

**University of Trieste: GLOBAL CHANGE ECOLOGY a.a.
2018-2019**

BIODIVERSITY AND ECOSYSTEM FUNCTIONING
Dr. Stanislao Bevilacqua (sbevilacqua@units.it)

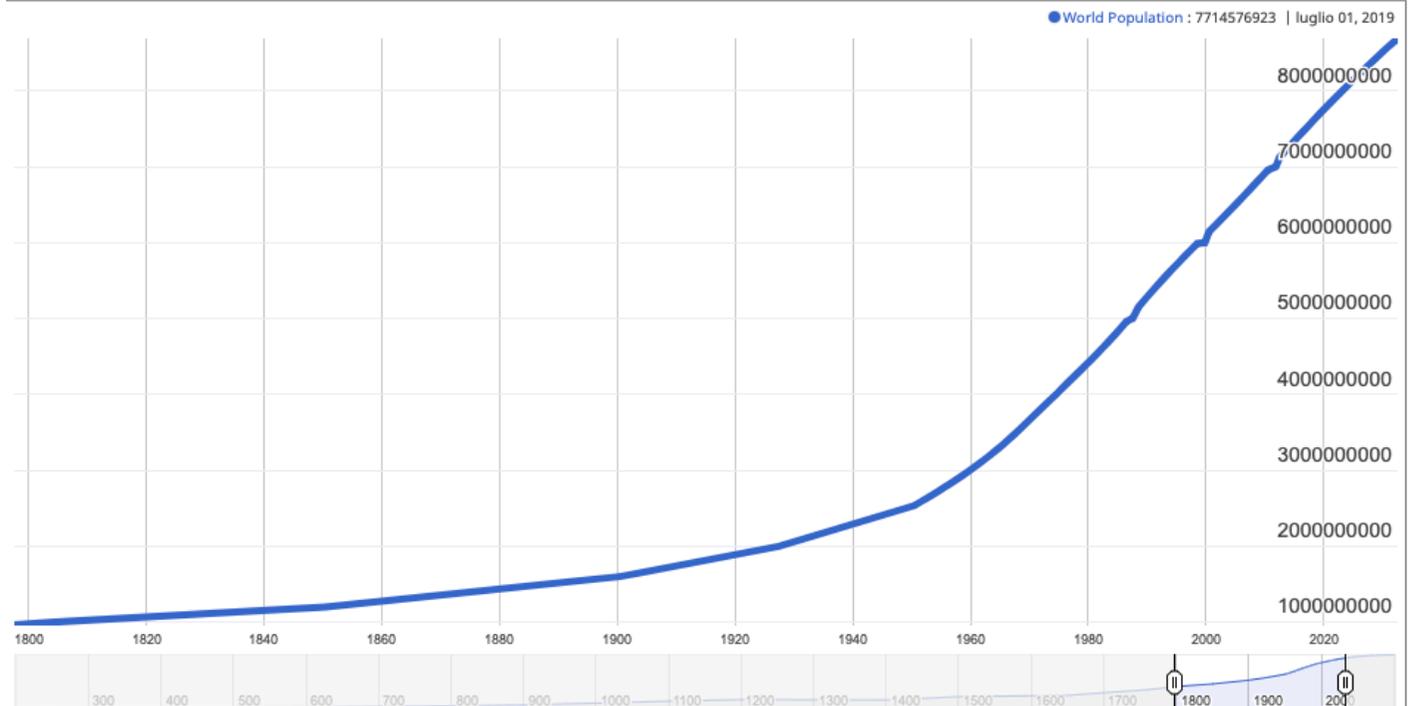
**Human threats to marine
ecosystems**



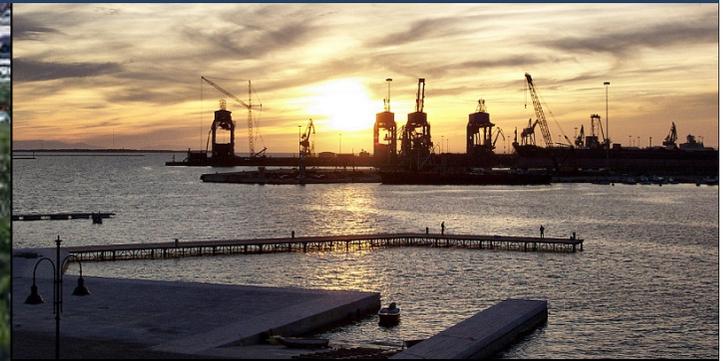
Population growth and human activities



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



Human activities and disturbance



Drivers of pressure



Chemical



Physical



Biological

Activity



Drivers



Pressure



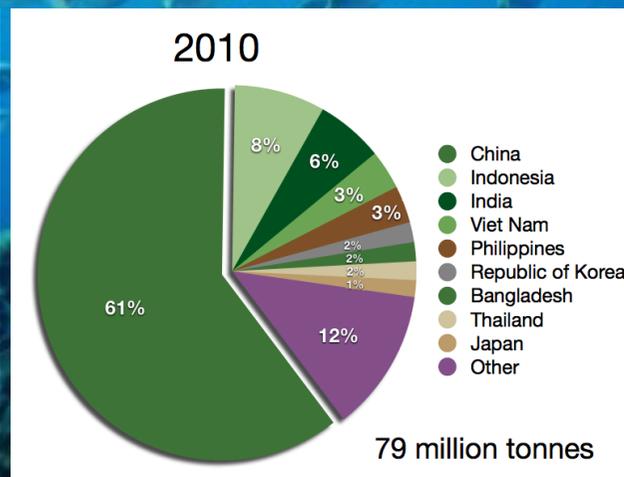
Impact

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

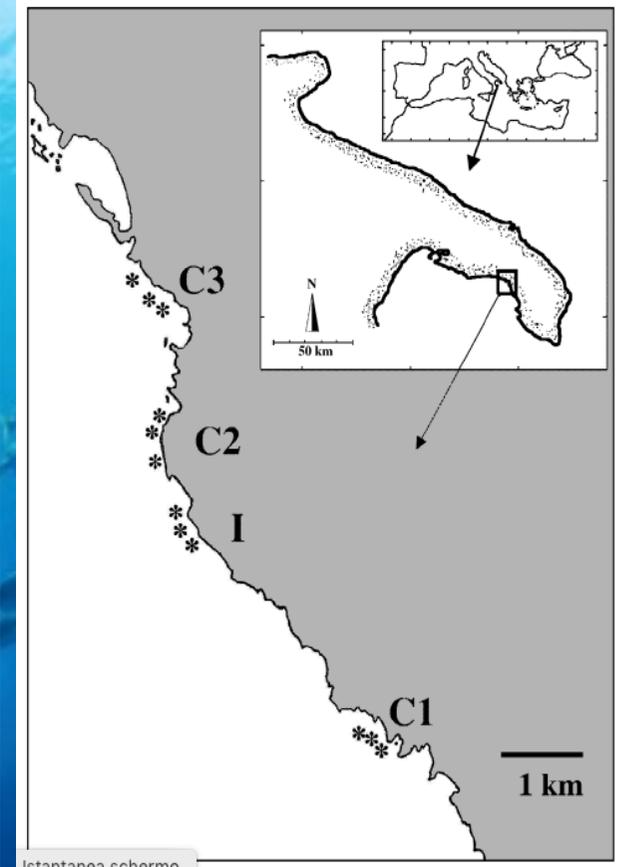
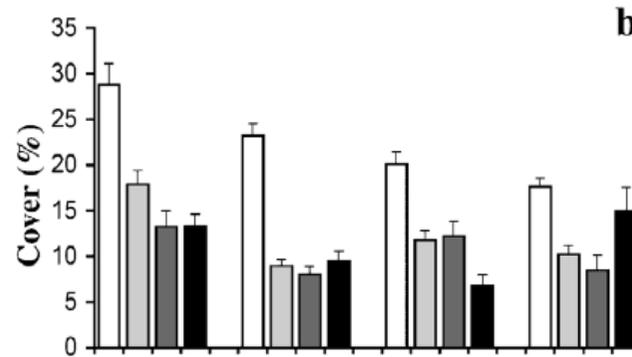
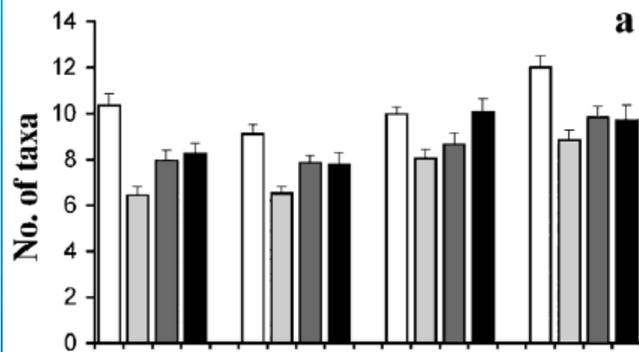
Organic-inorganic compounds



Sewage
outfalls
Aquaculture

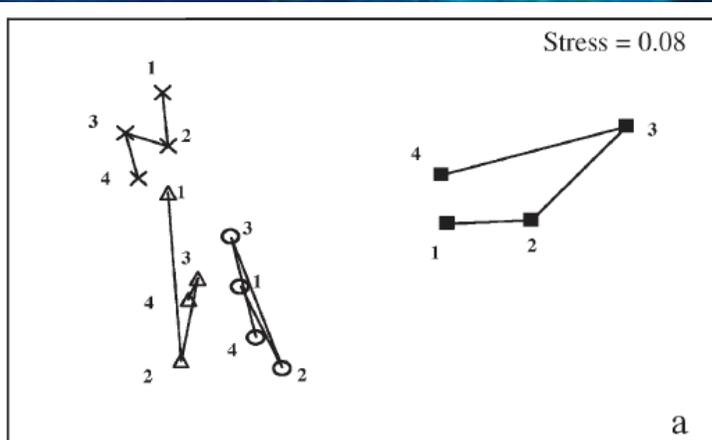
Direct introduction of nutrients and other substances (soap, hydrocarbons, etc.) in the marine system. Different effects, depending on the substances. Generally, change in community structure around the outfall (depending on the sewage flux) are frequent with increasing abundance of ephemeral opportunistic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

Local effects of sewage discharge



Source of variation	df	Time 1			Time 2			Time 3			Time 4			MS _{denom}
		MS	F	p										
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			

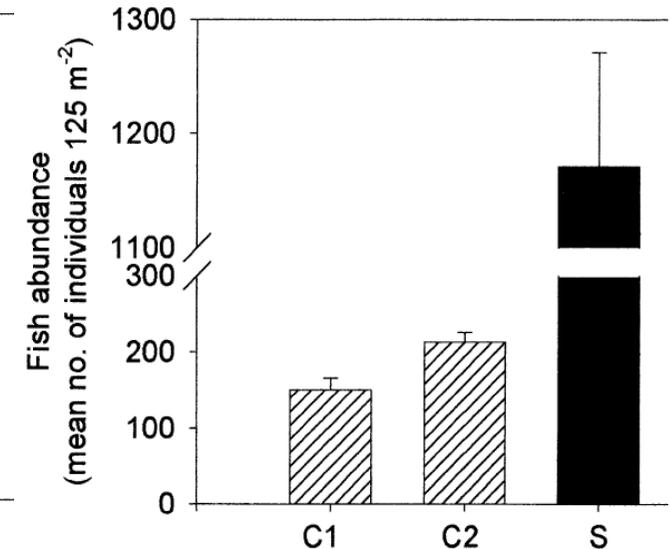
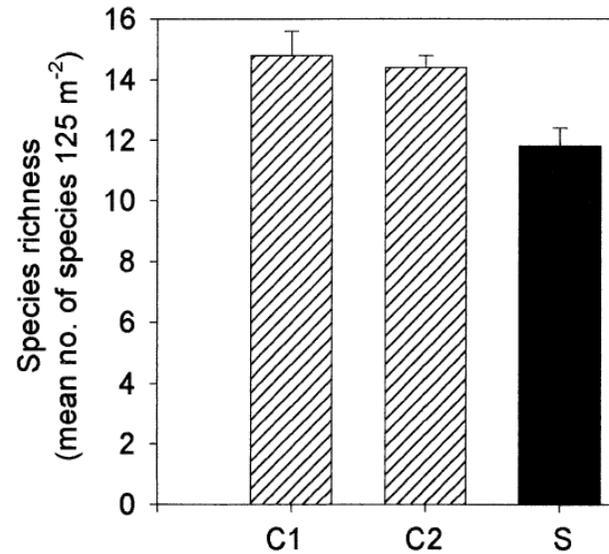
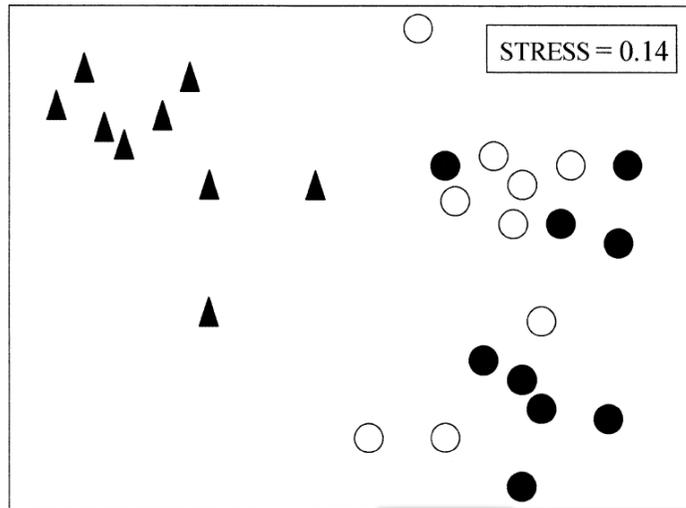
	Time 1			Time 2			Time 3			Time 4		
	C1	C2	C3									
C2	0.586			0.634			0.639			0.554		
C3	0.686	0.642		0.736	0.670		0.661	0.708		0.659	0.658	
I	0.740	0.740	0.731	0.739	0.714	0.793	0.825	0.856	0.871	0.692	0.740	0.808



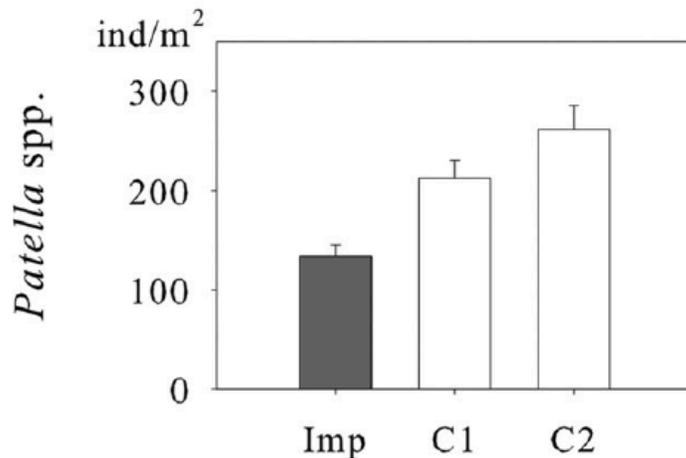
No significant effects on total cover and diversity of benthic assemblages. However, significant changes in assemblage structure, so composition and relative abundances were altered. Increased abundance of ephemeral algal species, with opportunistic algae present only at the impacted location.

Local effects of sewage discharge

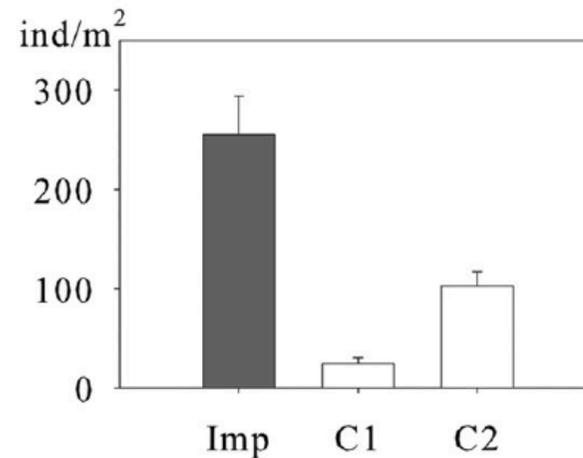
P. Guidetti et al. / Marine Environmental Research 53 (2002) 77-94



Atlantic shores



Mediterranean shores



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.

