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2022-16

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2 - 18 March 2009

The State of Marine Environments

Giulio De Leo

Università di Parma, Dip. di Scienze Ambientali
Italy

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

Theoretical Ecology Course

ICTP- March 2-13 2009

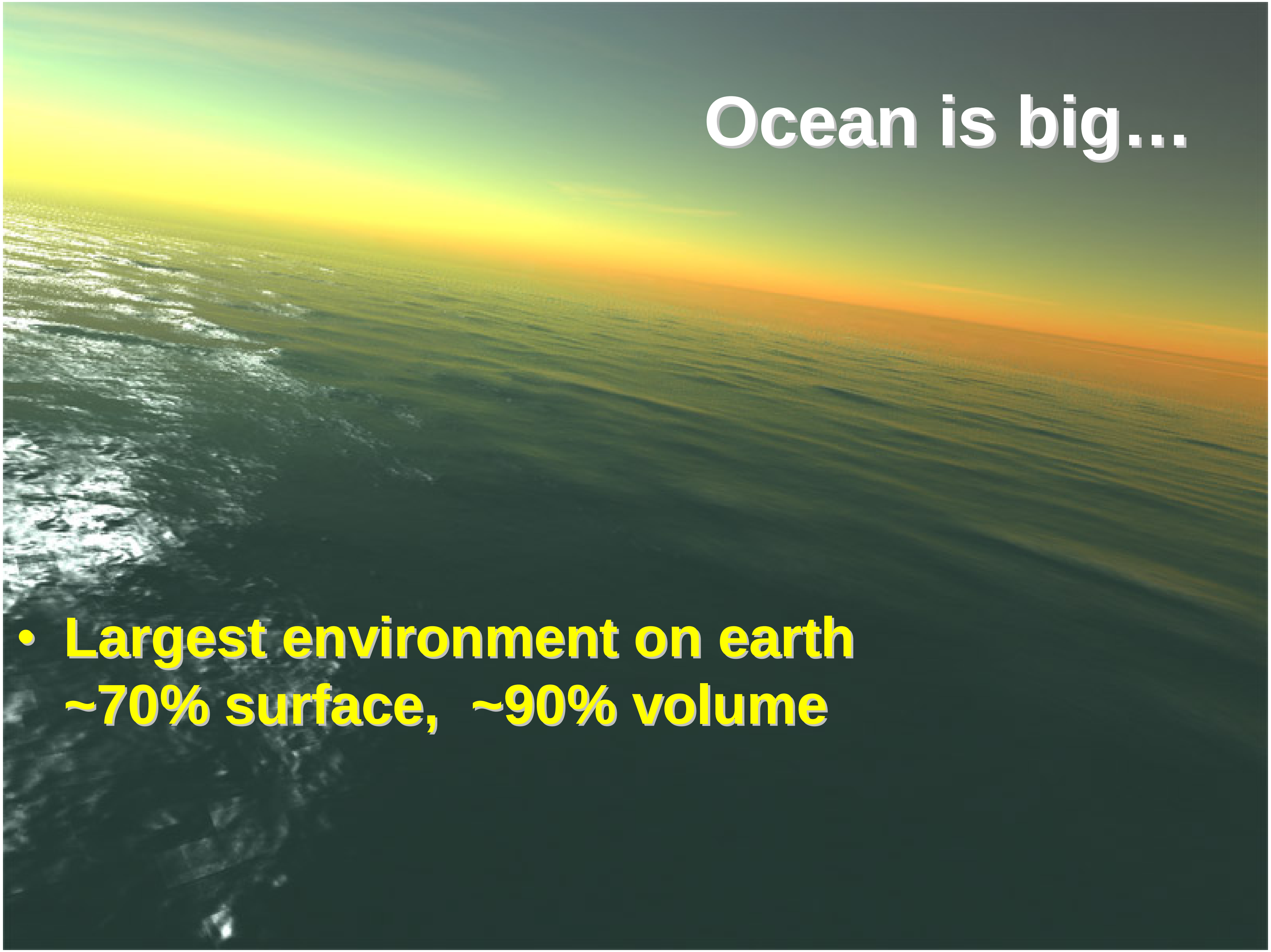
State of Marine Environment

Giulio De Leo

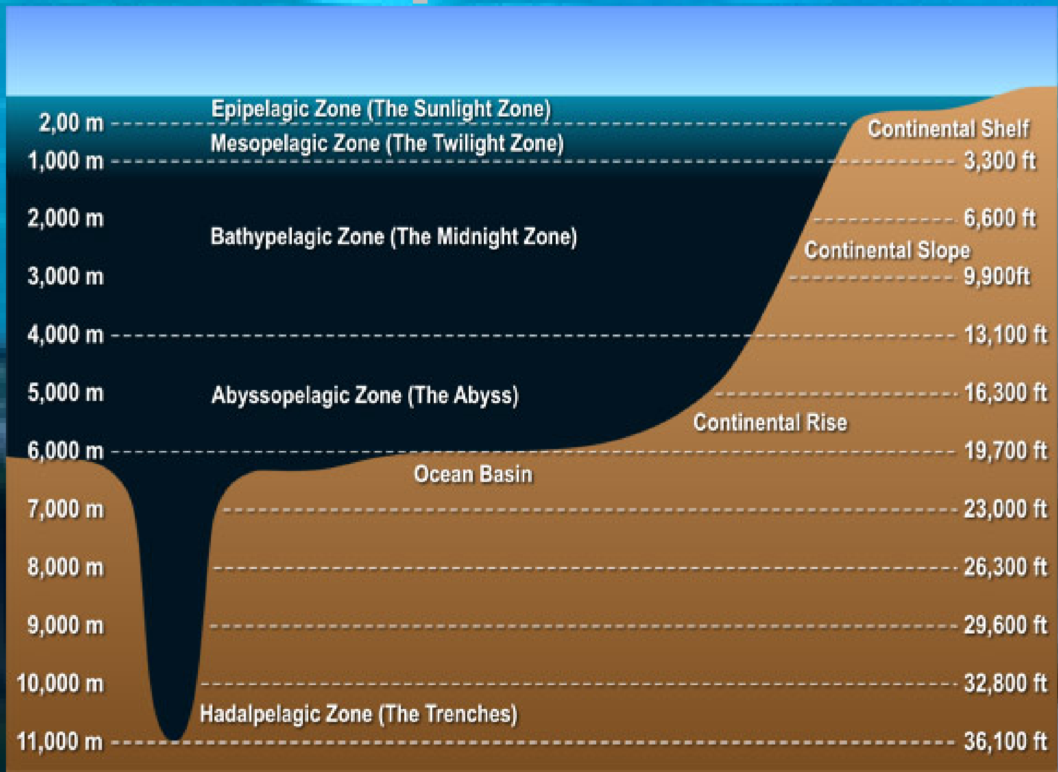
Dip. Scienze Ambientali
Università degli Studi di Parma, Italy
Email: giulio.deleo@unipr.it

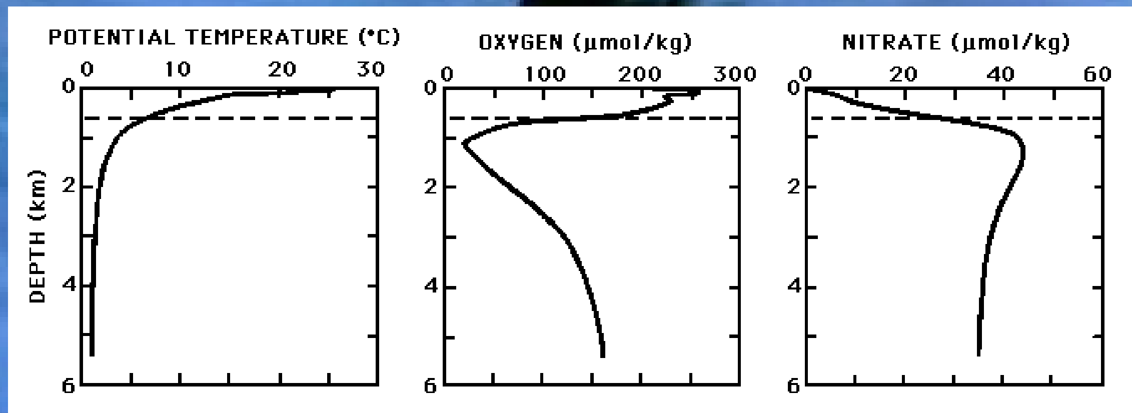
outline

- **The marine environment** → **Bio/Physical characteristics**
- **Why should we care?** → **Ecosystem services**
- **Shell we be worried?** → **Threats and impacts**
- **What can be done and how?** → **Ocean zoning, fishery management, Marine Reserves**


Ocean is big…
• Largest environment on earth
~70% surface, ~90% volume

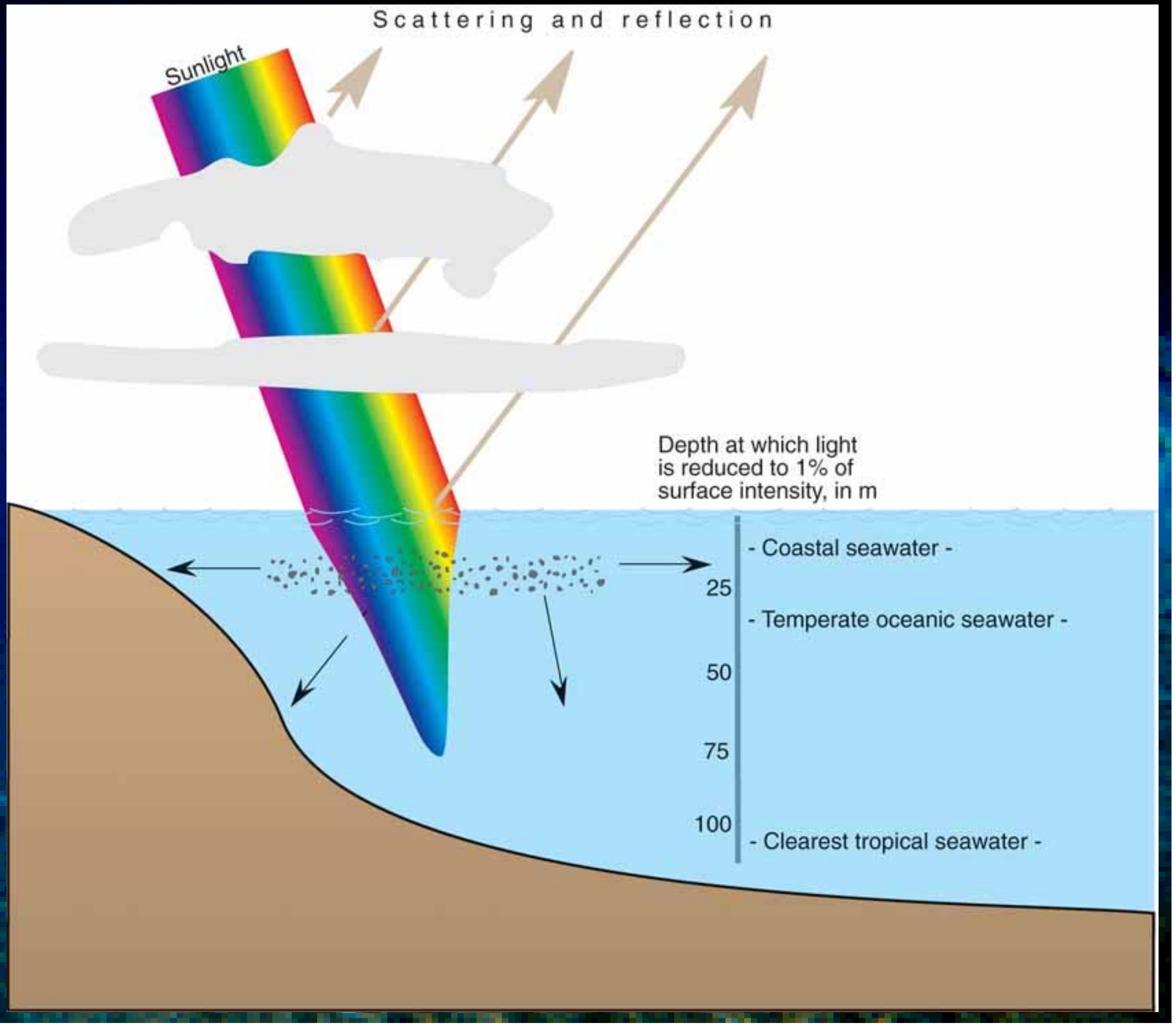
It is deep and 3D…





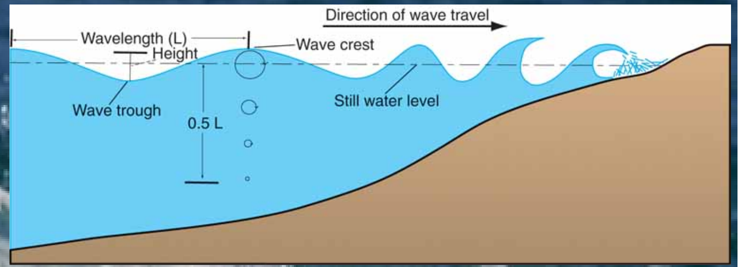
it is dense and dark…

- Medium: water 830 times denser than air (**pressure**). Greater ability to…
  - transmit **sound** (4 times greater than air)
  - absorb light (~98% **dark**)

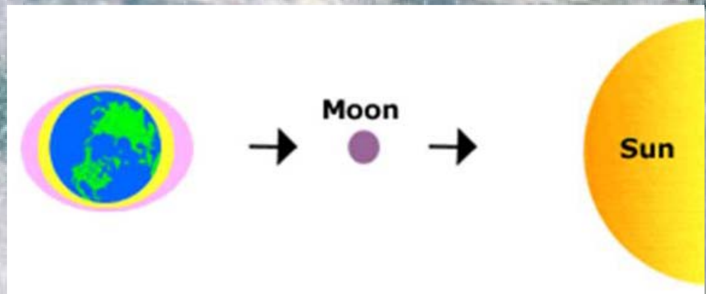


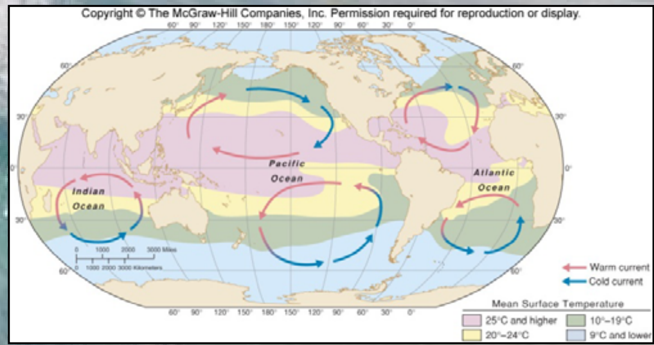
- It supports particles and large organisms afloat (plankton, macroalgae and inverts: lower investment in structural materials)

It is always in motion

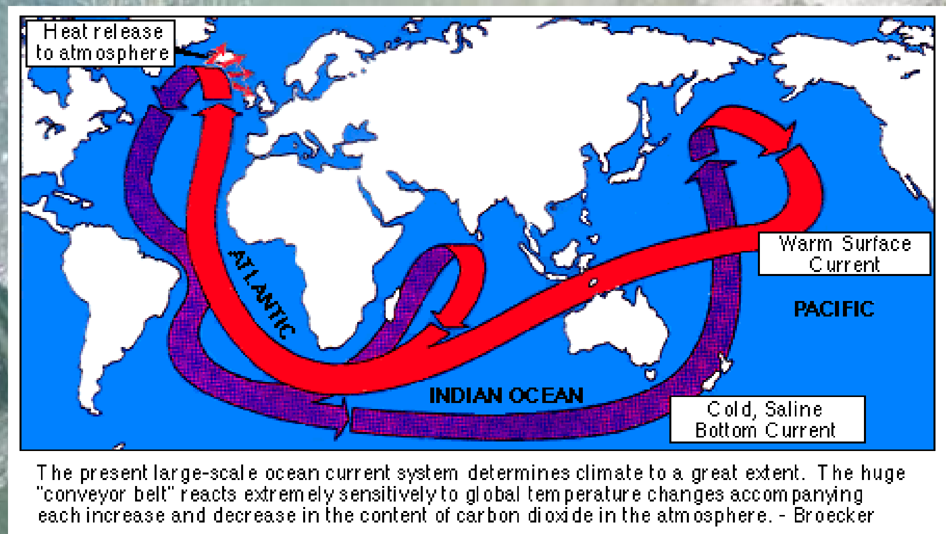


- Waves





- Tides
- Wind-driven circulation
- Density-driven circulation



Productivity

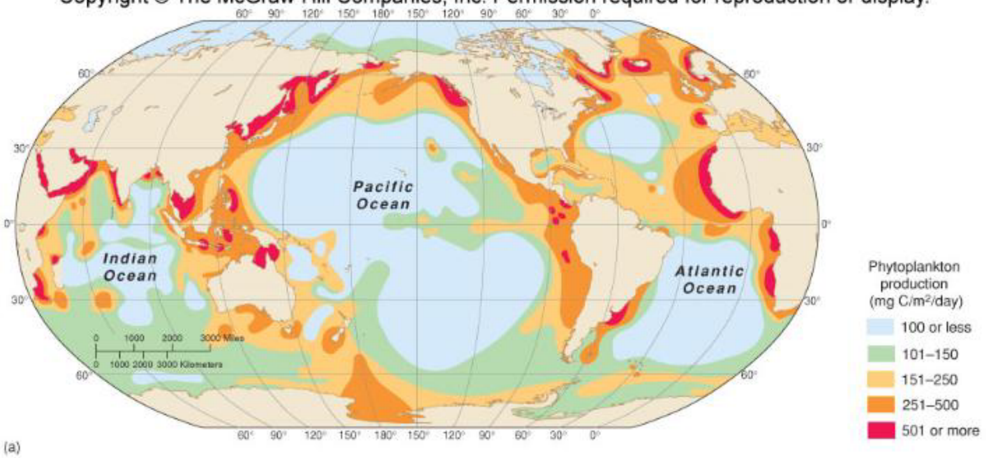


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Table 10.1 Typical Rates of Primary Production in Various Marine Environments

Environment	Rate of Production (Grams of Carbon Fixed/m^2/yr)
PELAGIC ENVIRONMENTS	
Arctic Ocean	<1–100
Southern Ocean (Antarctica)	40–260
Subpolar seas	50–110
Temperate seas (oceanic)	70–180
Temperate seas (coastal)	110–220
Central ocean gyres*	4–40
Equatorial upwelling areas*	70–180
Coastal upwelling areas*	110–370
BENTHIC ENVIRONMENTS	
Salt marshes	250–2,000
Mangrove forests	370–450
Seagrass beds	550–1,100
Kelp beds	640–1,800
Coral reefs	1,500–3,700
TERRESTRIAL ENVIRONMENTS	
Extreme deserts	0–4
Temperate farmlands	550–700
Tropical rain forests	460–1,600

Note: Production rates can be much higher at certain times or in specific locations, especially at high latitudes. Values for some selected terrestrial environments are given for comparison.

