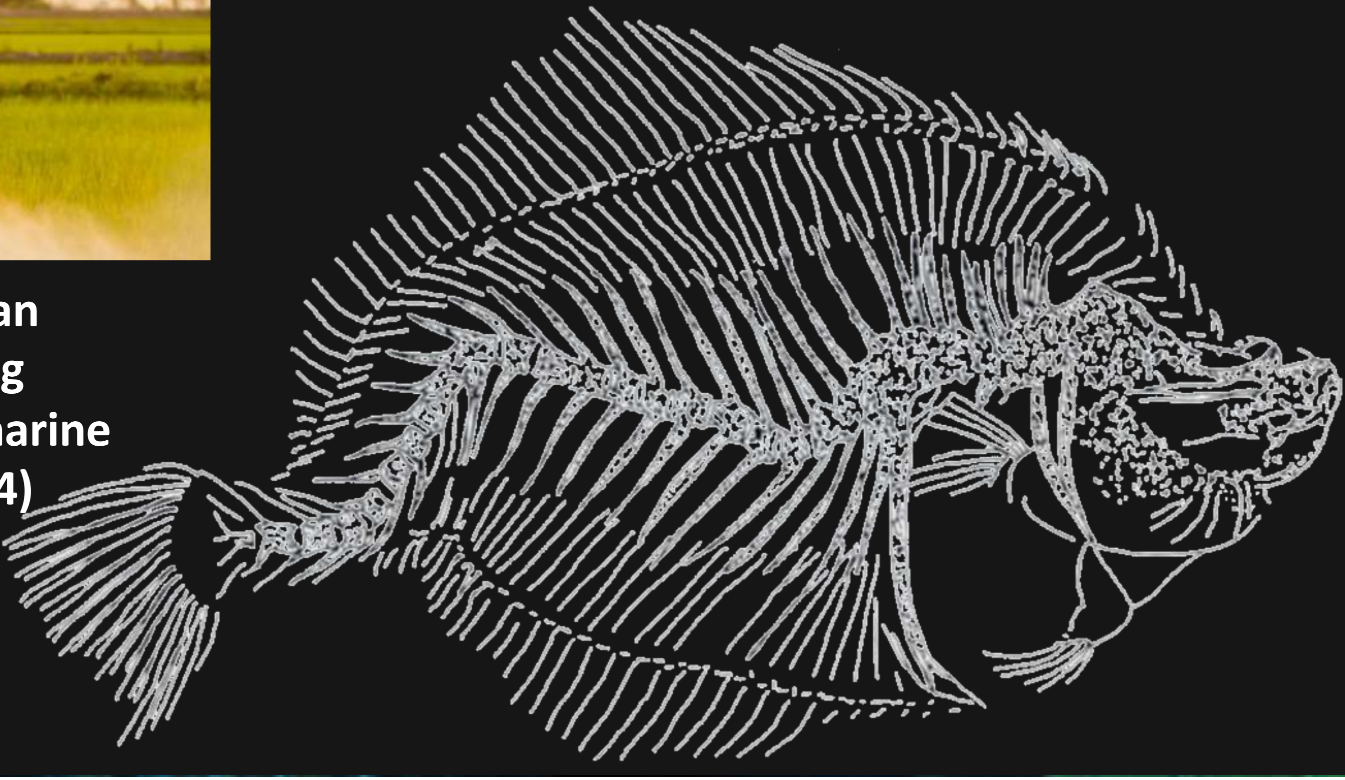
The dirty dozen

Effects on biota

(1) Glyphosate-compounds are the most heavily applied herbicides in the world and usage continues to rise; (2) Worldwide, GBHs often contaminate drinking water sources, precipitation, and air, especially in agricultural regions. (Myers et al. 2016).
Effect on marine biota poorly studied. Some study demonstrated that it can affect both cellular and biochemical parameters in mussels, highlighting a potential risk for aquatic invertebrates (Matozzo et al. 2018).

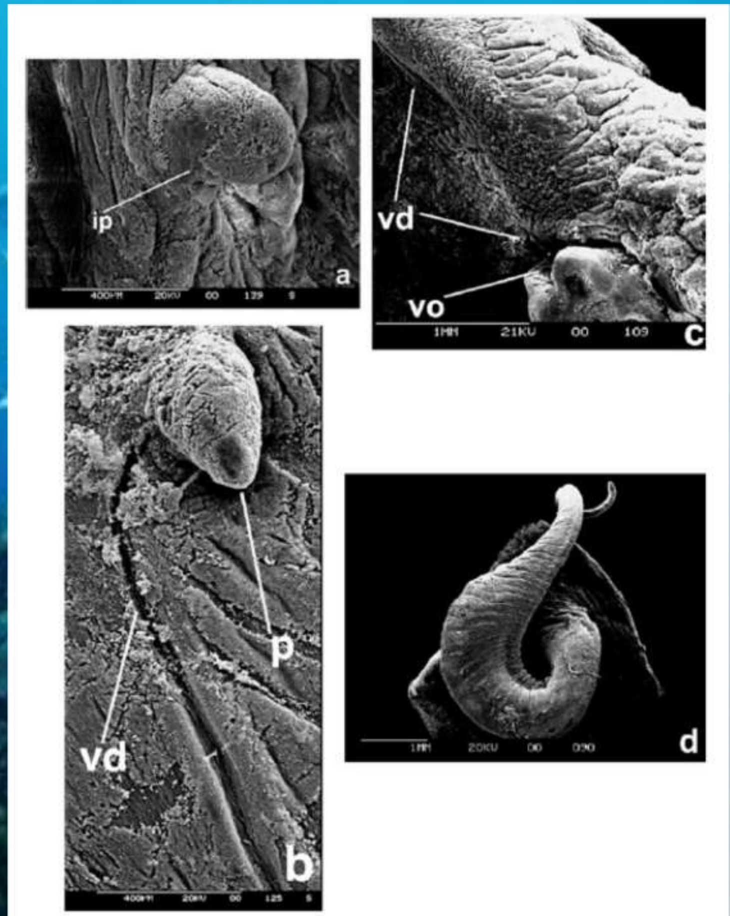
Persistence can be longer than previously though, suggesting potential dispersion in the marine systems (Mercurio et al. 2014)

Toxaphene: skeletal deformity on fish Bengtsson, 1979



Imposex

Induced Hermaphroditism by TBT (Tributyltin) in female of gonocoric molluscs



Terlizzi et al, 2004

Other compounds

Exposure to crack cocaine causes adverse effects on marine mussels Perna perna

August 2017 · Marine Pollution Bulletin 123(1-2)

DOI: 10.1016/j.marpolbul.2017.08.043

Project: Ecotoxicological study and environmental risk assessment of illicit drugs in marine ecosystems

Luciane Maranho · Mayana Fontes · A.S.S. Kamimura · Show all 12 authors · Camilo Dias Seabra Pereira

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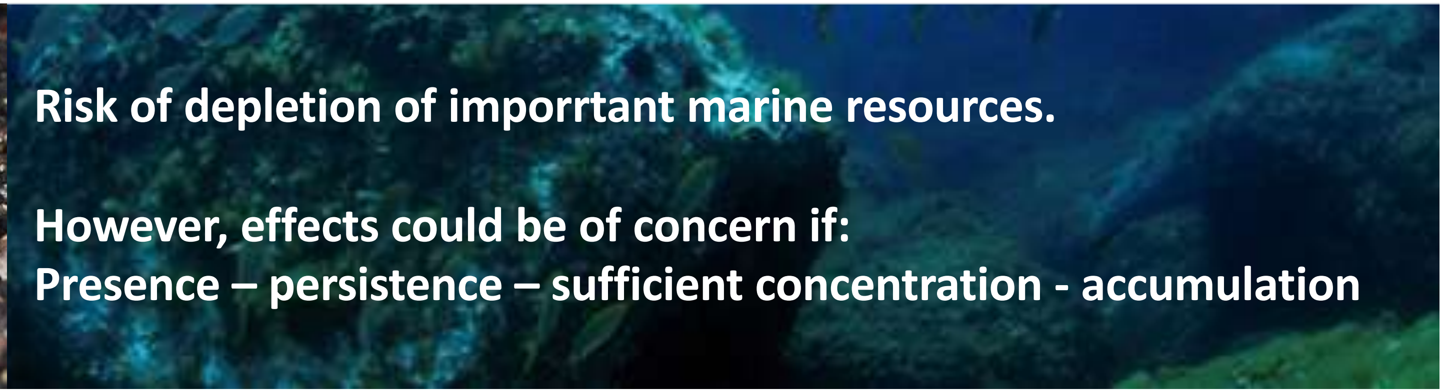
Sci Total Environ. 2016 Apr 1;548-549:148-154. doi: 10.1016/j.scitotenv.2016.01.051. Epub 2016 Jan 20.

Occurrence of pharmaceuticals and cocaine in a Brazilian coastal zone.

Pereira CDS[1], Maranho LA[2], Cortez FS[3], Pusceddu FH[3], Santos AR[3], Ribeiro DA[4], Cesar A[5], Guimarães LL[6].



Risk of depletion of imporrtant marine resources.

However, effects could be of concern if:
Presence – persistence – sufficient concentration - accumulation

Heavy metals

High concentration alters cell metabolism

Cu Hg Pb Cd Zn

Water Air Soil Pollut (2011) 221:191–202
DOI 10.1007/s11270-011-0782-0

Source and Fate of Heavy Metals in Marine Sediments from a Semi-Enclosed Deep Embayment Subjected to Severe Anthropogenic Activities

Daniel González-Fernández ·
M. Carmen Garrido-Pérez · Enrique Nebot-Sanz ·
Diego Sales-Márquez

- Urban wastewater discharge
- shipyard activities (painting and repairing)
- Steel factory and heavy industry (chemical, mining, paper mills)
- Port activities
- Dredging and refilling

Bioaccumulation and magnification

Beluga and narwhal from Eastern Canadian Arctic including Hudson Bay, was around **10-20 ng/g**. In minke whale liver from Greenland and Iceland, PFOS was up to 71 ng/g. In harbour porpoise from Icelandic waters, mean PFOS concentration was 38 ng/g. Pilot whale to 336 ng/g. In **polar bear** from Alaska, Bering Sea, Beaufort Sea, Chukchi Sea, East and West Greenland concentrations of PFOS in liver were markedly higher; up to a mean liver concentration of **2,878 ng/g.**

(Nordic Council of Ministers, Copenhagen 2011)

0.2-0.4 µg/L limit concentration of exposition (brief periods) for PFOS e PFOA (OMS)

Vol. 169: 65–76, 1998 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published August 6

Biomagnification of mercury in an Antarctic marine coastal food web

R. Bargagli*, F. Monaci, J. C. Sanchez-Hernandez, D. Cateni

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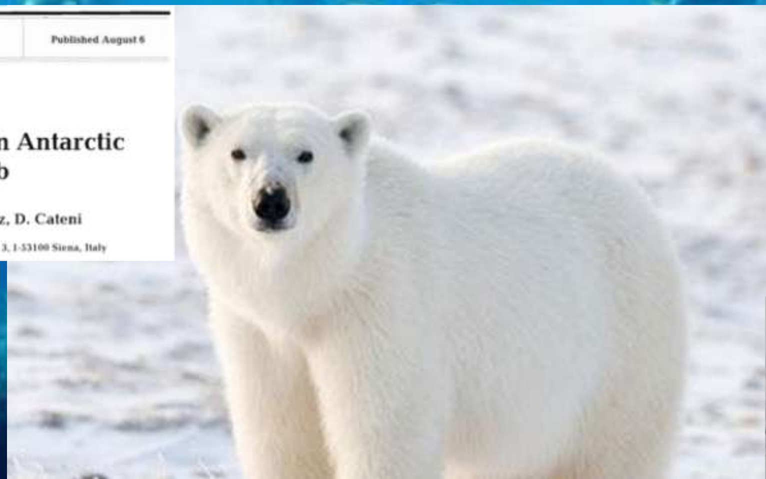


e.g., Hg

-Disruption of the nervous system
- Damage to brain functions
-DNA damage and chromosomal damage
-Allergic reactions, resulting in skin rashes, tiredness and headaches
-Negative reproductive effects, such as sperm damage, birth defects

Hydrocarbons

Galicia, 2002 (*Prestige*)
Galapagos, 2002 (*Jessica*)
Alaska, 2004 (*Exxon Valdez*)
BP's *Deepwater Horizon* oil spill Gulf of Mexico, 2010

Oil spills

Reduced diversity, change in community structure, death, carcinogenic effects, in Invertebrates.
Affected insulating ability of mammals, such as sea otters, and the water repellency of bird's feathers.
Suffocation and death from poisoning. Many birds and animals also ingest oil when they try to clean themselves, which can poison them.
Fish and shellfish may not be exposed immediately, but can come into contact with oil if it is mixed into the water column. When exposed to oil, adult fish may experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproduction impairment. Oil also adversely affects eggs and larval survival.

Field studies in the vicinity of the DWH spill indicate a significant reduction in abundance and diversity of benthic meiofauna and macrofauna as well as visual damage to deep-sea corals. (Buskey et al., 2016)

Plastics

ELSEVIER

Marine Pollution Bulletin

Volume 44, Issue 9, September 2002, Pages 842-852

Review

The pollution of the marine environment by plastic debris: a review

José G.B Derraik

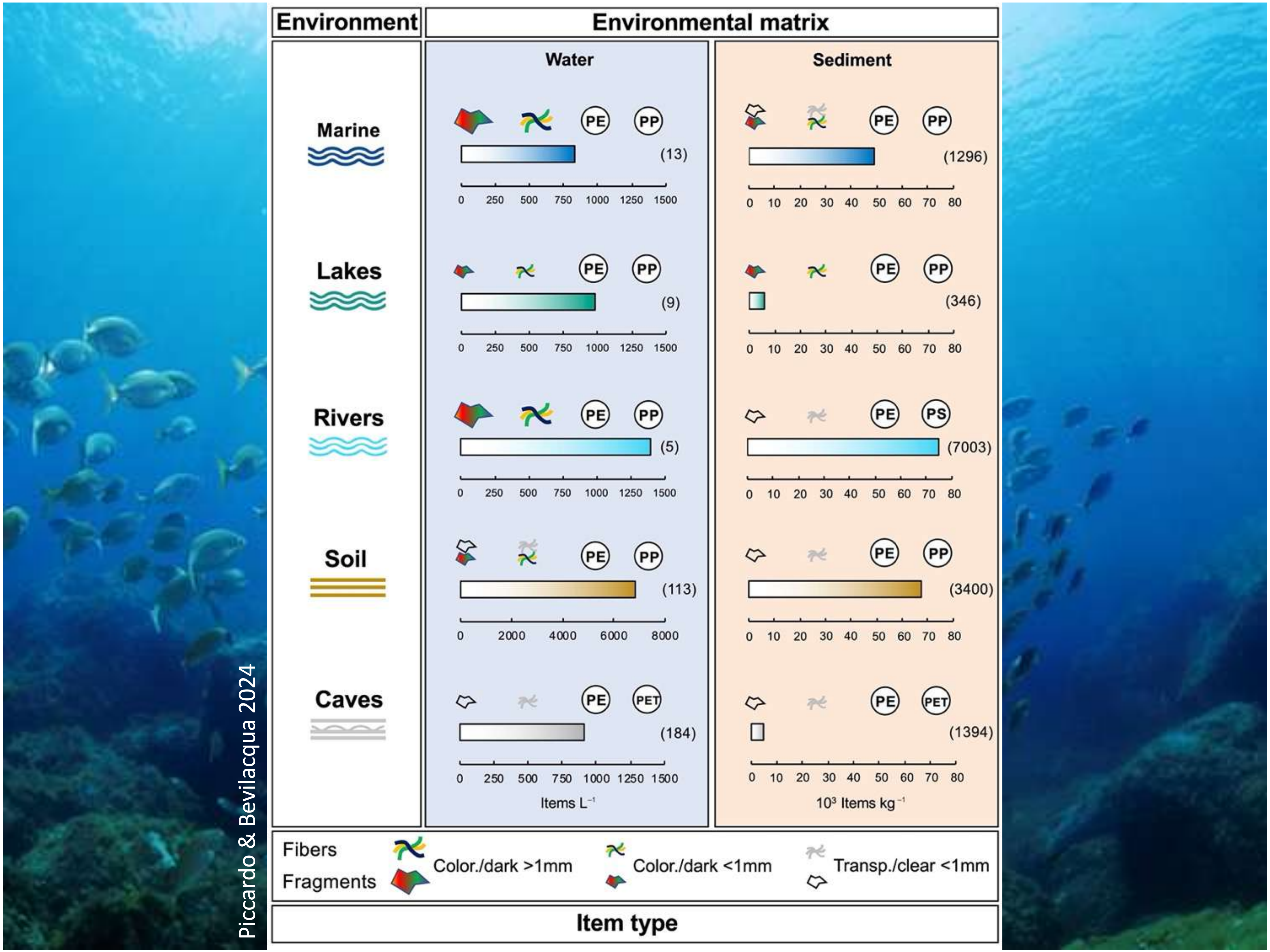
The threats to marine life are primarily mechanical due to ingestion of plastic debris and entanglement in packaging bands, synthetic ropes and lines, or drift nets. Other harmful effects from the ingestion of plastics include blockage of gastric enzyme secretion, diminished feeding stimulus, lowered steroid hormone levels, delayed ovulation and reproductive failure or death.

Turtles, birds, mammals and fish

Contamination with PCBs. Micro and Nano-?

Highlights

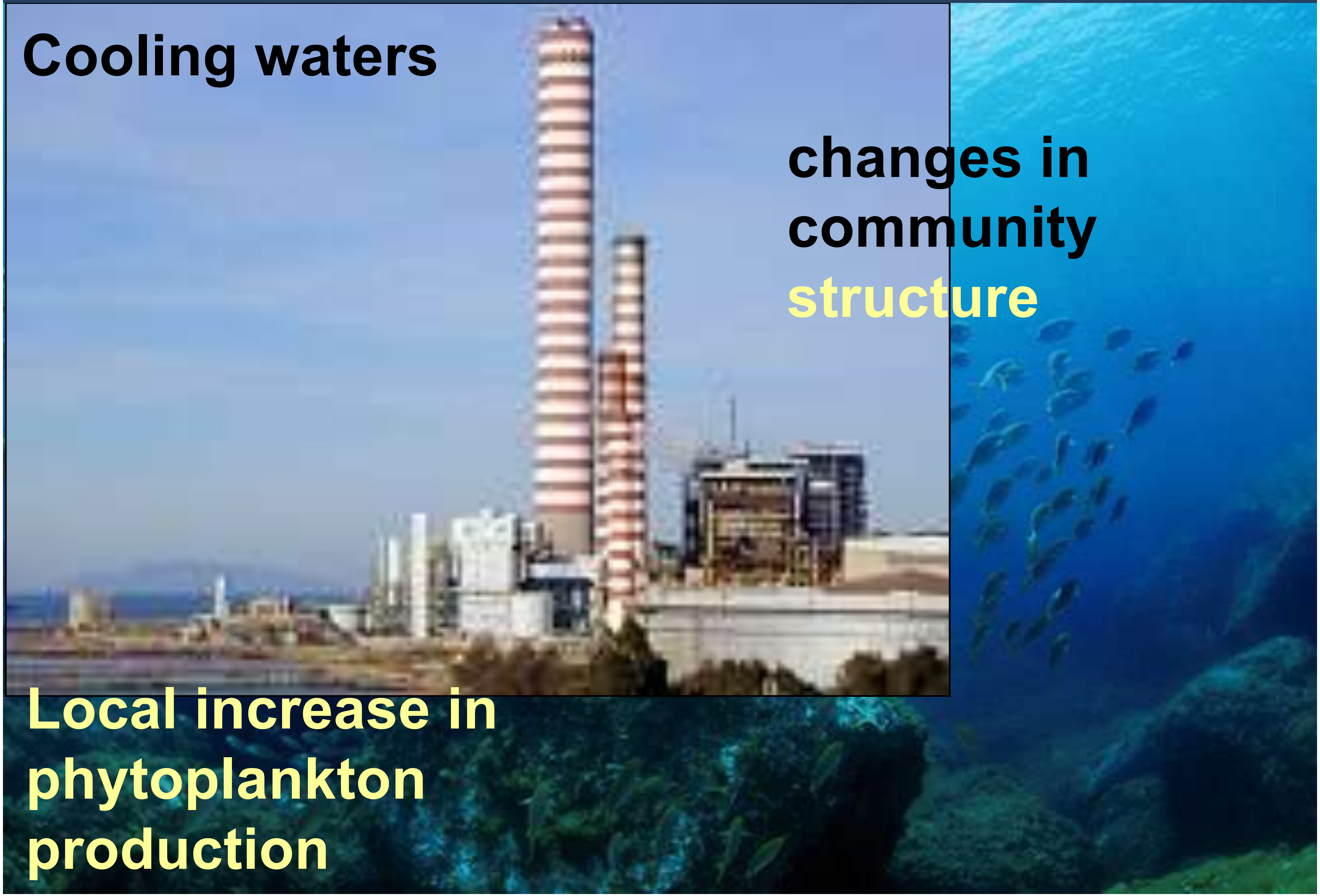
- At least 690 species have encountered marine debris.
- At least 17% of impacted species listed on the IUCN Red List as near threatened or above.
- 92% of the individual encounters with marine debris related to encounters with plastic.
- At least 10% of the species encountering marine debris had ingested microplastics.