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
predator control systems	Behavioral changes in coastal birds and marine mammals (e.g., avoidance)	poor	Vertebrates	local-meso	-	unidentified
	Direct mortality	poor	Vertebrates	local-meso	-	unidentified
fish escapement	Behavioral changes of wild fauna	medium	Vertebrates	local-meso	-	unidentified
	Disease transmission to other species	poor	various (probably fish)	meso-large	-	unidentified
release of uneaten food	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
	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
release of nutrients	Fragmentation of benthic habitat	poor	various	local-meso	-	slow
	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
antibiotics	Increase in harmful algal blooms	poor	various	local-meso	-	rapid
	Decline of seagrass meadows	poor-medium	marine plants & various indirectly	local-meso	-	slow
	Tainting of wild species	poor	various	local	-	rapid
	Changes in benthic bacterial community	poor	microbes	local	-	unidentified
pesticides	Resistant microbial strains	poor	various indirectly	unknown	-	unidentified
	Direct mortality and sublethal effects	poor	invertebrates	local	-	unidentified
disinfectants and antifoulants	Tainting of wild species	poor	various	local	-	unidentified
	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

Eutrophication

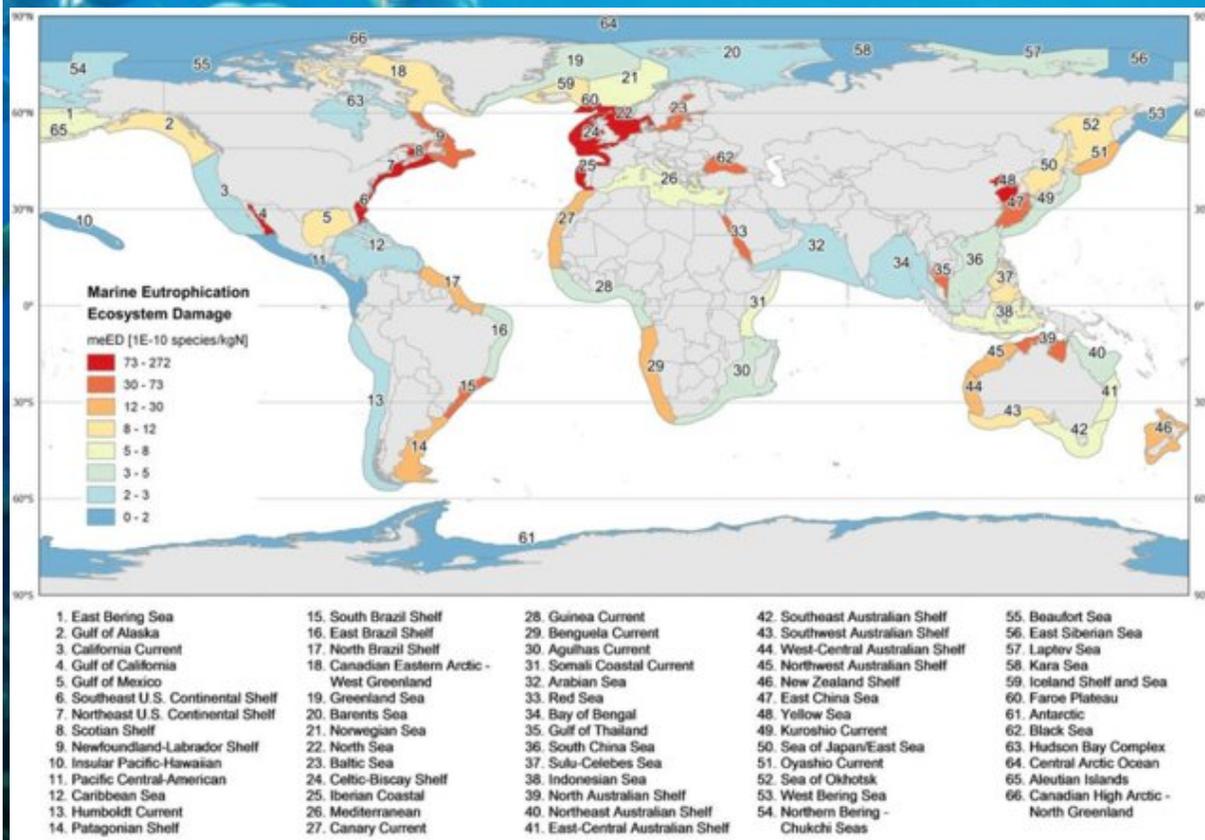
Abnormal nutrient/organic supply



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

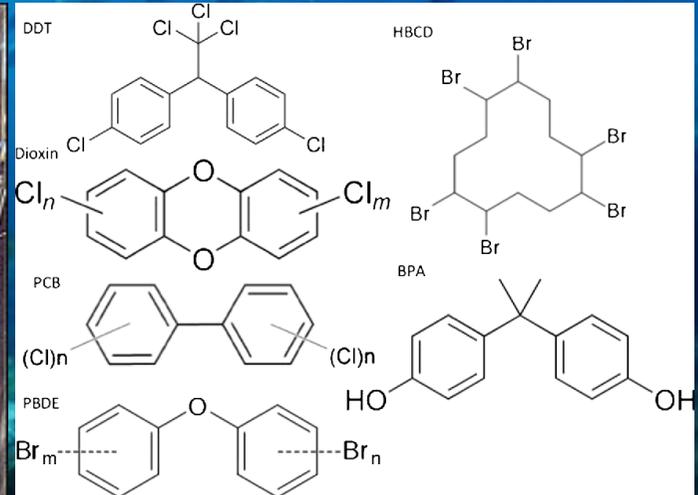
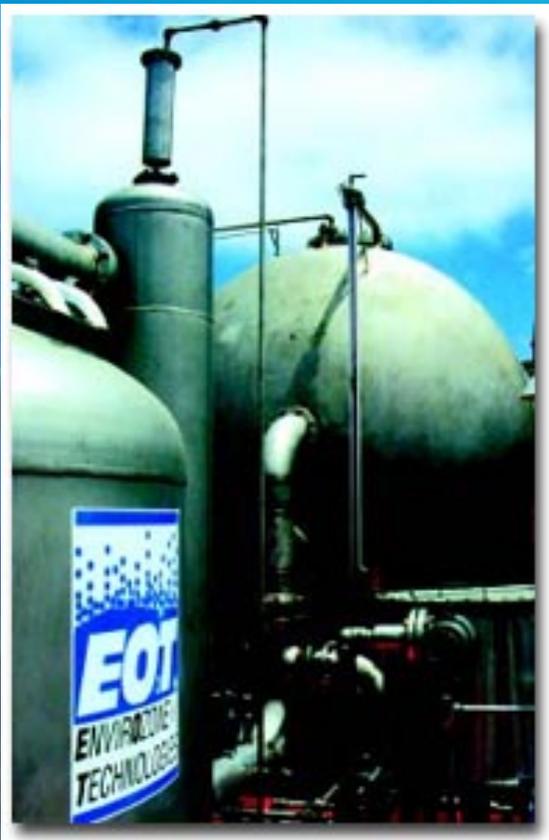
Synthetic compounds

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

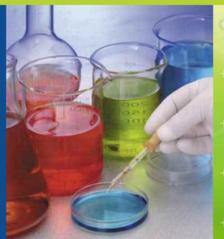


Pollutants

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.


**LISTA DELLE SOSTANZE VIETATE
(O IN RESTRIZIONE)**

100 pages of list for 1082 substances...

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

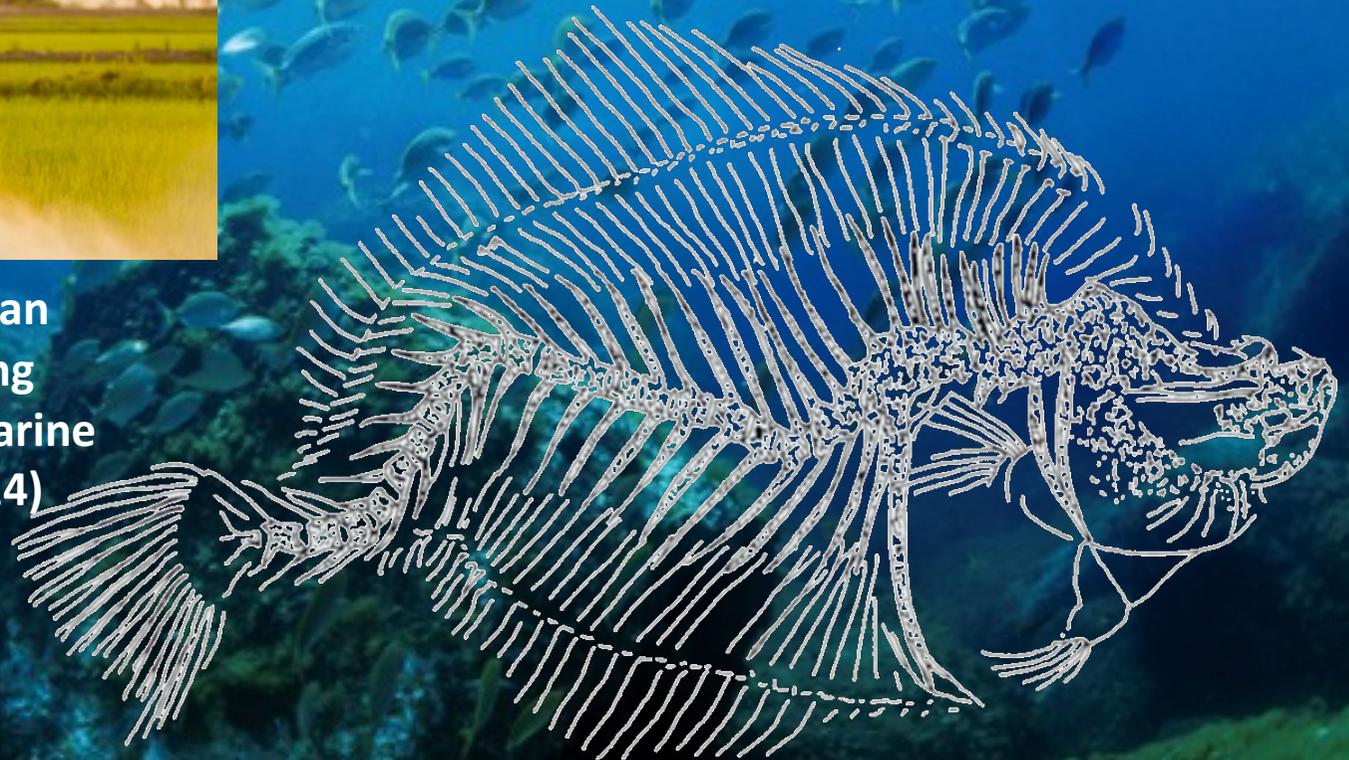
(1) Glyphosate-compounds are the most heavily applied herbicides in the world and usage continues to rise; (2) Worldwide, GBHs often contaminate drinking water sources, precipitation, and air, especially in agricultural regions. (Myers et al. 2016).

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 thought, suggesting potential dispersion in the marine systems (Mercurio et al. 2014)

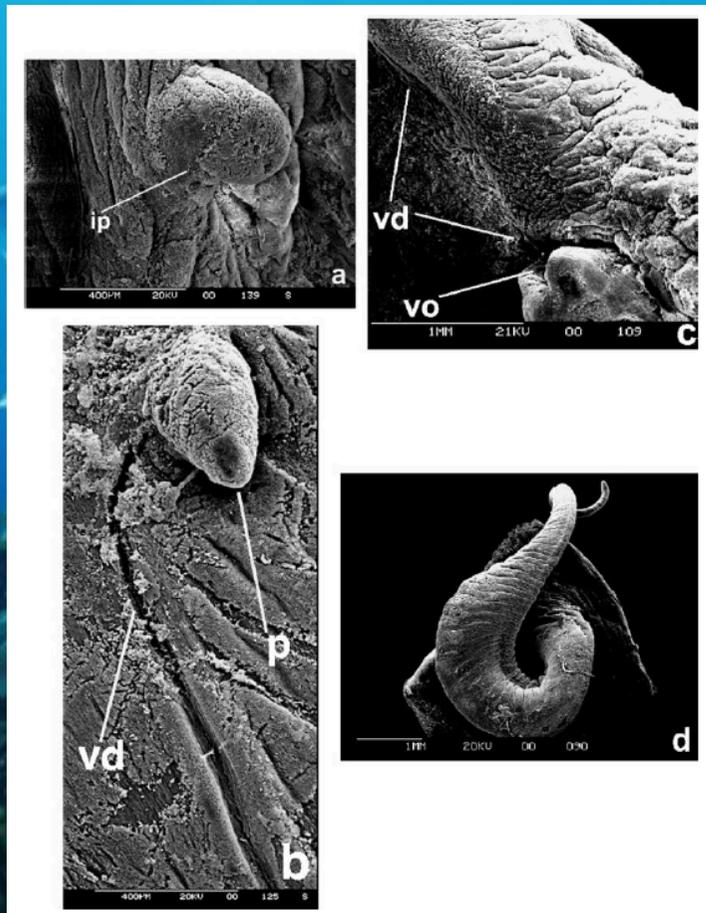
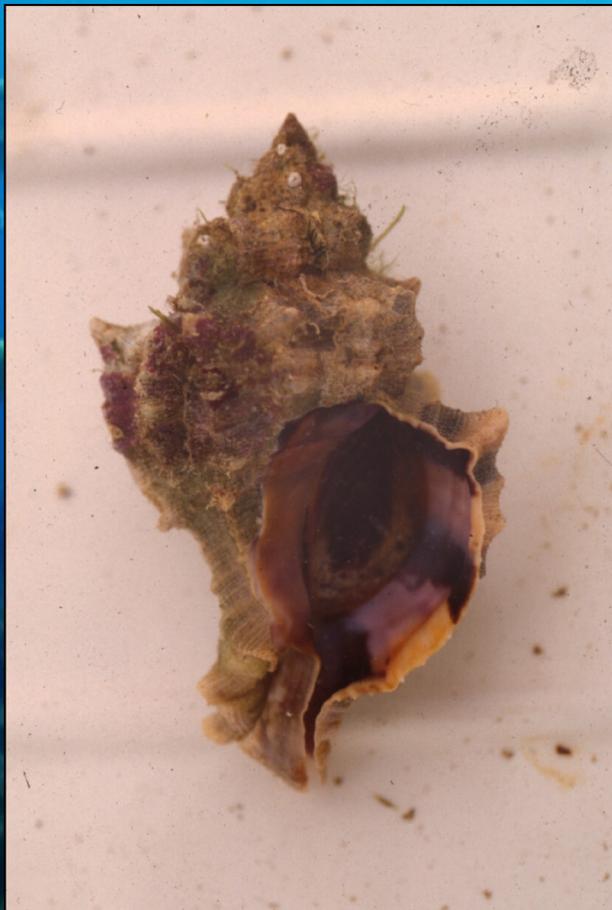
Toxaphene: skeletal deformity on fish Bengtsson, 1979



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 Maranhão ·



Mayana Fontes · A.S.S. Kamimura · [Show all 12 authors](#) ·



Camilo Dias Seabra Pereira

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 CDS¹, Maranhão LA², Cortez FS³, Pusceddu FH³, Santos AR³, Ribeiro DA⁴, Cesar A⁵, Guimarães LL⁶.



Risk of depletion of important 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 narwhale from Eastern Canadian Arctic including Hudson Bay, was around **10-20 ng/g**. In minke whale liver from Greenland and Iceland, PFOS was from less than 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)



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 a 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



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.