*See "Patterns of Production," p. 346.

Claudio Eliano (~170-230 ad)

"Man has explored only the upper layer of the sea. <u>I do not know *nor I care*</u> to find out whether at depth there are other fishes or marine monsters, or whether deep waters are inaccessible even to them"

(from "On animal nature")

Mosaics from emperor Adriano's hunting lodge.
Piazza Armerina, Sicily, 4th century ad

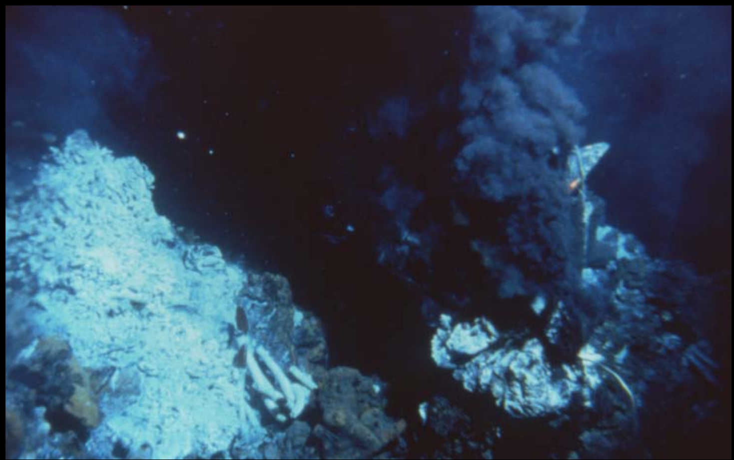
The discovery of the yeti crab, Kiwa hirsuta: new species, genus and family (*kiwaidae*)

- Described in December 2005, mentioned in newspaper article on March 7, 2006
- By 20 March 2006 over 200,000 web pages mentioned the yeti crab

Source: Bouchet 2006

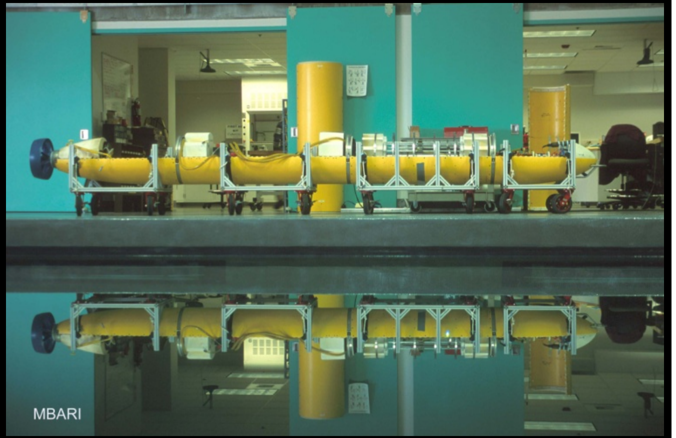
Deep sea hydrothermal vents:
'new' ecosystem discovered 30 years ago

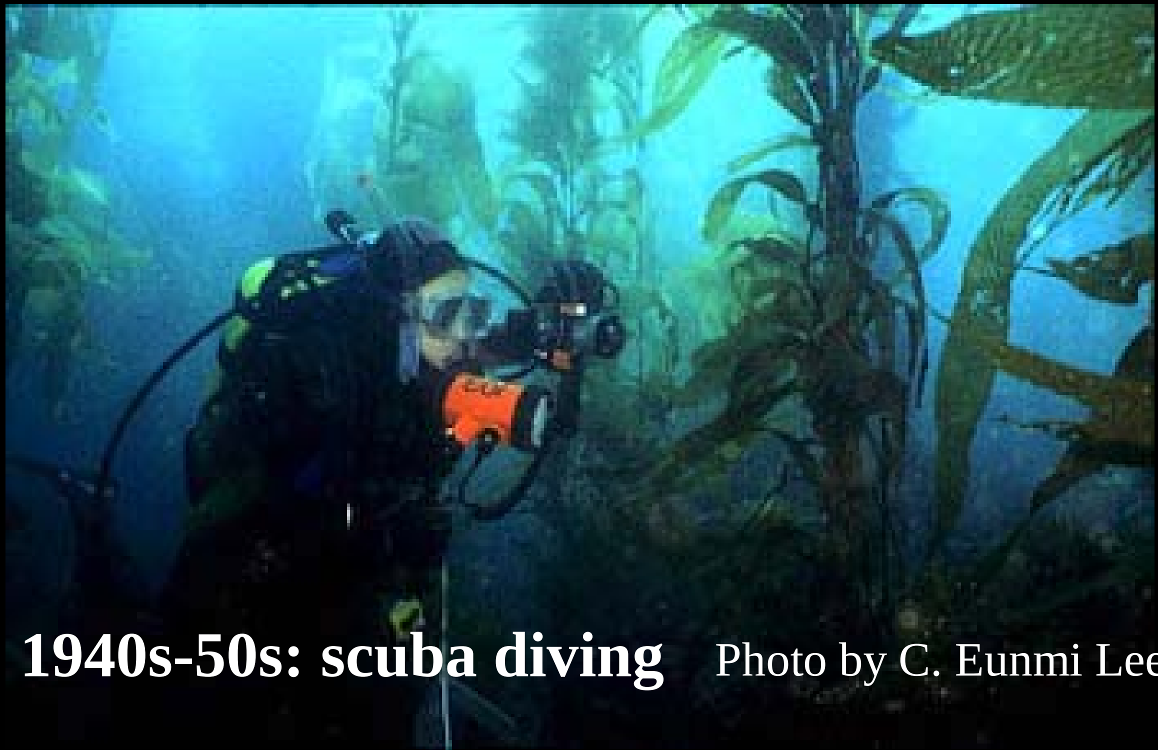
- Large numbers new species in poorly studied or unstudied habitats (e.g., deep sea),
- even families and one phylum, Cycliophora, discovered in recent years



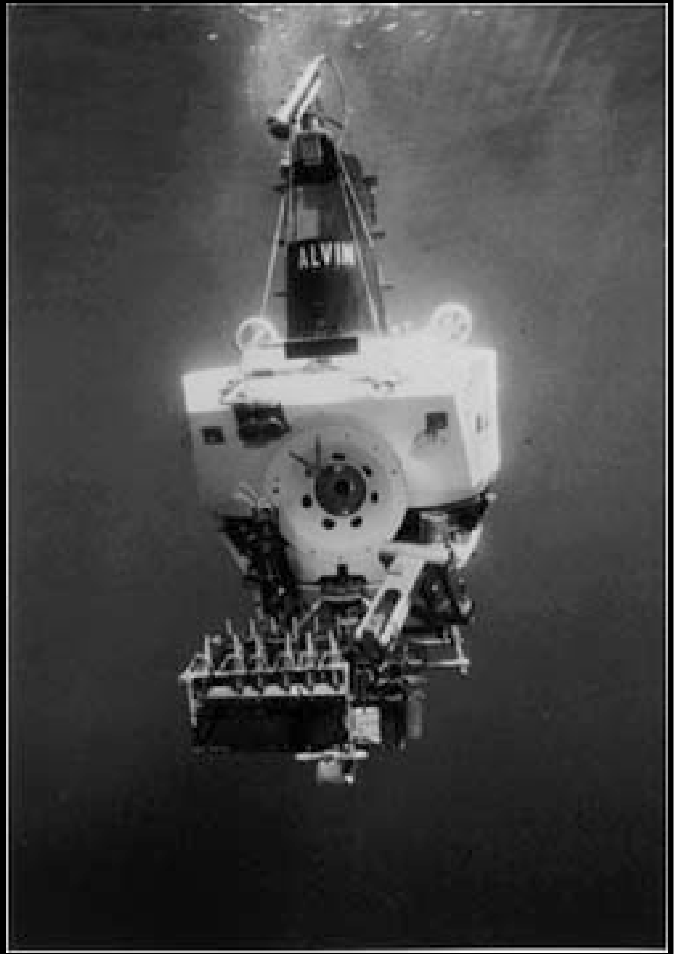
Marine biodiversity

- **Small portion of oceans explored**





1940s-50s: scuba diving Photo by C. Eunmi Lee



Much greater diversity at higher taxonomic levels in the sea than on land or freshwater

- **Of 82 eukariote phyla described,**
  - **60 have marine representatives compared to**
  - **40 on land**
  - **40 freshwater**

- **23 phyla are found only in the sea, including Echinoderms (~7000 species) and Foraminiferans ~4000 species)**

- **36 of 37 animal phyla have marine representatives (absent from oceans: velvet worms Onycophora)**

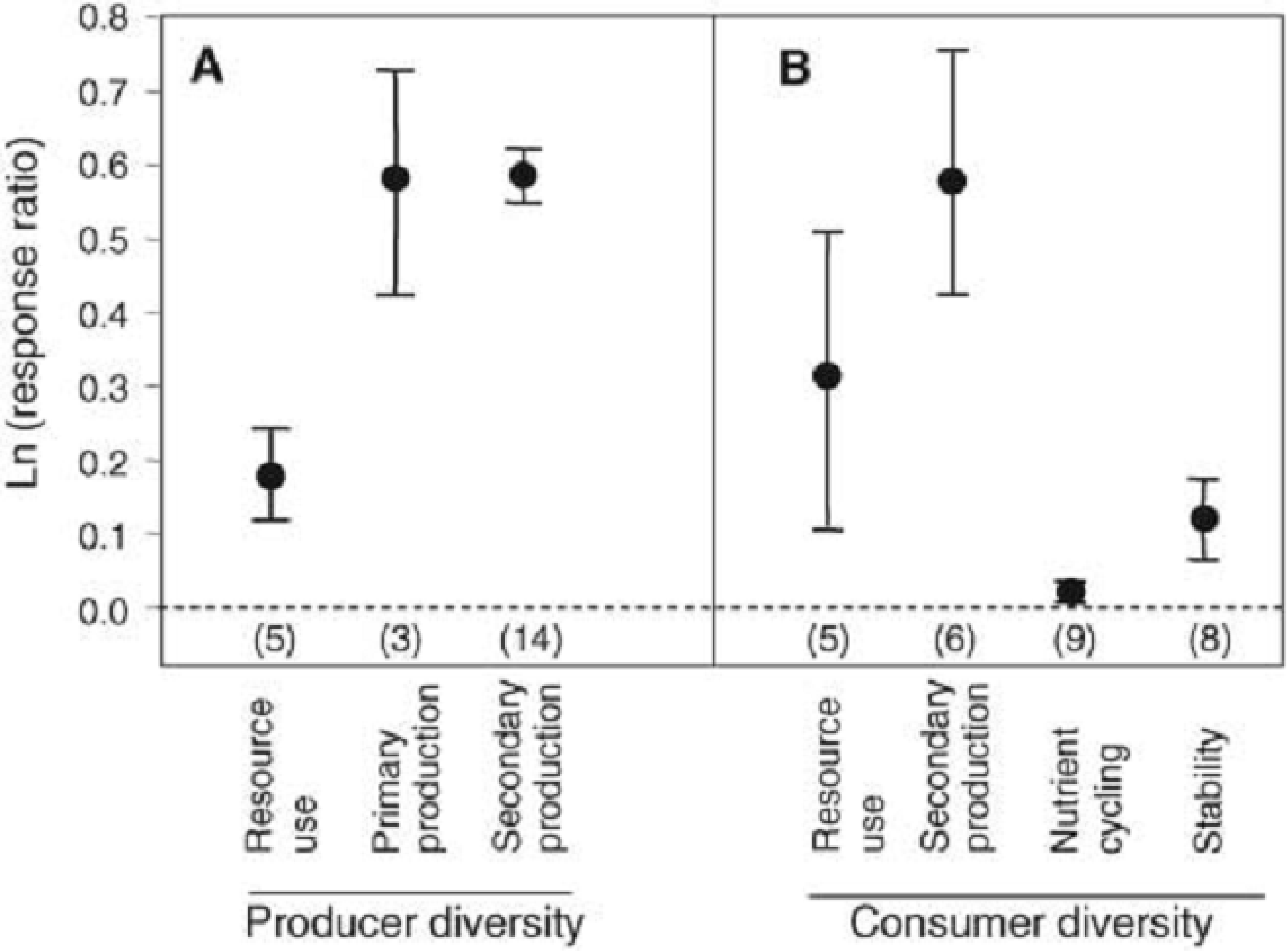
Source: Groombridge and Jenkins 2002. World Atlas of Biodiversity

Much greater species diversity on land or freshwater than in the sea

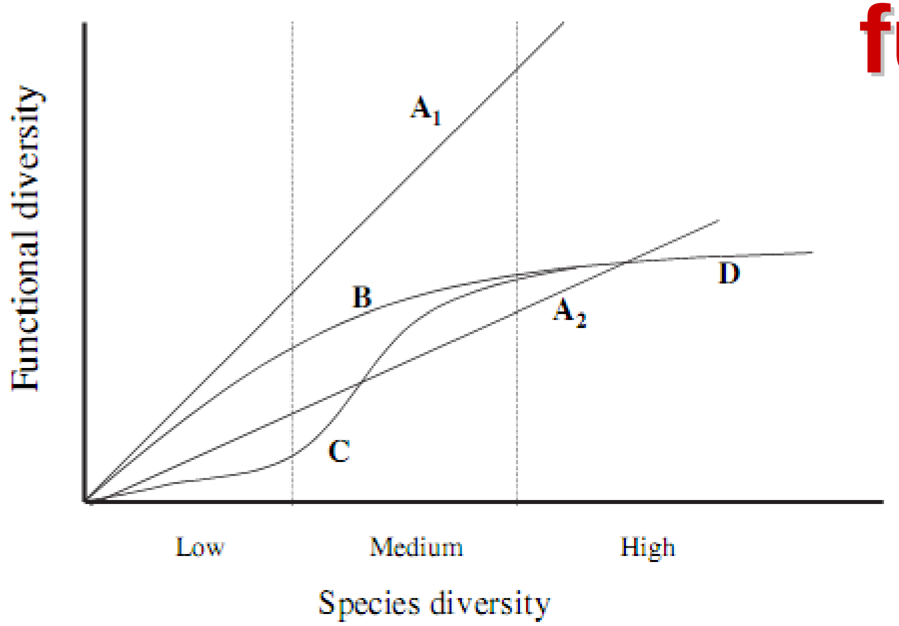
- 1.8 million species described to date,250,000 marine
- similar species diversity in the sea and freshwater, despite vastly different extent
- Possibly several millions of species still undescribed

Diversity begets stability, production and resource efficiency

(Worm et al. Science 2006)



Biodiversity vs. functional diversity



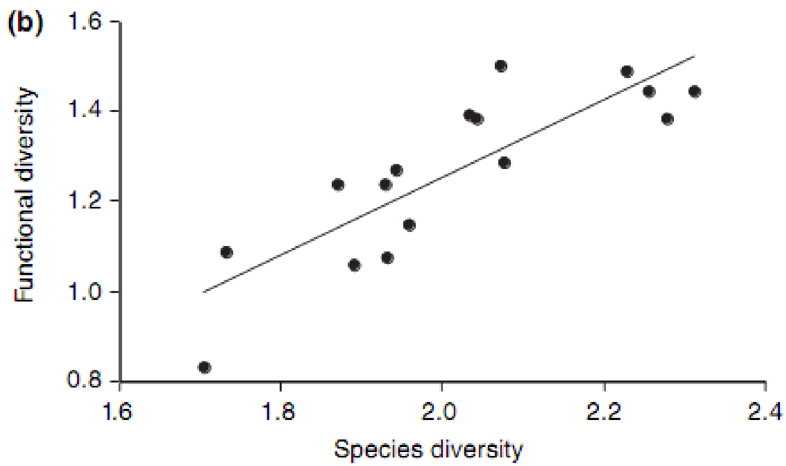


Figure 2 Relationship between functional and species richness (a), and functional and species diversity (b) across 16 rocky-reef locations sampled throughout the Channel Islands, CA. Each data point is the average richness or diversity over the 18 years of monitoring, at each of 16 rocky-reef locations.