Environment
Environmental matrix
Water
Sediment
Marine
PE PP (13)
PE PP (1296)
Lakes
PE PP (9)
PE PP (346)
Rivers
PE PP (5)
PE PS (7003)
Soil
PE PP (113)
PE PP (3400)
Caves
PE PET (184)
PE PET (1394)
0 250 500 750 1000 1250 1500
0 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80
Items L⁻¹
10³ Items kg⁻¹
Fibers
Fragments
Color./dark >1mm
Color./dark <1mm
Transp./clear <1mm
Item type
Piccardo & Bevilacqua 2024

Indirect sources

Radioactive substances

Thermal pollution



Cooling waters

changes in community structure

Local increase in phytoplankton production

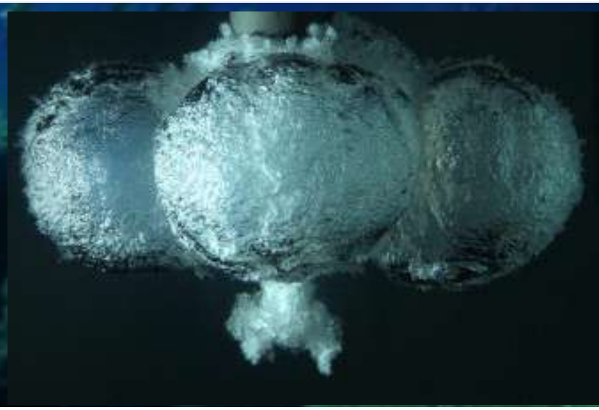
Acoustic noise

Table 1. Typical sources of anthropogenic noise. Omni: omnidirectional; CW: continous wave; V: vertical; H: horizontal; 10 000 lb = 4536 kg; 98 lb = 44 kg

Sound source	Source level (dB re 1 μPa @ 1 m)	Power (W)	Total energy per pulse (J)	Bandwidth Δ = 10 dB (Hz)	Source direction	Pulse duration (s)
Ship shock trial (10000 lb explosive)	304	0.021×10^{15}	0.042×10^{15}	0.5–50	Omni	2
Torpedo MK-46 (98 lb explosive)	289	0.66×10^{12}	0.066×10^{12}	10–200	Omni	0.1
Air-gun array	260	0.21×10^{9}	6.2×10^{6}	5–300	60 × 180° V	0.03
US Navy 53C ASW sonar	235	0.77×10^{6}	1.5×10^{6}	2000–8000	40 × 360° H	2
SURTASS LFA sonar	235	0.59×10^{6}	0.029×10^{9}	100–500	30 × 360° H	6–100
Pile-driving 1000 kJ hammer	237	0.46×10^{6}	0.023×10^{6}	100–1000	15 × 360° H	0.05
Multibeam sonar deep-water EM 122	245	0.077×10^{6}	760	11 500–12 500	1.0 × 120° V	0.01
Seal bombs (2.3 g charge)	205	2.6×10^{3}	79	15–100	Omni	0.03
Multibeam sonar shallow EM 710	232	2.2×10^{3}	4.5	70 000–100 000	0.5 × 140° V	0.002
Sub-bottom profiler SBP 120	230	2.1×10^{3}	210	3000–7000	3 × 35° V	0.1
Acoustic harassment device	205	1.3×10^{3}	330	8000–30 000	90 × 360°	0.15–0.5
Cargo vessel (173 m length, 16 knots)	192	66	–	40–100	80 × 180°	CW
Acoustic telemetry SIMRAD HTL 300	190	42	–	25 000–26 500	90 × 360°	CW
Small boat outboard engine (20 knots)	160	42×10^{-3}	–	1000–5000	80 × 180°	CW
Acoustic deterrent device	150	4.2×10^{-3}	1.4×10^{-3}	5000–160 000	90 × 360°	0.2–0.3
Operating windmill turbine	151	2.6×10^{-3}	–	60–300	15 × 360° H	CW

Hildebrand, 2009

>160 dB re 1 μPa 1m disturbance - >240, injuries or death



Physiological effects, injuries

Table 2. Example studies showing effects of anthropogenic noise on acoustic communication and physiological hearing system of marine organisms.

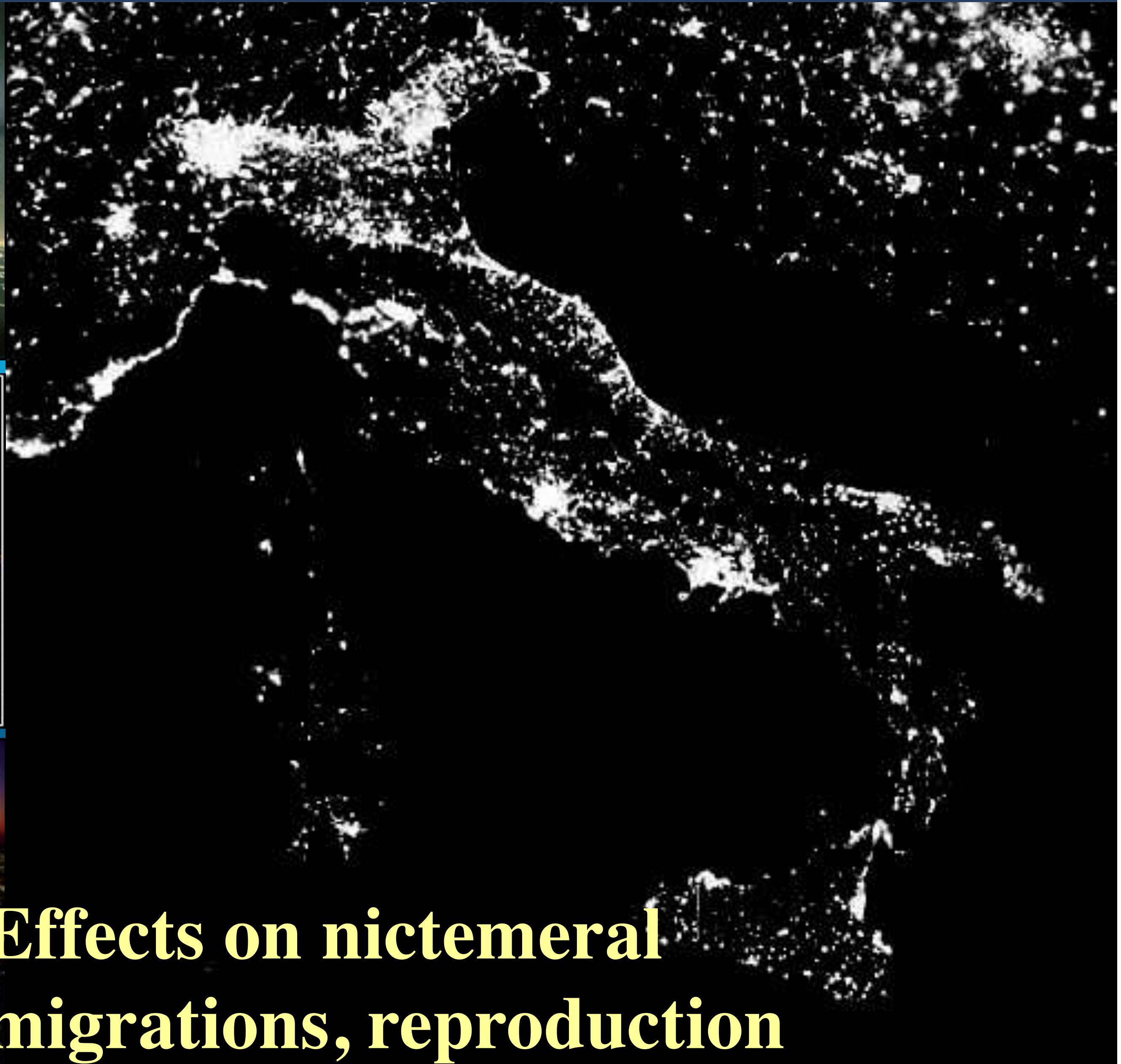
Species	Types of Anthropogenic Noise	Effects	References
M. angustirostris	increased ambient noise	constrains acoustic communication	Southall *et al.*, 2003 [45]
C. chromis *S. umbra* *G. cruentatus*	boating and shipping noise	reduces auditory sensitivity and shifts the hearing threshold	Codarin *et al.*, 2009 [7]
H. didactylus	boating and shipping noise	constrains acoustic communication and shifts the hearing threshold	Vasconcelos *et al.*, 2007 [46]
P. phocoena	seismic air-gun shooting	shifts the hearing threshold	Lucke *et al.*, 2009 [48]
T. truncatus	experimental noise emanating device	shifts the hearing threshold	Nachtigall *et al.*, 2004 [49]
P. auratus	seismic air-gun shooting	damages the hearing sensory epithelia	McCauley *et al.*, 2003 [37]
L. vulgaris *S. officinalis* *O. vulgaris* *I. coindetii*	experimental noise emanating device	damages the hearing sensory epithelia	André *et al.*, 2011 [52]
A. dux	seismic air-gun shooting	damage to internal fibers, statocysts, stomachs, and digestive tracts	Guerra *et al.*, 2011 [53]

Stranding

Species	Types of Anthropogenic Noise	Effects	References
Z. cavirostris	Sonar	causes mass strandings	Frantzis, 1998 [68]
A. dux	seismic air-gun shooting	causes mass strandings	Guerra *et al.*, 2011 [53]
Z. cavirostris *M. densirostris* *M. europaeus*	naval sonar	mass strandings	Cox, *et al.*, 2006 [70]
Z. cavirostris *M. densirostris* *M. europaeus*	naval sonar	mass strandings	Fernández, *et al.*, 2005 [71]
Z. cavirostris *M. densirostris* *M. europaeus*	naval sonar	mass strandings	Jepson, *et al.*, 2003 [72]
L. kempii *T. truncates* *C. caretta*	Underwater explosives	mass strandings	Klima *et al.*, 1988 [69]


Peng et al., 2015

Light



Effects on nictemeral migrations, reproduction

Alteration of the coastline

Changes of coastline

Discharge of solid materials

Changes in sedimentation

Degradation of ecosystems

Alteration of coastline

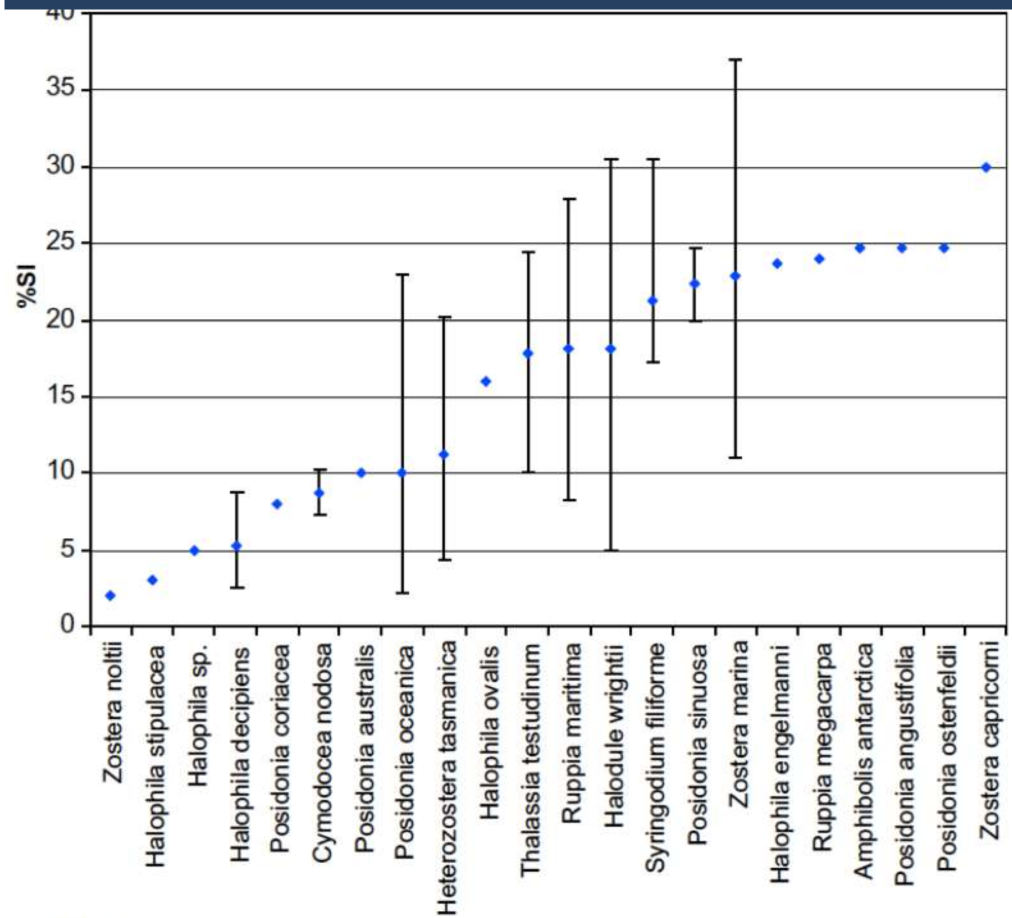
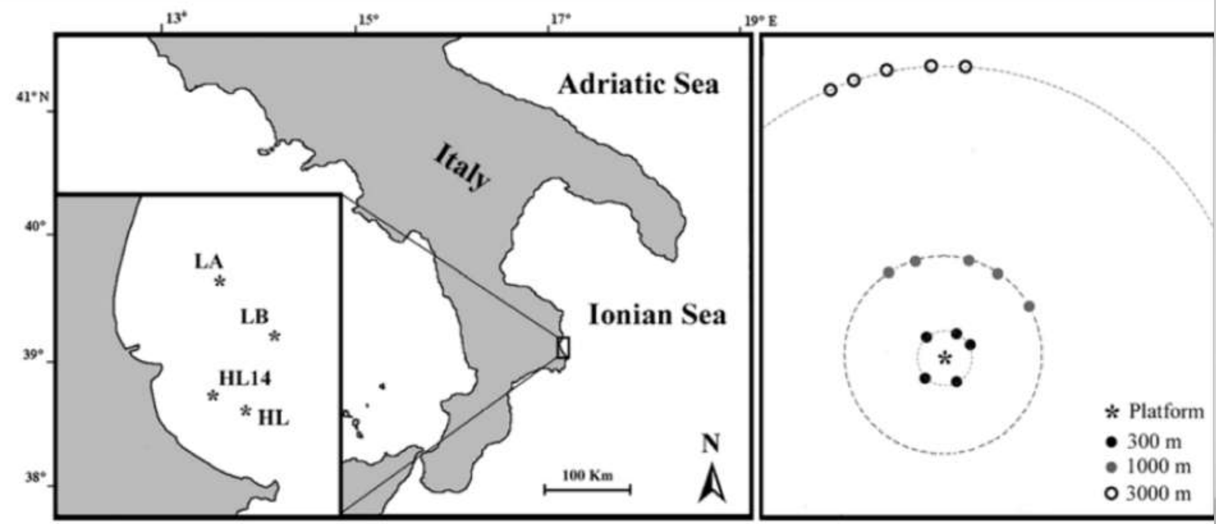


Table 3
Critical thresholds of seagrasses for sedimentation (cm/year)

Species	Location	Sedimentation (cm/yr)	Reference
Cymodocea nodosa	Mediterranean (Spain)	5	Marba and Duarte (1994)
Cymodocea rotundata	Philippines	1.5	Vermaat et al. (1997)
Cymodocea serrulata	Philippines	13	Vermaat et al. (1997)
Enhalus acoroides	Philippines	10	Vermaat et al. (1997)
Halophila ovalis	Philippines	2	Vermaat et al. (1997)
Posidonia oceanica	Mediterranean (Spain)	5	Manzanera et al. (1995)
Zostera noltii	Mediterranean (Spain)	2	Vermaat et al. (1997)

Artificial structures

Artificial structures



Offshore gas platforms in the North ionian Sea
(Terlizzi et al., 2008)

Table 1
PERMANOVA analyzing differences among assemblages at increasing distance from platforms based on Bray–Curtis dissimilarities of untransformed data (180 samples × 405 taxa)

Source of variability	d.f.	SS	MS	*F*	*P*	MS_{DEN}	Permutable units
Depth = De	1	118640.00	118640.00	6.553	0.000	P(De)	4 P(De) cells
Distance = Di	2	12850.00	6424.80	0.736	0.842	Di × P(De)	12 Di × P(De) cells
Platform = P(De)	2	36211.00	18105.00	5.123	0.000	Si(Di × P(De))	60 Si(Di × P(De)) cells
De × Di	2	11776.00	5887.90	0.675	0.896	Di × P(De)	12 Di × P(De) cells
Di × P(De)	4	34903.00	8725.90	2.469	0.000	Si(Di × P(De))	60 Si(Di × P(De)) cells
Site(Di × P(De)) = Si(Di × P(De))	48	169620.00	3533.80	1.775	0.000	Res	120 raw data units
Residual = Res	120	238890.00	1990.80				
Pair-wise tests for term Di × P(De)							
HL		HL14			LA		LB
300 m = 1000 m = 3000 m		300 m = 1000 m = 3000 m			300 m = 1000 m ≠ 3000 m		300 m ≠ 1000 m ≠ 3000 m

Artificial structures

Table 2
Summary of SIMPER analysis for platforms LA and LB

Species	300 m	1000 m	3000 m	300 m vs 1000 m (73.43)	300 m vs 3000 m (80.08)	1000 m vs 3000 m (72.73)
	Avg. ab.	Avg. ab.	Avg. ab.	Contr.%	Contr.%	Contr.%
LA						
Golfingia sp.	5.87	7.80	10.53	12.12	11.25	13.19
Levinsenia gracilis	2.13	2.73	12.40	6.00	11.23	10.86
Aricidea cfr *caterinae*	1.33	2.67	9.93	4.52	8.13	8.05
Monticellina dorsobranchialis	0.80	2.67	8.33	4.05	7.38	6.87
Timoclea ovata	0.67	3.13	3.84	3.84	0.61	2.29
Nucula sulcata	2.87	1.13	3.71	3.71	2.42	1.00
Prionospio cirrifera	0.53	2.33	3.31	3.31	2.92	3.24
Thyasira biplicata	0.87	2.40	7.47	3.22	5.90	5.54
Monticellina heterochaeta	1.20	2.00	3.33	3.13	2.83	3.07
Leucon mediterraneus	1.33	1.40	4.53	2.78	3.66	3.64
Chaetozone sp.	0.40	1.67	3.93	2.35	3.18	3.52
				300 m vs 1000 m (68.25)	300 m vs 3000 m (78.28)	1000 m vs 3000 m (79.12)
LB						
Golfingia sp.	4.40	3.33	2.87	3.09	2.32	2.36
Levinsenia gracilis	5.53	3.80	0.87	4.95	3.12	2.71
Aricidea cfr *caterinae*	3.93	3.80	1.00	3.95	2.18	2.73
Timoclea ovata	9.67	6.93	57.33	7.46	19.01	22.18
Prionospio cirrifera	0.00	0.67	1.53	0.59	1.17	1.58
Thyasira biplicata	7.60	3.33	1.00	4.12	4.17	2.08
Corbula gibba	5.20	1.20	0.87	3.29	2.81	0.98
Kelliella abissicola	8.33	3.67	15.53	6.26	6.81	7.00
Diplodonta apicalis	18.27	6.87	0.00	11.23	11.05	4.94
Parvicardium minimum	2.33	1.53	10.20	1.66	3.53	4.32
Nuculana (Jupiteria) commutata	5.20	2.67	11.47	2.88	4.50	5.42

Artificial structures

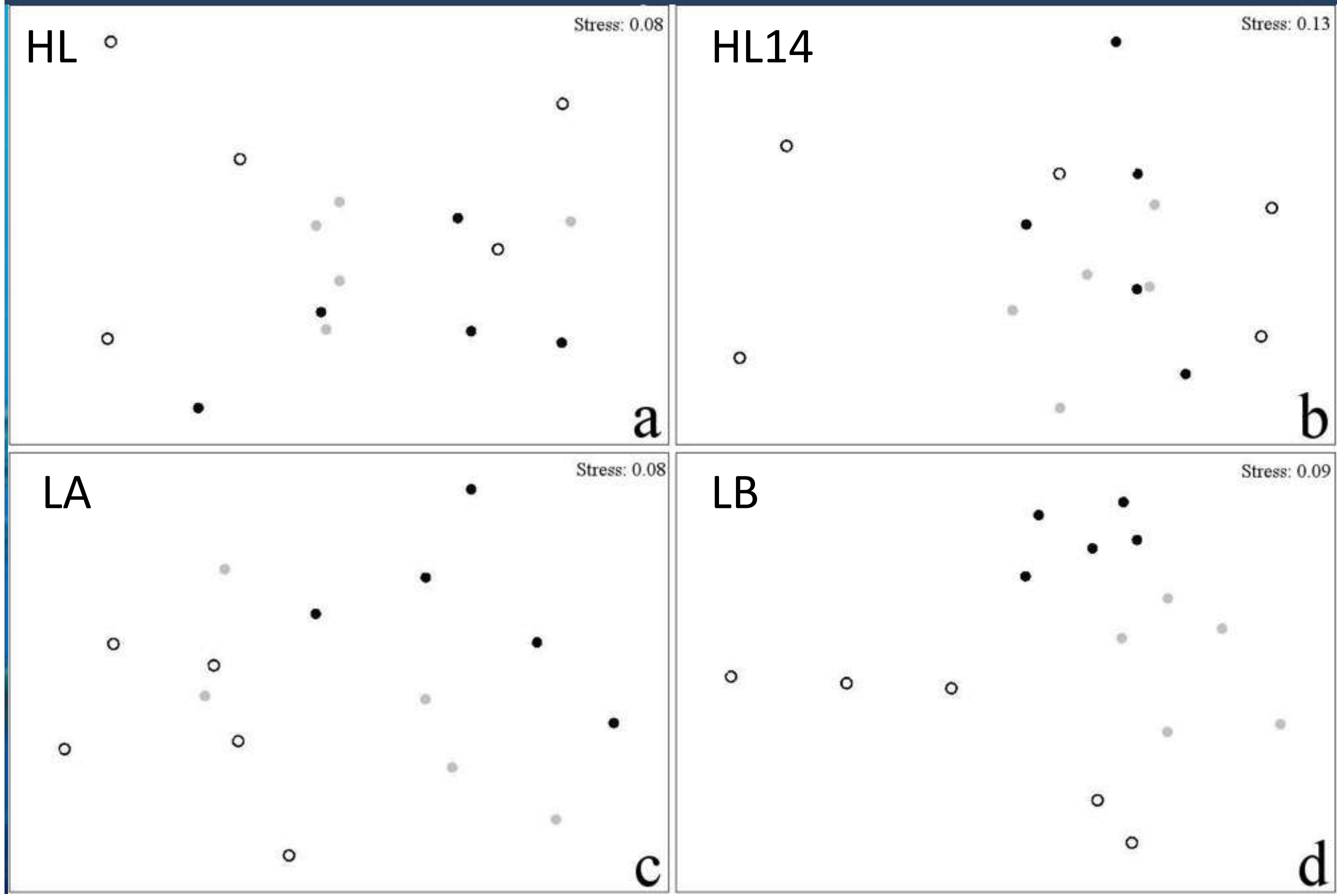


Table 3
Summary of PERMDISP analyses investigating differences in multivariate dispersion of replicates and sites at the three distances from platforms