Indirect sources



atmosphere

land



Radioactive substances

Energy production



experiments



Ships
and

Research
and
medicine



weapon

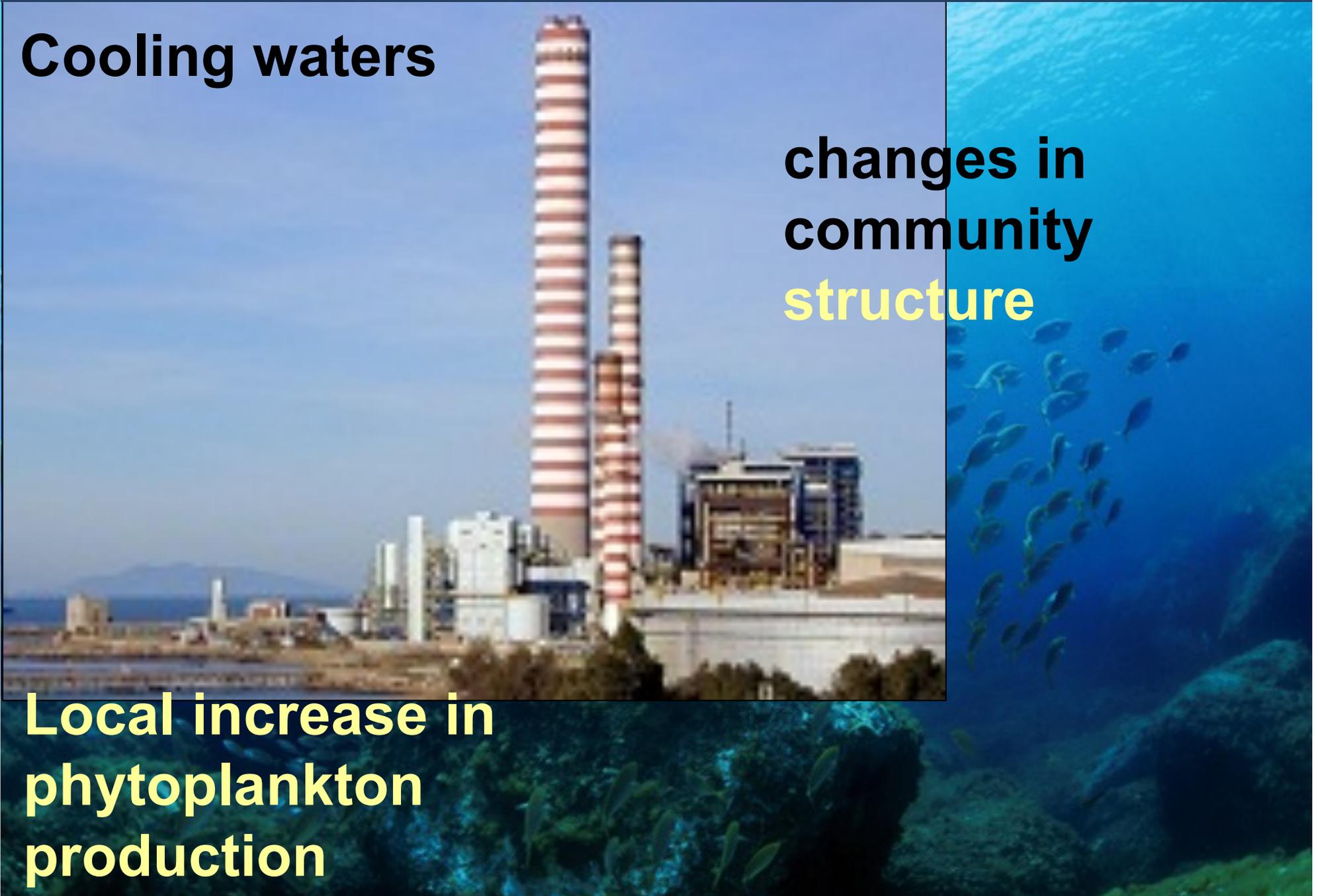


Thermal pollution

Cooling waters

**changes in
community
structure**

**Local increase in
phytoplankton
production**



Acoustic noise

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

Sound source	Source level (dB re 1 μ Pa @ 1 m)	Power (W)	Total energy per pulse (J)	Bandwidth $\Delta = 10$ 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	$60 \times 180^\circ$ V	0.03
US Navy 53C ASW sonar	235	0.77×10^6	1.5×10^6	2000–8000	$40 \times 360^\circ$ H	2
SURTASS LFA sonar	235	0.59×10^6	0.029×10^9	100–500	$30 \times 360^\circ$ H	6–100
Pile-driving 1000 kJ hammer	237	0.46×10^6	0.023×10^6	100–1000	$15 \times 360^\circ$ H	0.05
Multibeam sonar deep-water EM 122	245	0.077×10^6	760	11 500–12 500	$1.0 \times 120^\circ$ 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	$0.5 \times 140^\circ$ V	0.002
Sub-bottom profiler SBP 120	230	2.1×10^3	210	3000–7000	$3 \times 35^\circ$ V	0.1
Acoustic harassment device	205	1.3×10^3	330	8000–30 000	$90 \times 360^\circ$	0.15–0.5
Cargo vessel (173 m length, 16 knots)	192	66	–	40–100	$80 \times 180^\circ$	CW
Acoustic telemetry SIMRAD HTL 300	190	42	–	25 000–26 500	$90 \times 360^\circ$	CW
Small boat outboard engine (20 knots)	160	42×10^{-3}	–	1000–5000	$80 \times 180^\circ$	CW
Acoustic deterrent device	150	4.2×10^{-3}	1.4×10^{-3}	5000–160 000	$90 \times 360^\circ$	0.2–0.3
Operating windmill turbine	151	2.6×10^{-3}	–	60–300	$15 \times 360^\circ$ H	CW

Hildebrand, 2009

>160 dB re 1 μ Pa 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
<i>M. angustirostris</i>	increased ambient noise	constrains acoustic communication	Southall <i>et al.</i> , 2003 [45]
<i>C. chromis</i> <i>S. umbra</i> <i>G. cruentatus</i>	boating and shipping noise	reduces auditory sensitivity and shifts the hearing threshold	Codarin <i>et al.</i> , 2009 [7]
<i>H. didactylus</i>	boating and shipping noise	constrains acoustic communication and shifts the hearing threshold	Vasconcelos <i>et al.</i> , 2007 [46]
<i>P. phocoena</i>	seismic air-gun shooting	shifts the hearing threshold	Lucke <i>et al.</i> , 2009 [48]
<i>T. truncatus</i>	experimental noise emanating device	shifts the hearing threshold	Nachtigall <i>et al.</i> , 2004 [49]
<i>P. auratus</i>	seismic air-gun shooting	damages the hearing sensory epithelia	McCauley <i>et al.</i> , 2003 [37]
<i>L. vulgaris</i> <i>S. officinalis</i> <i>O. vulgaris</i> <i>I. coindetii</i>	experimental noise emanating device	damages the hearing sensory epithelia	André <i>et al.</i> , 2011 [52]
<i>A. dux</i>	seismic air-gun shooting	damage to internal fibers, statocysts, stomachs, and digestive tracts	Guerra <i>et al.</i> , 2011 [53]

Behavioral effects like startling, avoidance, foraging interruption

Stranding

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

Peng *et al.*, 2015



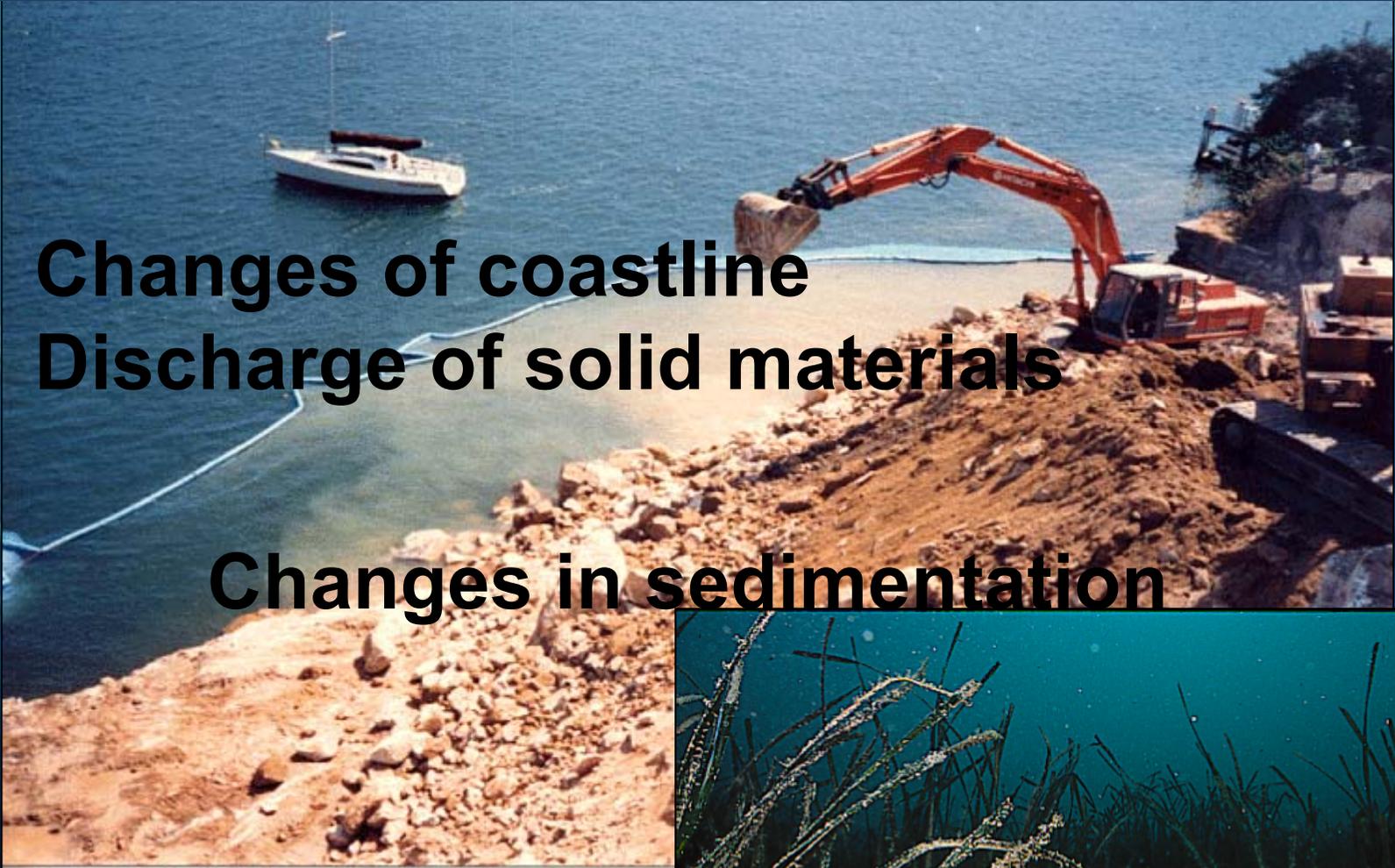
Light



**Effects on nictemeral
migrations, migrations,
reproductions**



Alteration of coastline



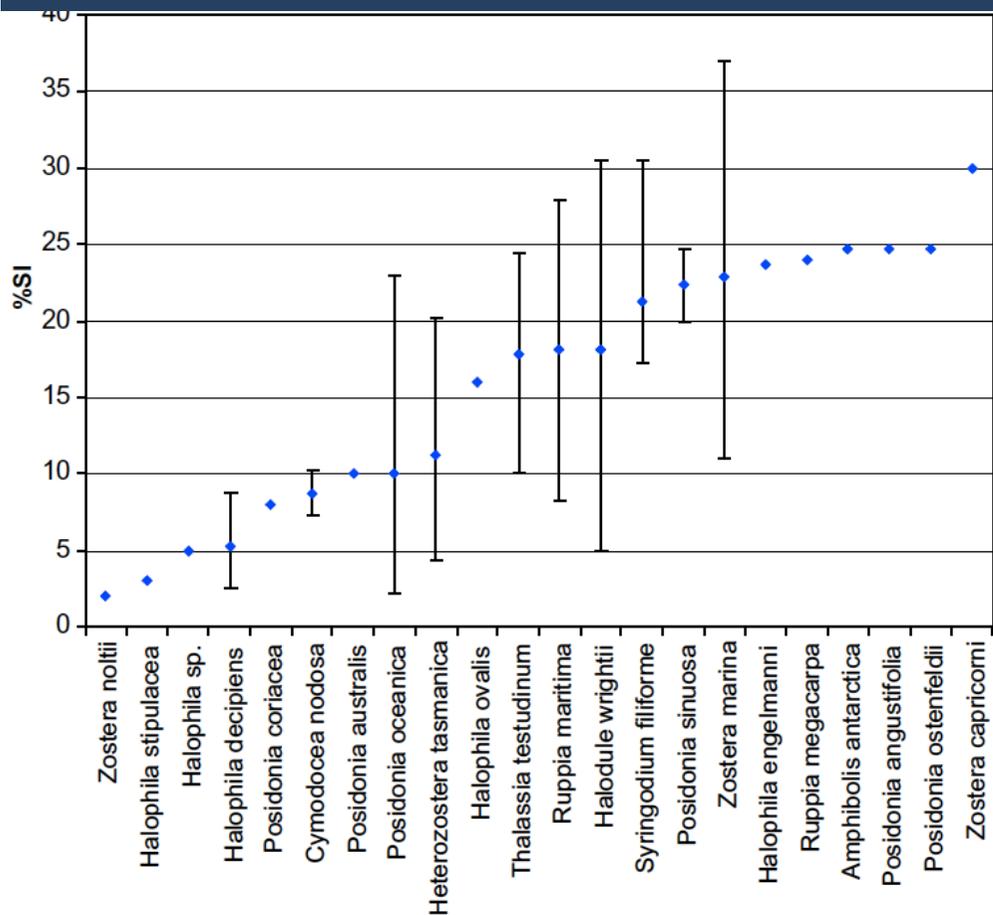
Changes of coastline
Discharge of solid materials

Changes in sedimentation

**Degradation of
ecosystems**



Alteration of coastline



Erftemeijer and Lewis, 2006

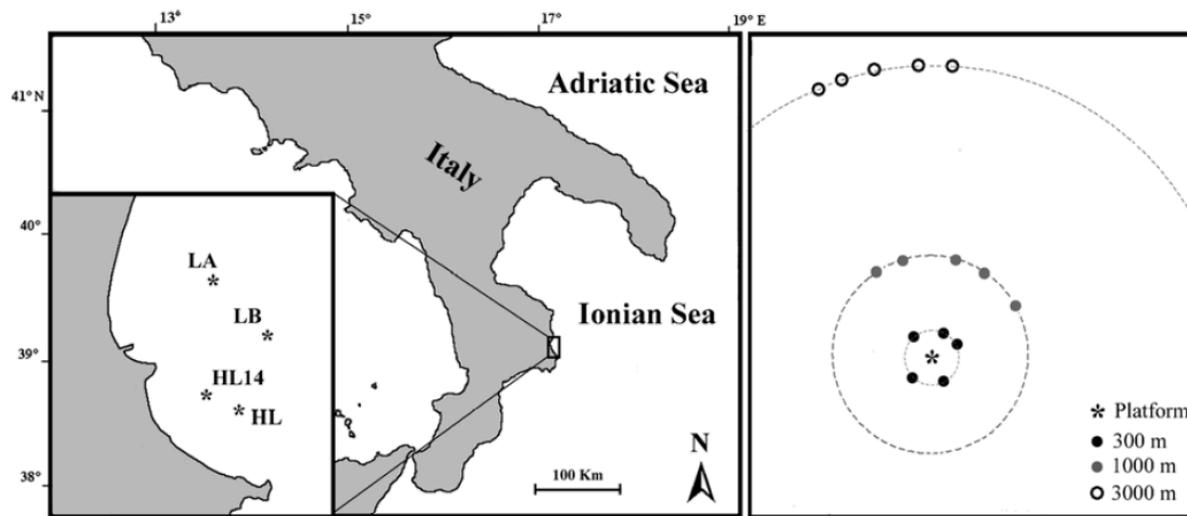
Table 3
Critical thresholds of seagrasses for sedimentation (cm/year)