Micheli & Halpern
Ecology Letters, 2005

Vol. 273: 291–302, 2004 | MARINE ECOLOGY PROGRESS SERIES Mar Ecol Prog Ser | Published June 8

Network structure and robustness of marine food webs

Jennifer A. Dunne[1,4,*], Richard J. Williams[2,4], Neo D. Martinez[3,4]

- **Main findings for the analysis of 4 marine foodwebs**
  - food webs from 4 different types of marine ecosystems share similar fundamental structural and ordering characteristics of other terrestrial foodwebs.
  - Given their relatively high connectance, marine food webs appear fairly robust to loss of most-connected taxa as well as random taxa.
  - Still, the short average path length between marine taxa (1.6 links) suggests that effects from perturbations, such as overfishing, can be transmitted more widely throughout marine ecosystems than previously appreciated.

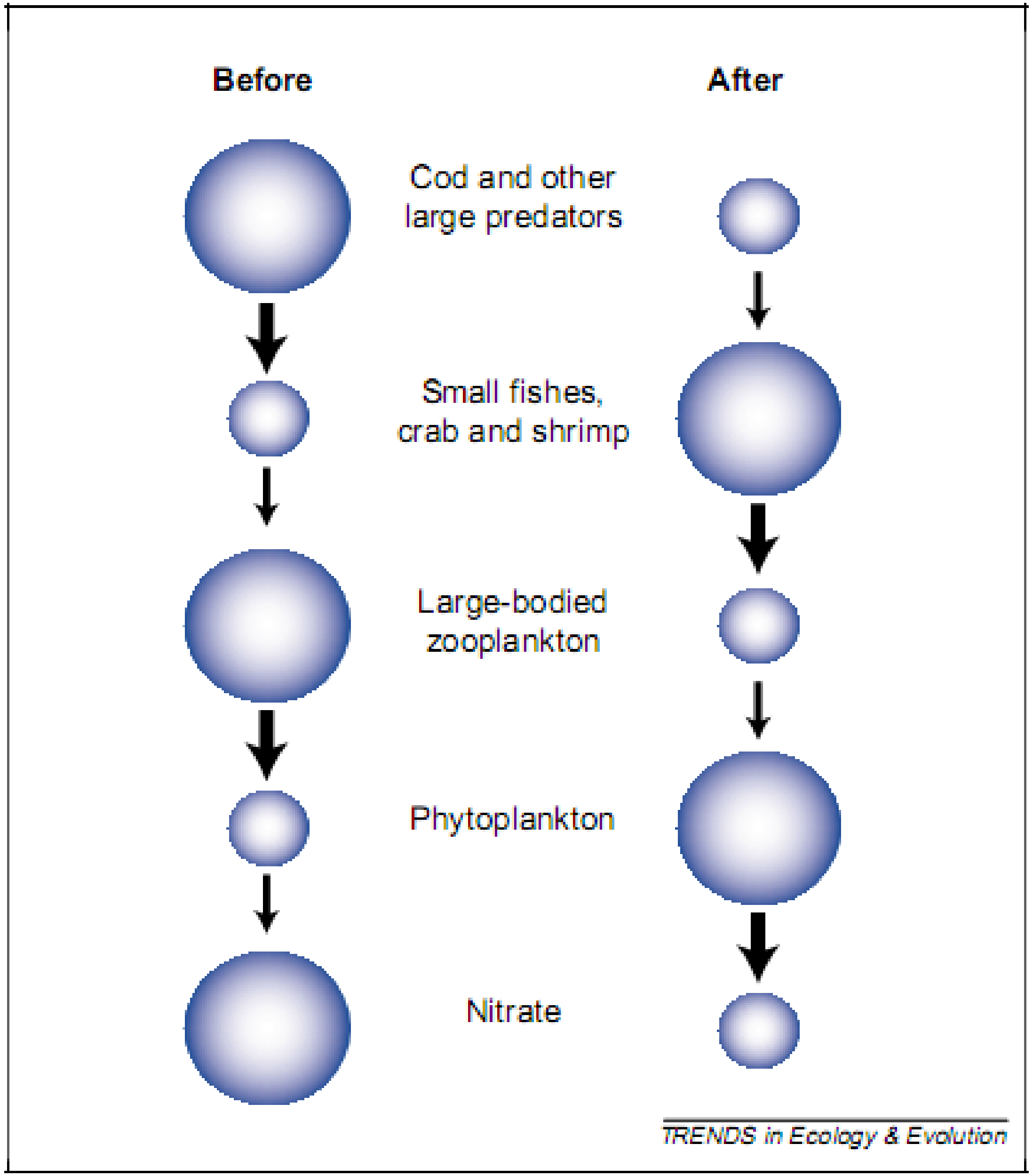


Figure 1. The cascading effect of the collapse of cod and other large predatory fishes on the Scotian Shelf ecosystem during the late 1980s and early 1990s. The size of the spheres represents the relative abundance of the corresponding trophic level. The arrows depict the inferred top-down effects.

Shaeffer et al. TREE 2005

outline

- The marine environment → Bio/Physical characteristics
- Why should we care? → Ecosystem services
- Shell we be worried? → Threats and Impacts
- What can be done? → Ecos. based management

Why shell we care about marine biodiversity?

- **Because human populations derive, directly or indirectly, benefits from ecosystems in terms of *ecosystem services and goods***

Table 18.1. Percentage of Animal Protein from Fish Products, 2000 (FAO 2003)

Region	Share of Animal Protein from Fish Products
	(percent)
Asia (excluding Middle East)	27.7
Oceania	24.2
Sub-Saharan Africa	23.3
Central America and Caribbean	14.4
North America	11.5
South America	10.9
Europe	10.6
Middle East and North Africa	9.0

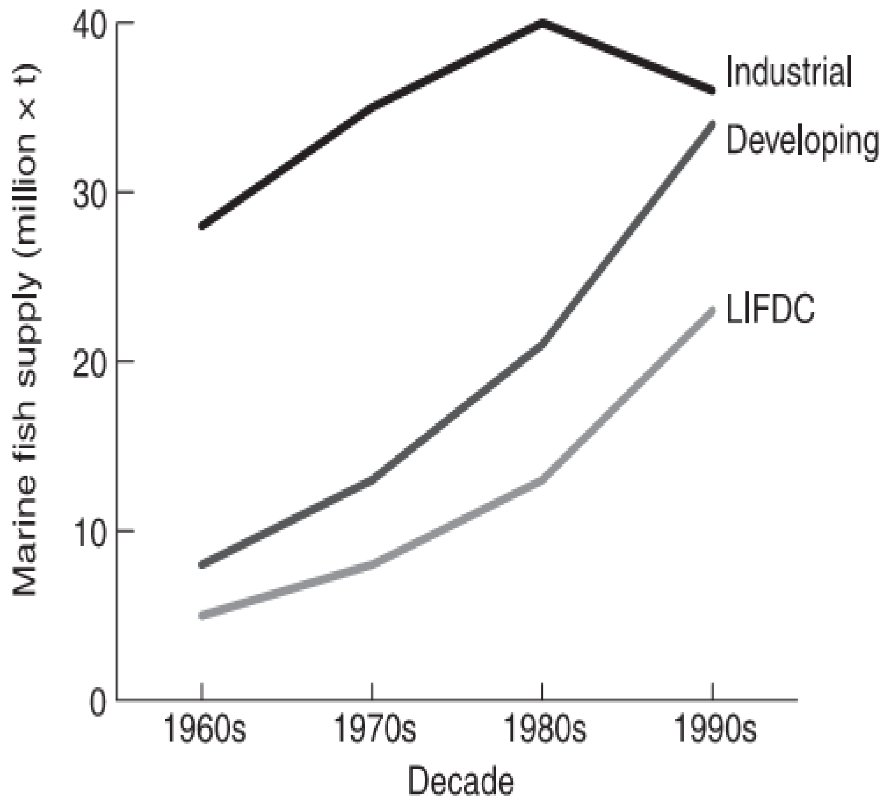


Figure 18.2. Average Domestic Marine Fish Supply, Lesser-Income Food-Deficit Countries, 1961–99 (FAO 2002)

Ecosystem Services

Services provided by ecosystems		
Provisioning Services *products obtained from ecosystems-*	**Regulating Services** *Benefits obtained from regulation of ecosystem processes*	**Cultural Services** *Nonmaterial benefits obtained from ecosystems*
Supporting Services *-Services necessary for the production of all other ecosystem services-*		

Source: adapted from MEA (2005)

Source: adapted from MEA (2005)

Ecosystem Services from coastal systems

Provisioning Services	Regulating Services	Cultural Services
-food – fish and shellfish -genetic resources -natural medicines and pharmaceuticals -ornamental resources - building materials	- carbon storage / climate regulation -erosion control -storm protection	-spiritual and religious values -knowledge systems / educational values -inspiration -aesthetic values -social traditions -sense of place -recreation and ecotourism
Supporting Services -sand formation -primary production		

Table 19.2. Summary of Ecosystem Services and Their Relative Magnitude Provided by Different Coastal System Subtypes. The larger circles represent higher relative magnitude.

Direct and Indirect Services	Estuaries and Marshes	Mangroves	Lagoons and Salt Ponds	Intertidal	Kelp	Rock and Shell Reefs	Seagrass	Coral Reefs
Food	●	●	•	●	•	●	•	●
Fiber, timber, fuel	●	⬤	●					
Medicines, other	•	•	•		●			•
Biodiversity	●	●	●	⬤	●	⬤	●	⬤
Biological regulation	●	⬤	●	•		•		●
Freshwater storage and retention	•		•					
Biochemical	•	•			•			•
Nutrient cycling and fertility	●	●	●	•	•	•		●
Hydrological	•		•					
Atmospheric and climate regulation	●	●	●	•		•	•	●
Human disease control	●	●	●	●		•	•	•
Waste processing	⬤	⬤	●			•	●	•
Flood/storm protection	●	●	•	•	•	●	●	⬤
Erosion control	●	⬤	•				•	•
Cultural and amenity	⬤	•	●	⬤	•	●	●	⬤
Recreational	⬤	•	•	⬤	•			⬤
Aesthetics	●	•	●	●				⬤

Source: MA 2005

How can we account for ecosystem services?

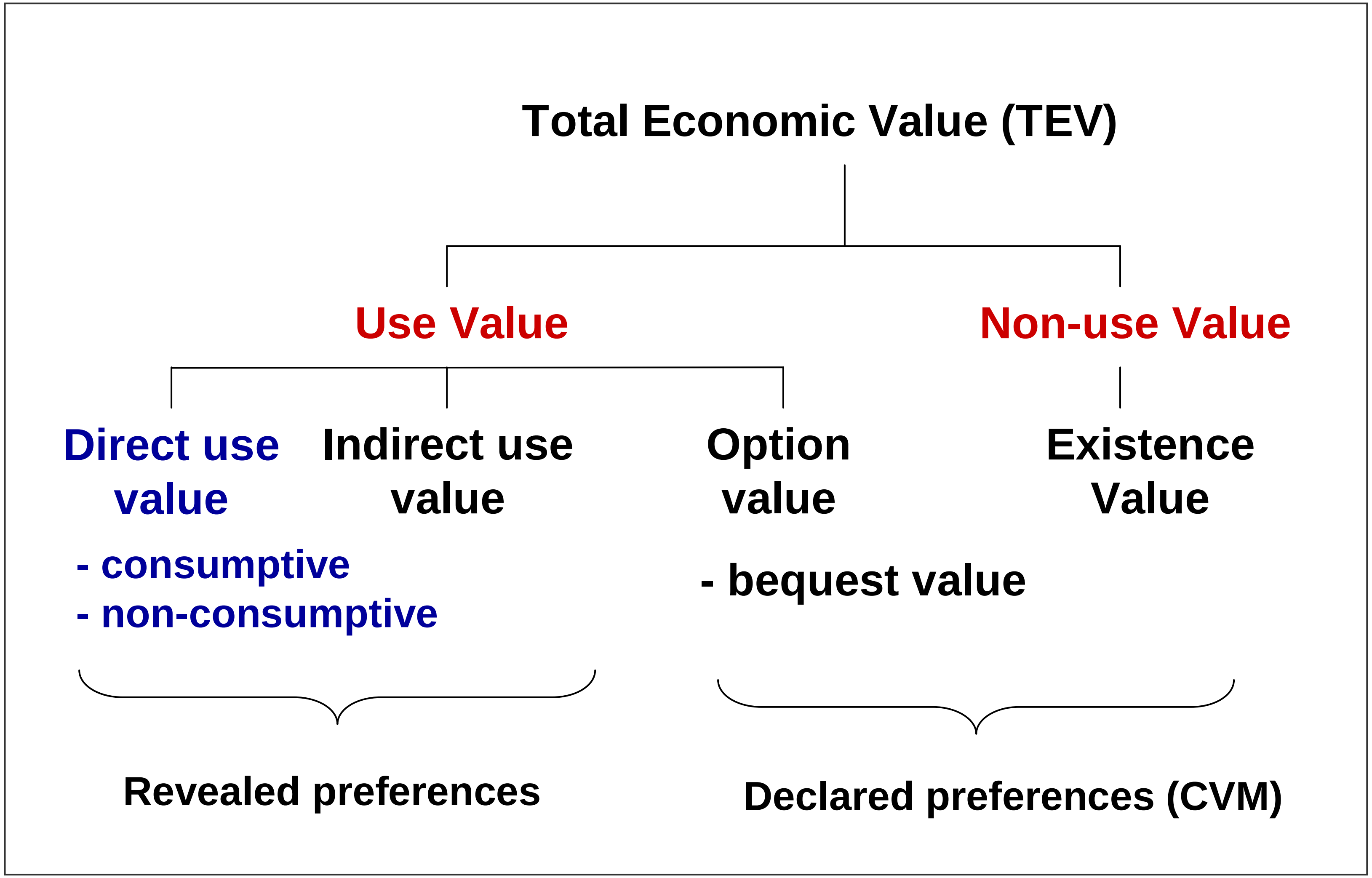
- Monetary valuation
  - – Cost benefit analysis
- Non-monetary valuation
  - – Multi- attribute analysis

- Ecosystem Based Management

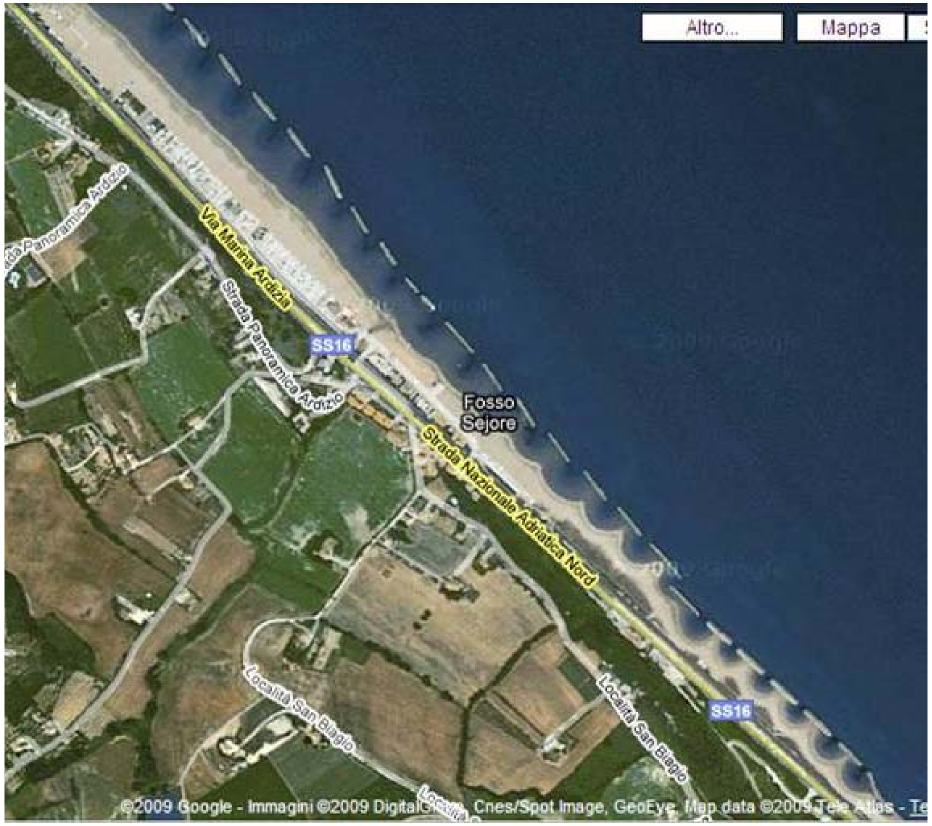
Purpose of Economic Valuation of Ecosystem Goods and Services