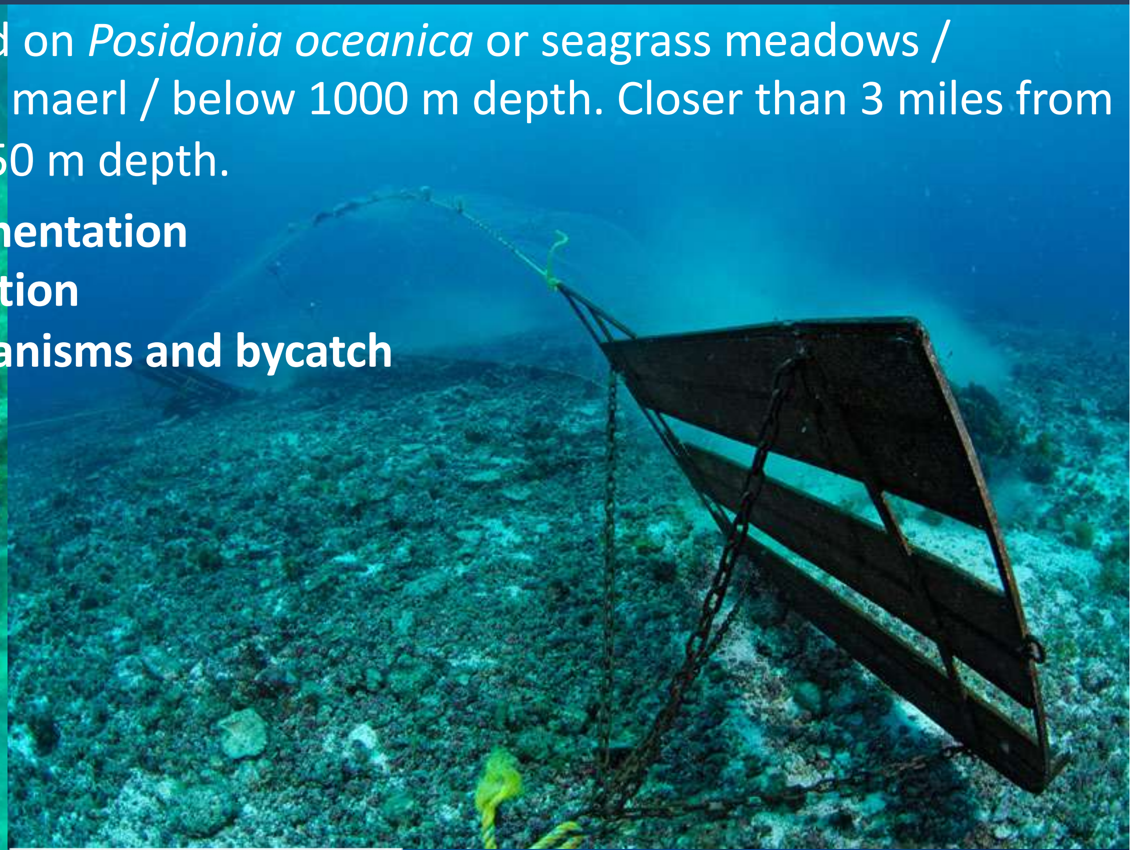
Source of variability	d.f.	HL		HL14		LA		LB	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*
Replicates dispersion									
Distance = Di	2	69.41	0.596ns	139.33	1.881ns	63.99	0.977ns	51.64	0.425ns
Site(Di) = Si(Di)	12	116.53	3.048**	74.08	3.018**	65.49	1.181ns	121.60	4.148**
Residual	30	38.23	24.55	55.45	29.32				
Sites dispersion									
Distance = Di	2	207.15	4.864*	113.70	10.050**	26.16	1.340ns	147.24	5.068*
Site(Di) = Si(Di)	12	42.58	11.31	19.52	29.06				
Pair-wise tests		300 m = 1000 m ≠ 3000 m		300 m = 1000 m ≠ 3000 m		300 m = 1000 m = 3000 m		300 m = 1000 m ≠ 3000 m	

Destructive fishing and other physical damages

Anchoring

Trawling banned on *Posidonia oceanica* or seagrass meadows / coralligenous or maerl / below 1000 m depth. Closer than 3 miles from coast or above 50 m depth.

Increased sedimentation
Habitat destruction
Removal of organisms and bycatch



Loss of sessile, emergent, high biomass species, increase in small-bodied infauna

70% reduction of mearl[a] habitat over 4 years

Decreased number of organisms, biomass, species richness, species diversity, an biogenic habitat structure

Trawl reduced density of large epifauna about 15% on each pass; trawl flown 15 cm abov seafloor had no detectable impact on large epifauna

Decreased abundance of large epifauna and infaunal species abundance

Decreased density of common echinoderms, polychaetes, and molluscs

Direct mortality of 5–60% for species following single passage of trawl

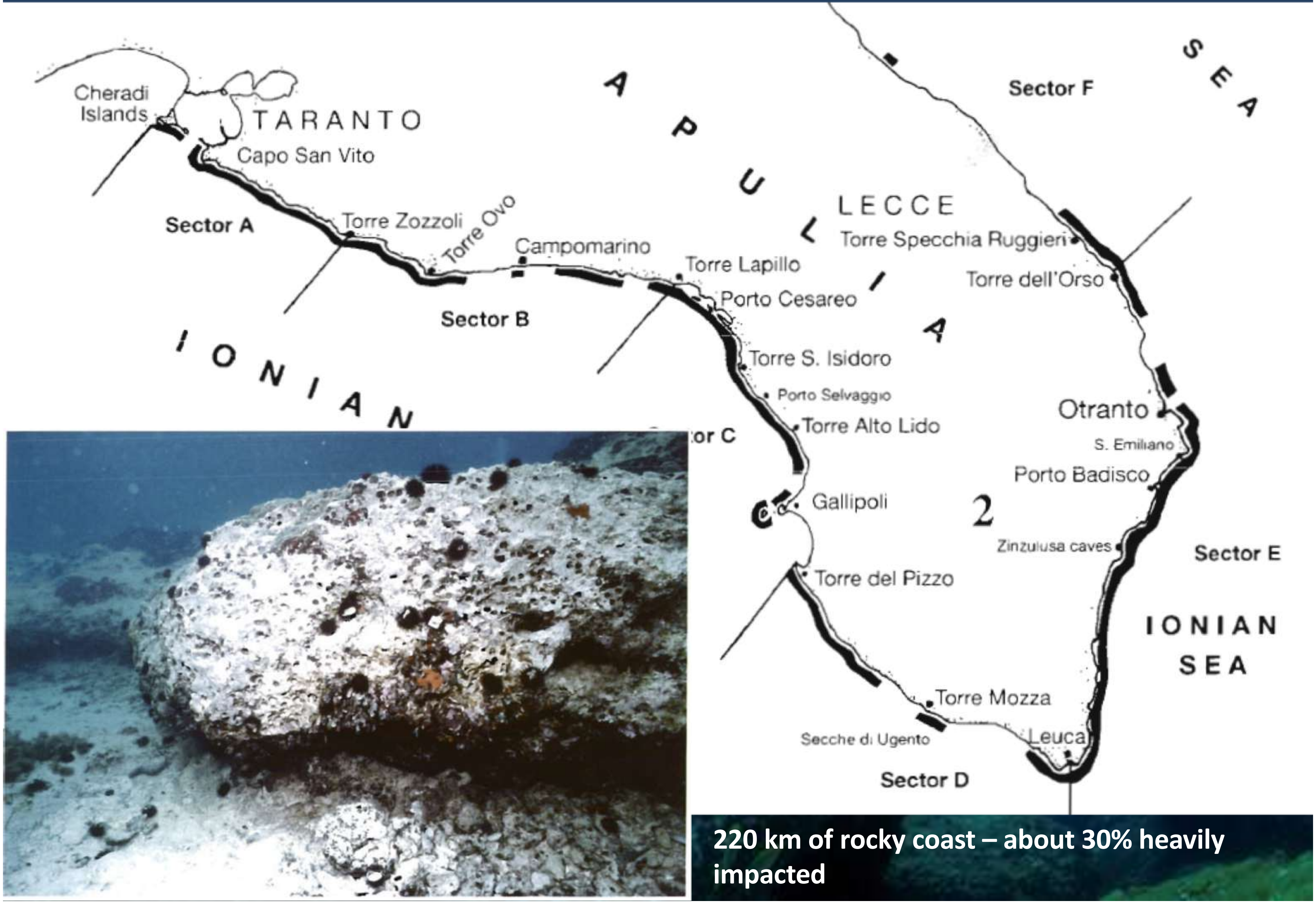
Removal of biogenic and physical habitat structure

Decreased diversity in trawled plots

Decrease in small-scale heterogeneity of sediment texture after trawling

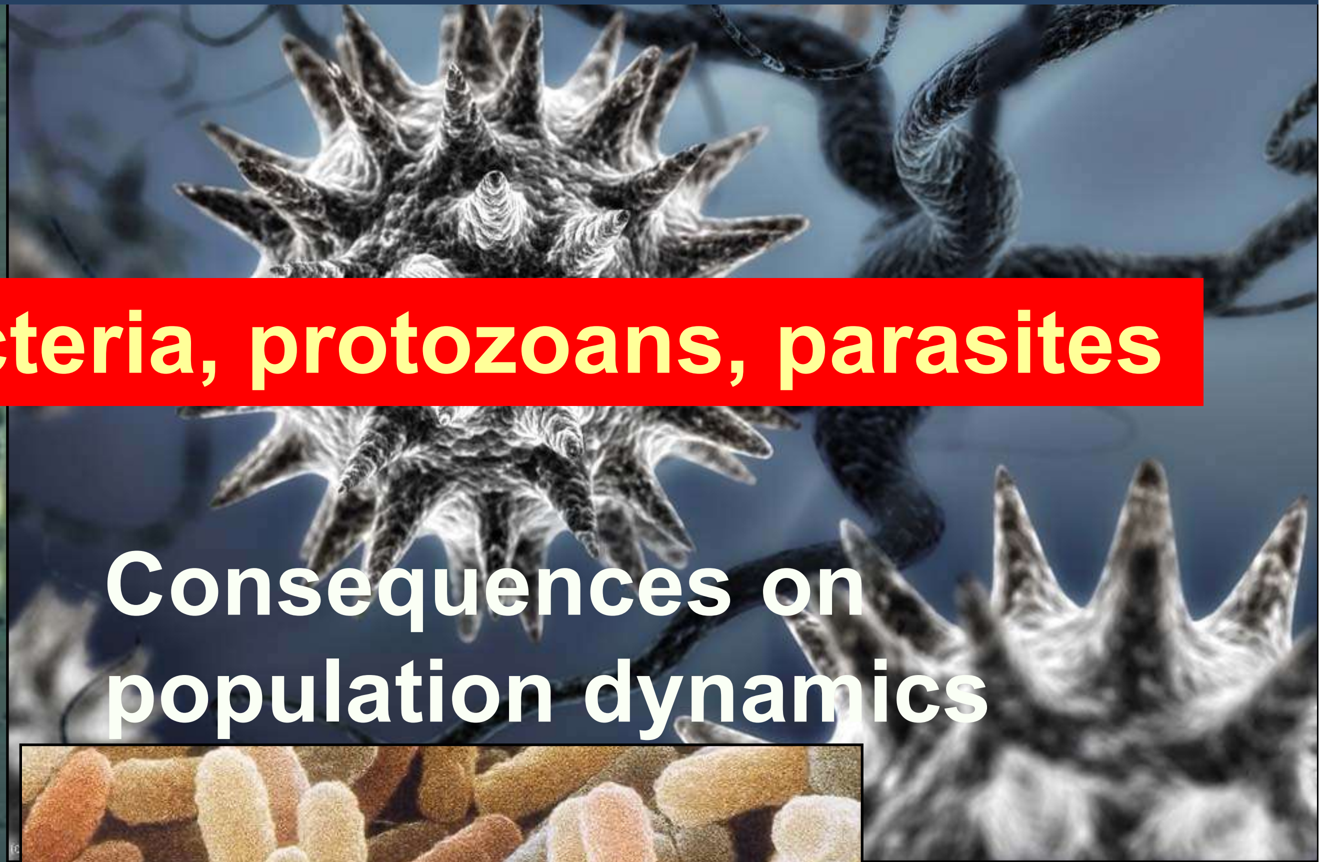
Thrush and Dayton, 2002

Destructive fishing (date mussels)



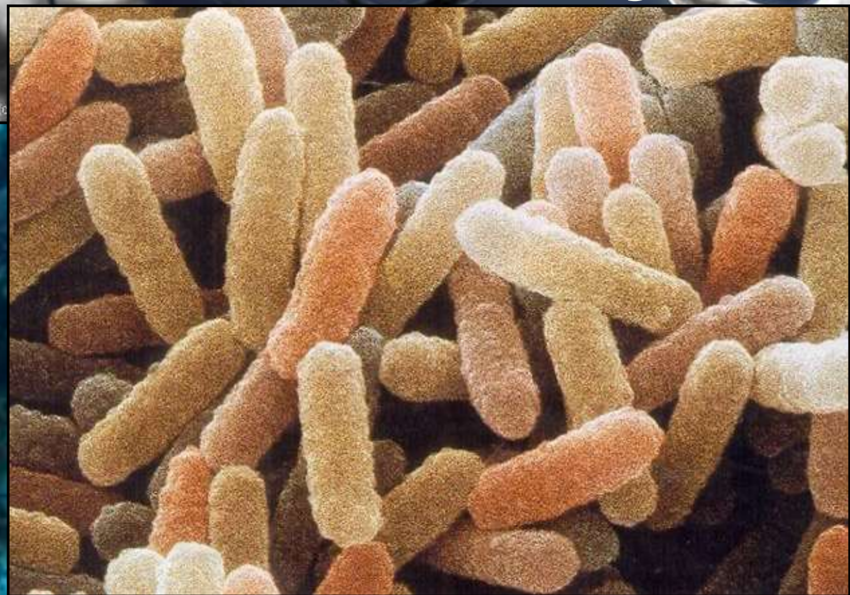
220 km of rocky coast – about 30% heavily impacted

Pathogens



Virus, bacteria, protozoans, parasites

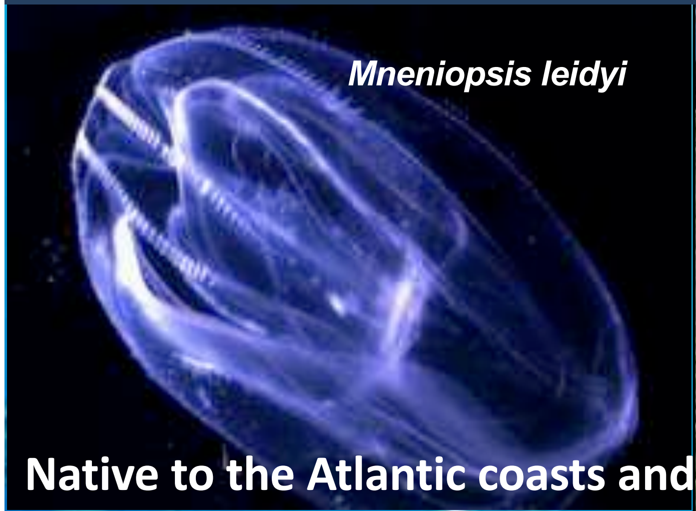
Consequences on population dynamics

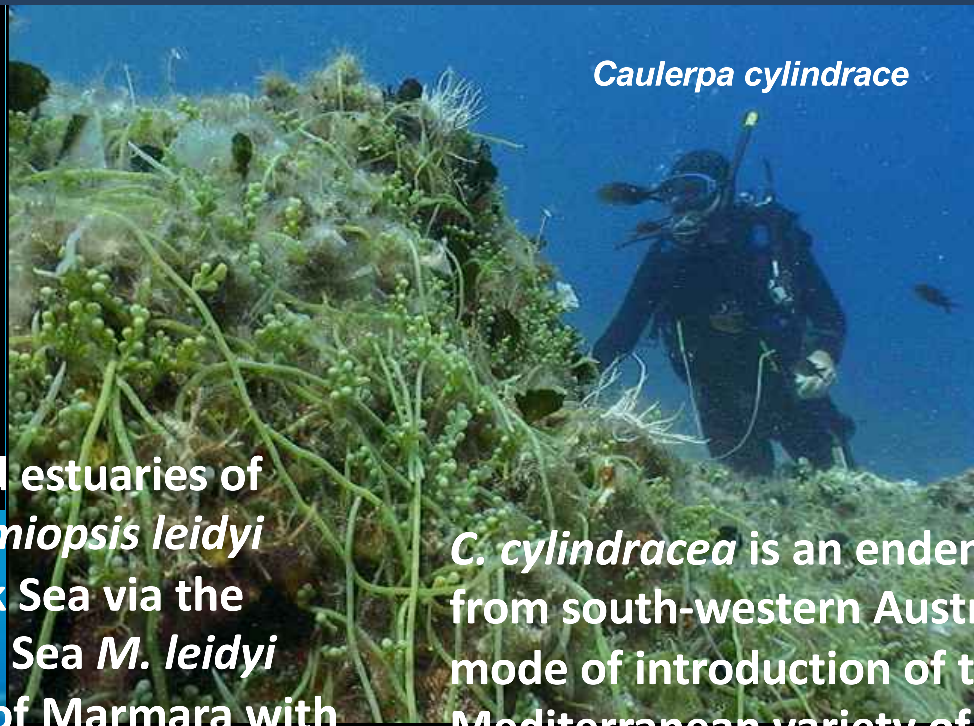


Nodavirus

Infection via aquaulture

Alien species

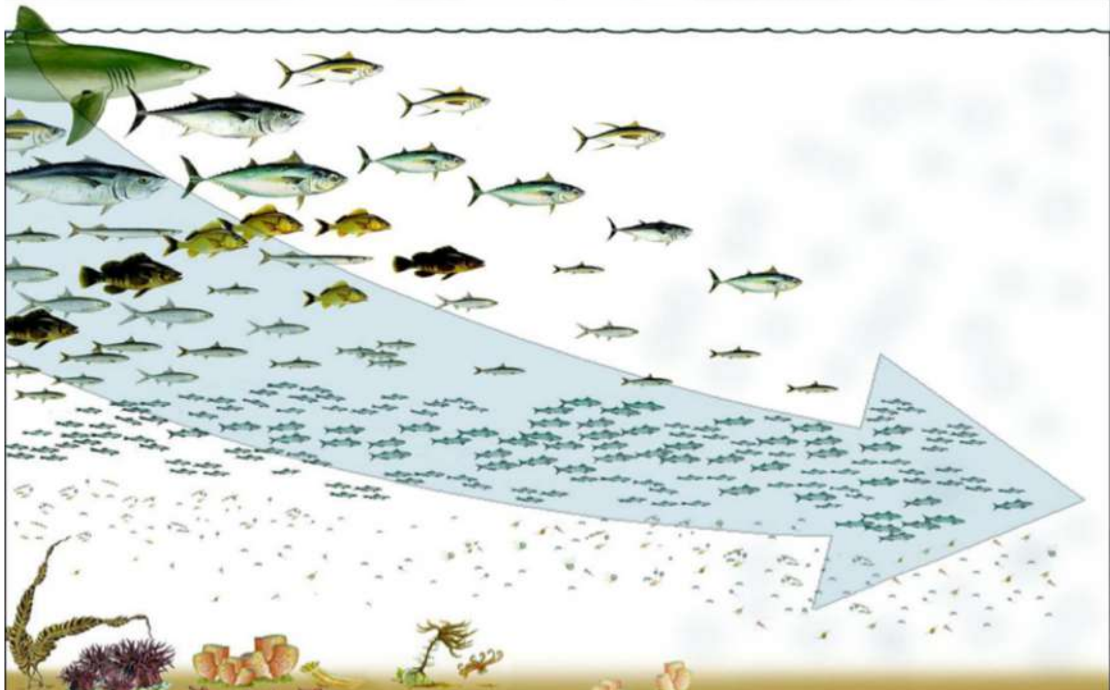




Native to the Atlantic coasts and estuaries of North and South America, *Mnemiopsis leidyi* was first introduced to the Black Sea via the ballast water of ships. The Black Sea *M. leidyi* population spread into the Sea of Marmara with the currents and thence into the north-western Aegean Sea, where it was first recorded in 1990. Soon afterwards, it was recorded off the Mediterranean coast of Turkey and in Syria. In the mid 2000s it appeared in France and the northern Adriatic Sea, and nowadays large blooms of this species are commonly reported in Israel, Italy and Spain. Severe predation on juvenile of target fish species and collapse of livestock and small-scale fisheries

***C. cylindracea* is an endemic species from south-western Australia. The mode of introduction of the invasive Mediterranean variety of the alga into the Mediterranean Sea remains speculative; however, maritime traffic (ballast water and ship hull fouling) and the aquarium trade are the most likely vectors for the introduction of this high-impact alga. It competes with native species, alters sediment entrapment , and produce secondary metabolites that could affect target fish species**

Fishery



Fishing down marine food webs (Pauly et al., 1998)