Species	Location	Sedimentation (cm/yr)	Reference
<i>Cymodocea nodosa</i>	Mediterranean (Spain)	5	Marba and Duarte (1994)
<i>Cymodocea rotundata</i>	Philippines	1.5	Vermaat et al. (1997)
<i>Cymodocea serrulata</i>	Philippines	13	Vermaat et al. (1997)
<i>Enhalus acoroides</i>	Philippines	10	Vermaat et al. (1997)
<i>Halophila ovalis</i>	Philippines	2	Vermaat et al. (1997)
<i>Posidonia oceanica</i>	Mediterranean (Spain)	5	Manzanera et al. (1995)
<i>Zostera noltii</i>	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 \times 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 \times P(De)	12 Di \times P(De) cells
Platform = P(De)	2	36211.00	18105.00	5.123	0.000	Si(Di \times P(De))	60 Si(Di \times P(De)) cells
De \times Di	2	11776.00	5887.90	0.675	0.896	Di \times P(De)	12 Di \times P(De) cells
Di \times P(De)	4	34903.00	8725.90	2.469	0.000	Si(Di \times P(De))	60 Si(Di \times P(De)) cells
Site(Di \times P(De)) = Si(Di \times P(De))	48	169620.00	3533.80	1.775	0.000	Res	120 raw data units
Residual = Res	120	238890.00	1990.80				
<i>Pair-wise tests for term Di \times P(De)</i>							
HL		HL14				LA	LB
300 m = 1000 m = 3000 m		300 m = 1000 m = 3000 m				300 m = 1000 m \neq 3000 m	300 m \neq 1000 m \neq 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						
<i>Golfingia</i> sp.	5.87	7.80	10.53	12.12	11.25	13.19
<i>Levinsenia gracilis</i>	2.13	2.73	12.40	6.00	11.23	10.86
<i>Aricidea</i> cfr <i>caterinae</i>	1.33	2.67	9.93	4.52	8.13	8.05
<i>Monticellina dorsobranchialis</i>	0.80	2.67	8.33	4.05	7.38	6.87
<i>Timoclea ovata</i>	0.67	3.13	3.84	3.84	0.61	2.29
<i>Nucula sulcata</i>	2.87	1.13	3.71	3.71	2.42	1.00
<i>Prionospio cirrifera</i>	0.53	2.33	3.31	3.31	2.92	3.24
<i>Thyasira biplicata</i>	0.87	2.40	7.47	3.22	5.90	5.54
<i>Monticellina heterochaeta</i>	1.20	2.00	3.33	3.13	2.83	3.07
<i>Leucon mediterraneus</i>	1.33	1.40	4.53	2.78	3.66	3.64
<i>Chaetozone</i> 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						
<i>Golfingia</i> sp.	4.40	3.33	2.87	3.09	2.32	2.36
<i>Levinsenia gracilis</i>	5.53	3.80	0.87	4.95	3.12	2.71
<i>Aricidea</i> cfr <i>caterinae</i>	3.93	3.80	1.00	3.95	2.18	2.73
<i>Timoclea ovata</i>	9.67	6.93	57.33	7.46	19.01	22.18
<i>Prionospio cirrifera</i>	0.00	0.67	1.53	0.59	1.17	1.58
<i>Thyasira biplicata</i>	7.60	3.33	1.00	4.12	4.17	2.08
<i>Corbula gibba</i>	5.20	1.20	0.87	3.29	2.81	0.98
<i>Kelliella abissicola</i>	8.33	3.67	15.53	6.26	6.81	7.00
<i>Diplodonta apicalis</i>	18.27	6.87	0.00	11.23	11.05	4.94
<i>Parvicardium minimum</i>	2.33	1.53	10.20	1.66	3.53	4.32
<i>Nuculana (Jupiteria) commutata</i>	5.20	2.67	11.47	2.88	4.50	5.42



Artificial structures

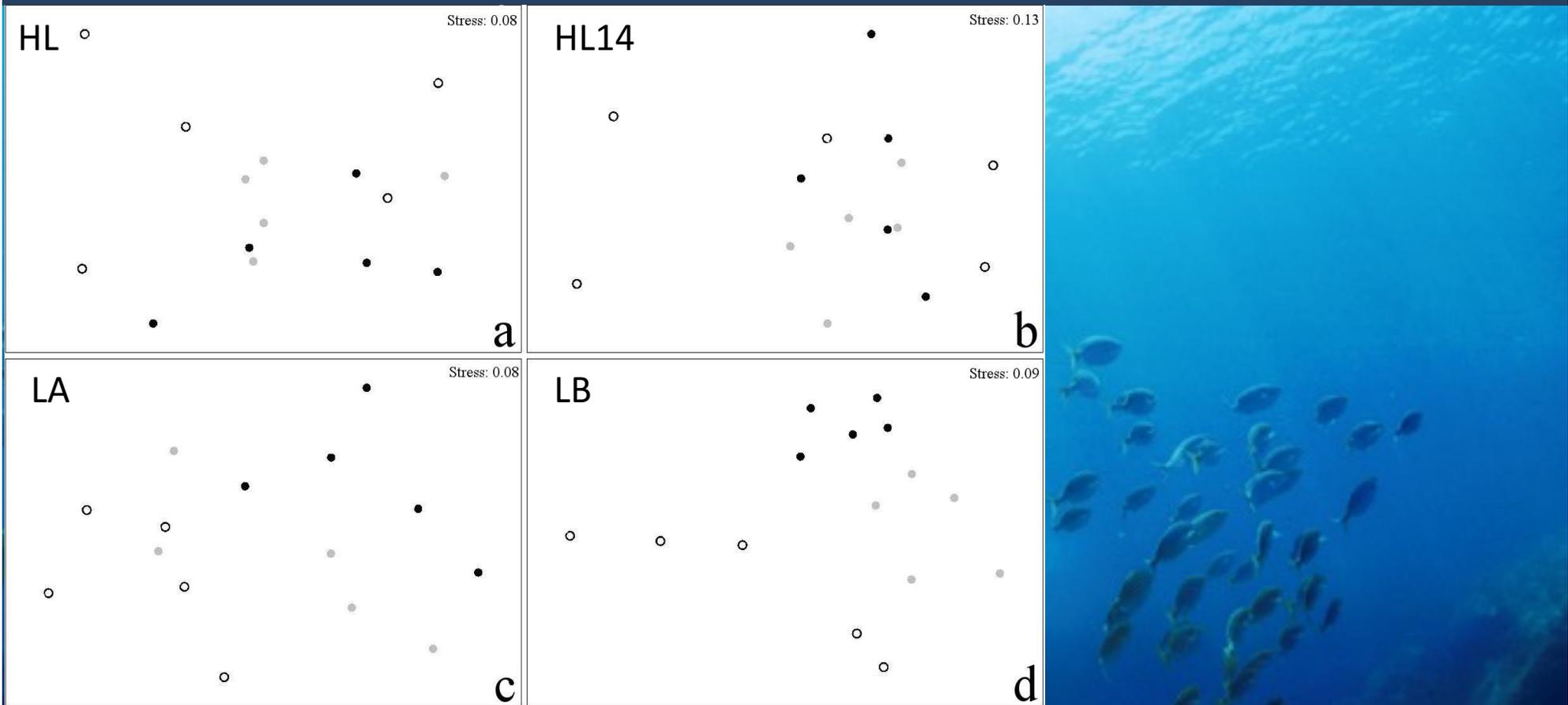


Table 3

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
<i>Replicates dispersion</i>									
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				
<i>Sites dispersion</i>									
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

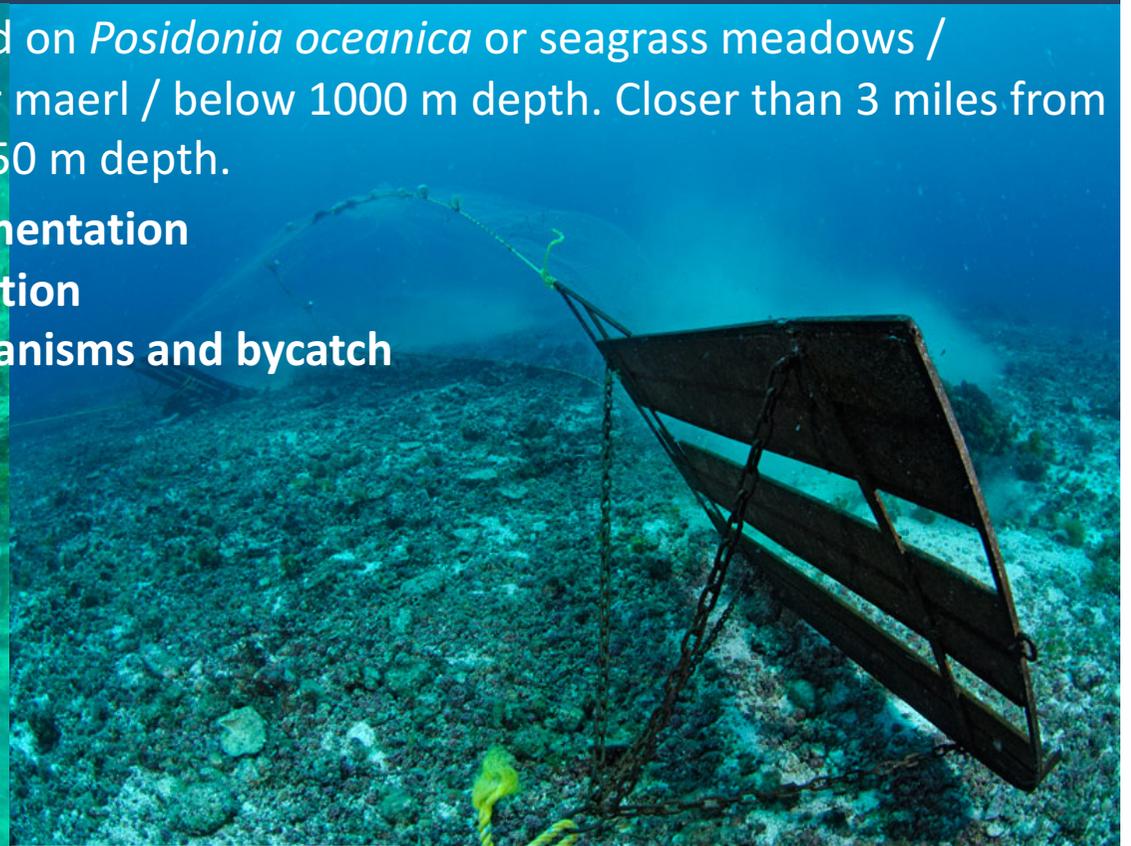
Anchoring

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 maerl^a habitat over 4 years

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

Trawl reduced density of large epifauna about 15% on each pass; trawl flown 15 cm above 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

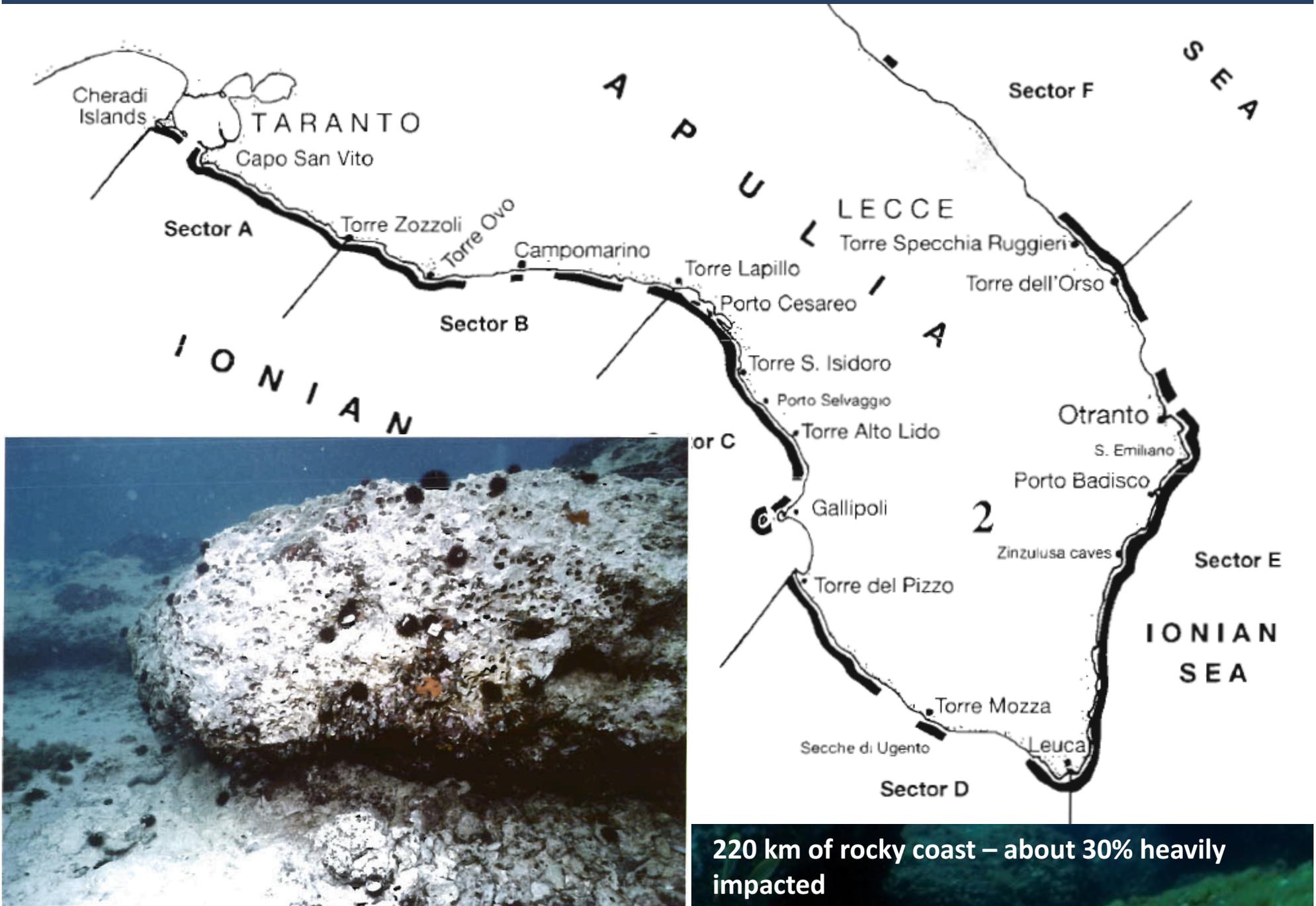
Removal of biogenic and physical habitat structure

Decreased diversity in trawled plots

Decrease in small-scale heterogeneity of sediment texture after trawling

Thrush and Dayton, 2002

Destructive fishing (date mussels)