- **The purpose of economic valuation is to obtain reliable, objective information (in monetary terms) on the benefits and costs of conserving ecosystems so as to inform decision-making.**

Total Economic Valuation



An example: coastal protection



Mangroves and 2004 Tsunami

Mangrove Services:

- nursery and adult fishery habitat
- fuelwood & timber
- carbon sequestration
- traps sediment
- detoxifies pollutants
- protection from erosion & disaster

Mangroves and 2004 Tsunami

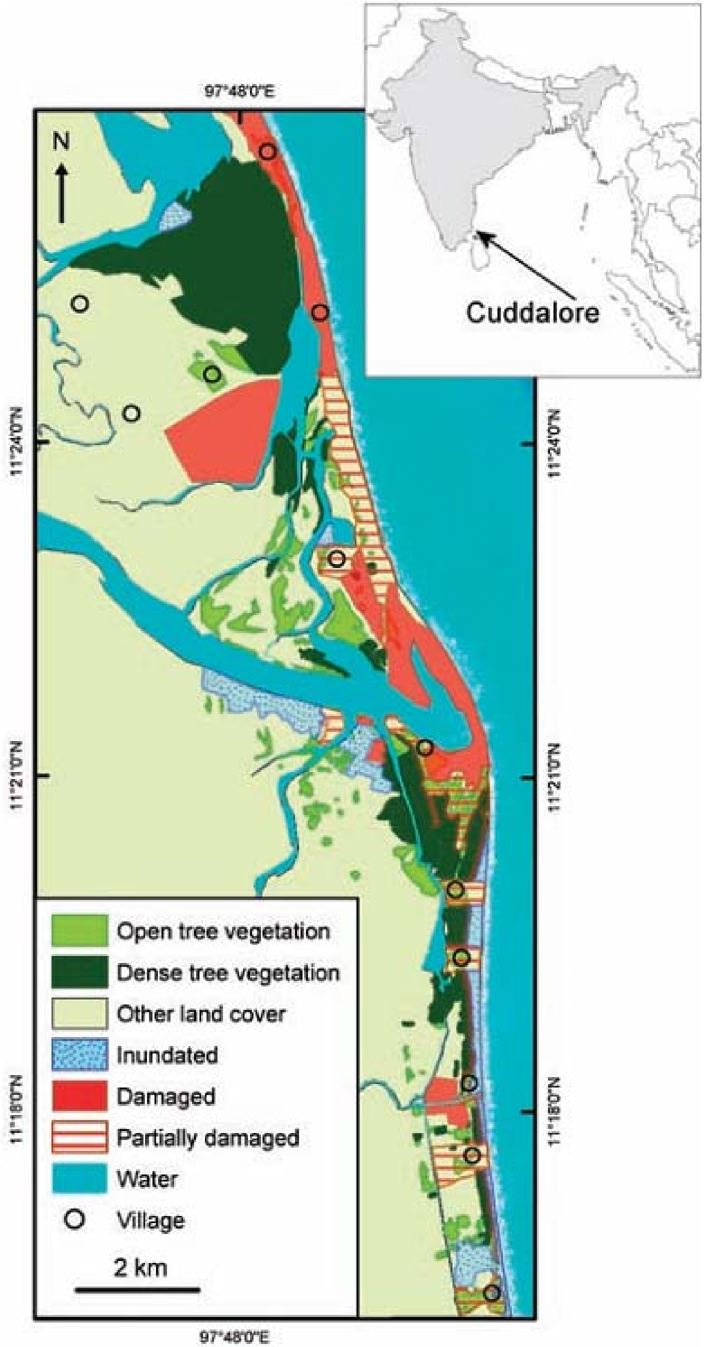
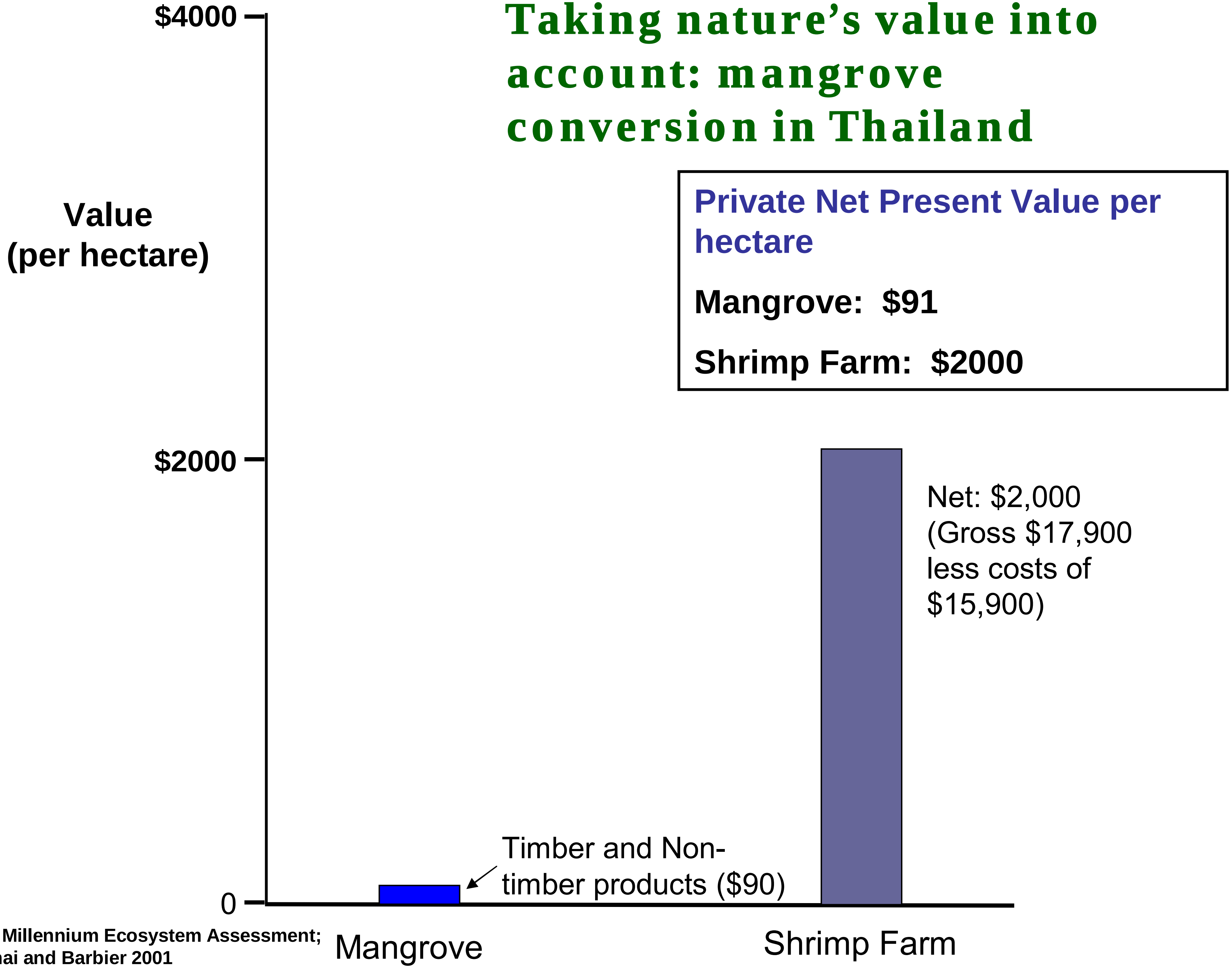


Fig. 1. Pre-tsunami tree vegetation cover and post-tsunami damages in Cuddalore District, Tamil Nadu, India.

Taking nature's value into account: mangrove conversion in Thailand



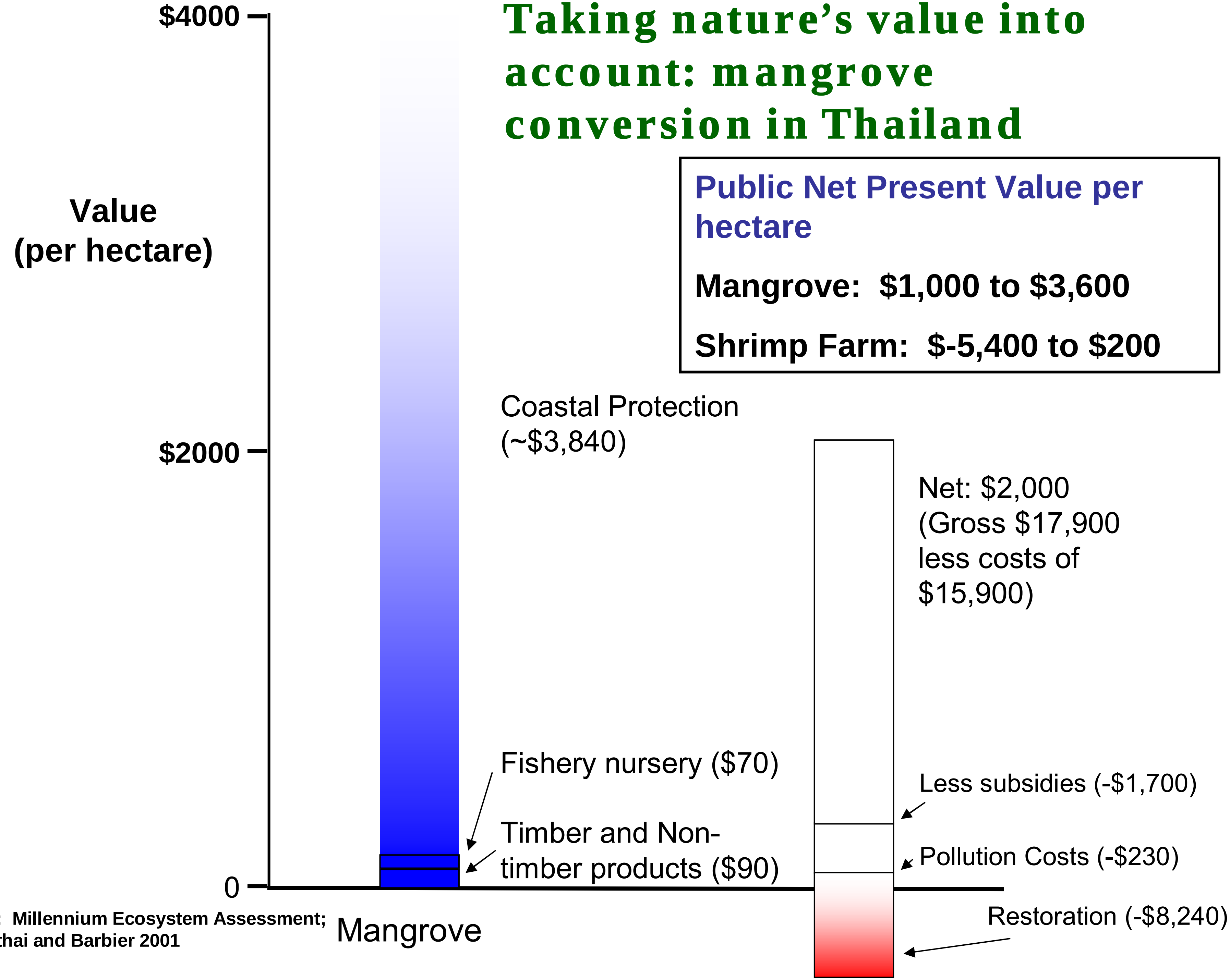
Source: Millennium Ecosystem Assessment; Sathirathai and Barbier 2001

Taking nature's value into account: mangrove conversion in Thailand

Public Net Present Value per hectare

Mangrove: $1,000 to $3,600

Shrimp Farm: $-5,400 to $200

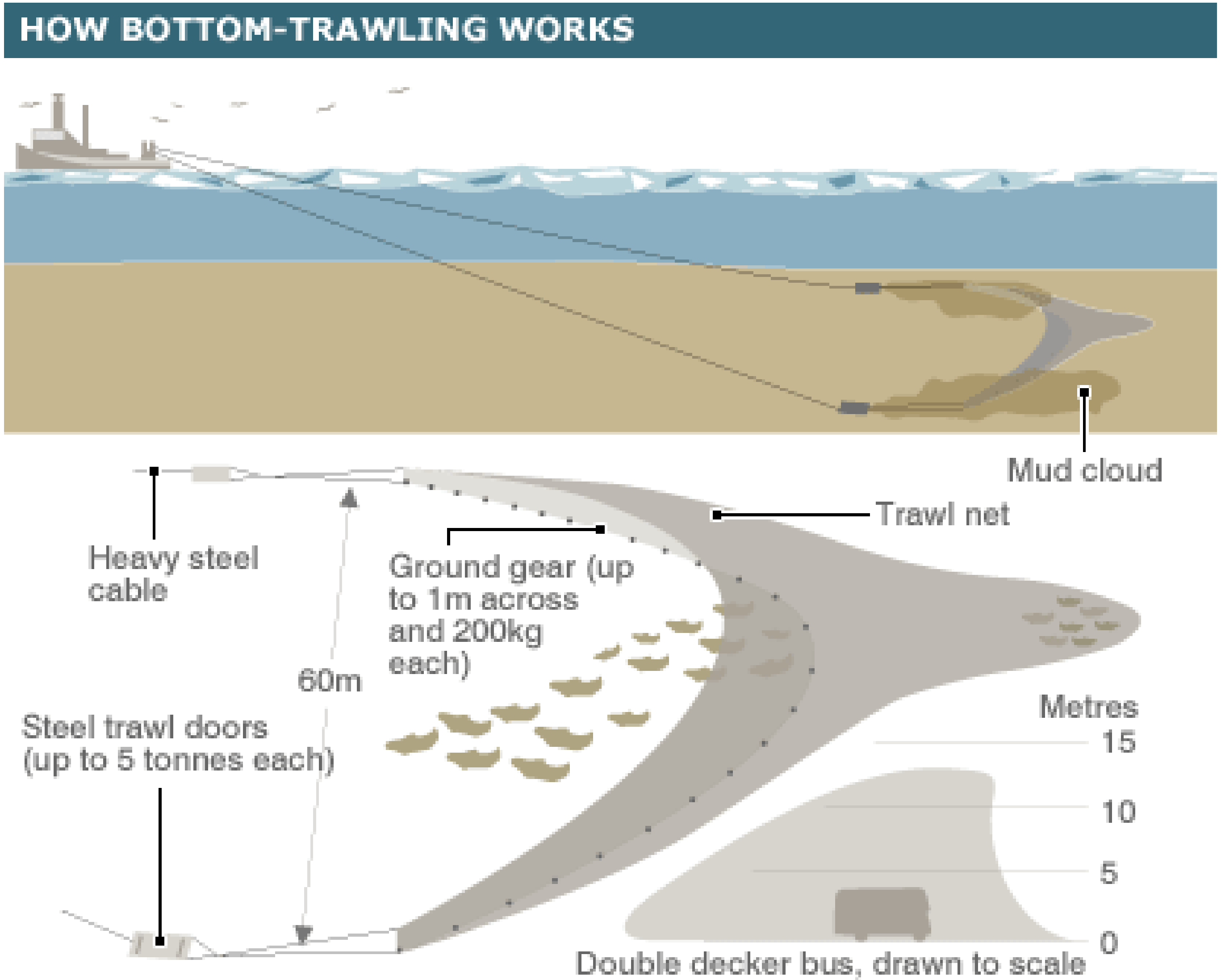


Source: Millennium Ecosystem Assessment; Sathirathai and Barbier 2001

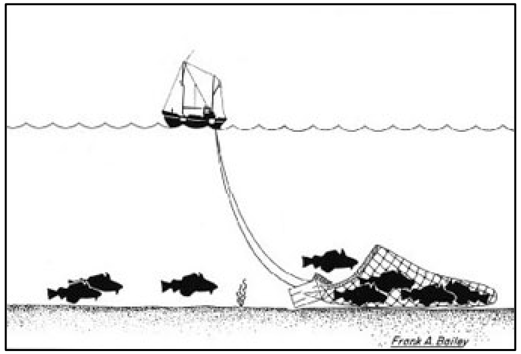
outline

- The marine environment → Bio/Physical characteristics
- Why should we care? → Ecosystem services
- **Shell we be worried? →Threats & Impacts**
- What can be done? → Ecos. based management