Overexploitation

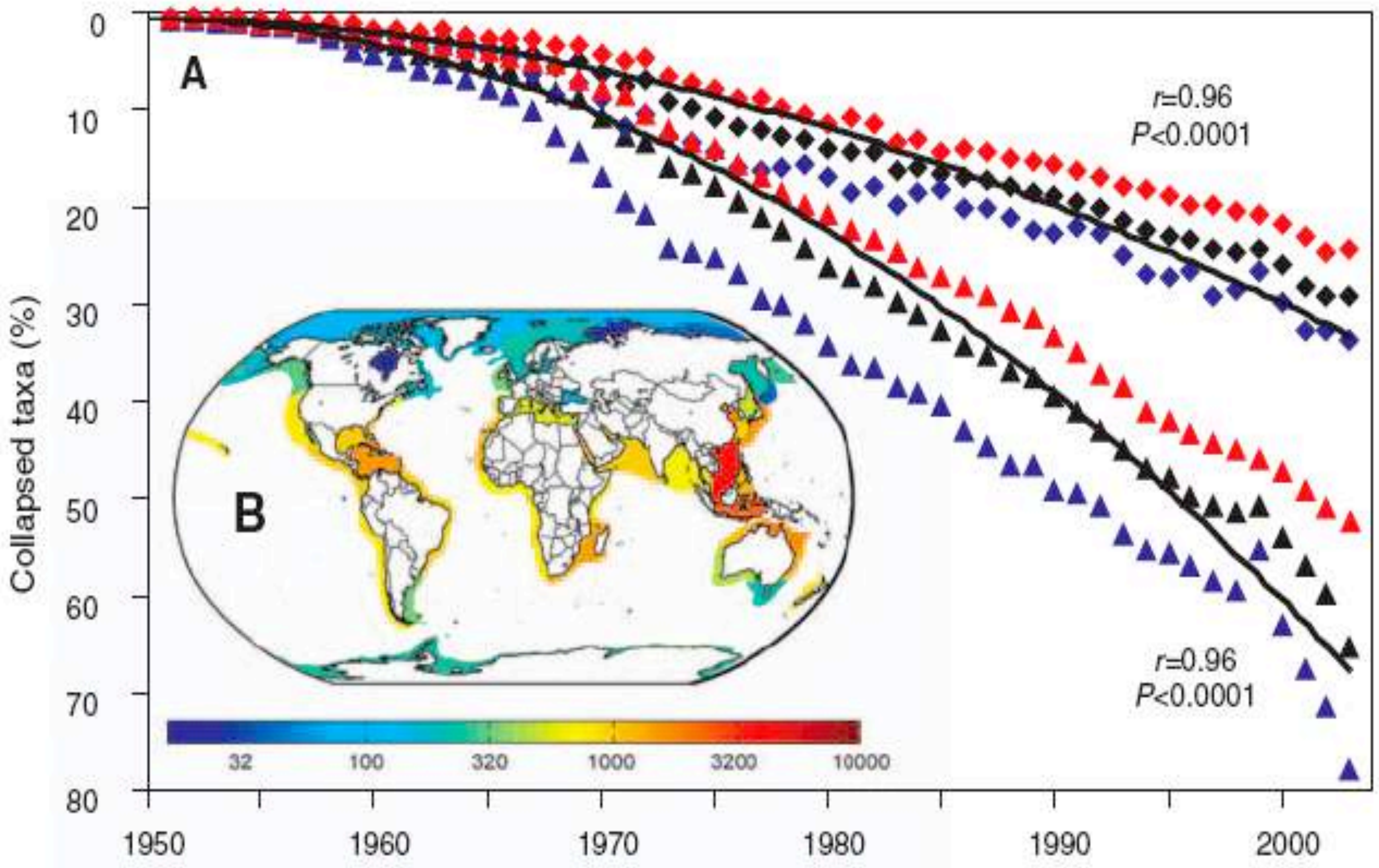
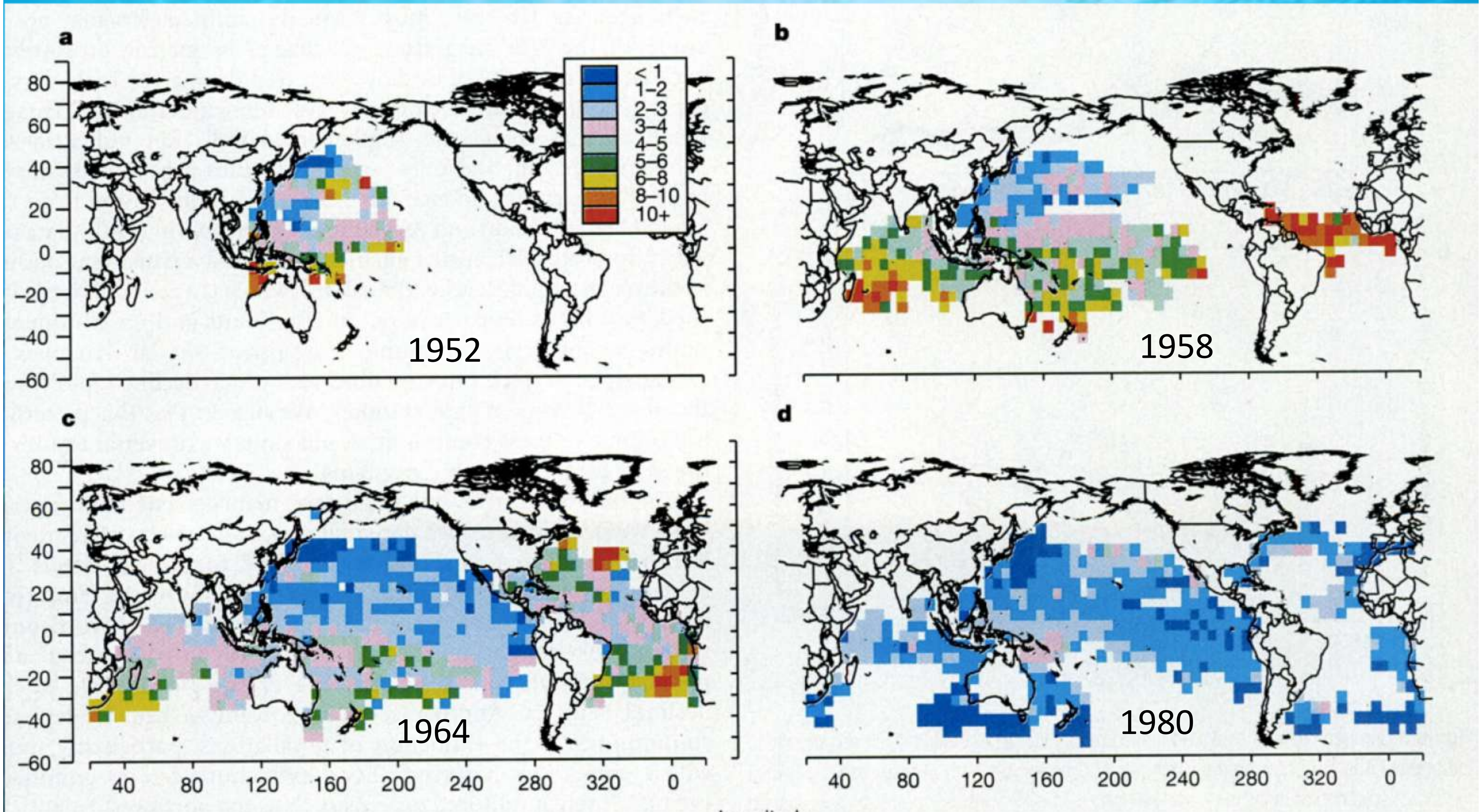


Fig. 3. Global loss of species from LMEs. (**A**) Trajectories of collapsed fish and invertebrate taxa over the past 50 years (diamonds, collapses by year; triangles, cumulative collapses). Data are shown for all (black), species-poor (<500 species, blue), and species-rich (>500 species, red) LMEs. Regression lines are best-fit power models corrected for temporal autocorrelation.

Worm et al. Science 2006

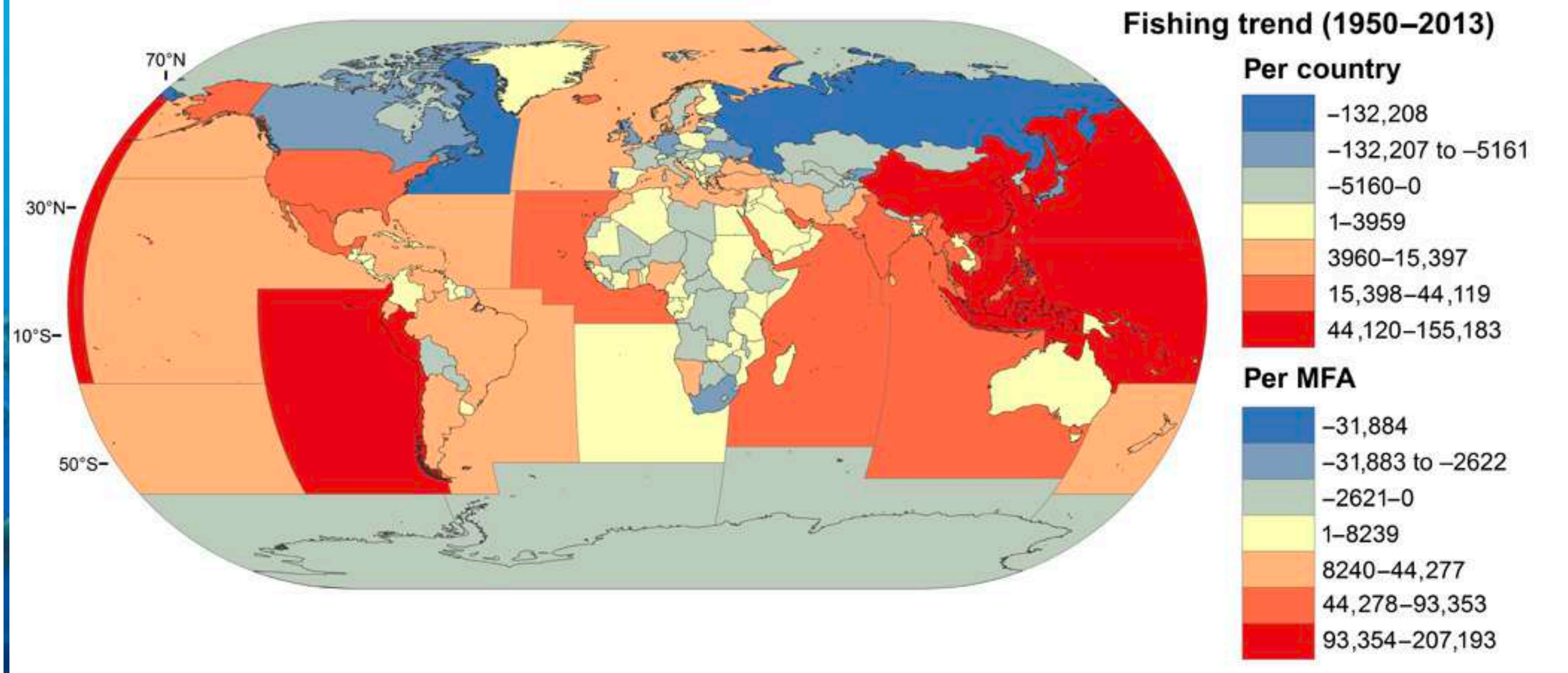
Fishery



Myers & Worm 2003

Decrease in top predator fish catches

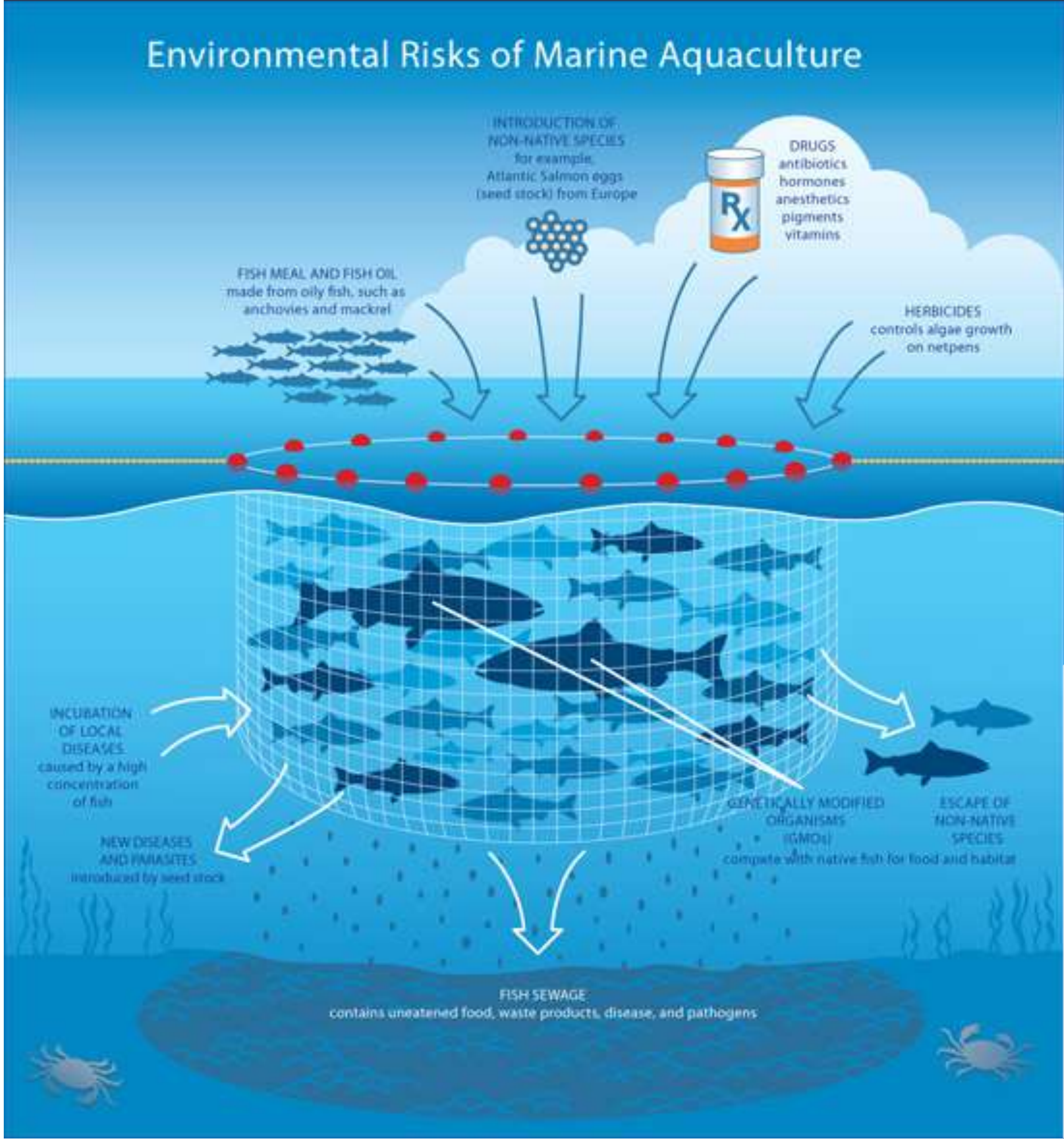
Fishery



Fisheries are declining in many areas, and in most cases they are close or under the limit of unsustainable yelds

Ramirez et al. 2017

Aquaculture



Introduction of drugs (antibiotic, antifouling)

Spread of pathogens and parasites to wild populations

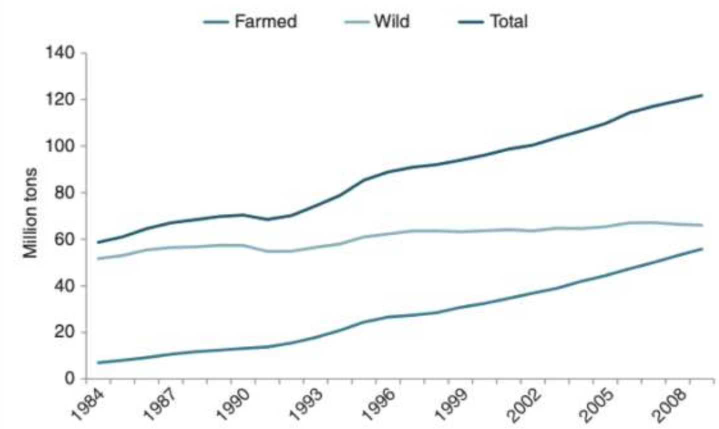
Introduction of alien species

Increasing nutrient load from fishmeal, fecal pellets

GMOs

Fishmeal, depletion of fish stocks, agriculture, and the problem of energy

FIGURE 1.2: Evolution of World Food Fish Production, 1984–2009



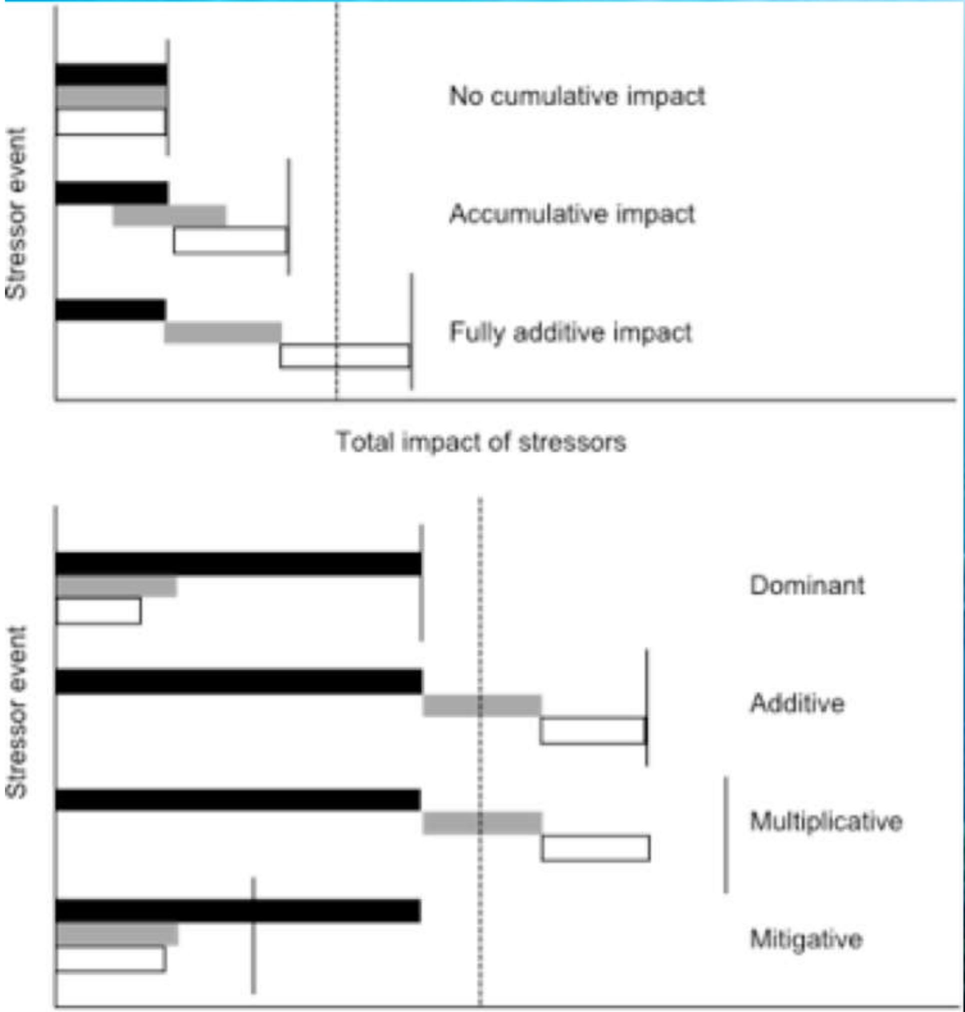
Source: FishStat.

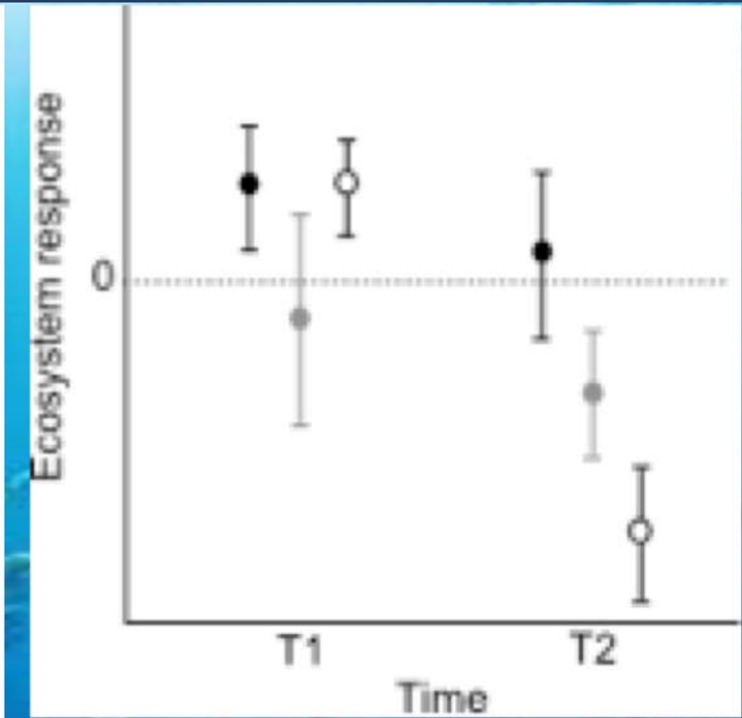
Aquaculture

Table 1. Effects of aquaculture on marine biotic communities (modified after Milewski, 2001).