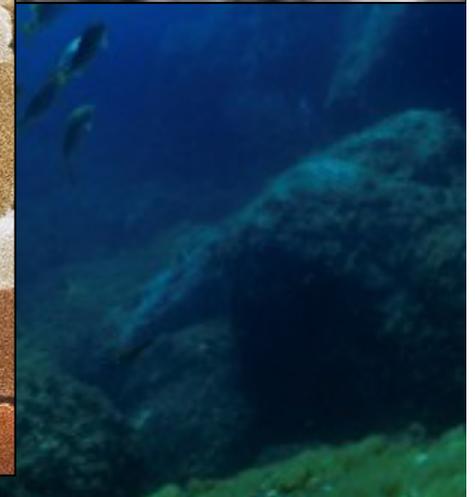
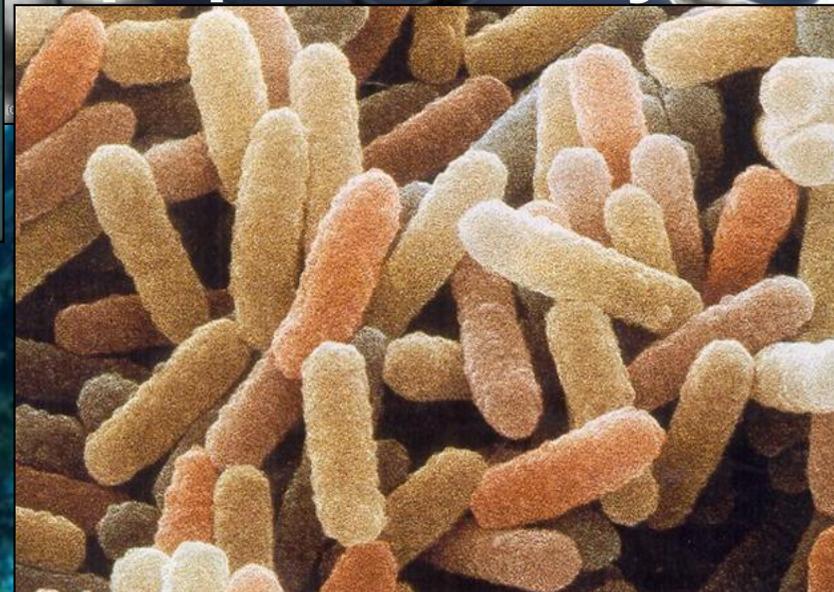
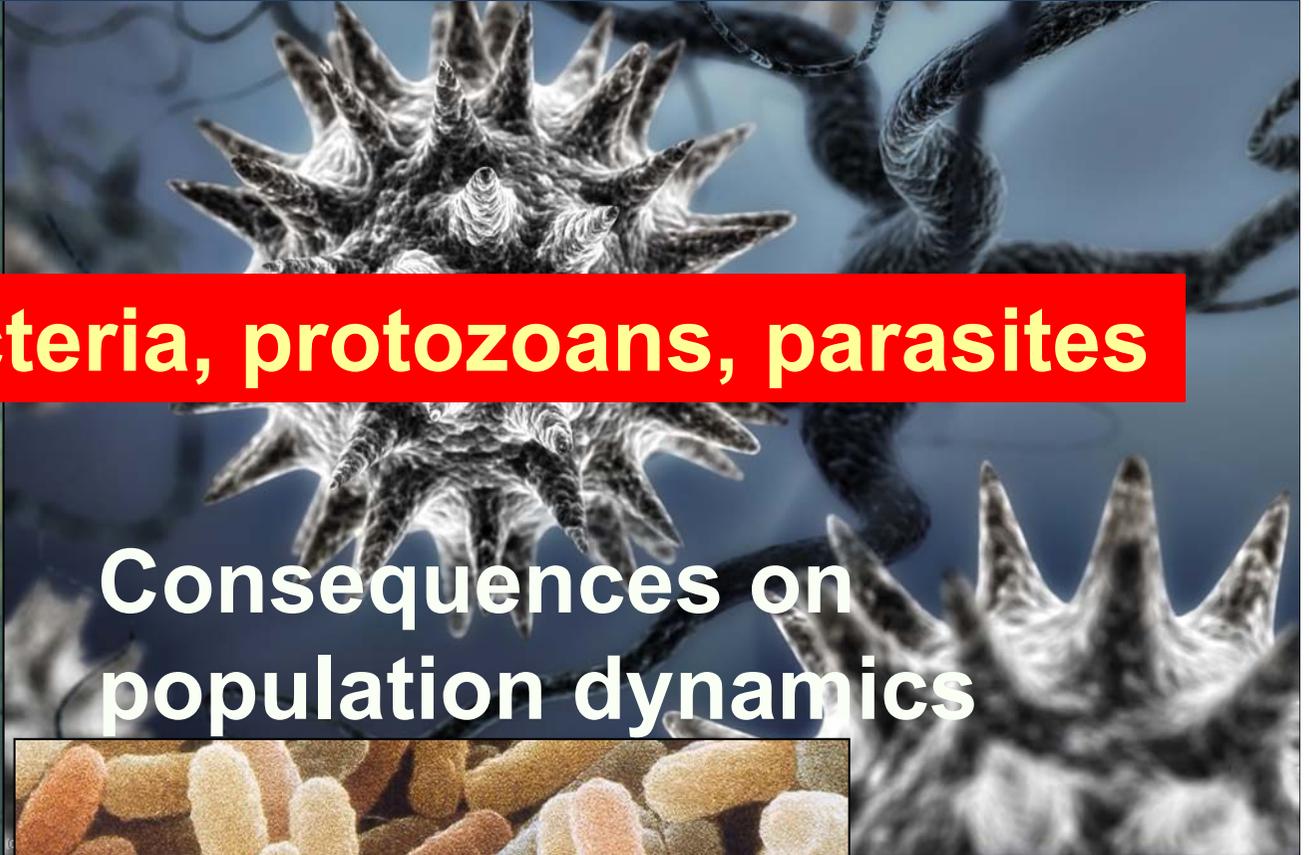
Pathogens

Virus, bacteria, protozoans, parasites

**Consequences on
population dynamics**

Nodavirus

Infection via aquaculture

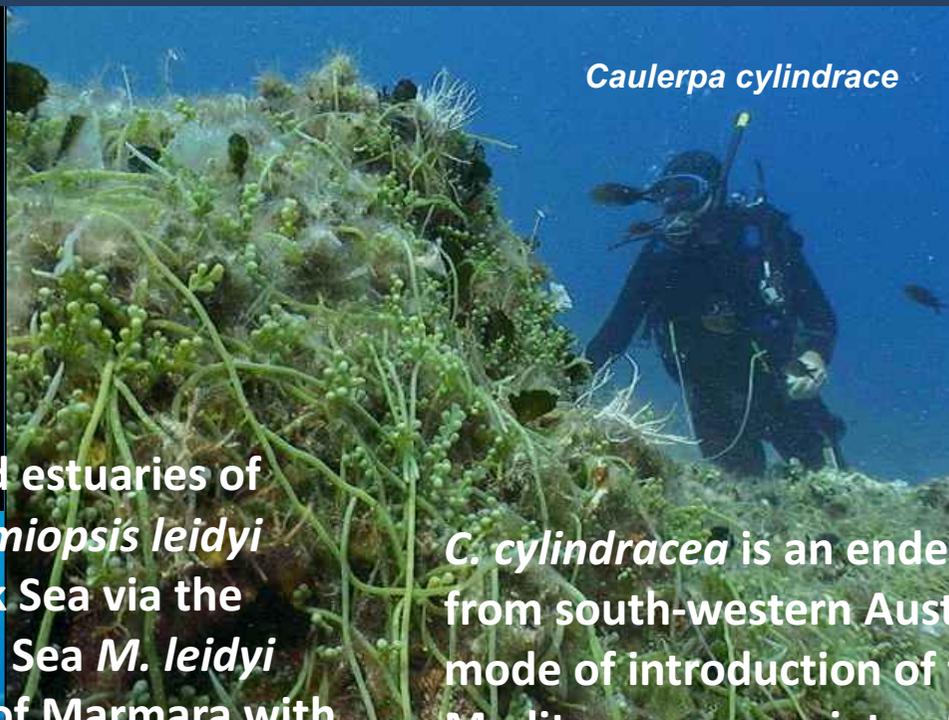


Alien species



Mnemiopsis leidyi

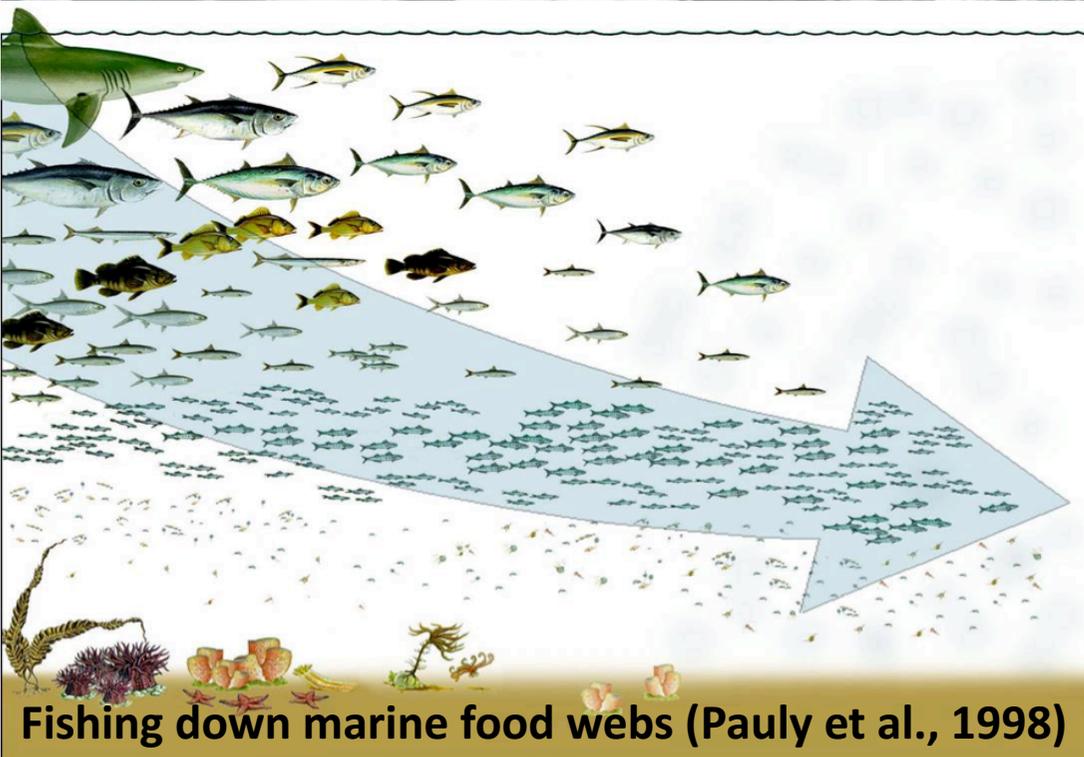
Native to the Atlantic coasts and estuaries of North and South America, *Mnemiopsis leidyi* was first introduced to the Black Sea via the ballast water of ships. The Black Sea *M. leidyi* population spread into the Sea of Marmara with the currents and thence into the north-western Aegean Sea, where it 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



Caulerpa cylindracea

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

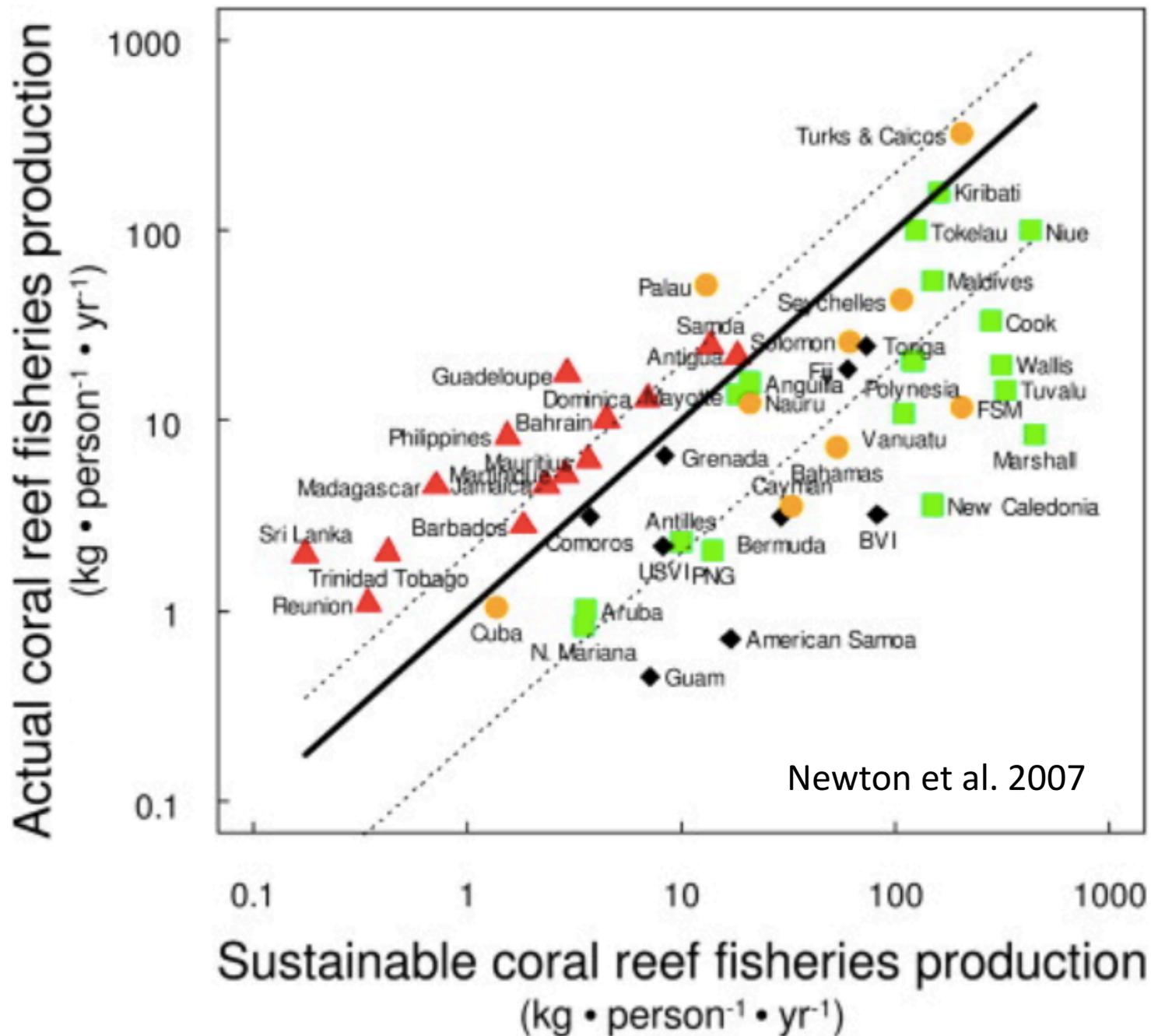
Fishery



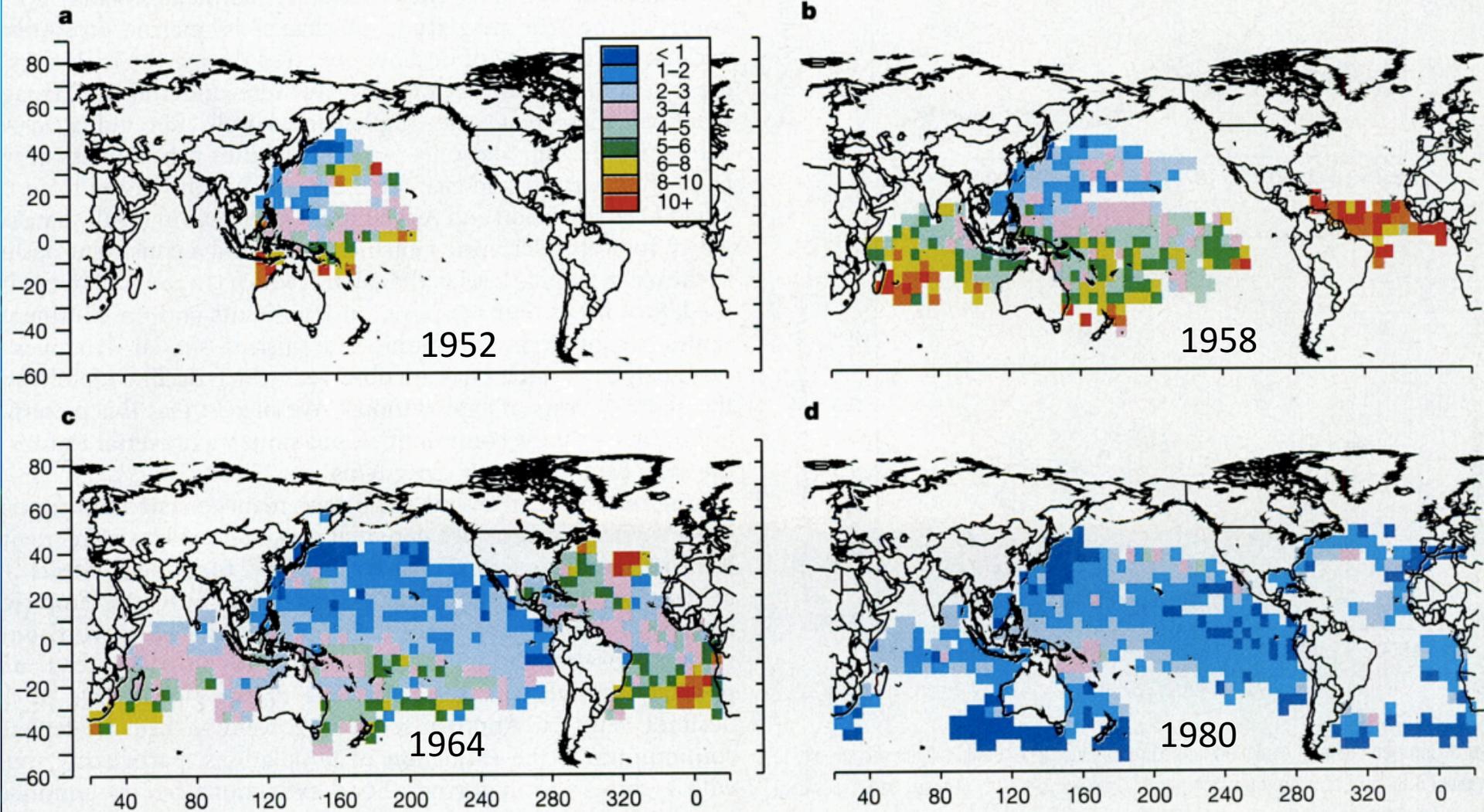
Fishing down marine food webs (Pauly et al., 1998)