Habitat loss & alteration



HOW BOTTOM-TRAWLING WORKS
Mud cloud
Trawl net
Heavy steel cable
Ground gear (up to 1m across and 200kg each)
60m
Steel trawl doors (up to 5 tonnes each)
Metres
15
10
5
0
Double decker bus, drawn to scale



UNTRAWLED | **TRAWLED**

Oculina varicosa coral off northeast Florida (G. Gilmore and L. Horn, NURC/UNC)

Deep sea coral and sponge ecosystem off NW Australia (Sainsbury)

Diverse corals and sponges off Aleutian Islands, Alaska (NOAA Fisheries)

Pollution


Suspended sediment
• Increased turbidity
• Reduce productivity
• Change in settlement success
• Change in fish behavior

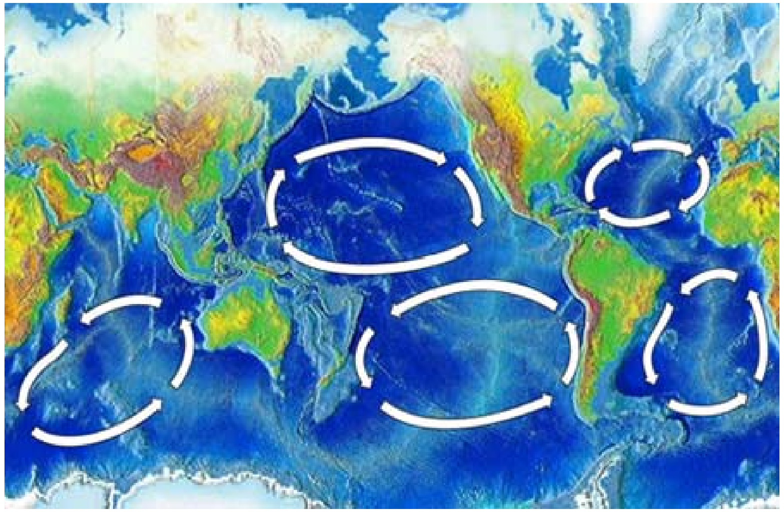
Organic pollution

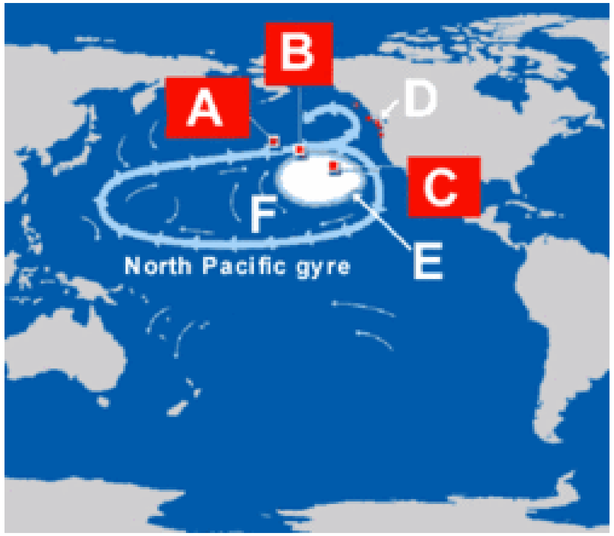
- Eutrophication and anoxic crises
- Harmful algal blooms
- Bottom-up effects (seaweed overgrowing coral communities)
- Coliform bacteria from sewage spills

Chemical pollution

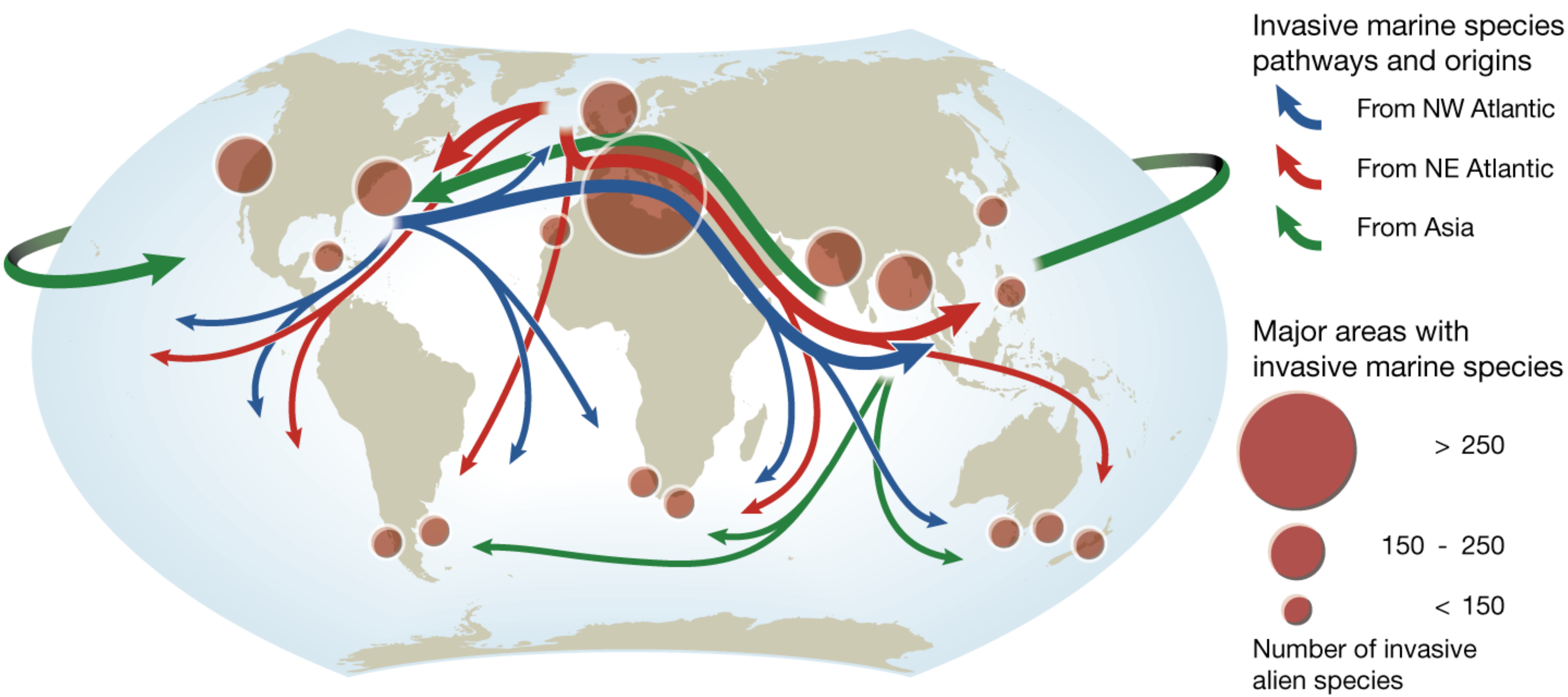
- herbicides and pesticides
- heavy metals
- oil and chemicals
- endocrines disruptors

Plastic pollution





Invasive species



Anguillicola crassus

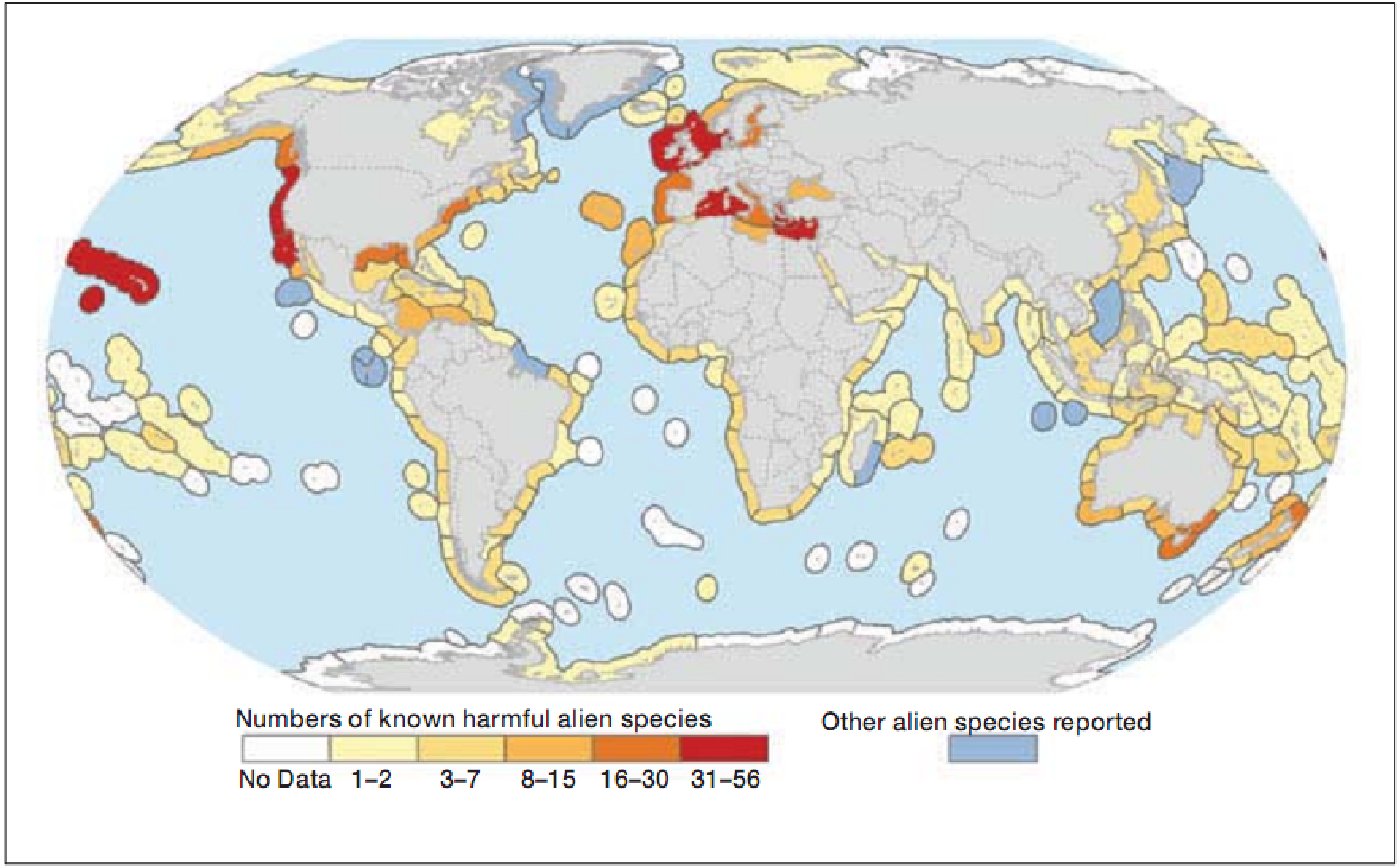
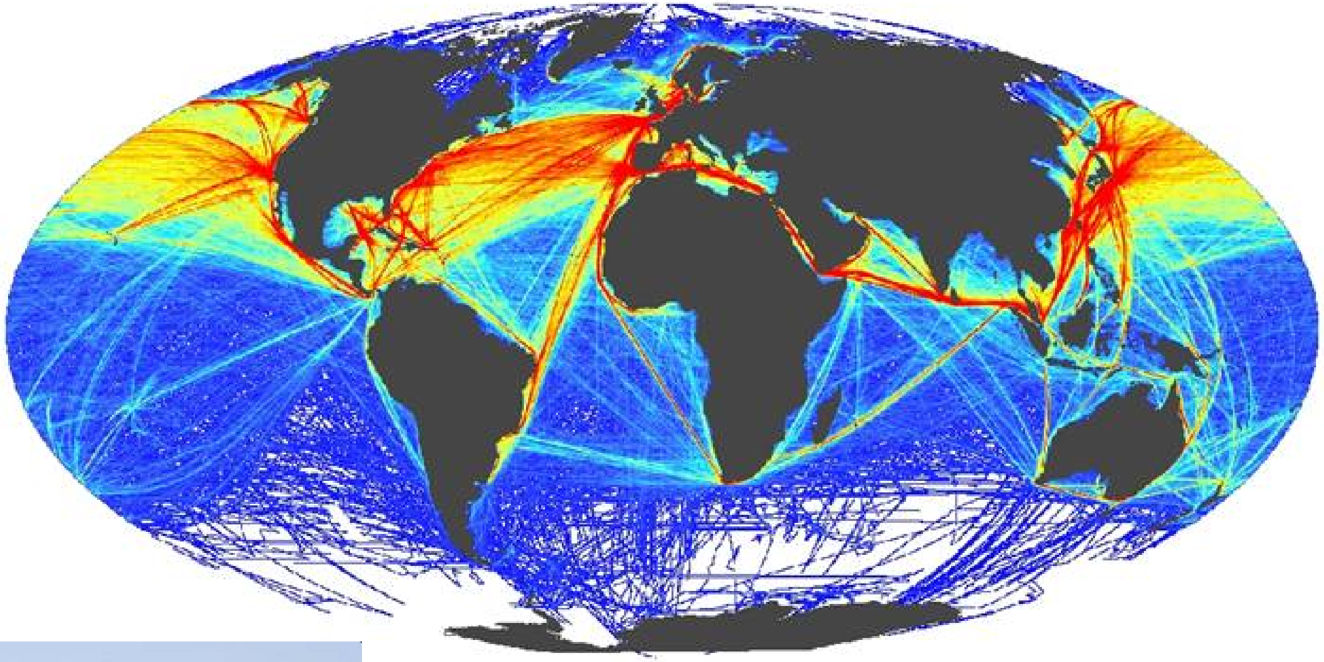
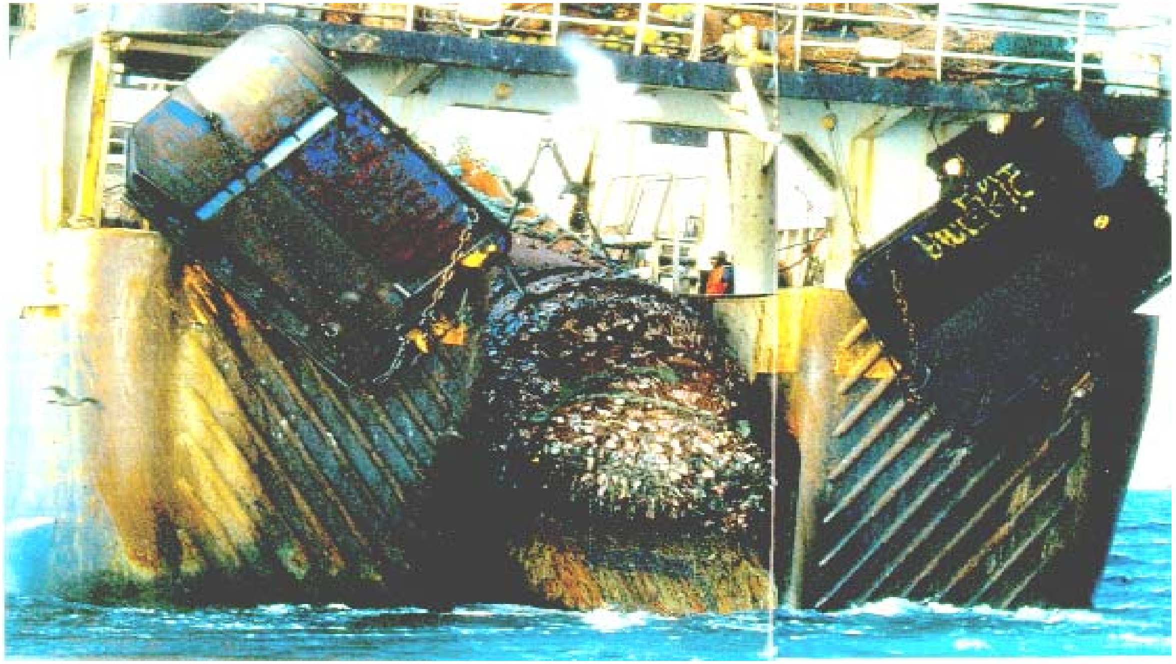


Figure 1. *Map of the number of harmful alien species by coastal ecoregion, with darker red shades indicating a greater number of species with high ecological impact scores (3 or 4). Ecoregions in which only less harmful species have been documented are shown in dark blue.*