Source of pressure	Potential effect on biota	Level of scientific documentation	Communities affected	Relevant/expected spatial scale	type of impact	Estimated recovery of the community
physical structure	Direct mortality through entanglement	poor	Vertebrates	local	-	medium
	Behavioral changes in coastal pelagic fish	medium	Vertebrates (Fish)	local	?	unidentified
	Behavioral changes in coastal birds and marine mammals (e.g., avoidance)	poor	Vertebrates	local-meso	-	unidentified
predator control systems	Direct mortality	poor	Vertebrates	local-meso	-	unidentified
	Behavioral changes of wild fauna	medium	Vertebrates	local-meso	-	unidentified
fish escapement	Disease transmission to other species	poor	various (probably fish)	meso-large	-	unidentified
	Genetic interactions with wild fish	High	Vertebrates (Fish)	meso-large	-	slow
	Displacement of wild fish from natural habitat (e.g., through competition, predation)	poor	Vertebrates (Fish)	meso-large	-	unidentified
release of uneaten food	Suffocation and displacement of benthic organisms	High	Macrofauna	local	-	slow
	Loss of foraging, spawning and/or nursery habitat for wild species	High	various	local	-	slow
	Loss of biodiversity	High	Macrofauna	local	-	slow
	Fragmentation of benthic habitat	poor	various	local-meso	-	slow
release of nutrients	Change in water quality	poor	various	local-meso	-/+	rapid
	Mortality of plankton (including fish and invertebrate egg and larvae)	poor	various	local	-	rapid
	Increased primary productivity	poor	various	local-meso	-/+	rapid
	Shift in plankton community composition	poor	Phytoplankton	local-meso	?	rapid
	Increase in harmful algal blooms	poor	various	local-meso	-	rapid
	Decline of seagrass meadows	poor-medium	marine plants & various indirectly	local-meso	-	slow
antibiotics	Tainting of wild species	poor	various	local	-	rapid
	Changes in benthic bacterial community	poor	microbes	local	-	unidentified
	Resistant microbial strains	poor	various indirectly	unknown	-	unidentified
pesticides	Direct mortality and sublethal effects	poor	invertebrates	local	-	unidentified
	Tainting of wild species	poor	various	local	-	unidentified
disinfectants and antifoulants	Direct mortality and sublethal effects	poor	invertebrates	local	-	unidentified
	Tainting of wild species	poor	invertebrates	local-meso	-	unidentified
	Changes in physiology	po	Istantanea schermo	local-meso	-	unidentified

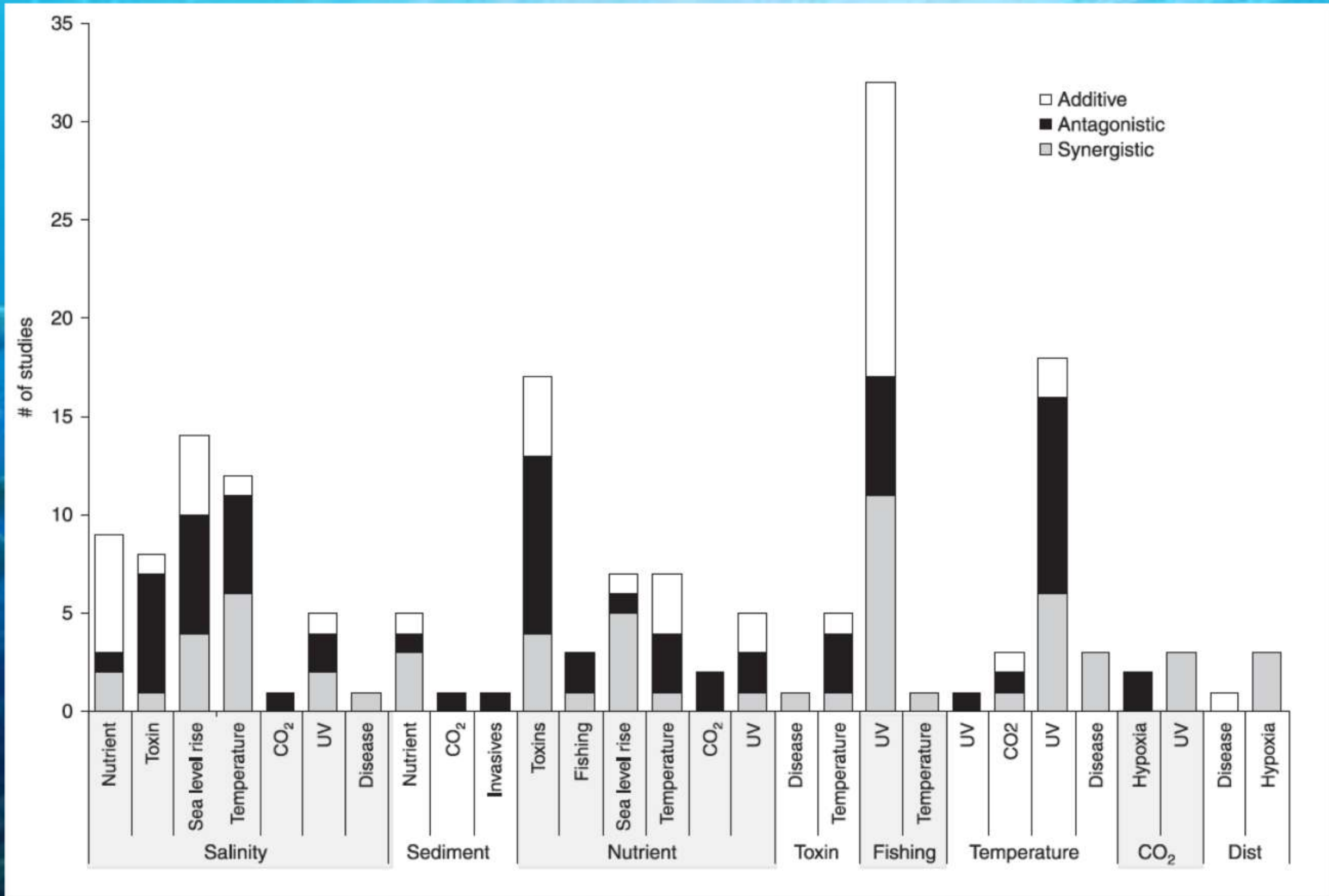
From isolated to cumulative impacts





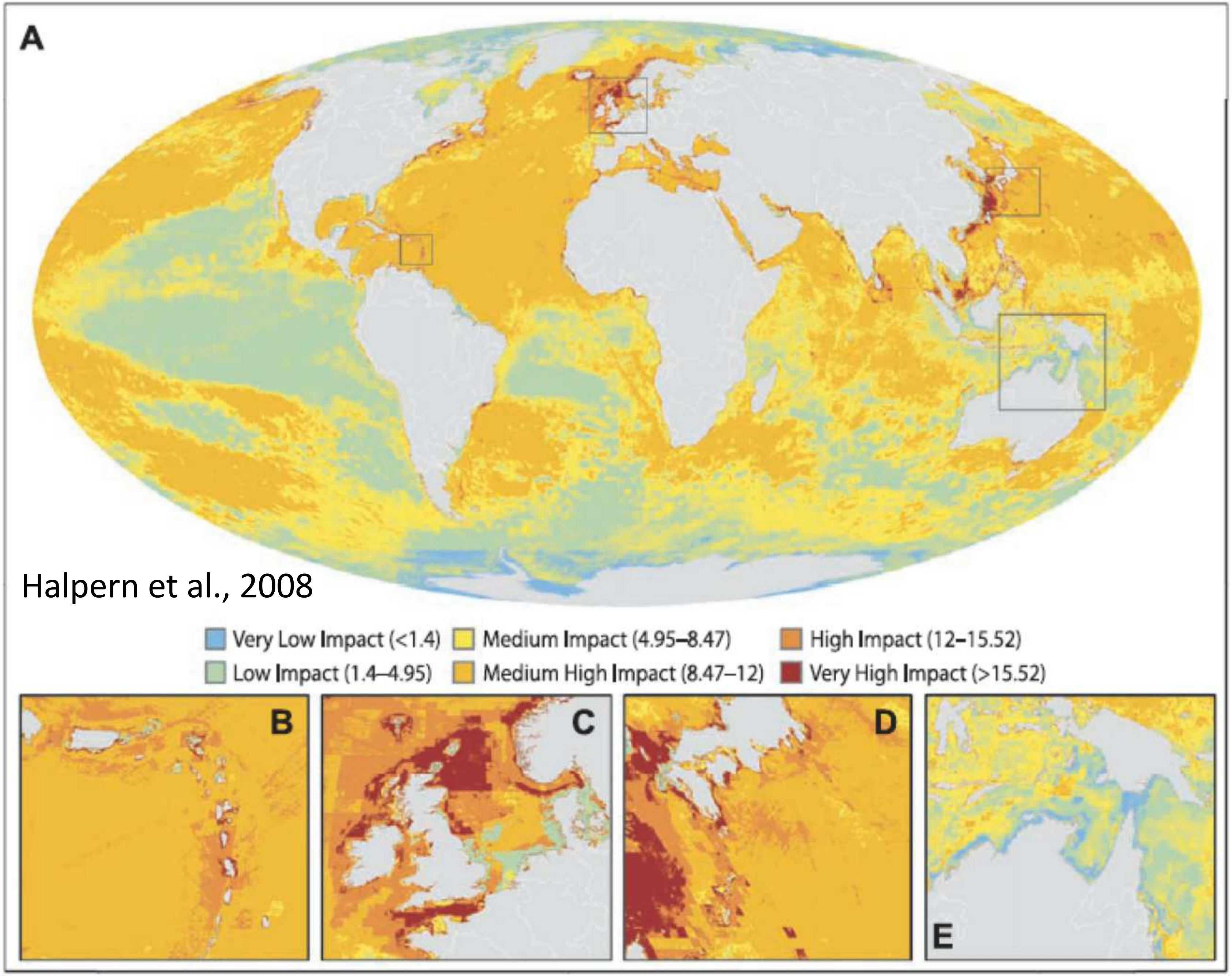
Crain, C. M.; Kroeker, K. & Halpern, B. S. (2008). Interactive and cumulative effects of multiple human stressors in marine systems, *Ecology Letters* 11: 1304-1315.

From isolated to cumulative impacts



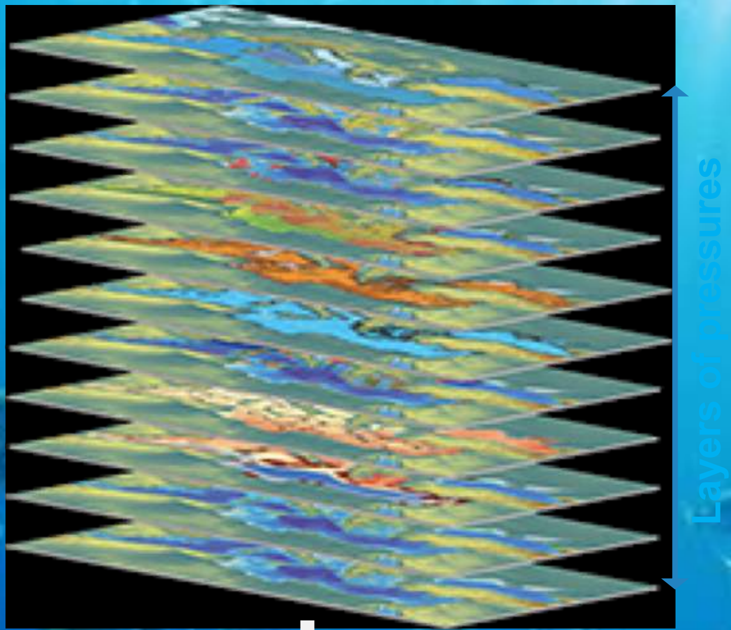
In many cases different stressors have synergistic effect, meaning that the combination of more disturbances often lead to worse impacts than what expected considering them in isolation

Estimating cumulative impacts



Halpern et al., 2008

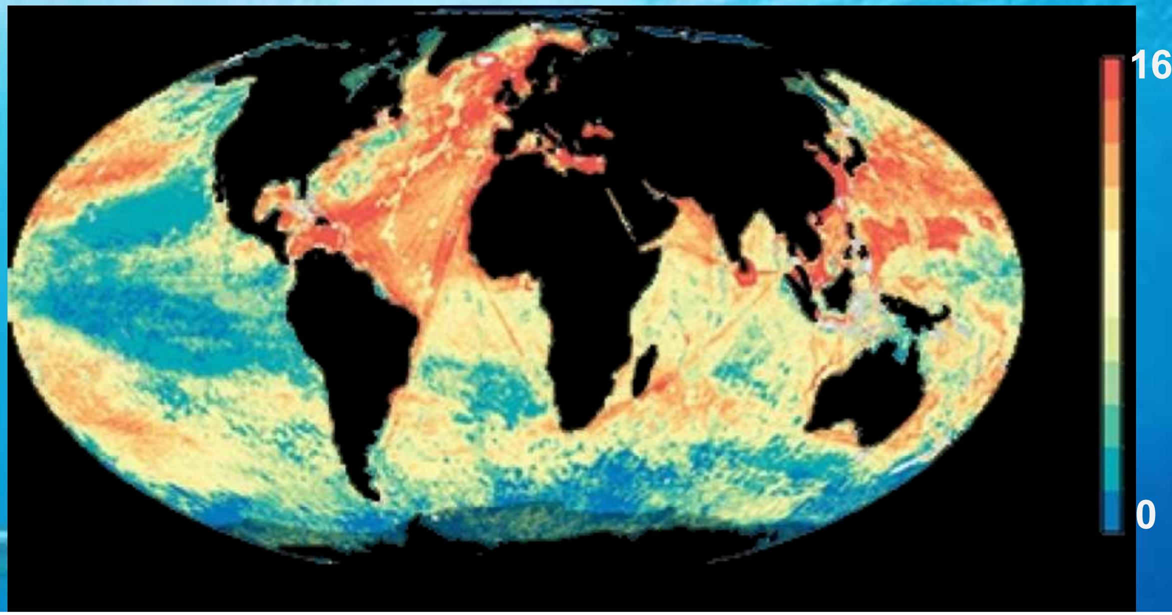
The additive formula



Sensitivity weights by expert opinion

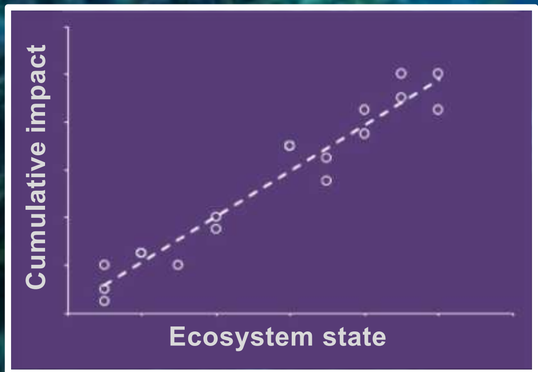
Computing geo-referred impact score

$$I_c = \sum P_i w_i E_j$$



Map of cumulative impact

Cumulative impact score versus ecosystem state



Linear response to pressure

Additivity of impacts

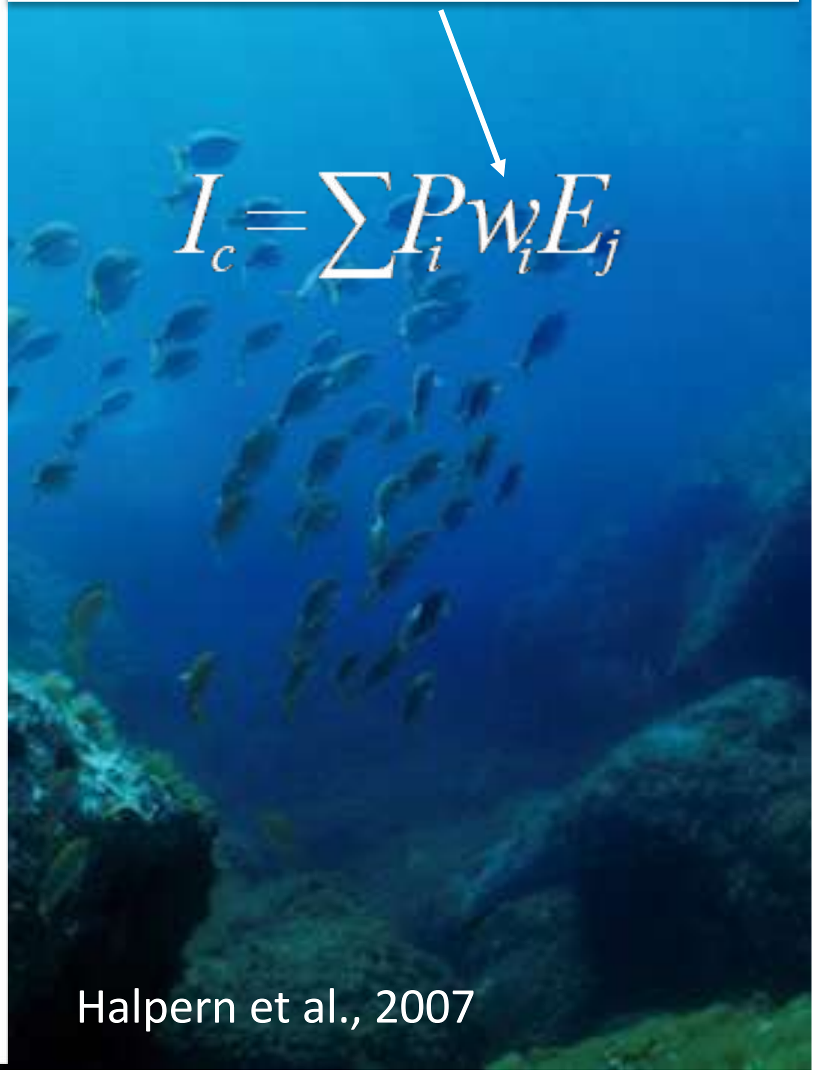
Expert-based sensitivity

Resolution and downscaling

Scores

	Intertidal					Coastal				
	Rocky intertidal	*Intertidal mud*	*Beach*	*Mangrove*	*Salt marsh*	*Coral reef*	*Seagrass*	*Kelp forest*	*Rocky reef*	*Suspension-feeder reef*[c]
Threat[b]	13	5	7	7	14	24	6	7	9	5
Freshwater input										
increase	1.6	1.3	0.3	1.8	1.9	1.5	1.6	0.0	1.5	1.7
decrease	1.1	1.1	0.0	2.6	1.9	0.4	1.4	0.0	0.6	1.2
Sediment input										
increase	2.4	2.0	1.1	2.2	2.2	2.8	2.9	1.2	2.0	2.2
decrease	0.6	1.6	0.7	1.3	1.7	0.4	0.5	0.0	0.0	1.5
Nutrient input[d]										
into oligotrophic water	1.8	1.1	0.2	1.4	1.4	2.4	2.1	0.0	1.7	0.0
into eutrophic water	1.3	2.1	0.6	2.1	2.3	1.1	2.0	0.8	1.5	2.8
Pollutant input										
atmospheric	0.8	0.7	0.0	0.9	1.6	0.9	0.6	0.0	0.5	1.8
point, organic	2.4	2.1	1.9	2.0	1.5	2.2	1.9	0.8	2.1	2.4
point, nonorganic	2.2	1.7	0.8	1.1	2.0	1.9	0.4	0.2	1.6	2.4
nonpoint, organic	2.1	2.8	0.1	1.4	1.7	1.2	1.0	1.0	2.2	2.8
nonpoint, nonorganic	2.1	1.6	0.6	0.5	2.0	0.7	0.8	0.0	2.2	2.7
Coastal engineering	2.7	2.1	2.8	3.1	2.3	2.3	2.4	0.0	1.9	3.0
Coastal development	2.7	2.9	3.2	3.4	2.8	2.9	3.3	1.2	2.5	3.2
Direct human	2.8	2.2	2.7	3.3	1.6	2.3	2.5	1.6	2.5	3.0
Aquaculture	2.0	2.0	0.1	3.1	1.7	1.8	2.1	0.0	1.9	1.5
Fishing										
demersal, destructive	1.2	1.4	0.2	0.0	1.0	1.2	0.2	1.5	2.7	3.1
demersal, nondestructive	0.8	1.9	0.9	0.9	1.0	1.6	1.1	2.1	2.9	0.7
pelagic, high bycatch	0.9	0.0	0.1	0.0	0.5	0.5	0.0	0.0	2.6	0.0
pelagic, low bycatch	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	2.6	0.0
aquarium	1.4	0.0	0.0	0.7	0.5	1.6	0.4	0.0	1.8	0.0
illegal/unregulated/unreported	1.2	0.0	0.7	0.0	0.4	1.0	0.6	0.0	1.2	0.0
artisanal, destructive	1.1	0.5	0.8	1.2	0.5	2.0	0.0	1.5	2.3	1.2
artisanal, nondestructive	1.4	0.3	0.5	2.2	0.6	2.5	0.6	0.0	2.1	0.7
recreational	2.0	1.7	0.4	2.1	0.5	2.1	2.2	2.3	2.6	1.3
Climate change										
sea level	2.5	1.9	2.1	3.0	3.1	2.4	2.6	1.6	1.5	1.8
sea temperature	2.8	1.4	0.6	2.4	1.4	2.8	2.1	2.0	1.9	0.8
ocean acidification	0.9	1.0	0.0	1.2	1.3	1.1	1.4	0.0	1.1	0.7
ozone/UV	0.9	1.3	0.0	0.2	1.1	0.8	0.5	0.1	0.7	0.0
Species invasion	2.8	2.9	0.9	1.0	2.8	1.5	1.2	1.3	2.5	2.6
Disease	1.3	1.8	0.0	1.7	1.1	2.2	1.0	0.7	1.8	2.1
Harmful algal blooms	1.9	2.2	0.9	1.6	2.0	1.8	2.3	0.4	1.7	2.5
Hypoxia	1.2	2.1	0.6	0.6	1.9	0.8	1.3	1.0	1.6	2.9
Ocean-based pollution	1.3	0.8	0.5	1.2	1.2	1.2	0.5	0.1	1.7	0.0
Commercial activity	0.3	1.9	1.9	2.0	1.4	1.5	1.9	0.0	1.4	0.0
Ocean mining	0.9	0.0	0.3	0.0	1.1	0.8	0.4	0.0	1.3	0.0
Offshore development	0.7	0.0	0.4	0.0	0.7	0.2	0.0	0.5	0.7	0.0
Benthic structures	1.0	0.9	0.8	1.3	0.9	0.5	1.6	0.0	1.7	0.4
Ecotourism	1.6	0.0	1.0	2.3	1.3	1.8	1.5	0.8	1.7	0.3
Summed threat	58.9	51.4	28.4	55.7	54.9	57.2	48.9	22.4	66.6	53.2
Average threat	1.5	1.4	0.7	1.5	1.4	1.5	1.3	0.6	1.8	1.4