Fishery



Fishery

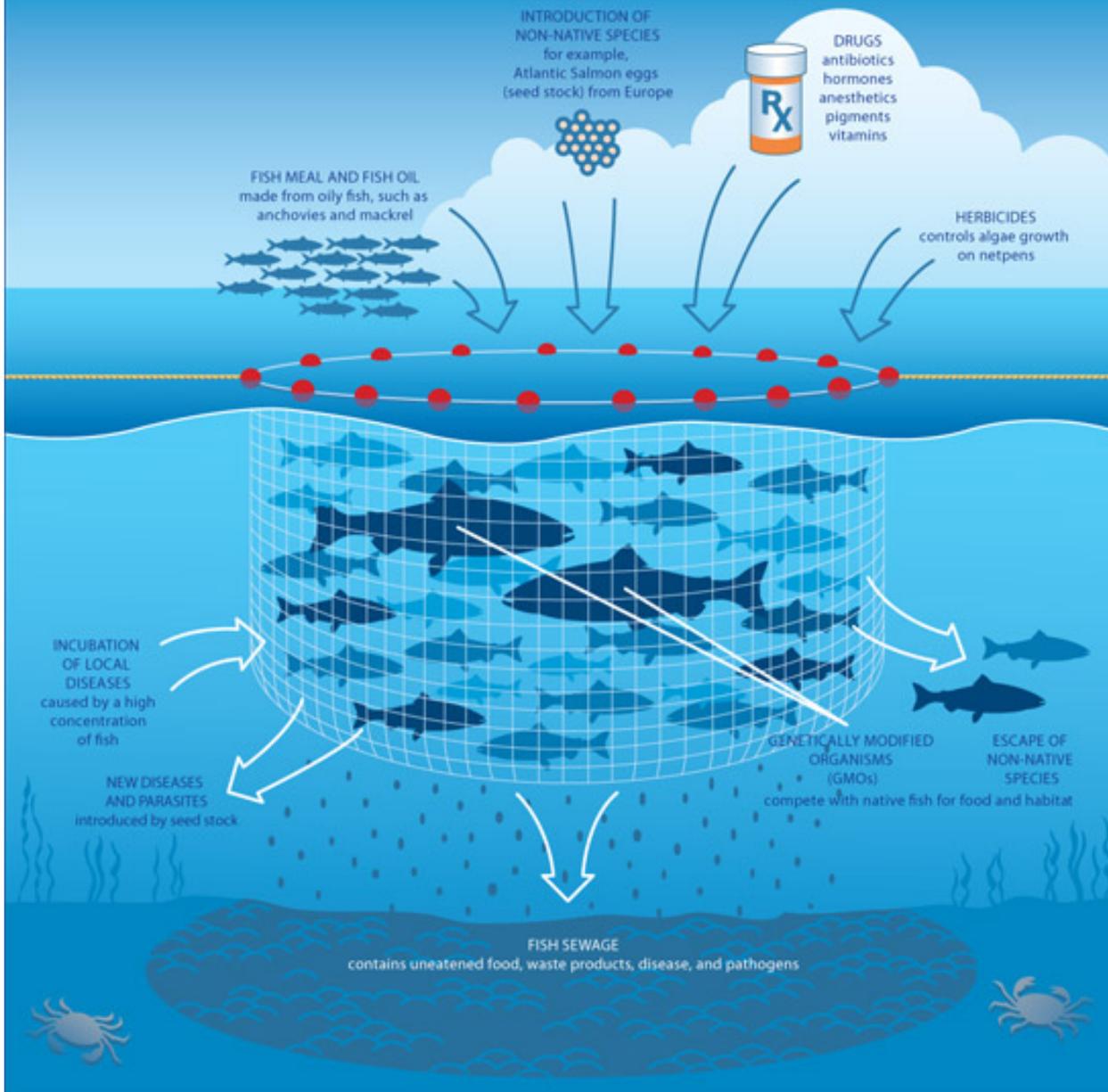


Myers & Worm 2003

Decrease in top predator fish catches

Aquaculture

Environmental Risks of Marine Aquaculture



Introduction of drugs (antibiotic, antifouling)

Spread of pathogens and parasites to wild populations

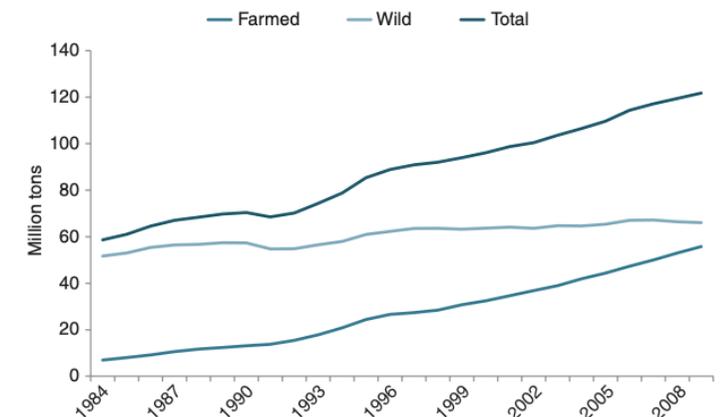
Introduction of alien species

Increasing nutrient load from fishmeal, fecal pellets

GMOs

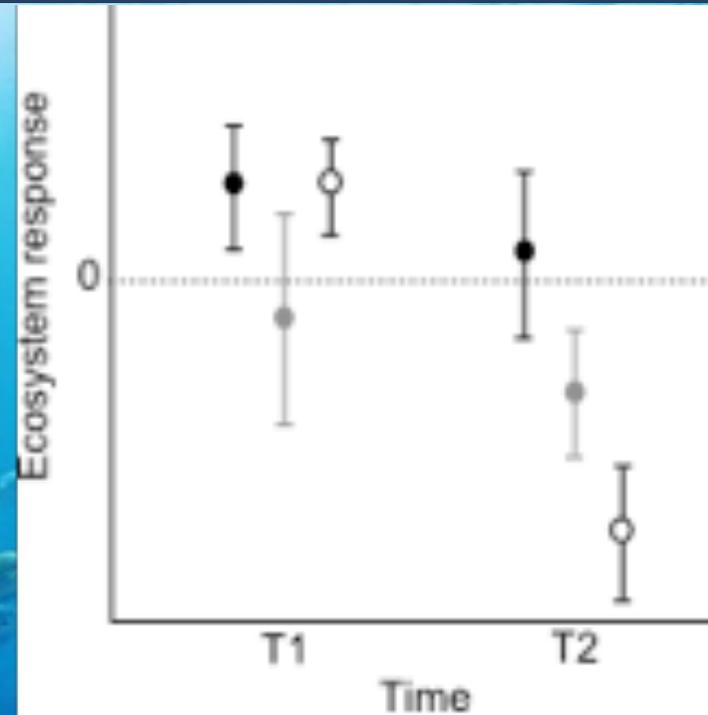
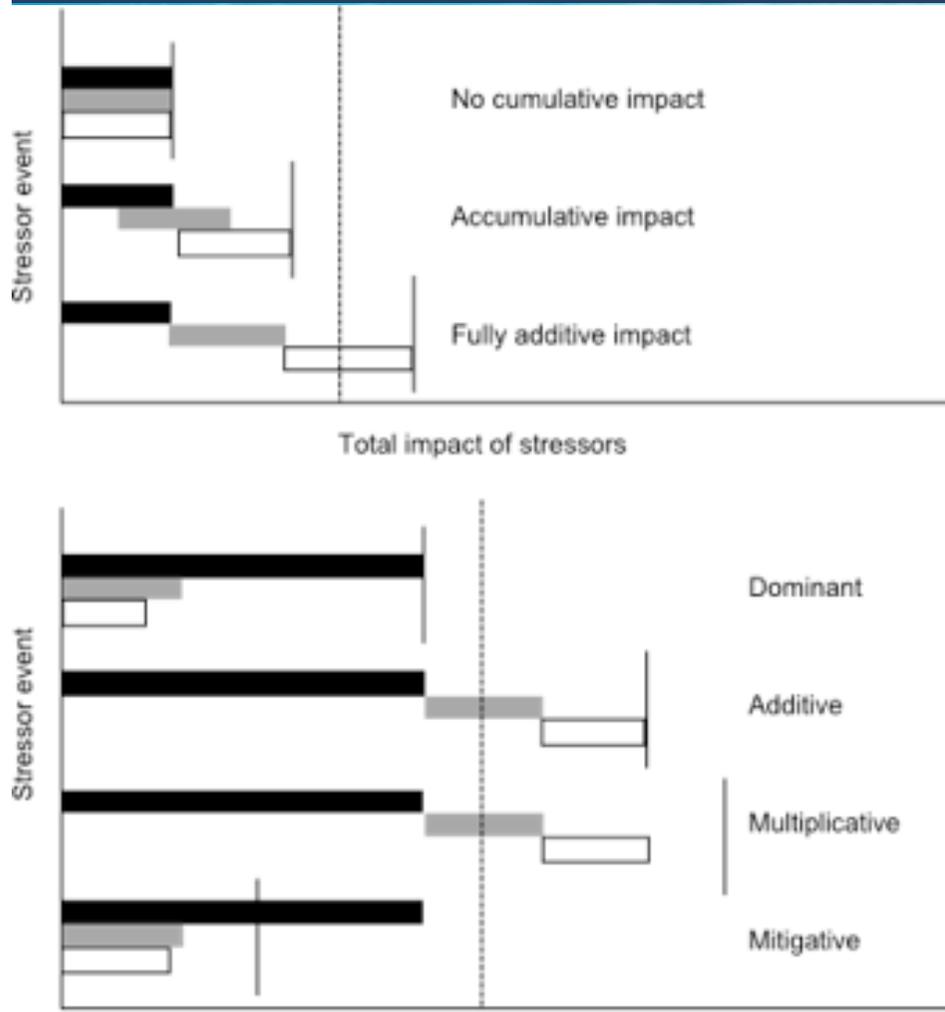
Fishmeal, depletion of fish stocks, agriculture, and the problem of energy

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



Source: FishStat.

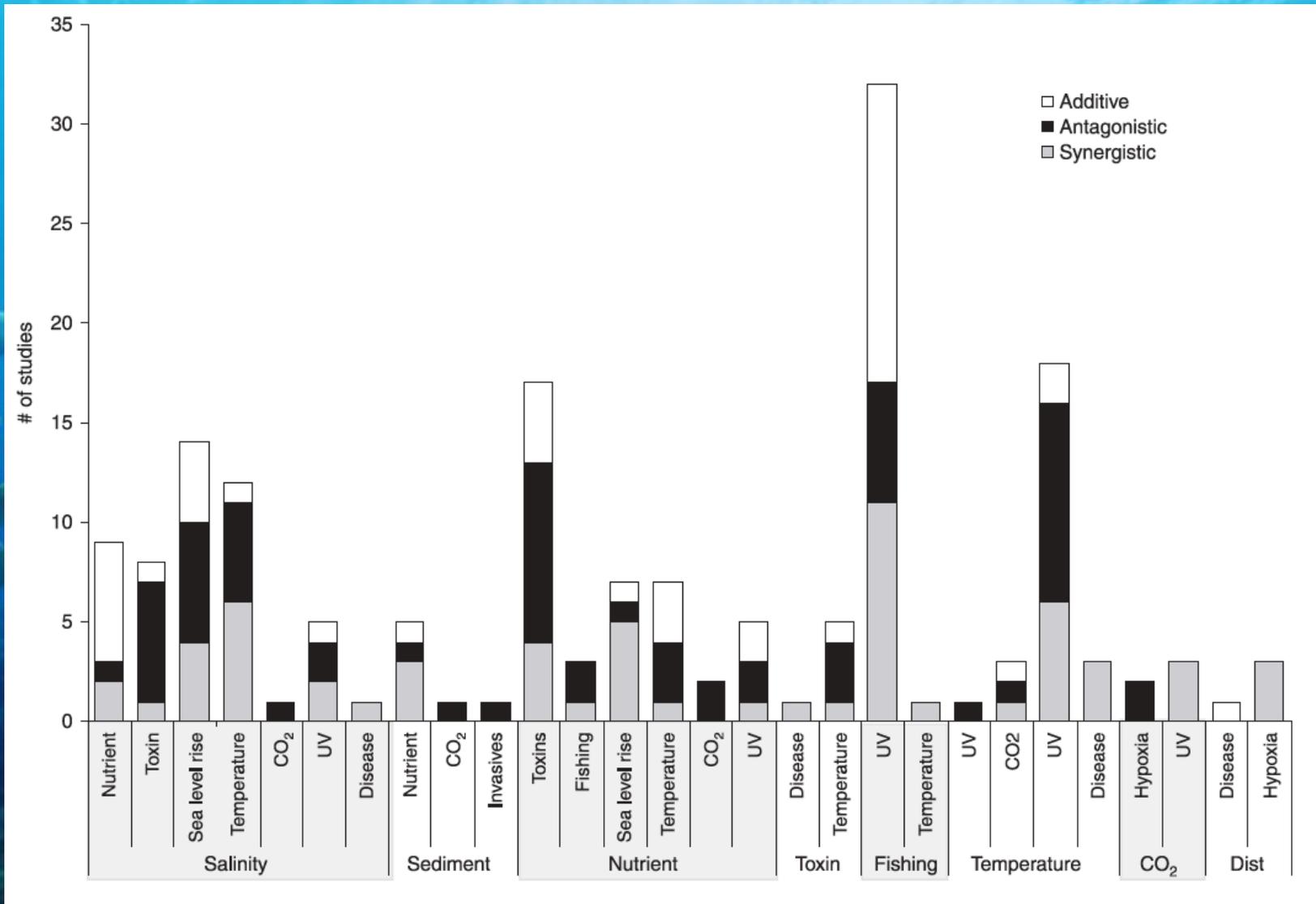
From isolated to cumulative impacts



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.