Shipping



Overfishing



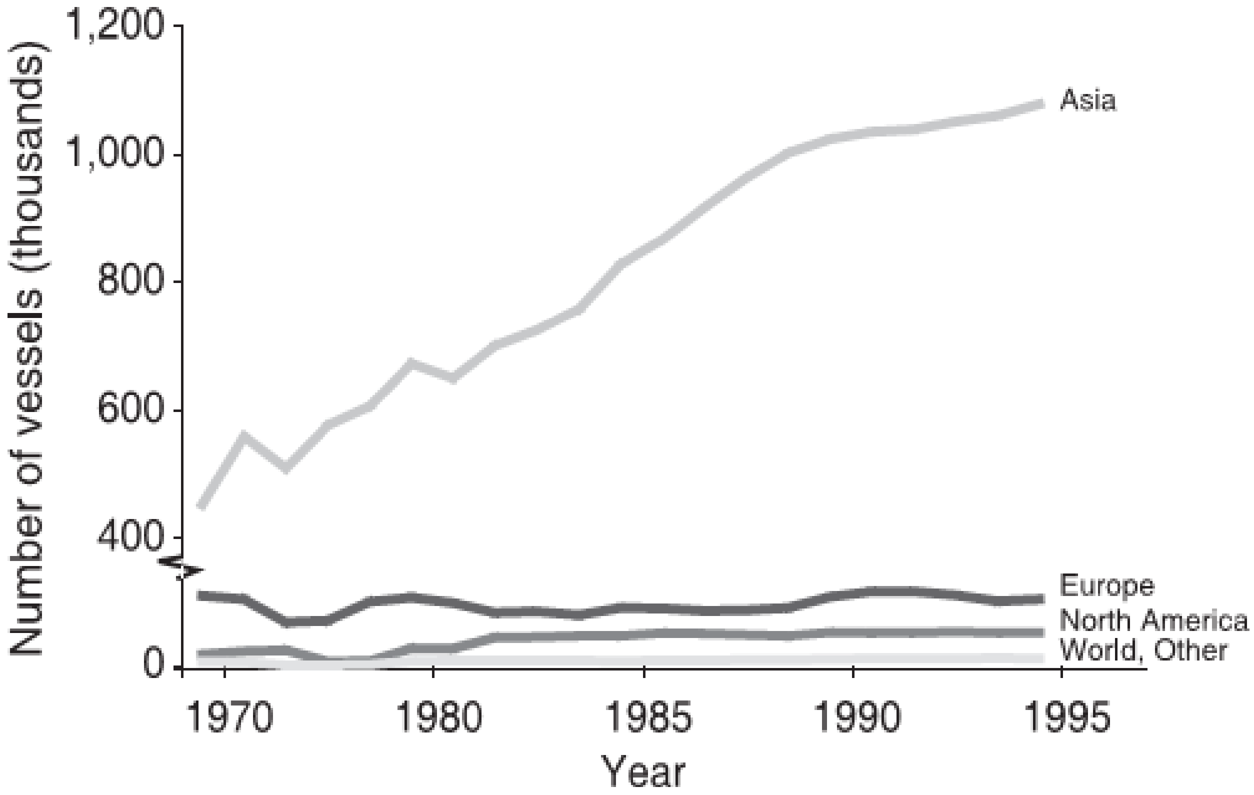
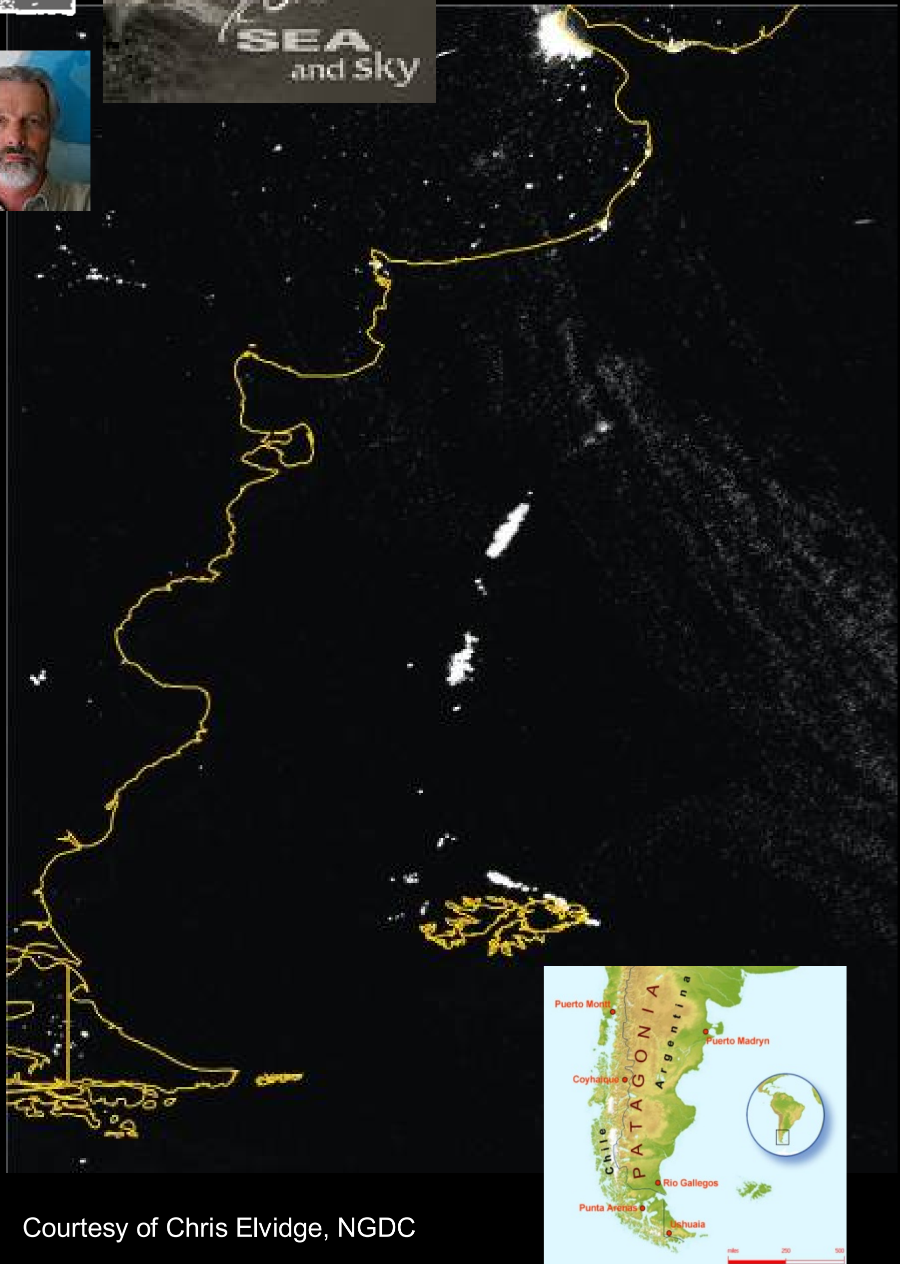


Figure 18.11. Trend in Fishing Vessels, 1976–2000 (FAO 2003)

Squid fishery: Patagonian Sea

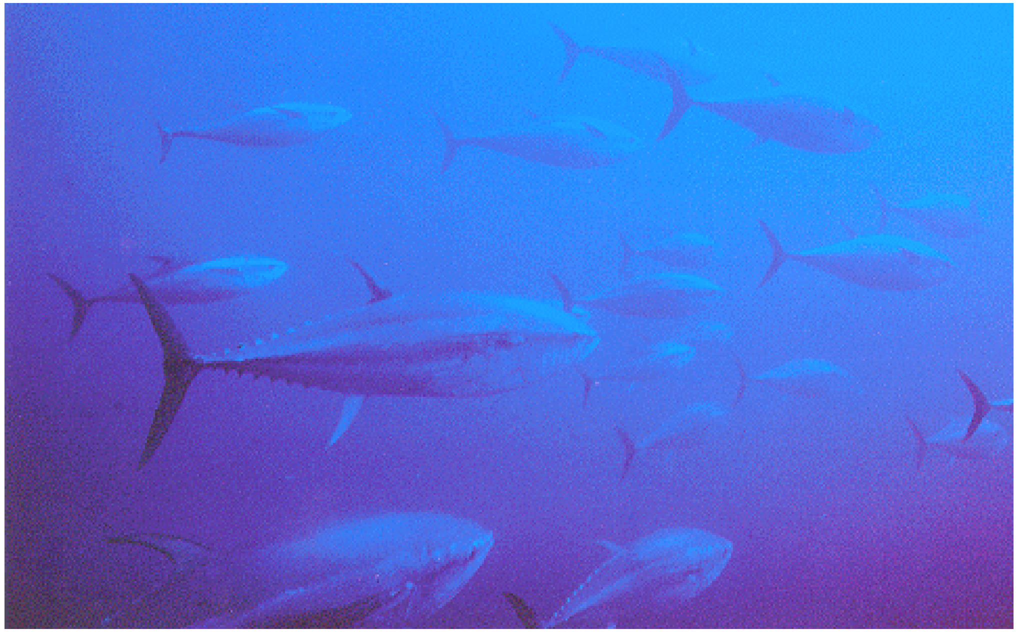


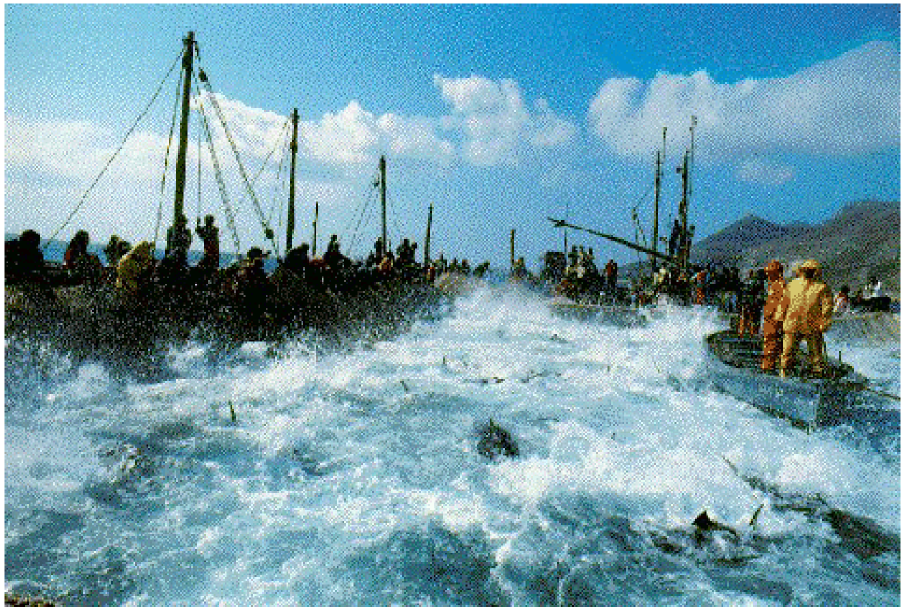
Courtesy of Chris Elvidge, NGDC

Escuadrilla aeronaval, Base Zar, Trelew, Argentina

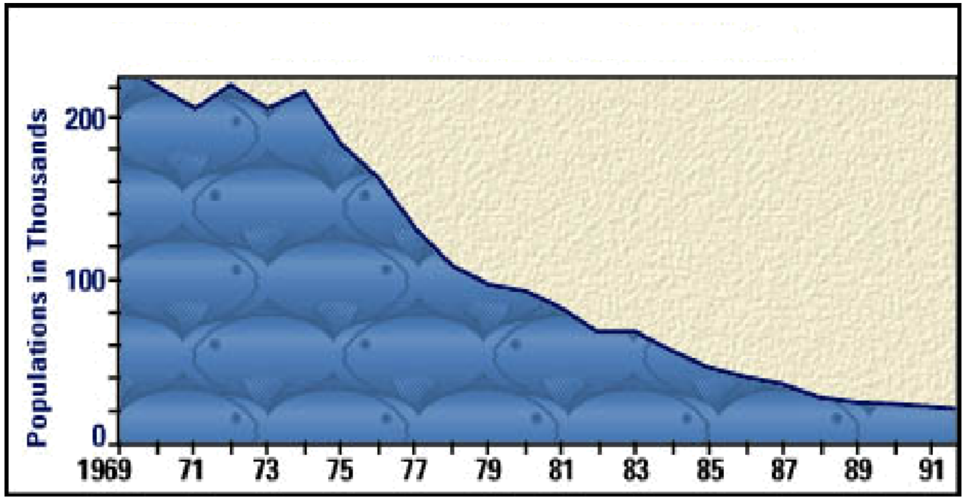
Stock	Peak Catch (year)	1981 Catch	Reference
Antarctic blue whales	29,000 whales (1931)	Nil	FAO[a] (1979)
Antarctic fin whales	27,000 whales (1938)	Nil	FAO[a] (1979)
Hokkaido herring	850,000 tons (1913)	Nil	Murphy (1977)
Peruvian anchoveta	12.3 million tons (1970)	0.3 million tons	IMARPE[b] (1974)
Southwest African pilchard	1.4 million tons (1968)	Nil	Butterworth (1980)
North Sea herring	1.5 million tons (1962)	Negligible	Saville (1980)
California sardine	640,000 tons (1936)	Nil	Murphy (1977)
Georges Bank herring	374,000 tons (1968)	Nil	Sinderman (1979)
Japanese sardine	2.3 million tons (1939)	17,000 tons (1973)	Murphy (1977)

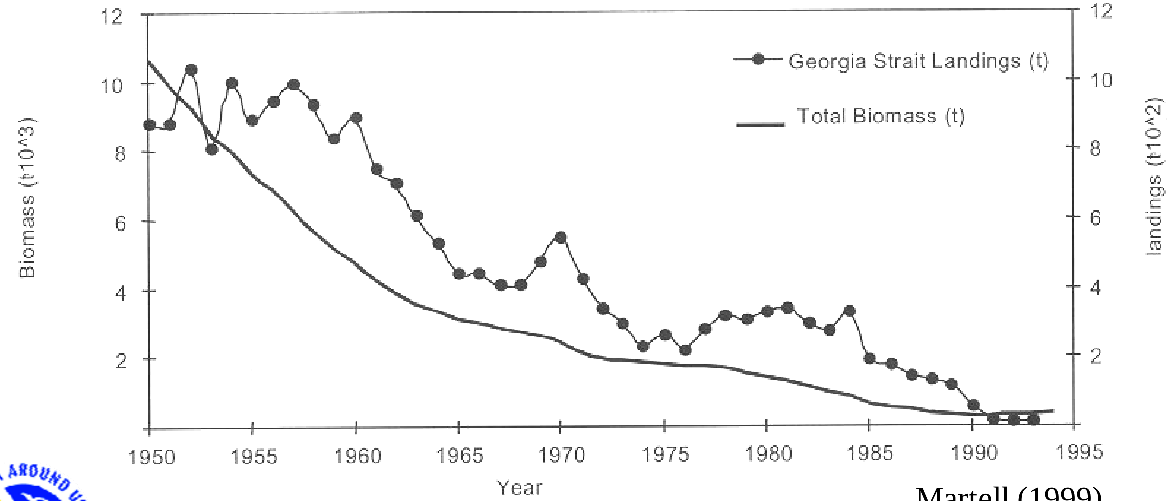
[a] United Nations Food and Agriculture Organization.
[b] Institut del Mar del Peru.