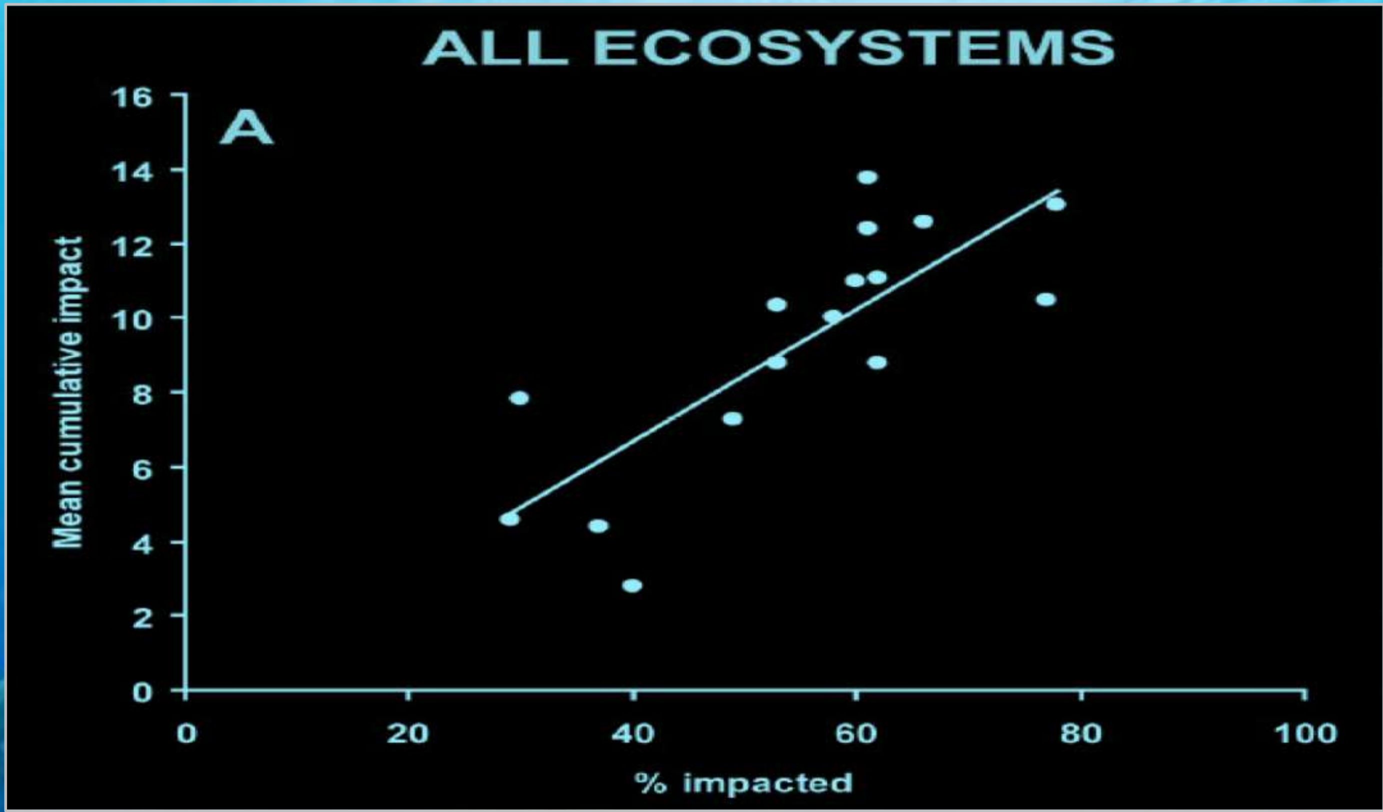
Score from expert opinion. For each ecosystem and each threat a sensitivity score has been assigned



$$I_c = \sum P_i w_i E_j$$

Halpern et al., 2007

Pressure response relationship



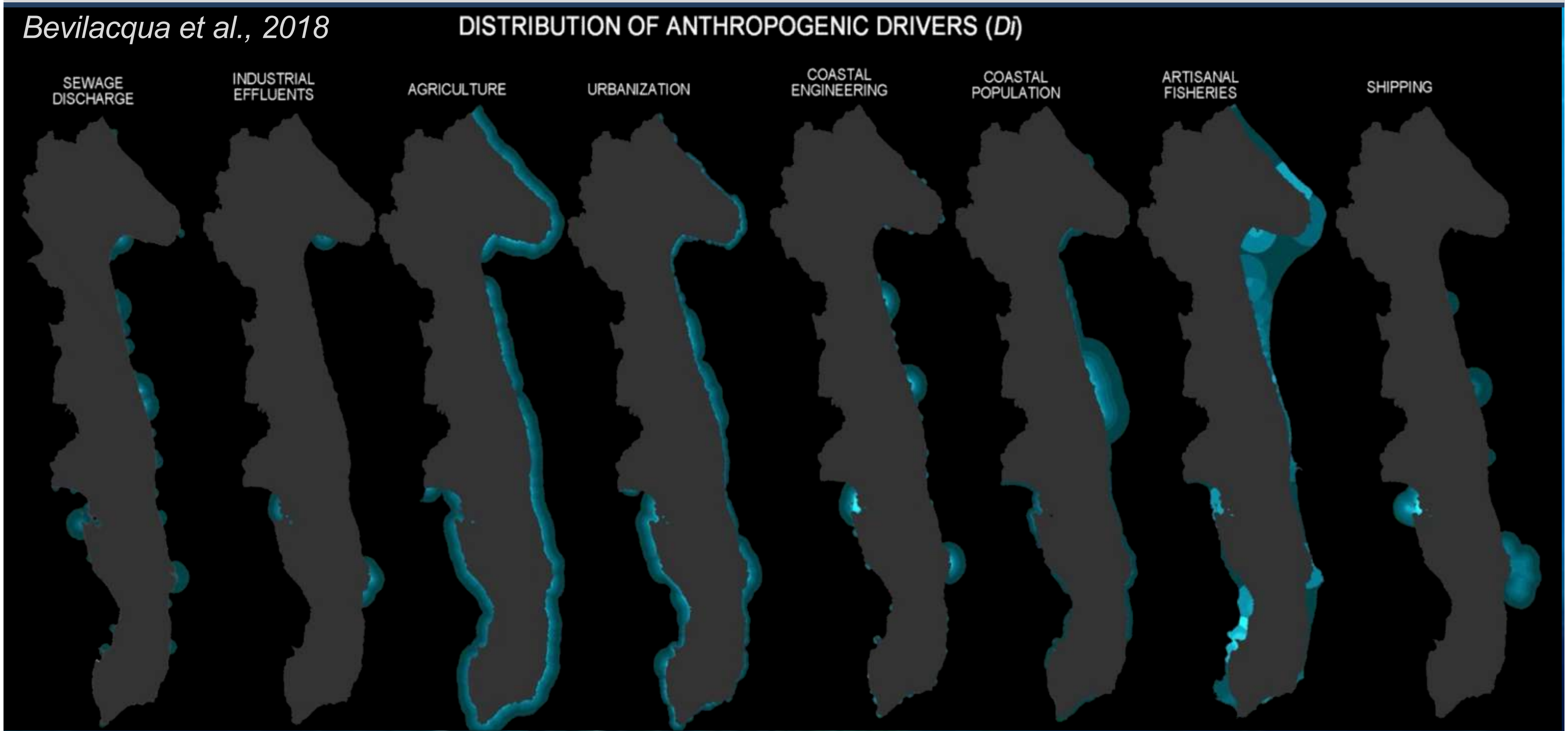
$I_c = 0.1762 \times$ [level of system degradation] $- 0.3381$

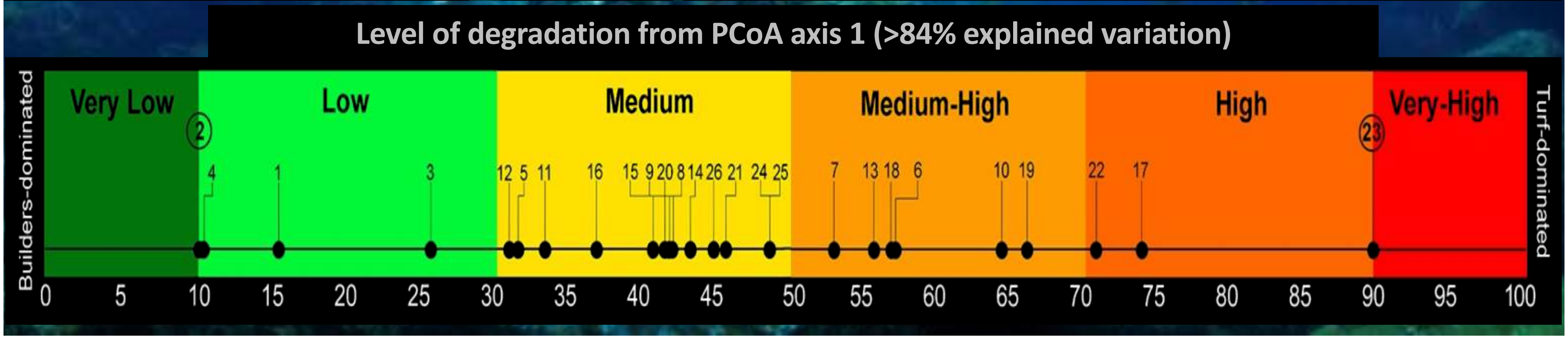
Halpern et al., 2008. Science

<10%	very low	(<1.4)
10-30%	low	(1.45-4.95)
30-50%	medium	(4.95-8.47)
50-70%	medium-high	(8.47-12)
70-90%	high	(12-15.52)
>90%	very high	(>15.52)

A case study on coralligenous outcrops

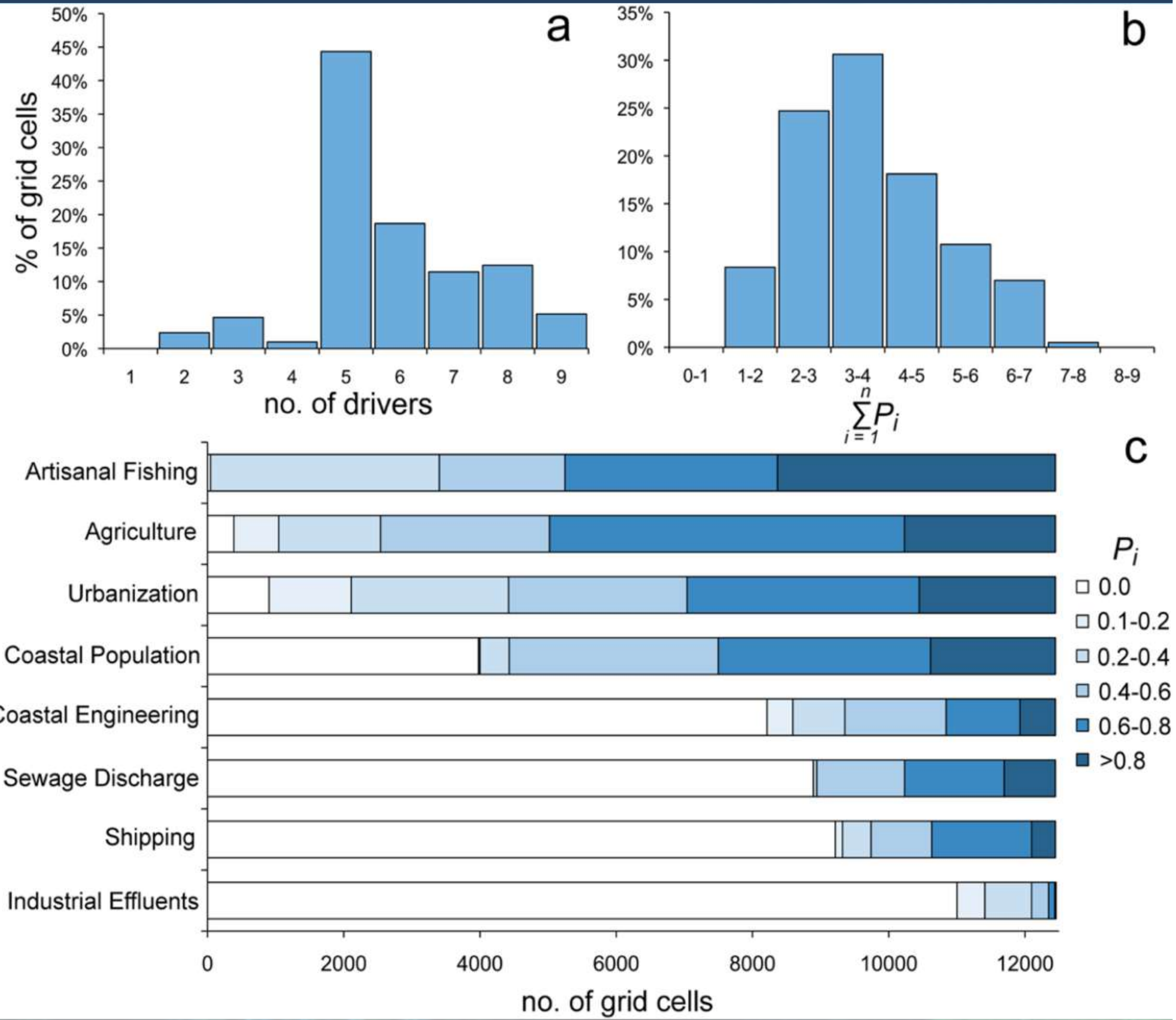
Bevilacqua et al., 2018



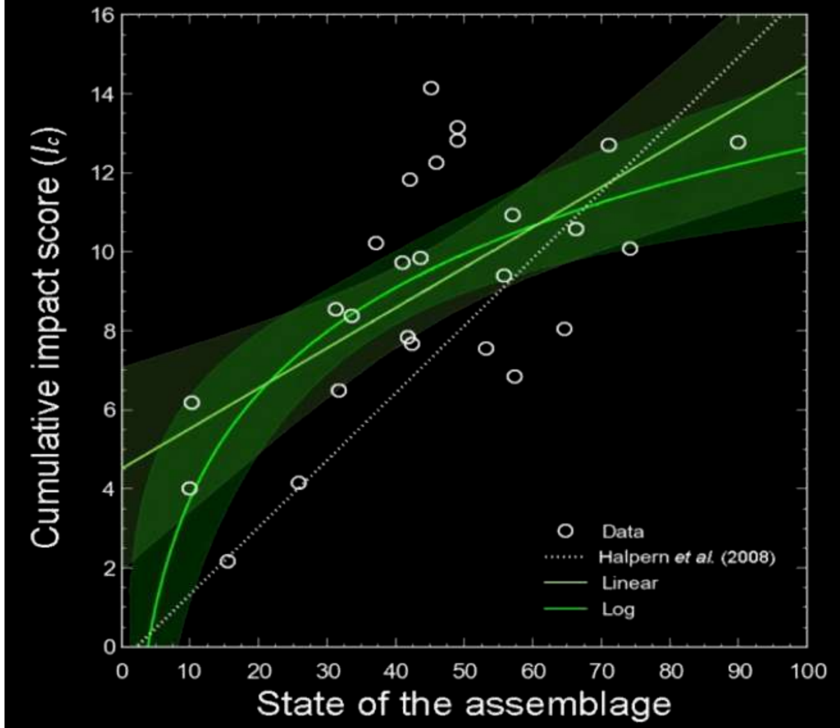


A case study on coralligenous outcrops

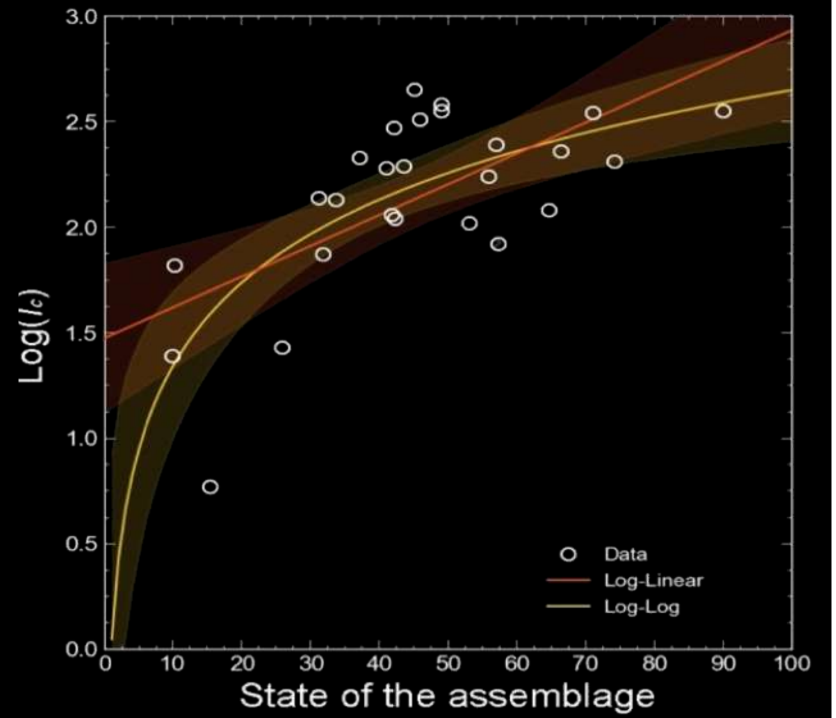
Bevilacqua et al., 2018

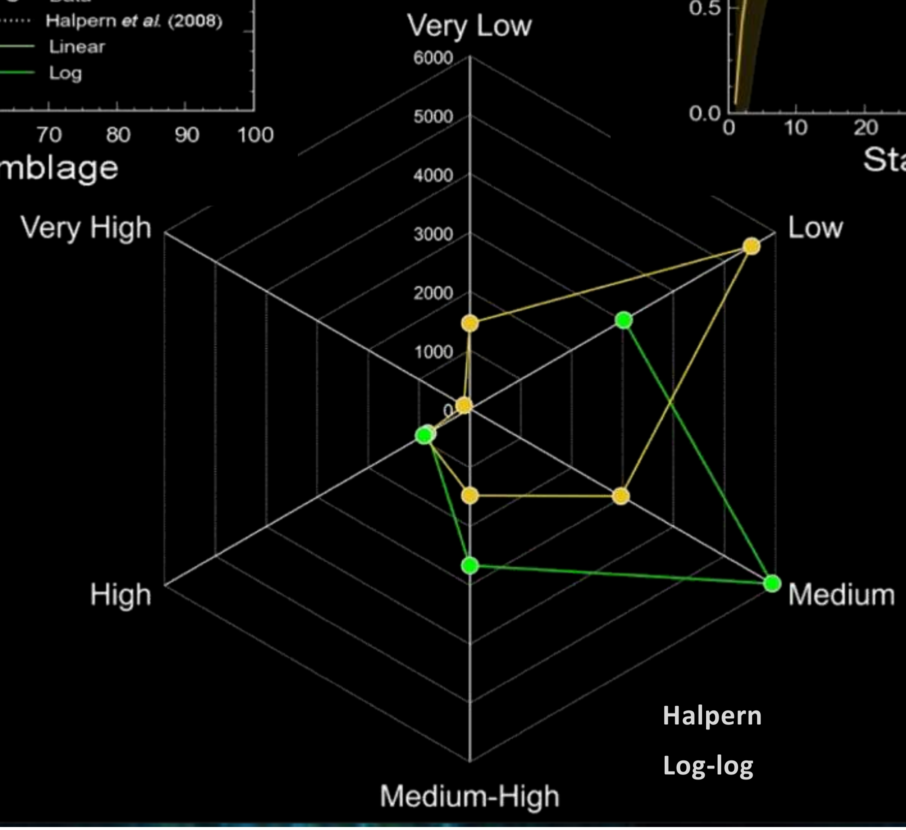


Pressure-response relationship



A log-log model best fitted the pressure-response relationship
Halpern's linear model was unlikely





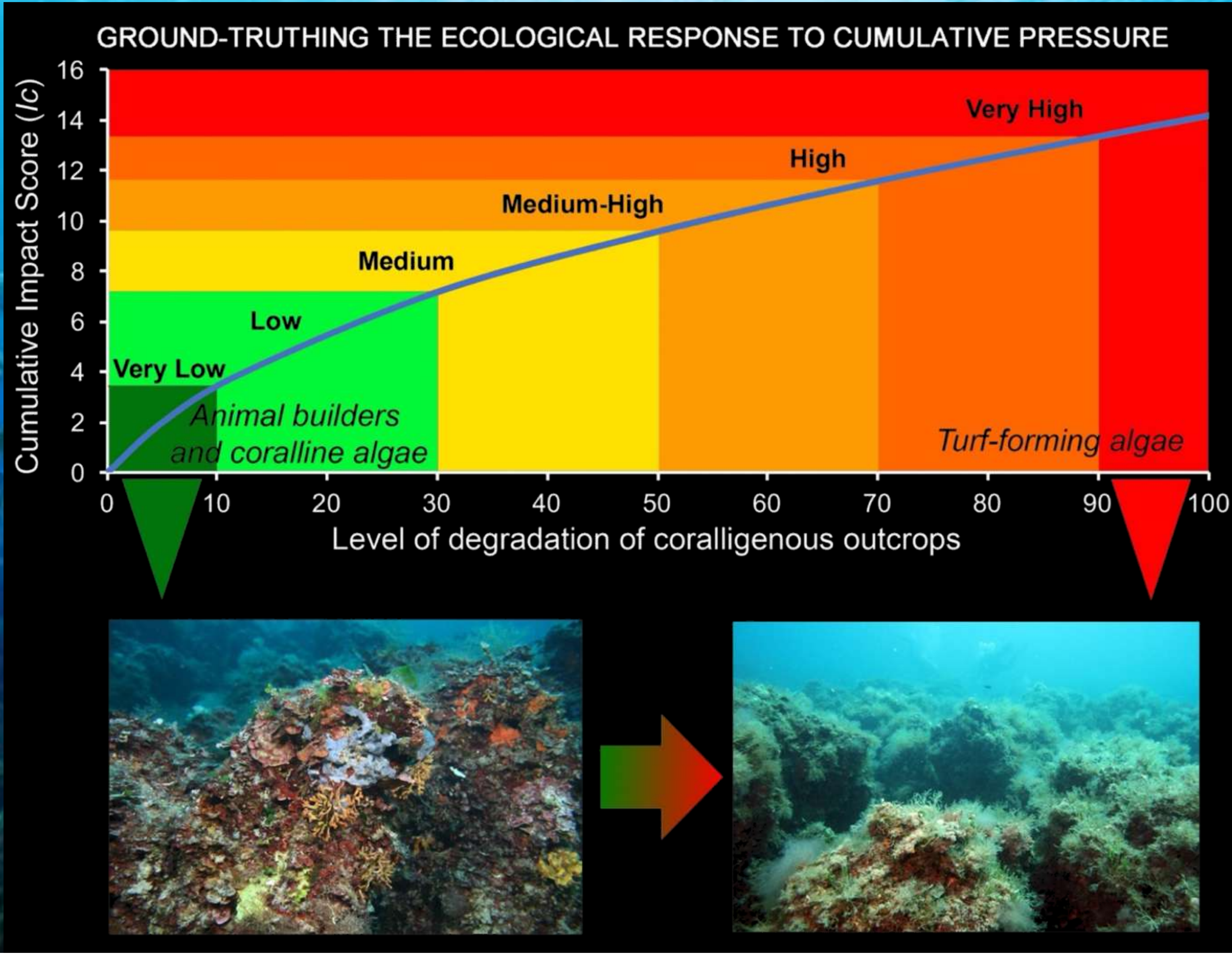
Thresholds from Halpern's linear model

- very low (<1.4)
- low (1.45-4.95)
- medium (4.95-8.47)
- medium-high (8.47-12)
- high (12-15.52)
- very high (>15.52)