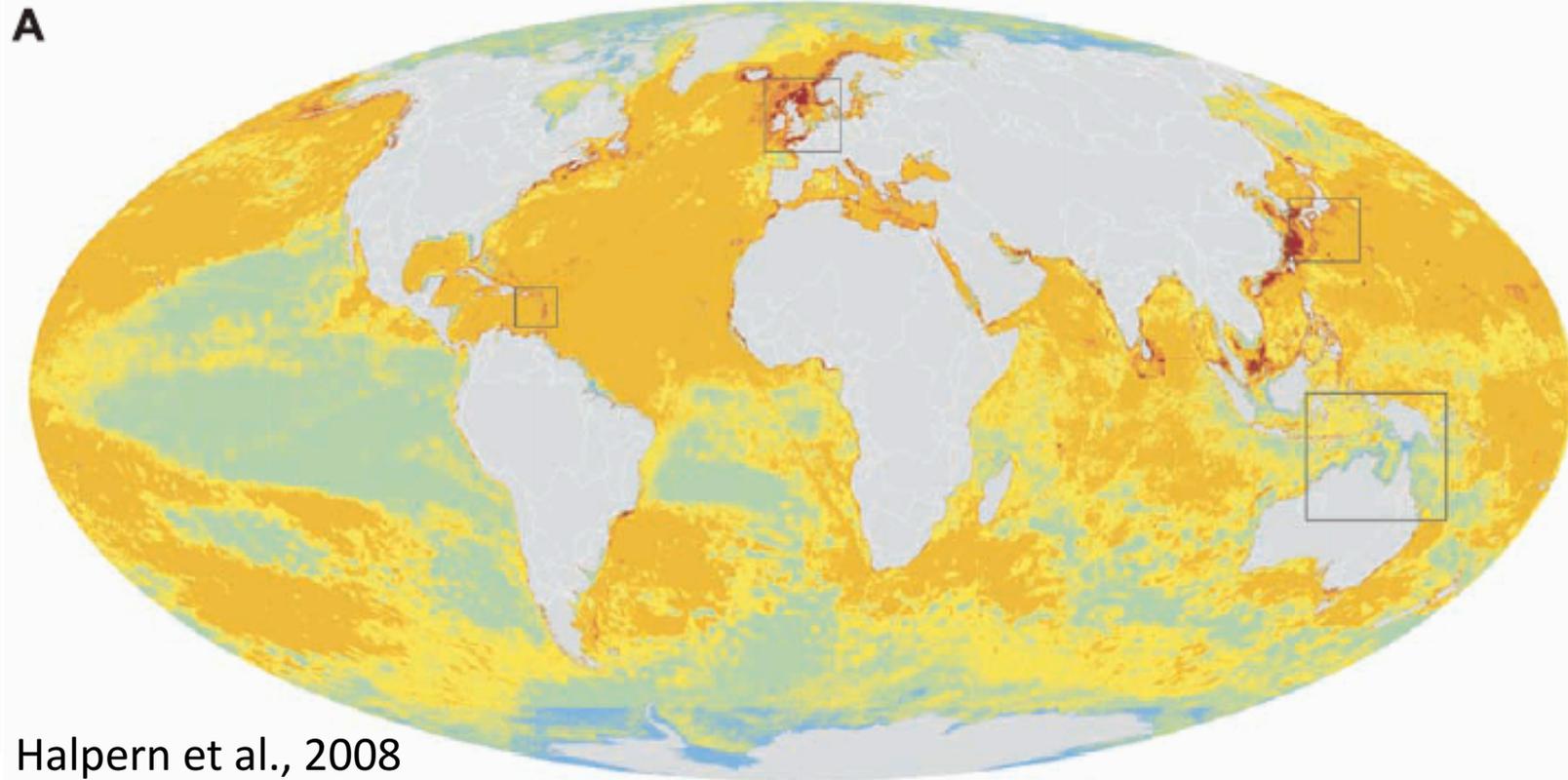


From isolated to cumulative impacts

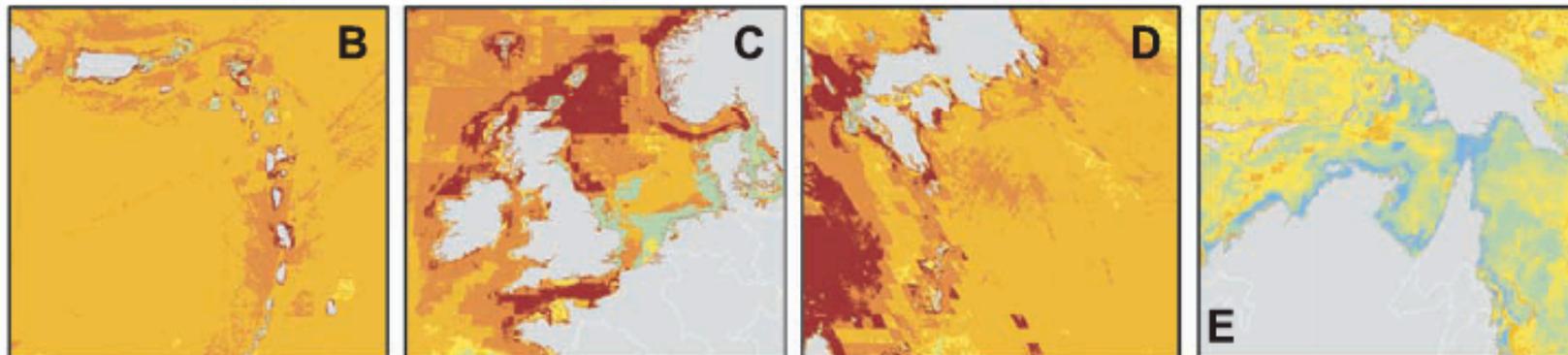
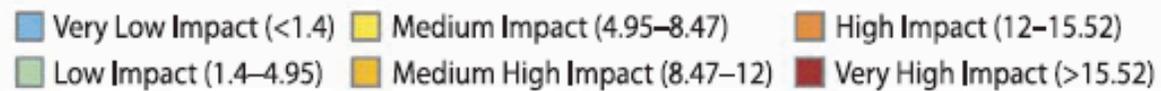


In many cases different stressors have synergistic effect, meaning that the combination of more disturbances often lead to worse impacts than what expected considering them in isolation

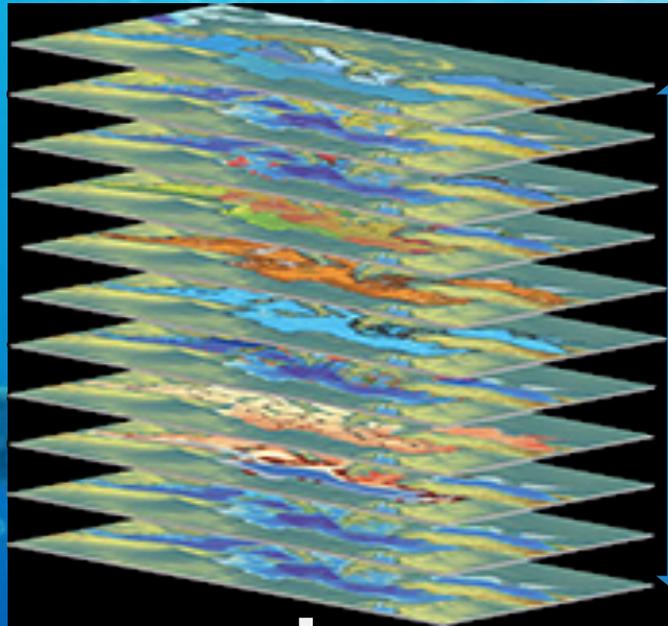
Estimating cumulative impacts



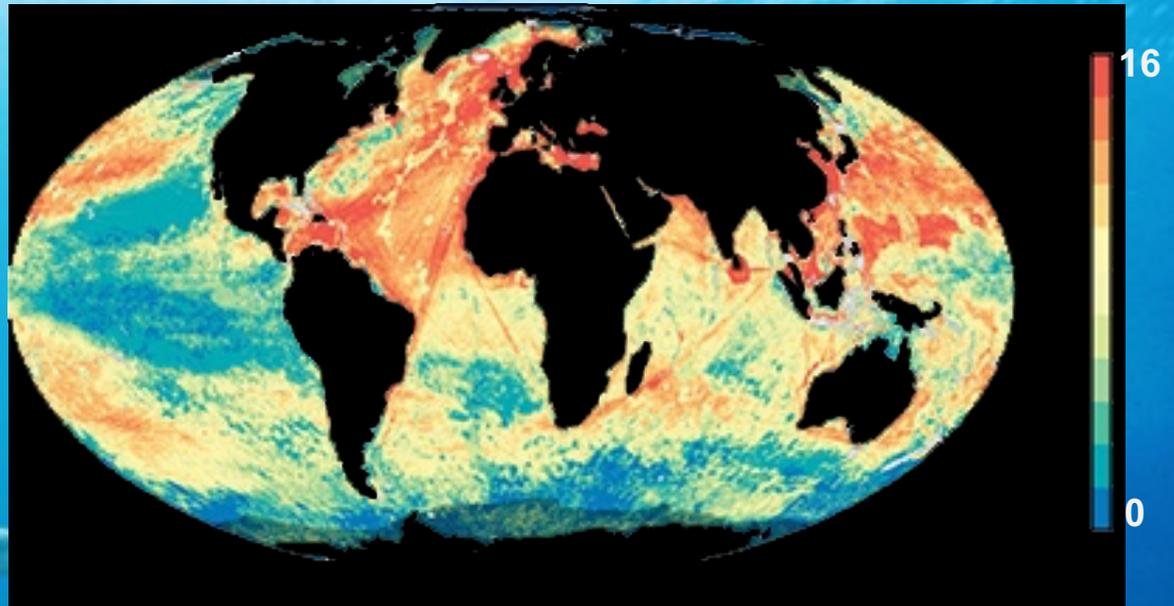
Halpern et al., 2008



The additive formula



Layers of pressures



Map of cumulative impact



+

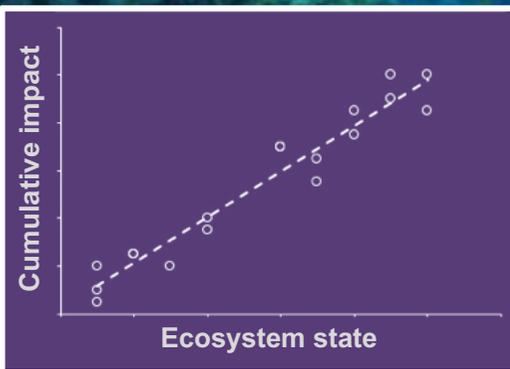
Sensitivity weights by expert opinion

+

Computing geo-referred impact score

$$I_c = \sum_i P_i w_i E_j$$

Cumulative impact score versus ecosystem state



Linear response to pressure

Additivity of impacts

Expert-based sensitivity

Resolution and downscaling

Scores

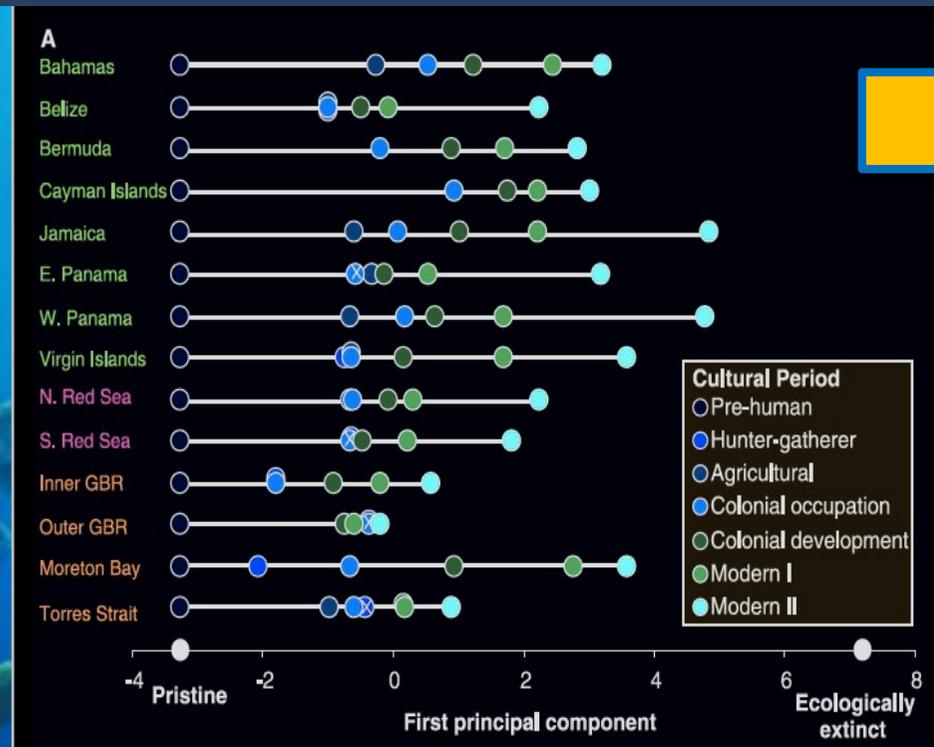
Threat ^b	Intertidal					Coastal				Suspension-feeder reef ^c
	Rocky intertidal	Intertidal mud	Beach	Mangrove	Salt marsh	Coral reef	Seagrass	Kelp forest	Rocky reef	
Freshwater input	13	5	7	7	14	24	6	7	9	5
increase	1.6	1.3	0.3	1.8	1.9	1.5	1.6	0.0	1.5	1.7
decrease	1.1	1.1	0.0	2.6	1.9	0.4	1.4	0.0	0.6	1.2
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	2.0
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