Bluefin tuna in the Atlantic …



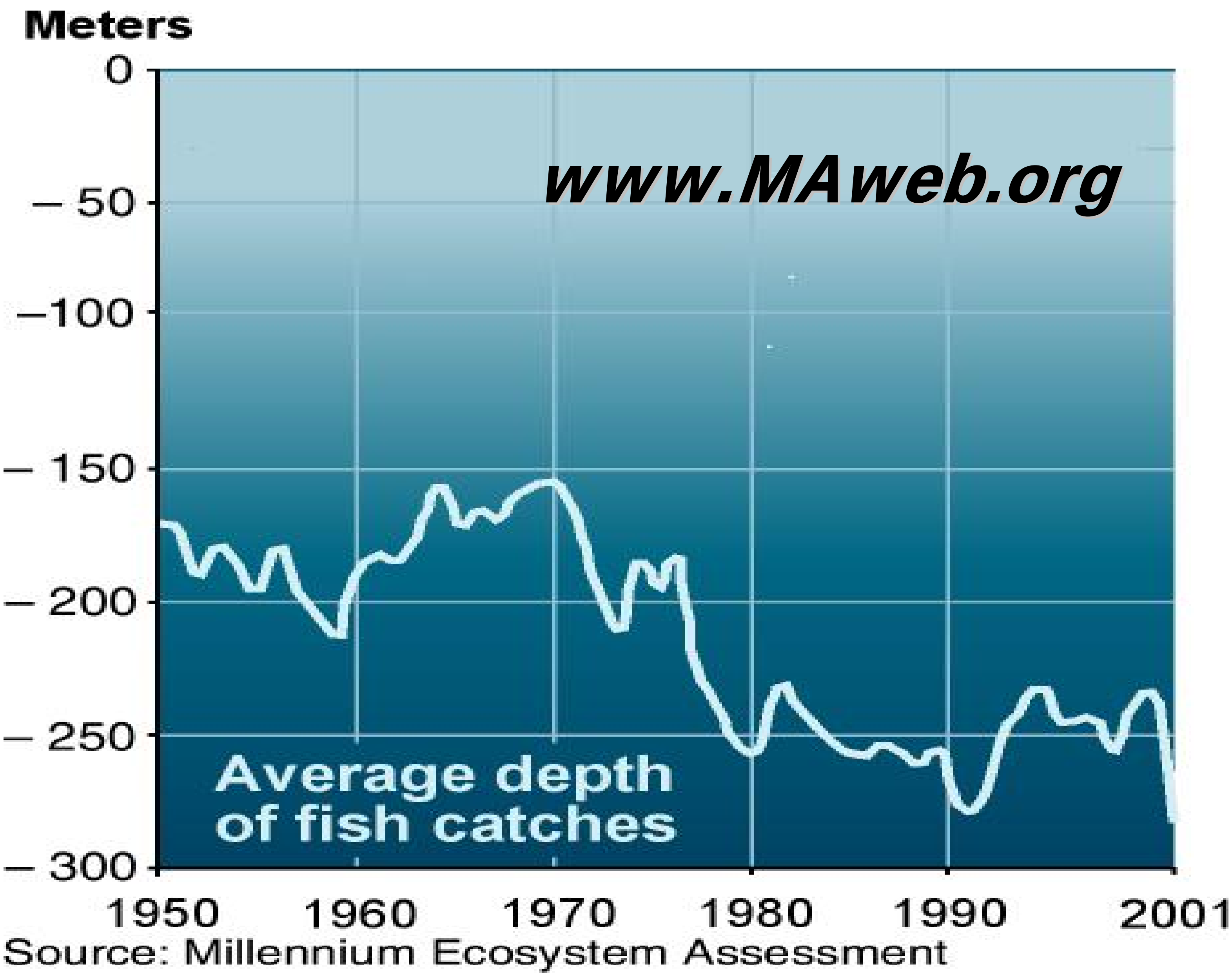


Martell (1999)

Lingcod in British Columbia …

Global assessments of stock biomass (FAO 2004) support the conclusions that

- **a remarkable fraction of the world's fished biodiversity is overexploited or depleted (*24% of assessed stocks in 2003*)**
- **this fraction is increasing (*from 10% in 1974*),**
- **recovery of depleted stocks under intense management is still an exception (*1% in 2003*).**


Meters
0
– 50
–100
– 150
– 200
– 250
– 300
www.MAweb.org
Average depth
of fish catches
1950
1960
1970
1980
1990
2001
Source: Millennium Ecosystem Assessment

by-catch

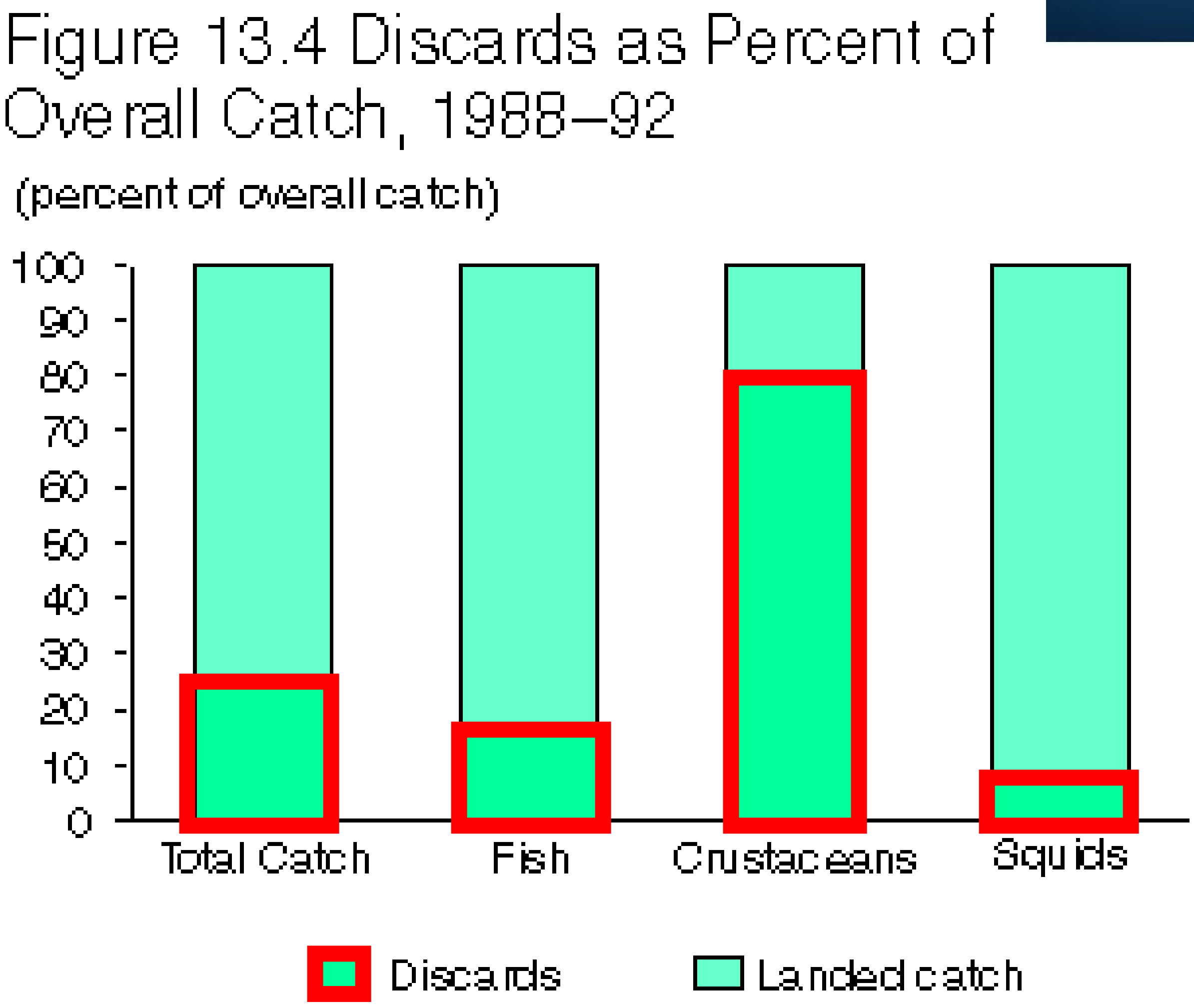
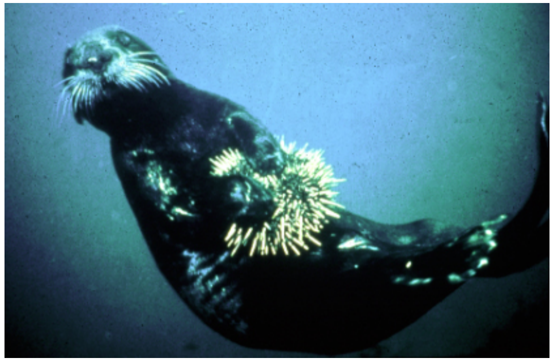


Figure 13.4 Discards as Percent of Overall Catch, 1988–92
(percent of overall catch)
100
90
80
70
60
50
40
30
20
10
0
Total Catch
Fish
Crustaceans
Squids
Discards
Landed catch

Exploitation of marine resources:

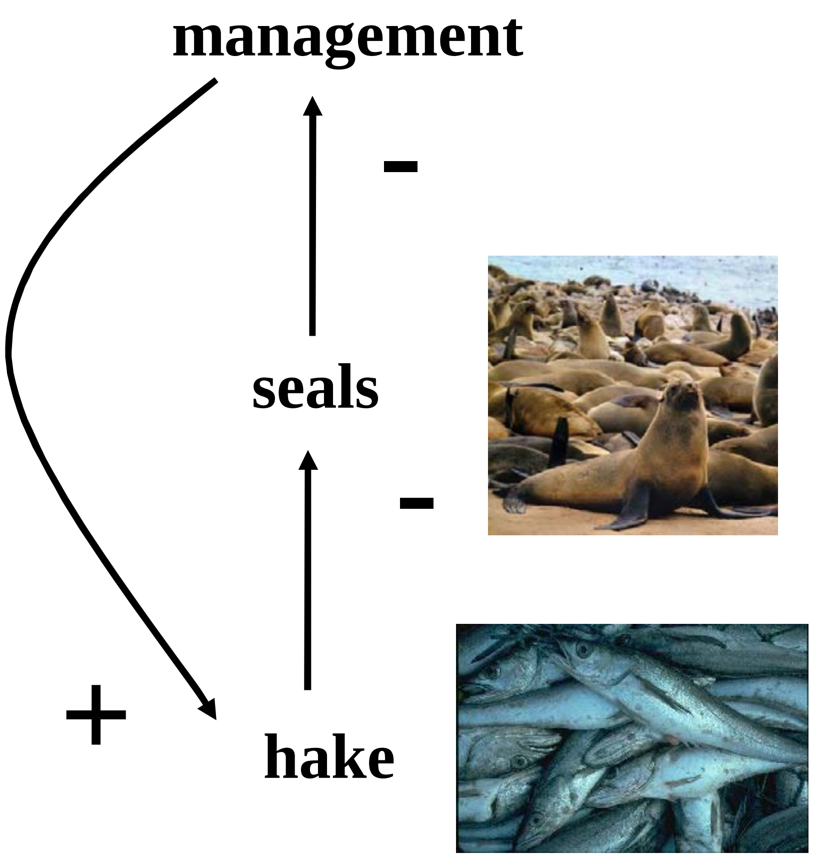
- Direct impacts on target species
- Impacts on non-target species (e.g. bycatch)
- Impacts on habitat and other indirect effects (e.g., competition for prey and trophic cascades)

Single species can have disproportionate influences: trophic cascades in kelp forests



Estes and Palmisano 1974; Estes and Duggins 1995

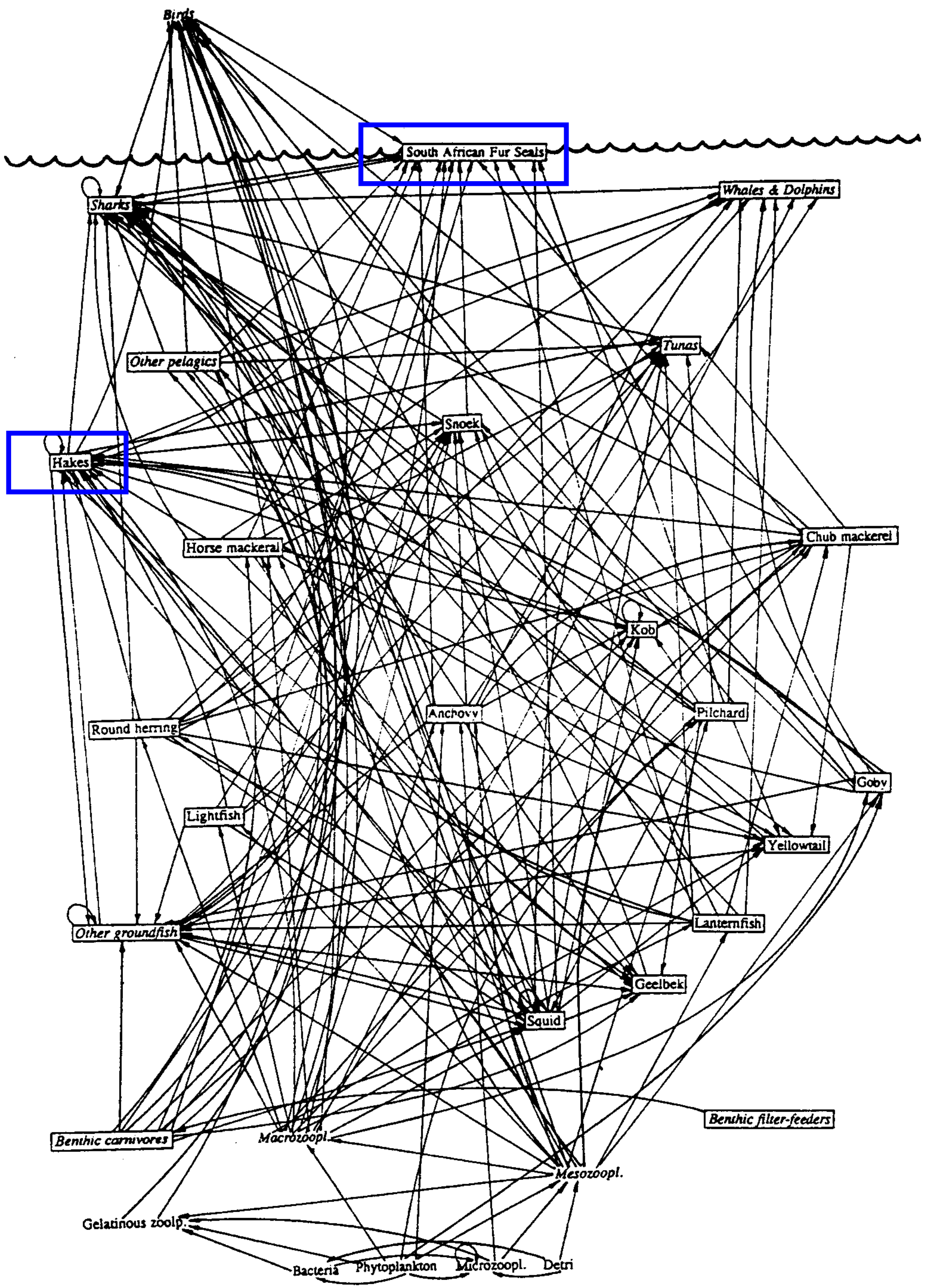
Mammal-fisheries interactions in marine pelagic ecosystems: direct and indirect effects



• **Focal system embedded in web of interactions (28 million possible pathways of influence from seals to hake)**

• **Culling of fur seals more likely to be detrimental than beneficial to total yields of all exploited species (**Yodzis 1998. *Journal of Animal Ecology*)

➢ **Complex systems shaped by multiple interactions and human influences**



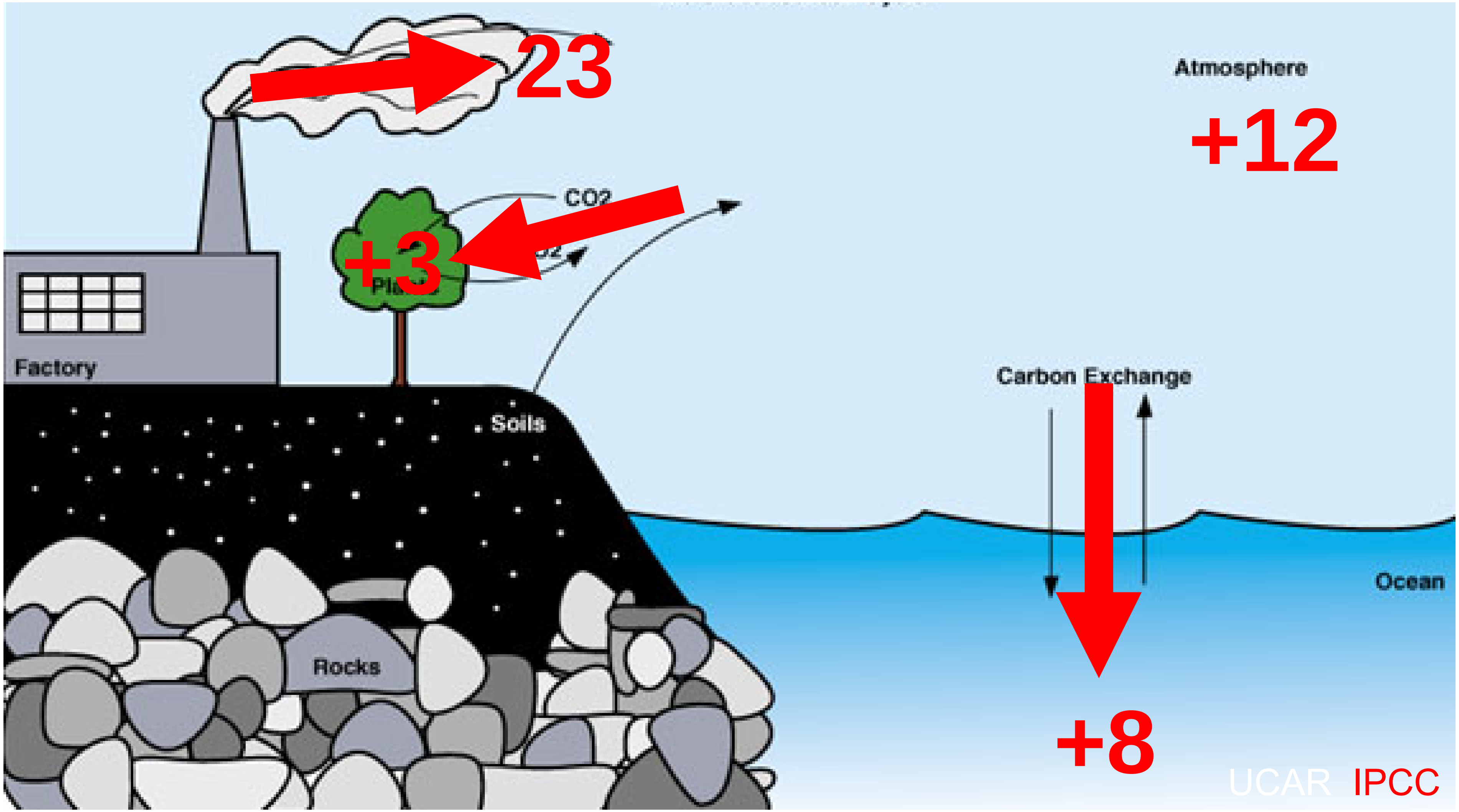
Climate change

- **Increase temperature**
  - **Physiological impacts**
    - →Increase metabolism
    - →Reduce duration of the larval plaktonic phase
    - →Reduced connectivity
  - **Range shift**