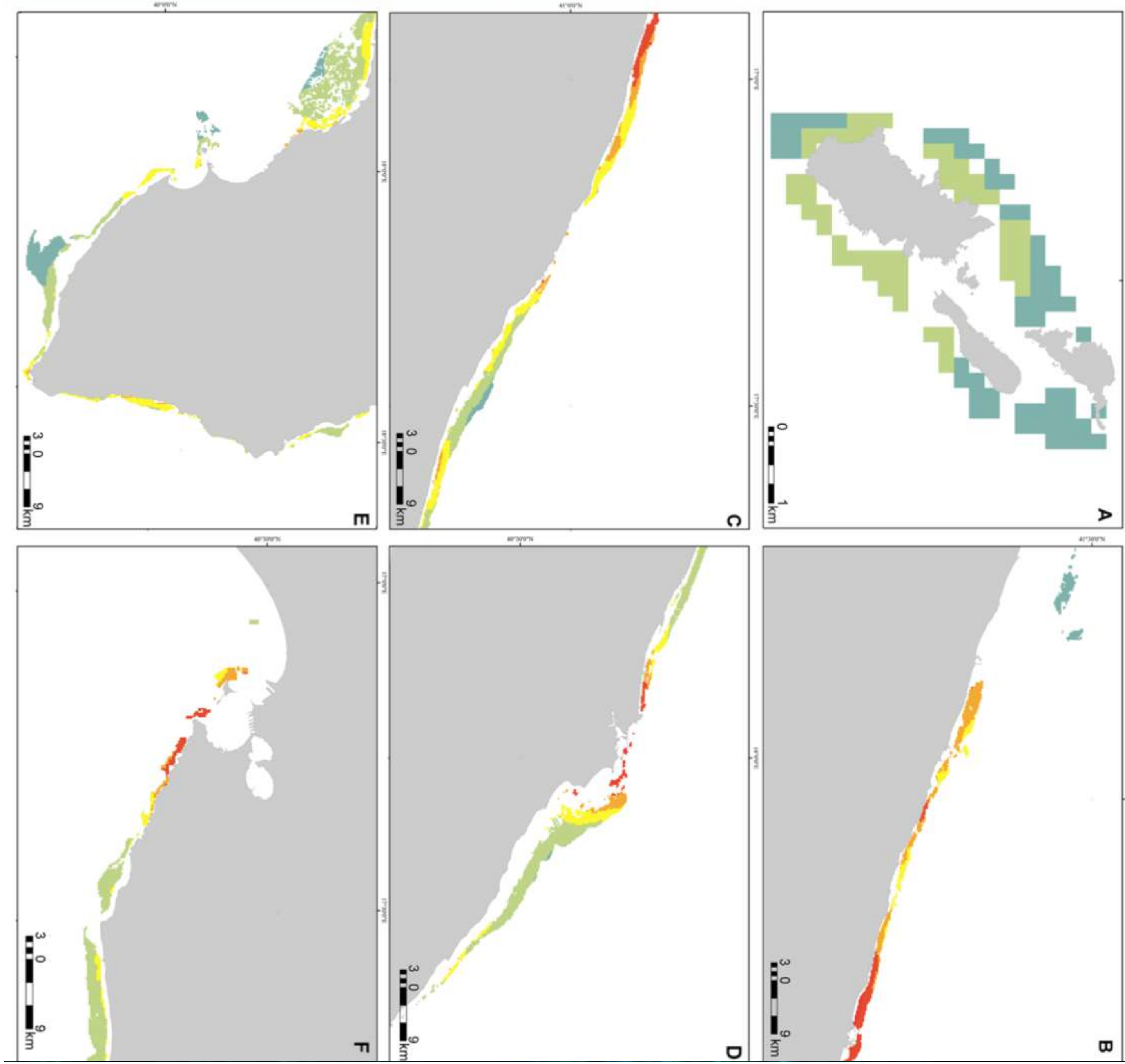
Thresholds from log-log model

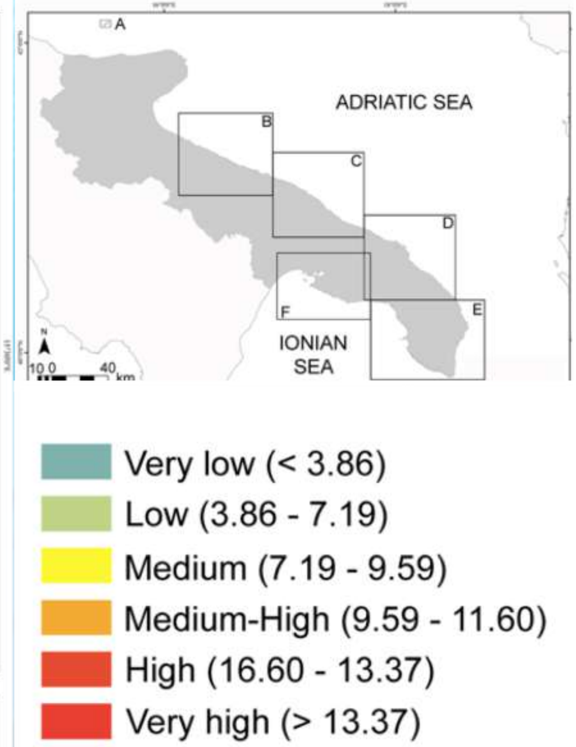
- very low (<3.86)
- low (3.86-7.19)
- medium (7.19-9.59)
- medium-high (9.59-11.6)
- high (11.6-13.37)
- very high (>13.37)

Status of coralligenous



A case study on coralligenous outcrops





Habitat loss and degradation

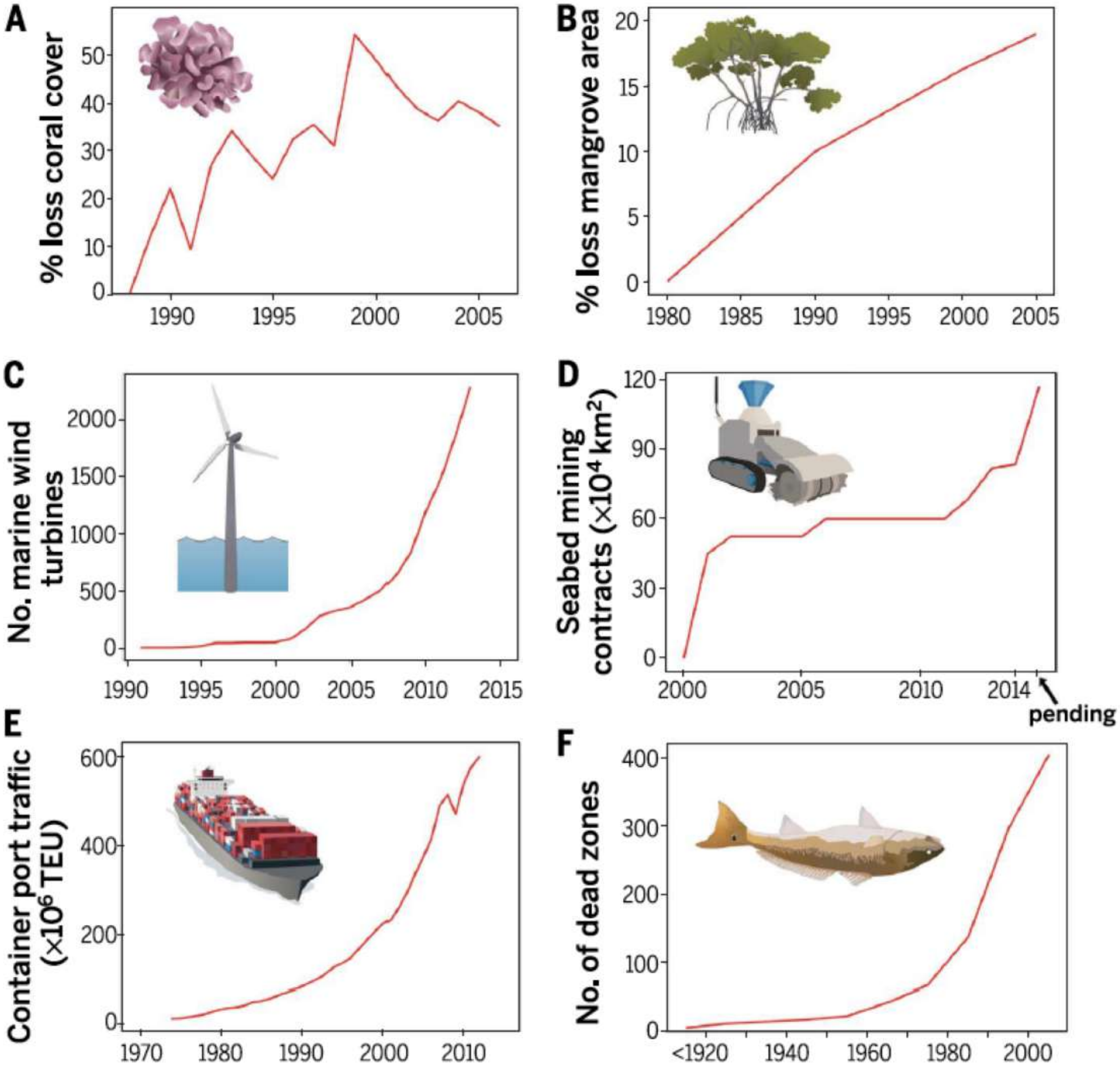
85% of European coasts are degraded. Salt marshes and seagrass experienced about 50% loss over last decades. (Airoldi & Beck 2007)

Characteristic	Value	Main references
Coastline length [a]	325,892 km	Pruett & Cimino 2000
Population within 50 km [b]	200 x 10^6	Stanners & Bourdeau 1995
Degraded coastlines	85 %	EEA 1999a
Years of impact [c]	2500 yr	Rippon 2006, Lotze et al. 2006
Artificial coastlines	22,000 km^2	EEA 2005
Defended / eroding coastlines	7600 / 20,000 km	EC 2004
Increase in N / P loads 1940s-1980s	2-4 / 4-8 fold	Nehring 1992, EEA 2001, Karlson et al. 2002
No. invasive species	450-600	Reise et al. 2006
MPAs (No. / total surface)	1129/ 236,000 km^2	UNEP/WCMC 2006, MPA Global 2006
Present coastal wetlands / loss since 1900s	51,910 km^2 / >65%	Nivet & Frazier 2004, EEA 2006a
Present seagrasses / historical losses [d]	7290 km^2 / > 65%	Duarte 2002, Green & Short 2003
Present wild native oyster reefs / historical losses [d]	Scarce / > 90%	Mackenzie et al. 1997
Present macroalgal beds / historical losses [d]	Unknown/2-4m in depth	Vogt & Schramm 1991, Eriksson 2002

[a] Including islands
[b] In the 1990s
[c] Since beginning of modification and transformation of coastal landscapes
[d] Estimate based on reviewed local to regional sources.

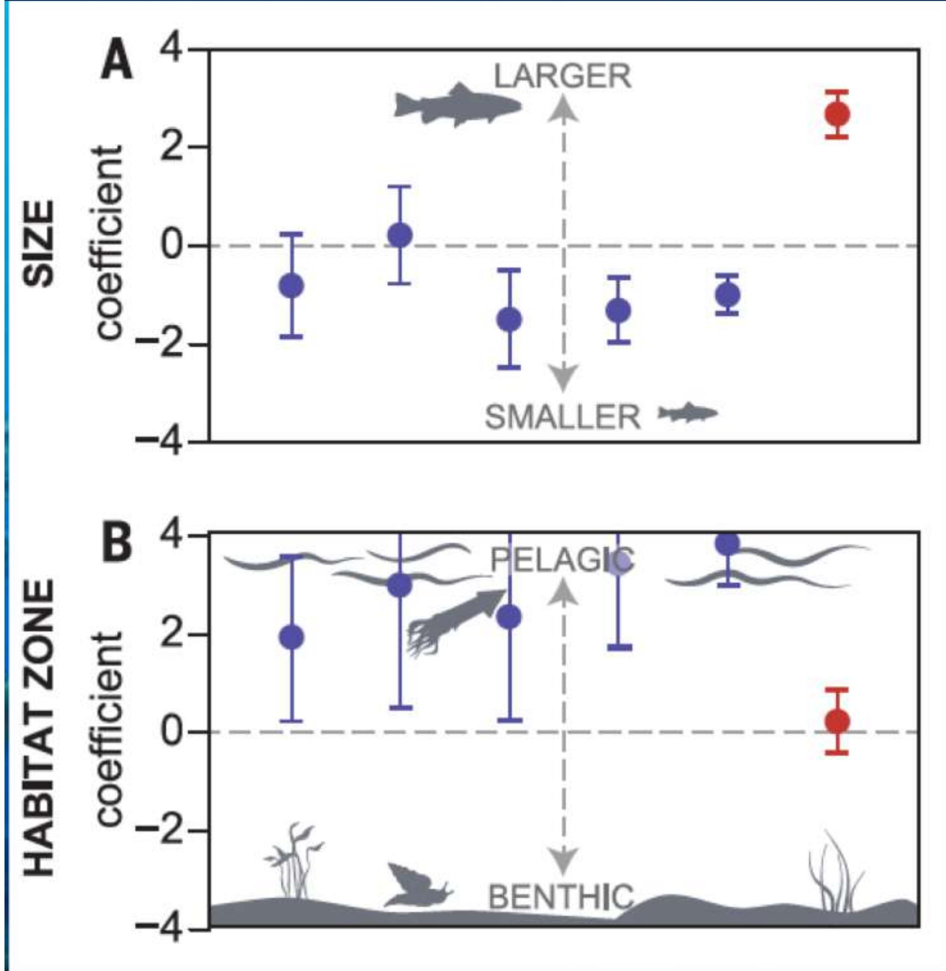


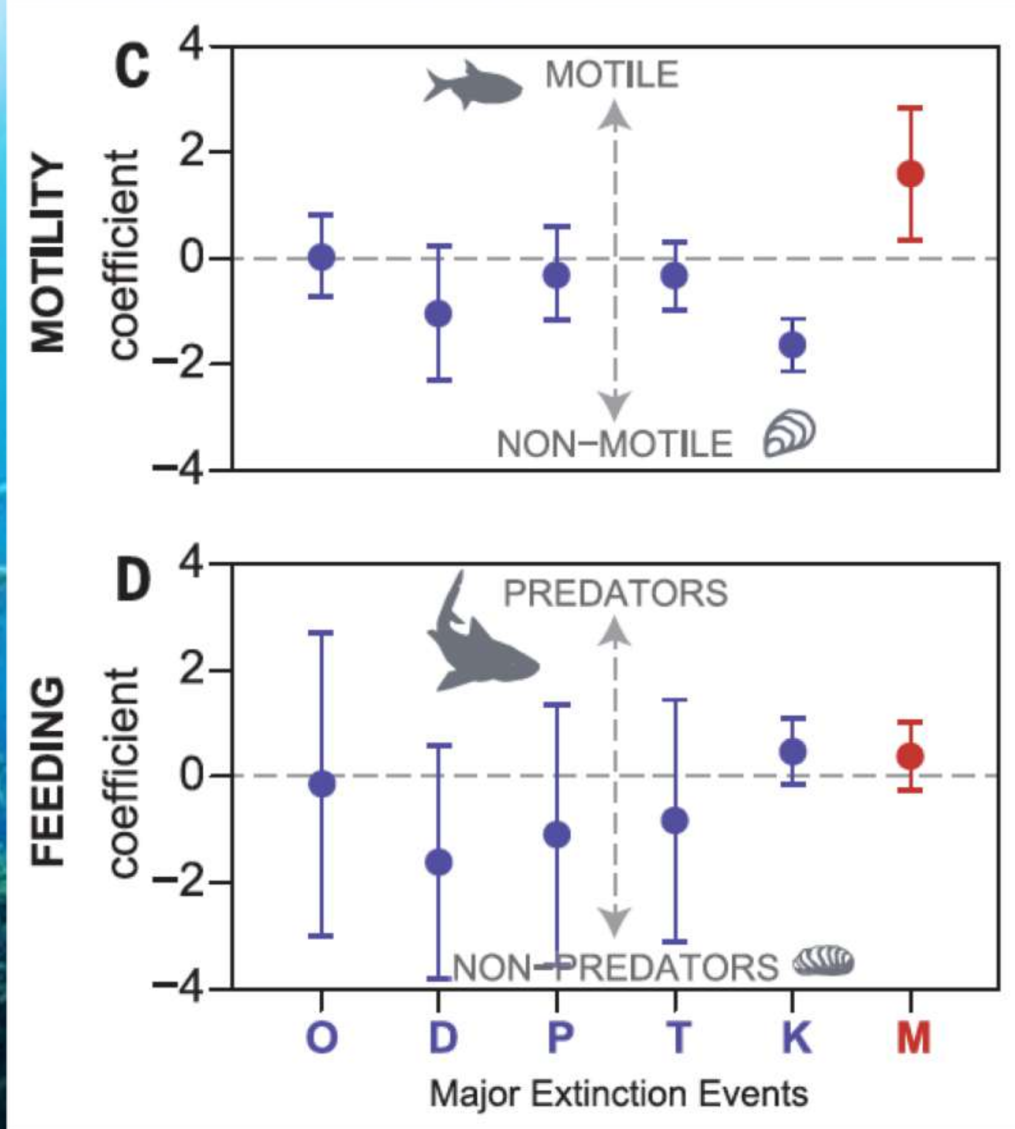

Habitat loss or degradation



McCauley et al. 2015

Modern extinction risk

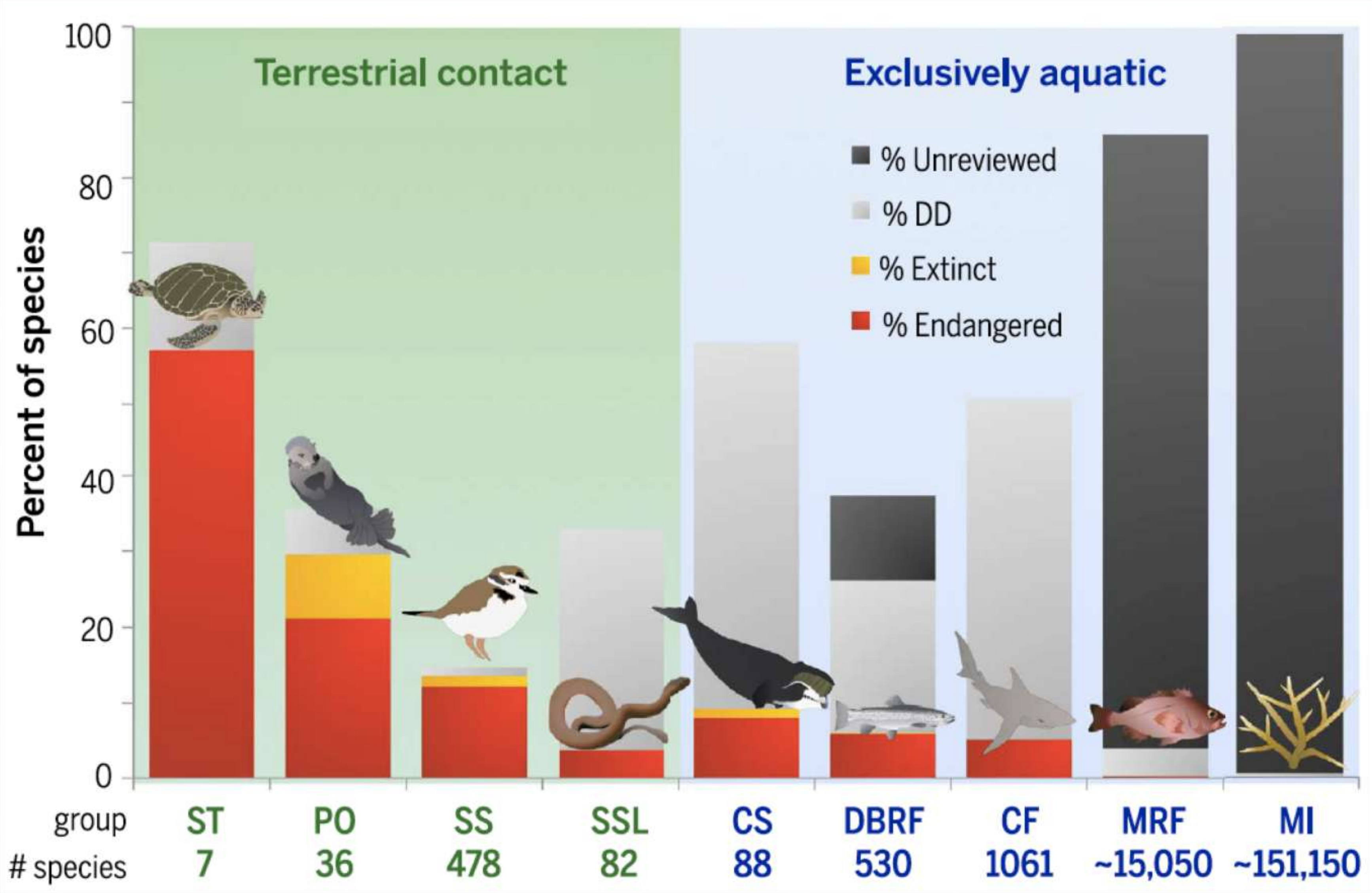




Payne et al. 2016

Ecological selectivity of extinction threat in the modern oceans is unlike any previous mass extinction. Previous mass extinction events (blue symbols) preferentially eliminated pelagic genera and, sometimes, smaller genera, whereas the modern extinction threat (red symbols) is strongly associated with larger body size and moderately associated with motility