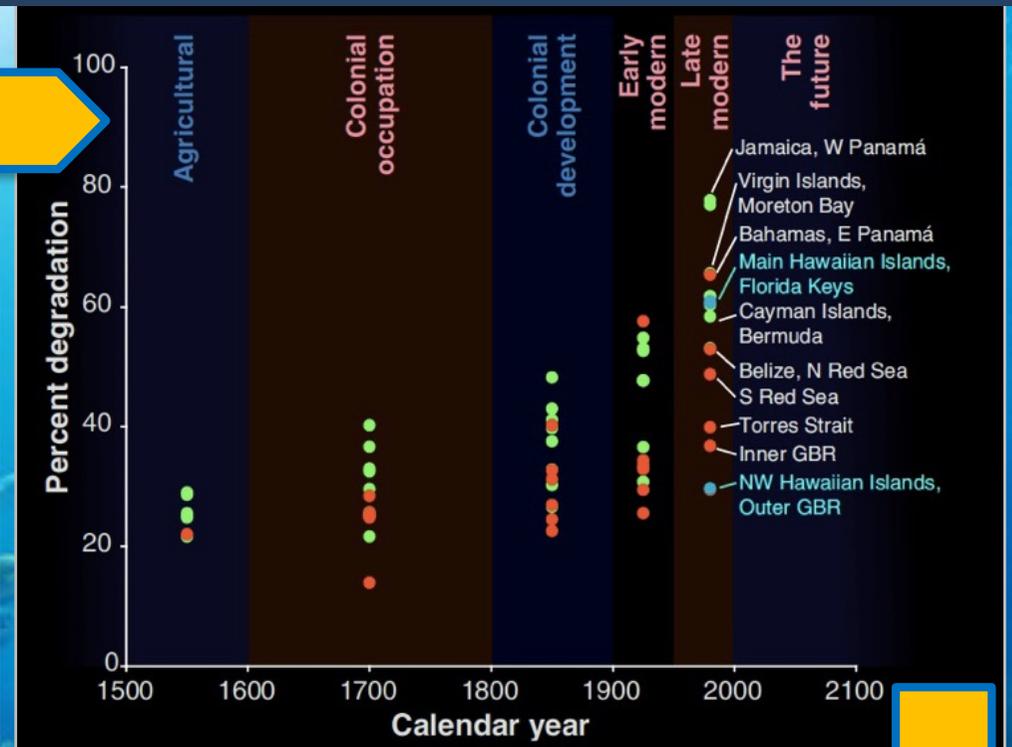
$$I_c = \sum_i P_i W_i E_j$$

Halpern et al., 2007

Pressure response relationship



Pandolfi et al., 2003. Science

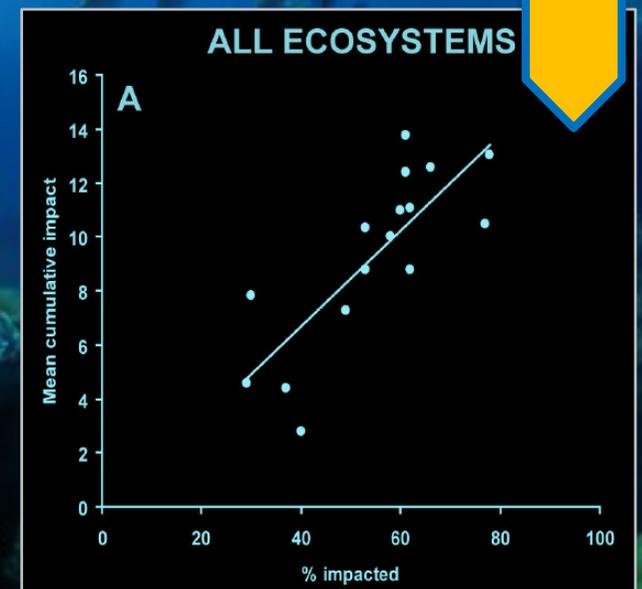


Pandolfi et al., 2005. Science

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

Halpern et al., 2008. Science

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



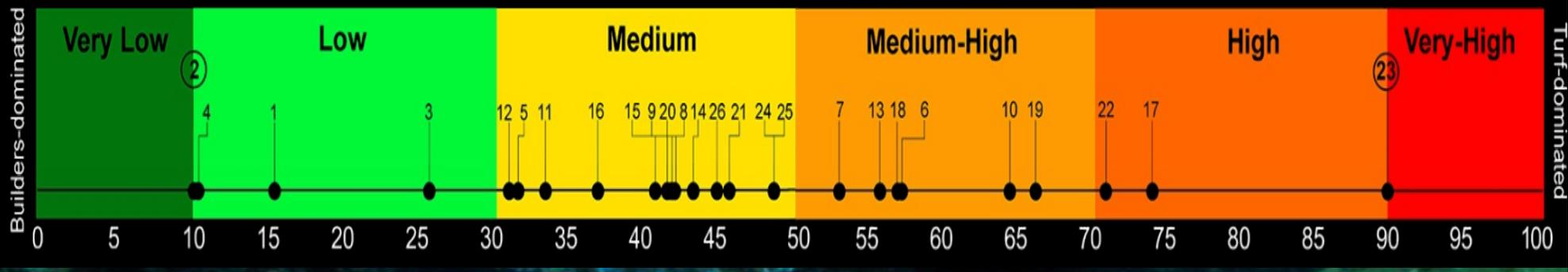
A case study on coralligenous outcrops

Bevilacqua et al., 2018

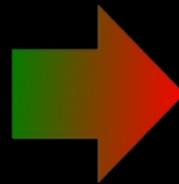
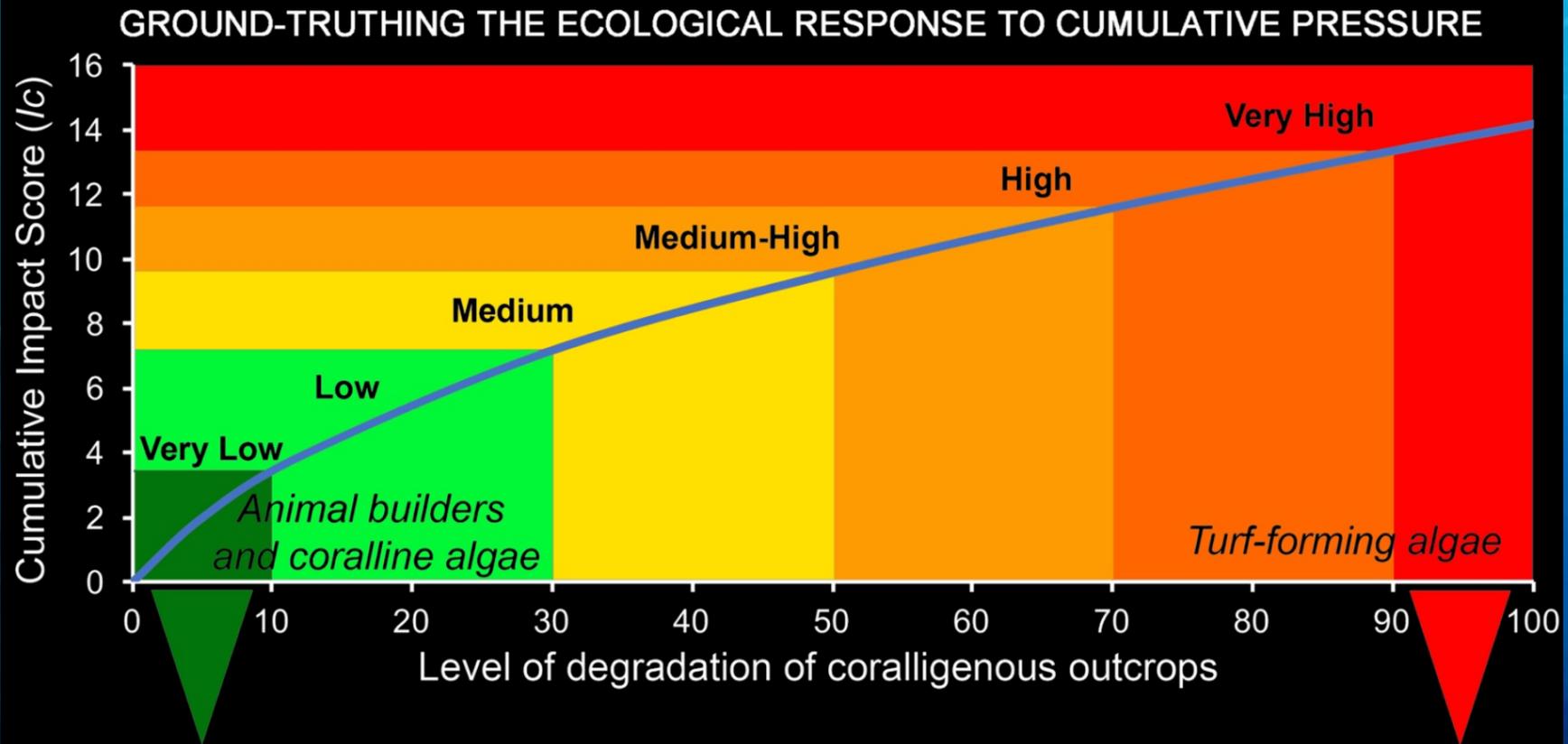
DISTRIBUTION OF ANTHROPOGENIC DRIVERS (D_i)



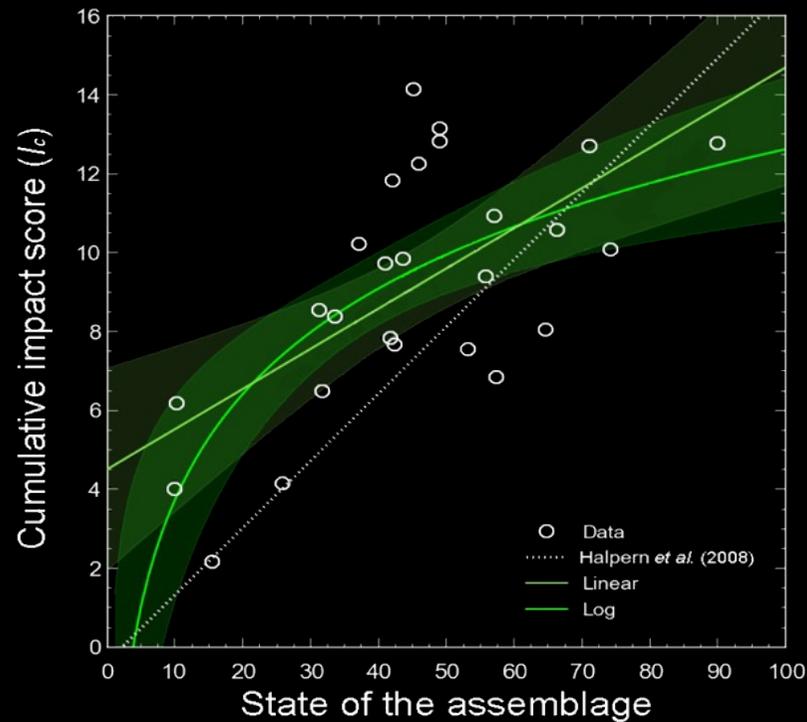
Level of degradation from PCoA axis 1 (>84% explained variation)



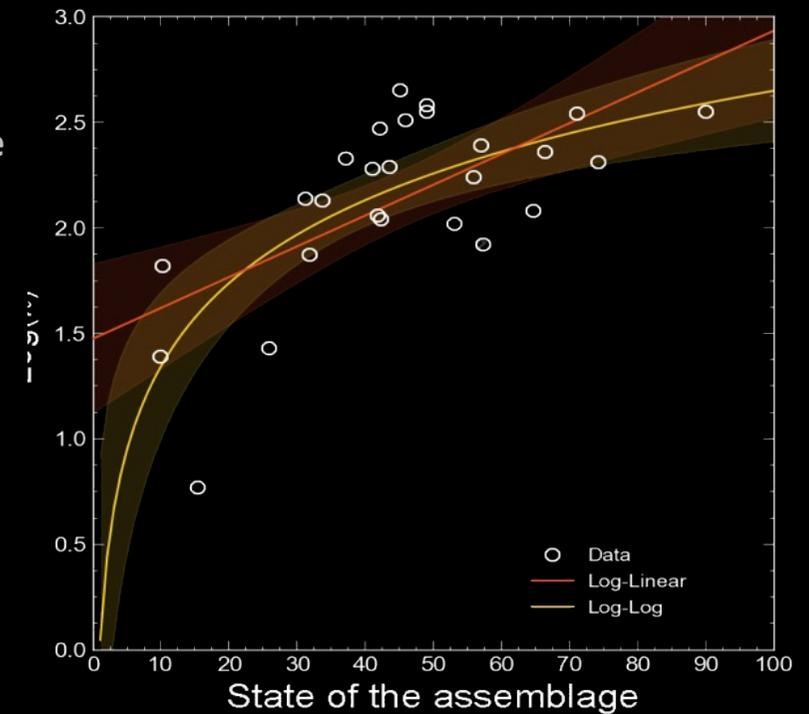
Status of coralligenous



Pressure-response relationship

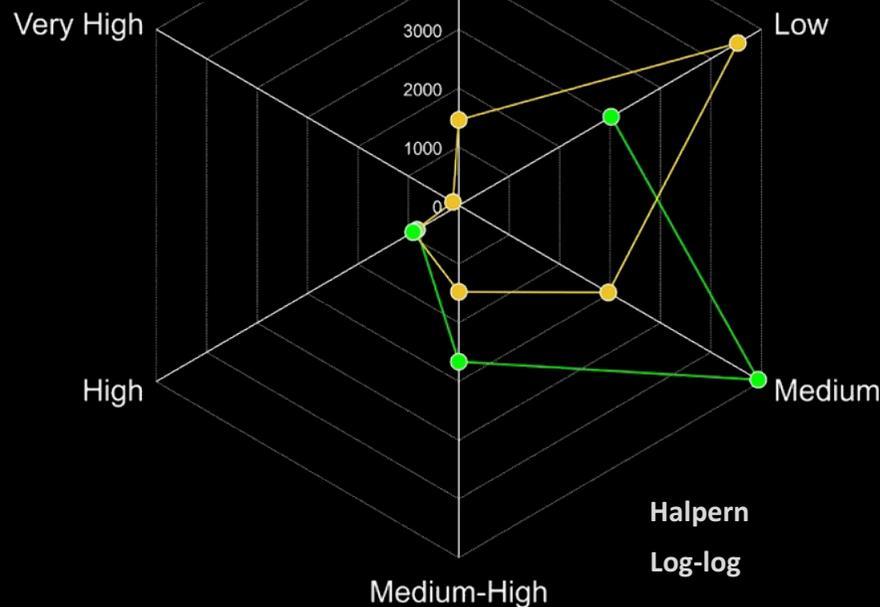


A log-log model
 best fitted the
 pressure-response
 relationship
 Halpern's linear
 model was
 unlikely



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)

Mitigation strategies

Preventing and regulating



Safe transports

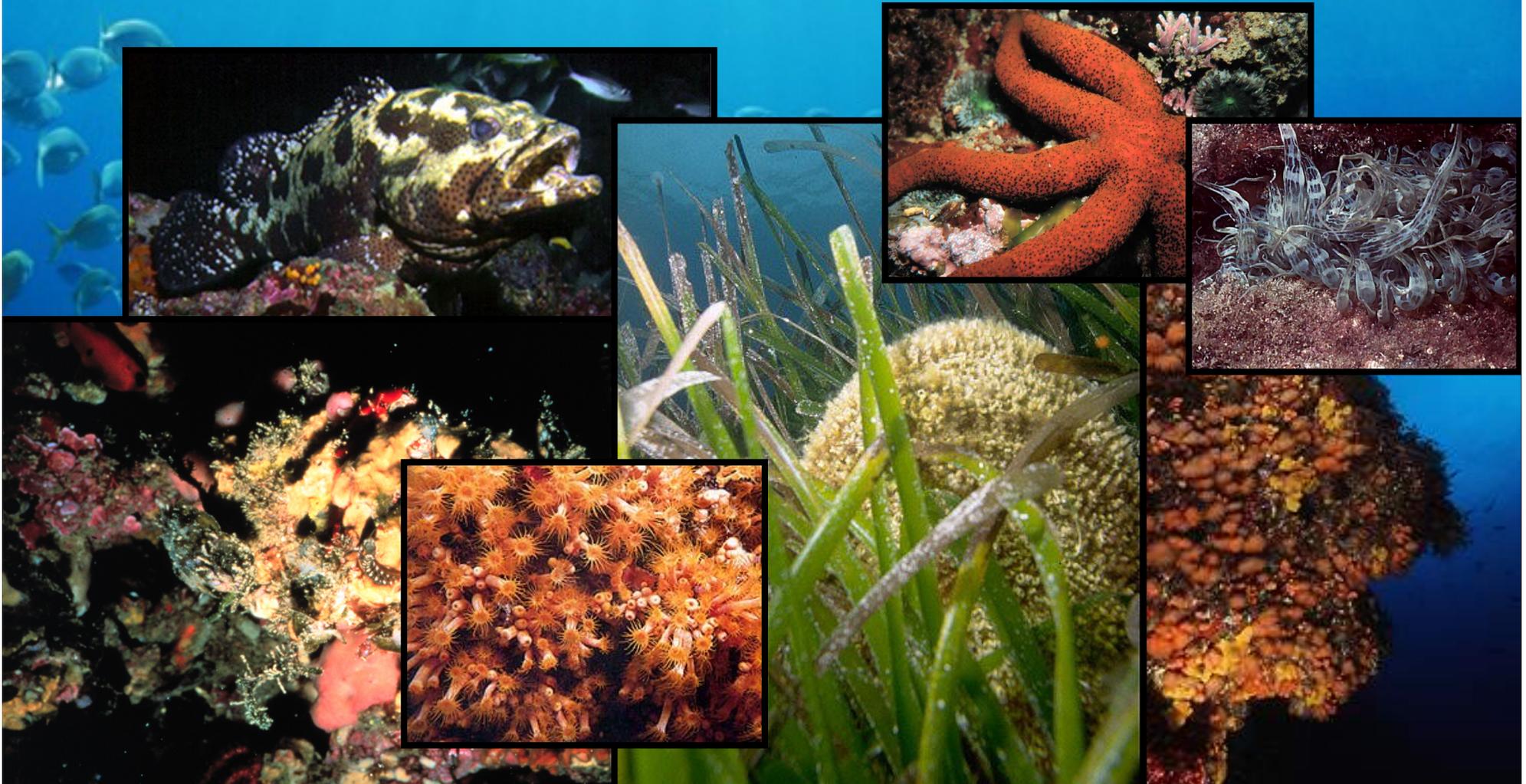


recycling



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 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.