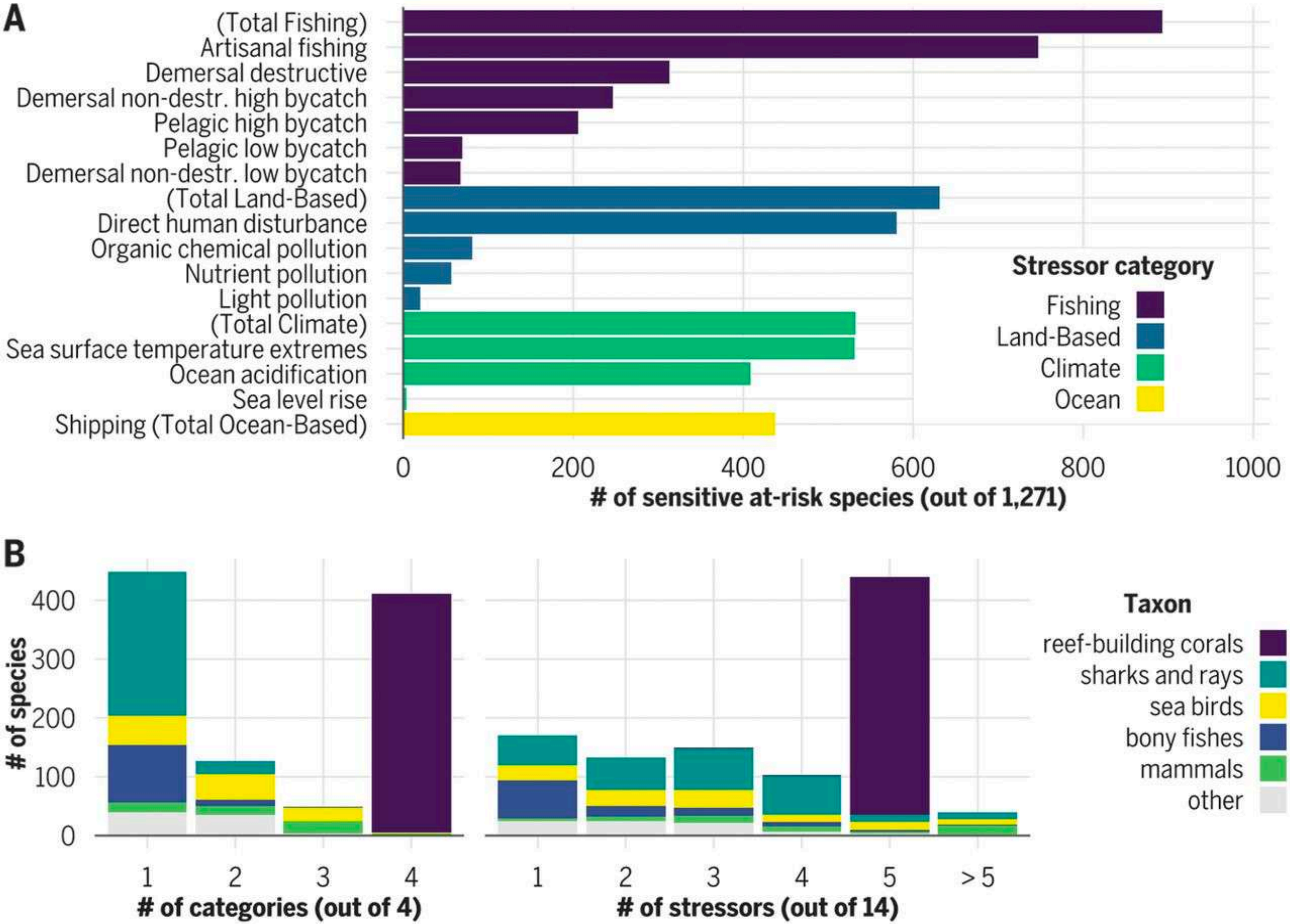
Modern extinction risk



McCauley et al. 2015

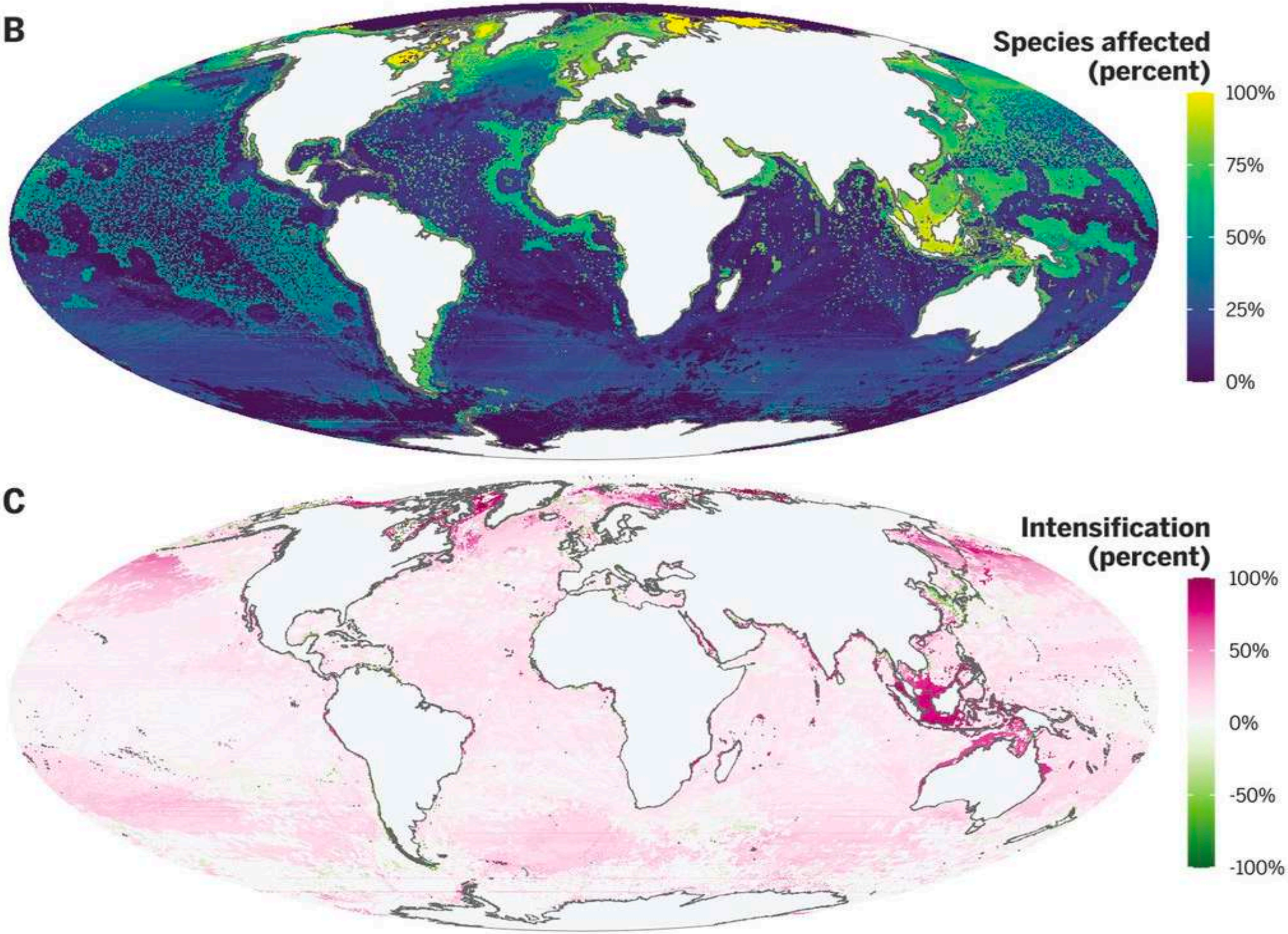
Threat from defaunation is portrayed for different groups of marine fauna as chronicled by the IUCN Red List. Threat categories include "extinct" (orange), "endangered" (red; IUCN categories "critically endangered" + "endangered"), "data deficient" (light gray), and "unreviewed" (dark gray).

Modern extinction risk



O'Hara et al. 2021

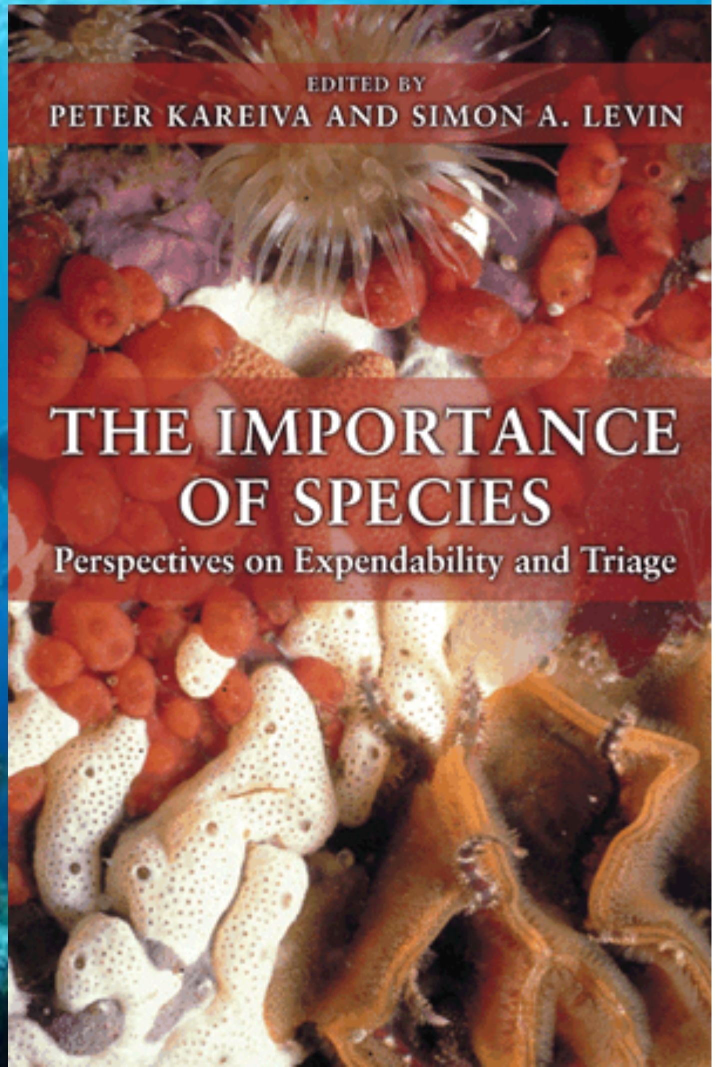
Modern extinction risk



O'Hara et al. 2021

Consequences of this loss?

- What are the consequences of biodiversity loss (and invasions) at local and regional scale on the functioning of ecosystems?
- Although we know (more or less) the effects of productivity, disturbance, nutrients on diversity, the inverse relationships are still debated.
- The risk of ecosystem collapse fuelled an intense research on the potential effects of biodiversity loss



Are there ‘expendable species’?

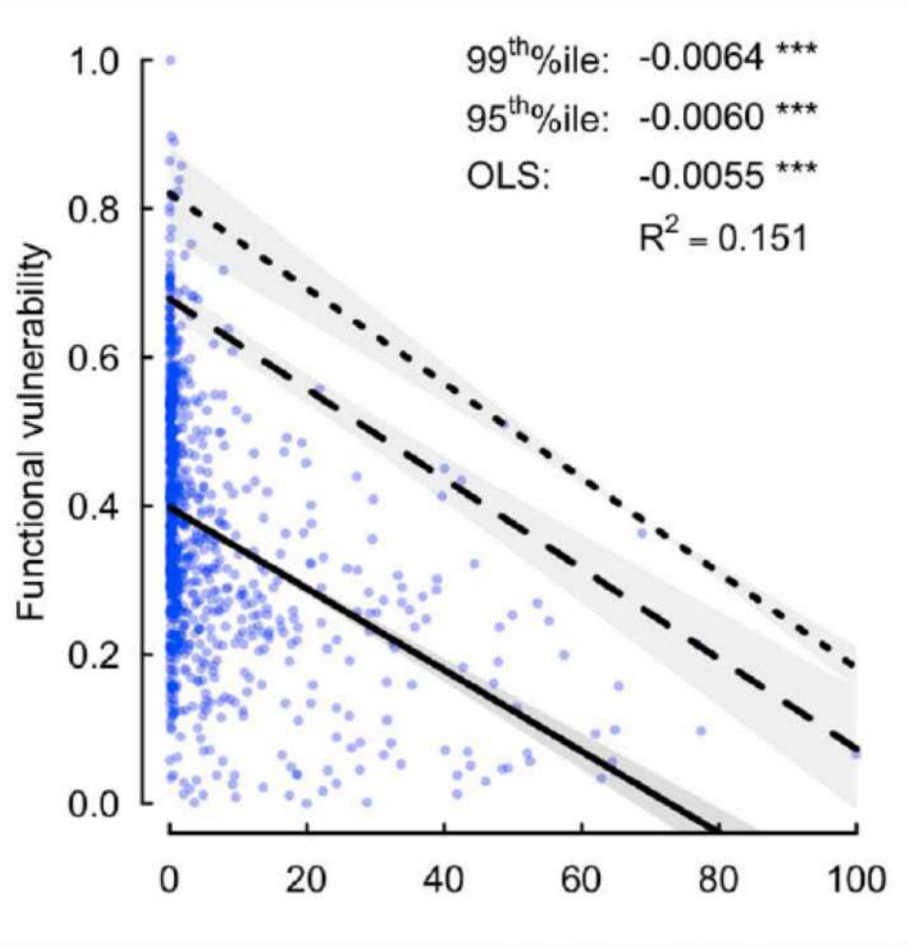
By correlating richness and diversity with basic ecosystem processes, these investigations lend support to the hypothesis that **species diversity significantly influences ecosystem functioning** and, in turn, provides support for the conservation of biodiversity.

The effect of biodiversity, however, **could vary** depending on the the response variable (function) and the identity of species, although there are evidence that multifunctionality is enhanced at higher level of diversity.

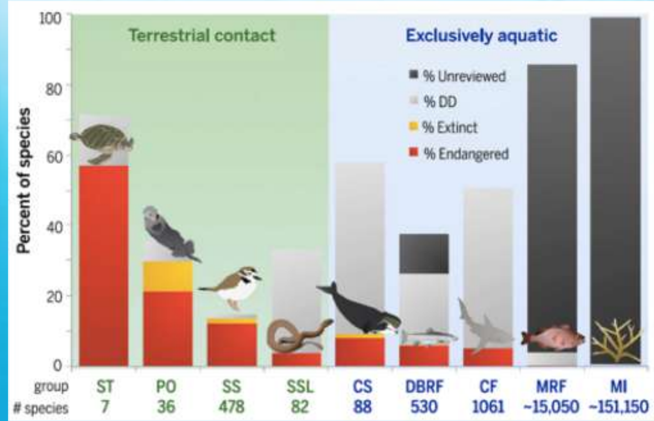
Nonetheless, the majority of these investigations demonstrated that conservation of a relatively small number of generally dominant species is sufficient to maintain most processes, and there is remarkably little evidence to support the idea that less common species, those likely of highest conservation concern, are important in the maintenance of ecosystem functioning.

Loss of particular species leads to drastic changes, whereas loss of others have little or no effects, especially if belonging to redundant functional groups

Are there ‘expendable’ species’



Functional vulnerability of coral fish species. Rarest species account for more vulnerable functional traits (i.e. traits poorly represented in other species (Mouilliot et al. 2013))

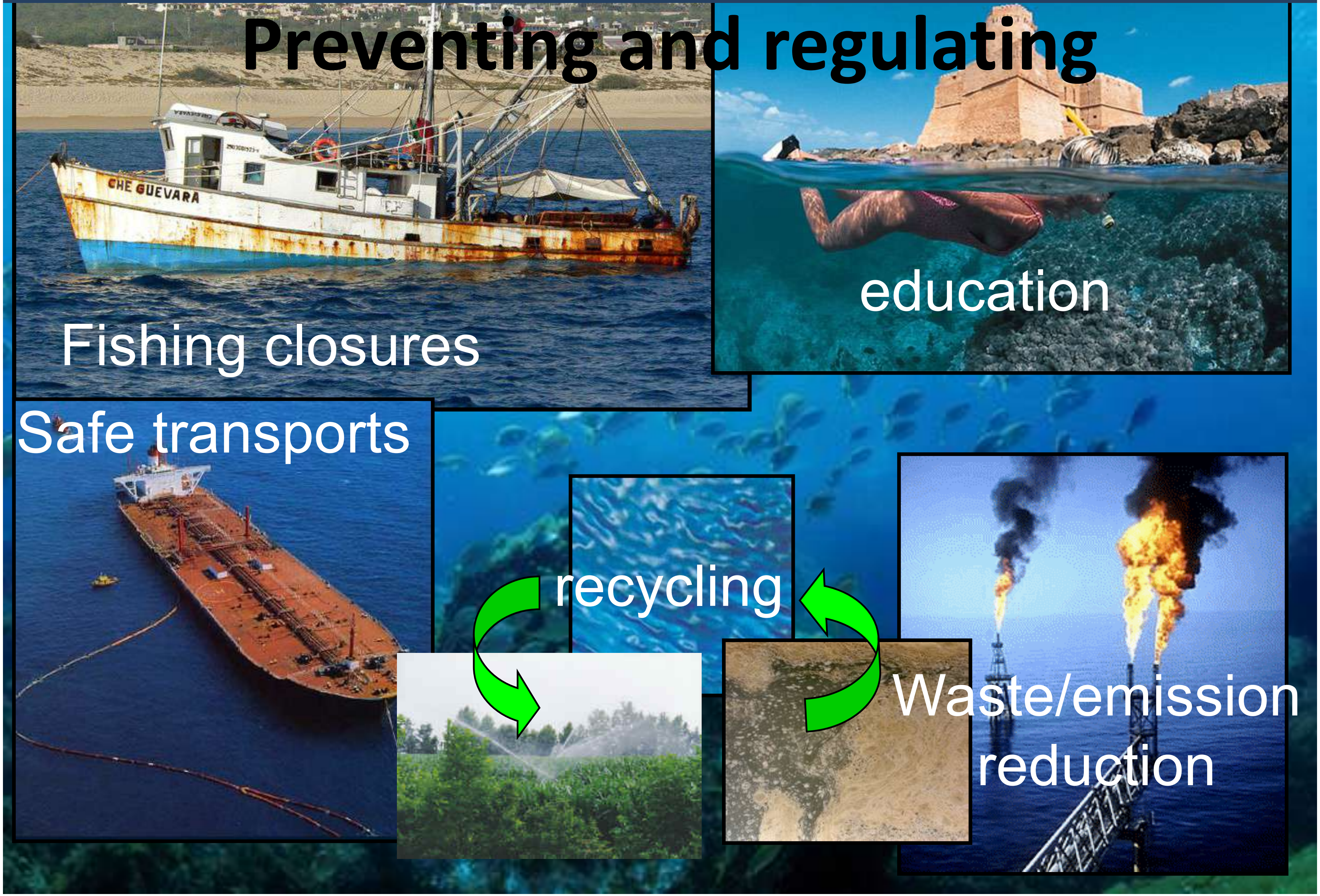


A given species which is expendable now, could be considered expendable in the future?

Current species loss could cause changes, but it is difficult that an empty niche will stay empty for long time, but time is at evolutionary scale, so is truly important for life on Earth or for us?

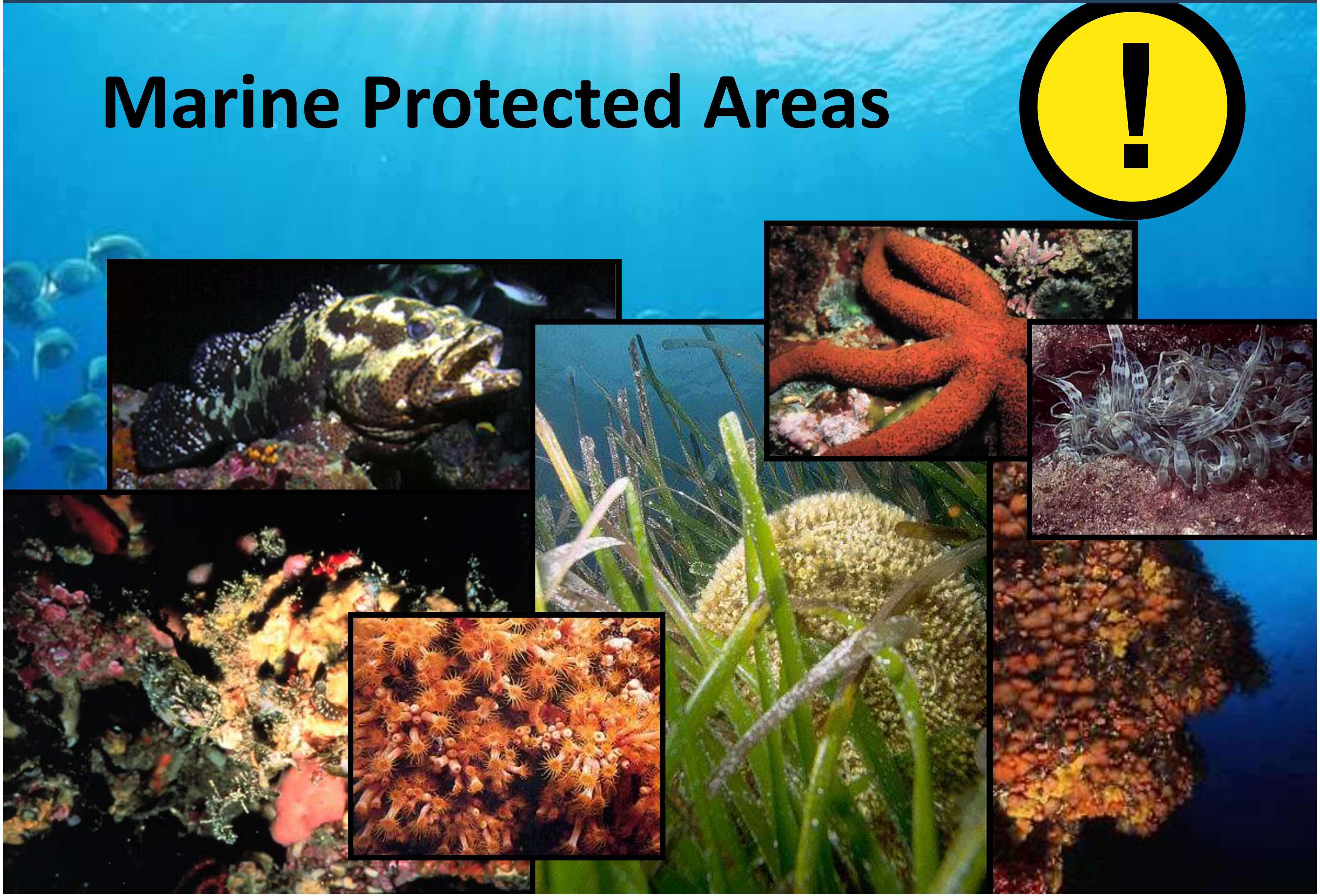
What does we loose when a species is lost? Could we considered expendable or not what we don’t know yet?

Mitigation strategies



Mitigation strategies

Marine Protected Areas



Monitoring

Environmental and biological monitoring is at the core of applied ecological research, providing invaluable insights on patterns and processes underlying the dynamics of ecosystems, and producing sets of data that are instrumental for progresses in theoretical ecology. Monitoring is also essential for environmental policy, since systematic collections of data are necessary to inform the adaptive management of environmental issues whether concerning the assessment and mitigation of human impacts, the effectiveness of conservation strategies, the success of restoration, or the surveillance of the ecological quality status of ecosystems.