Coral bleaching

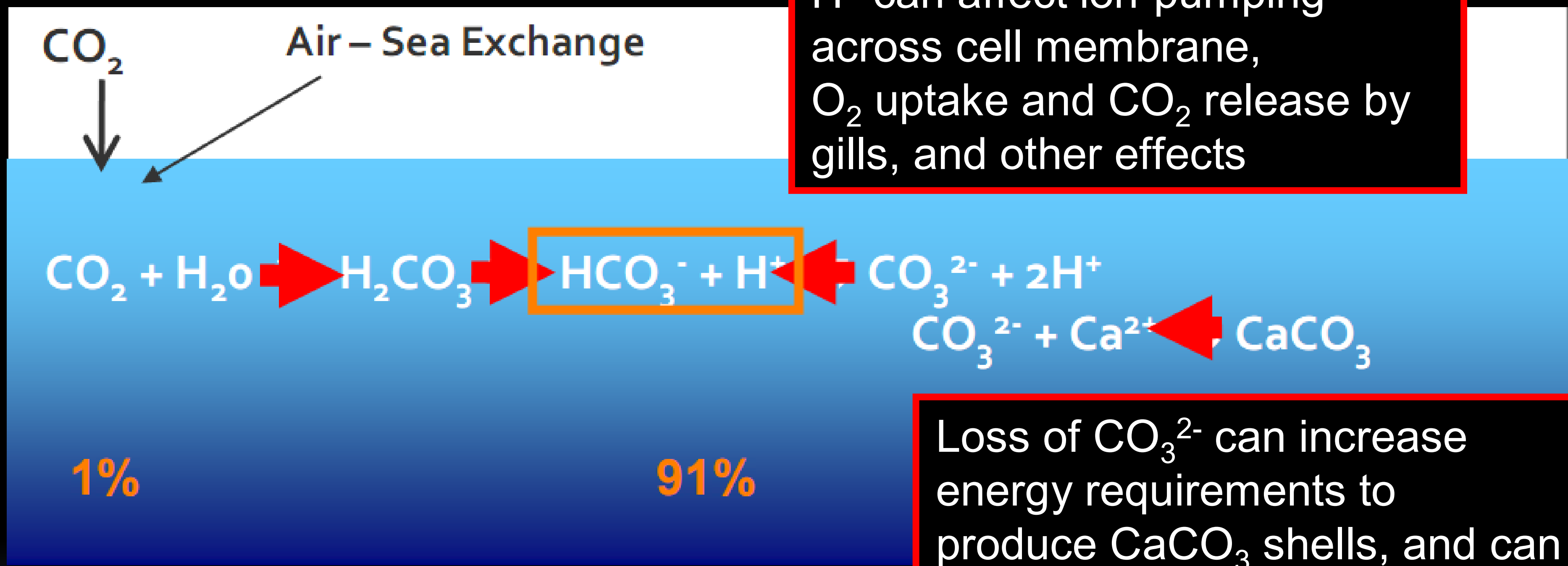
- **Ocean acidification**

The 1990's global net CO_2 budget



Units are pounds CO_2 per person per day, global averages

Each American adds 120 pounds CO_2 to the atmosphere and 40 pounds of CO_2 to the oceans each day



H^+ can affect ion-pumping across cell membrane, O_2 uptake and CO_2 release by gills, and other effects

Loss of CO_3^{2-} can increase energy requirements to produce $CaCO_3$ shells, and can lead to $CaCO_3$ dissolution

Addition of CO_2 to seawater:

↑ acidity ↓ pH

↓ carbonate saturation

↓ calcification

Coral growth decreases with more CO_2

CO_2 makes it harder for corals to make their aragonite skeletons

Adam Laverty

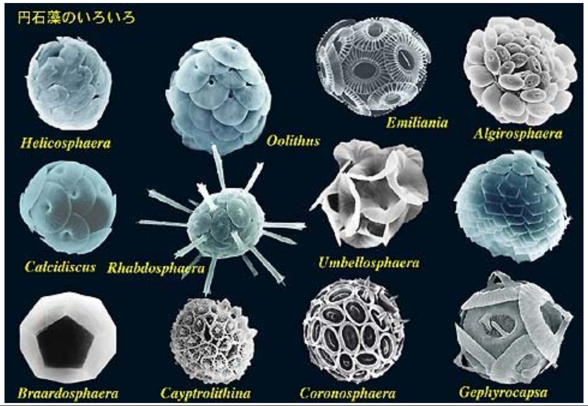
Corals need to produce their skeletons fast enough to keep up with the fish and other creatures that are chewing on them

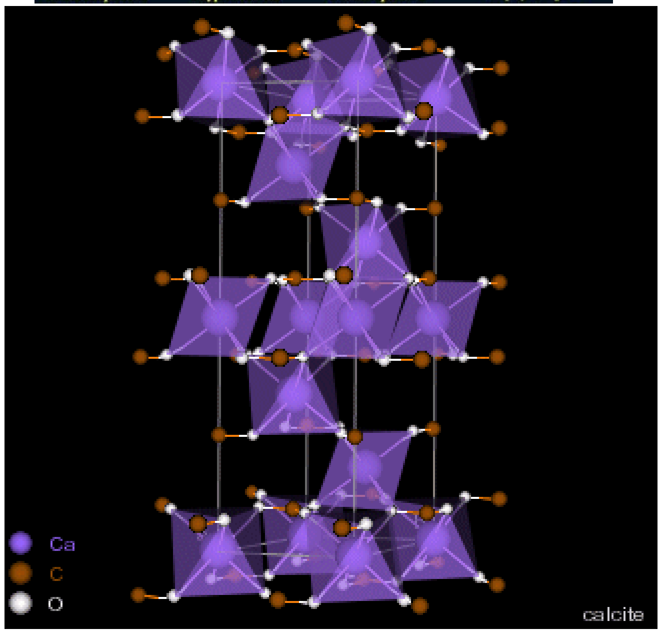
(and to keep up with increasing sea-levels)

Two forms of calcium carbonate

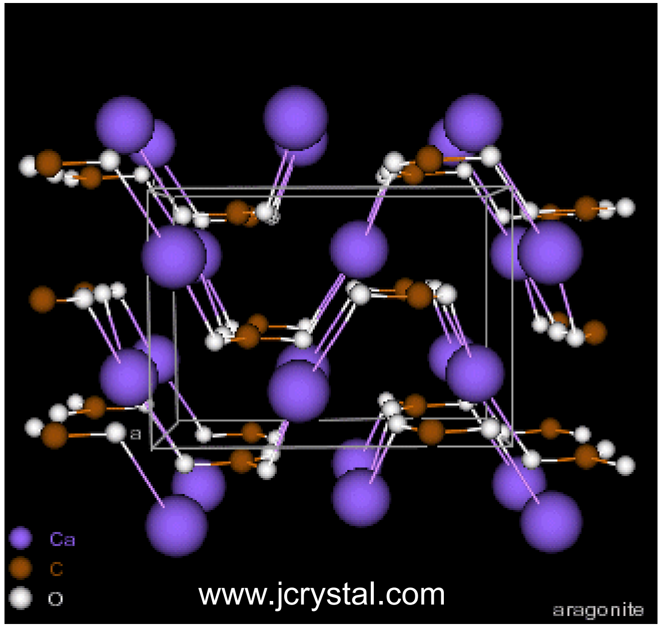
Calcium carbonate = $CaCO_3$

Calcite (plankton)

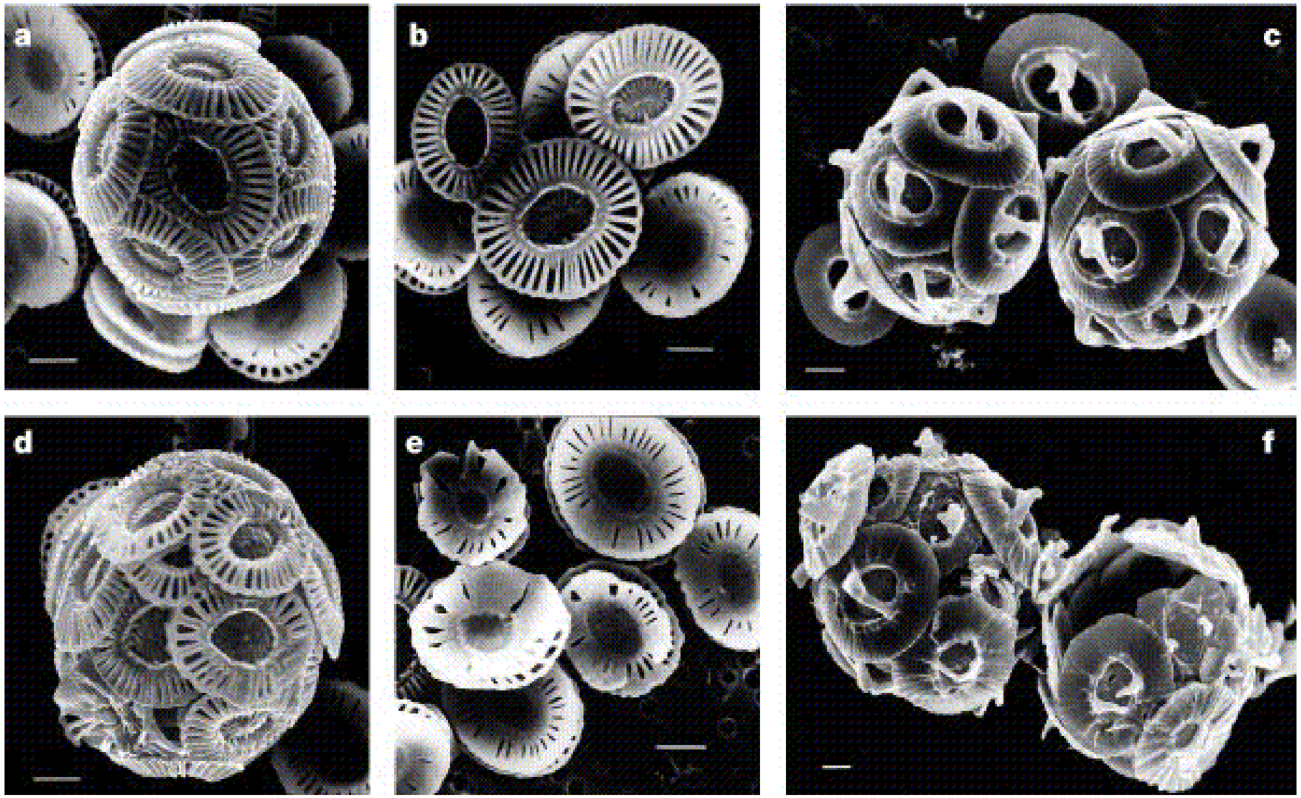




Aragonite (corals)



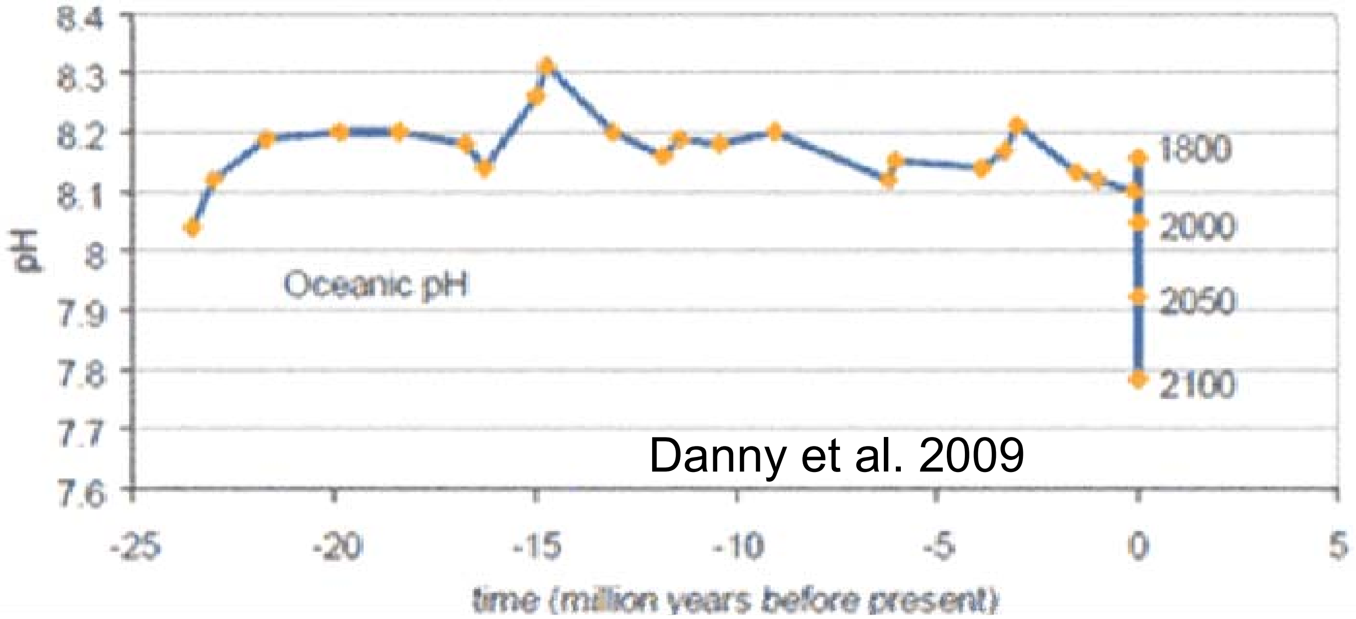
Malformed coccoliths at high CO_2

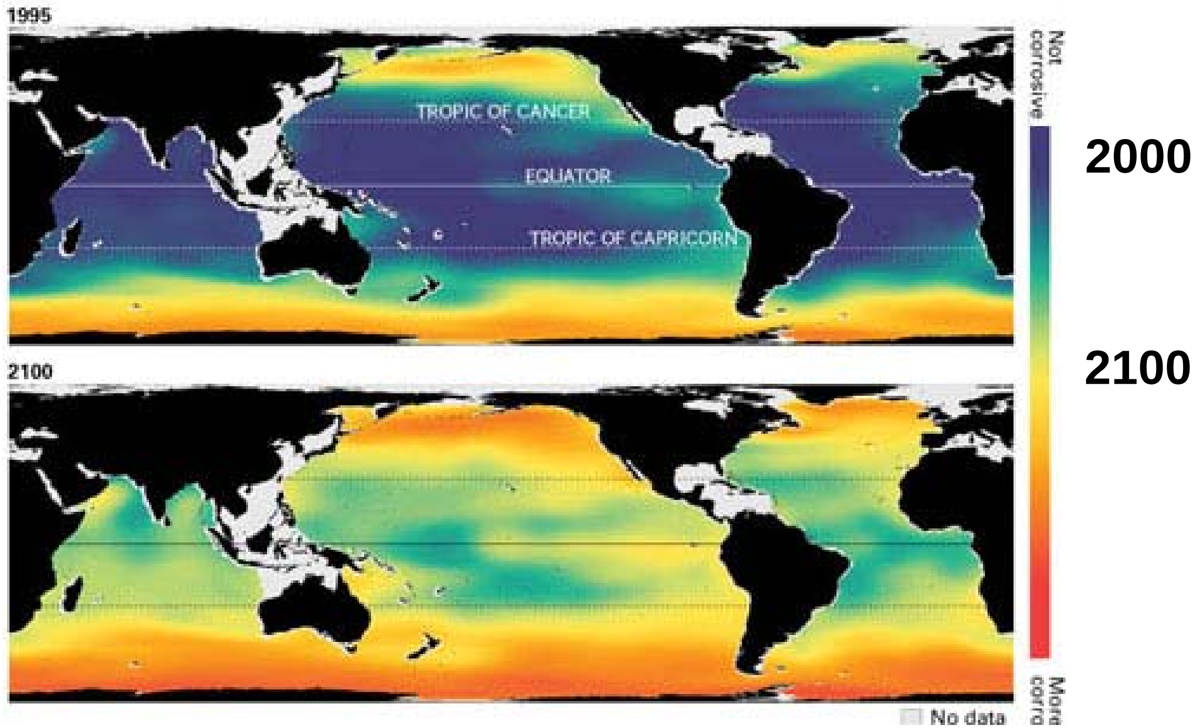


Normal CO_2

High CO_2

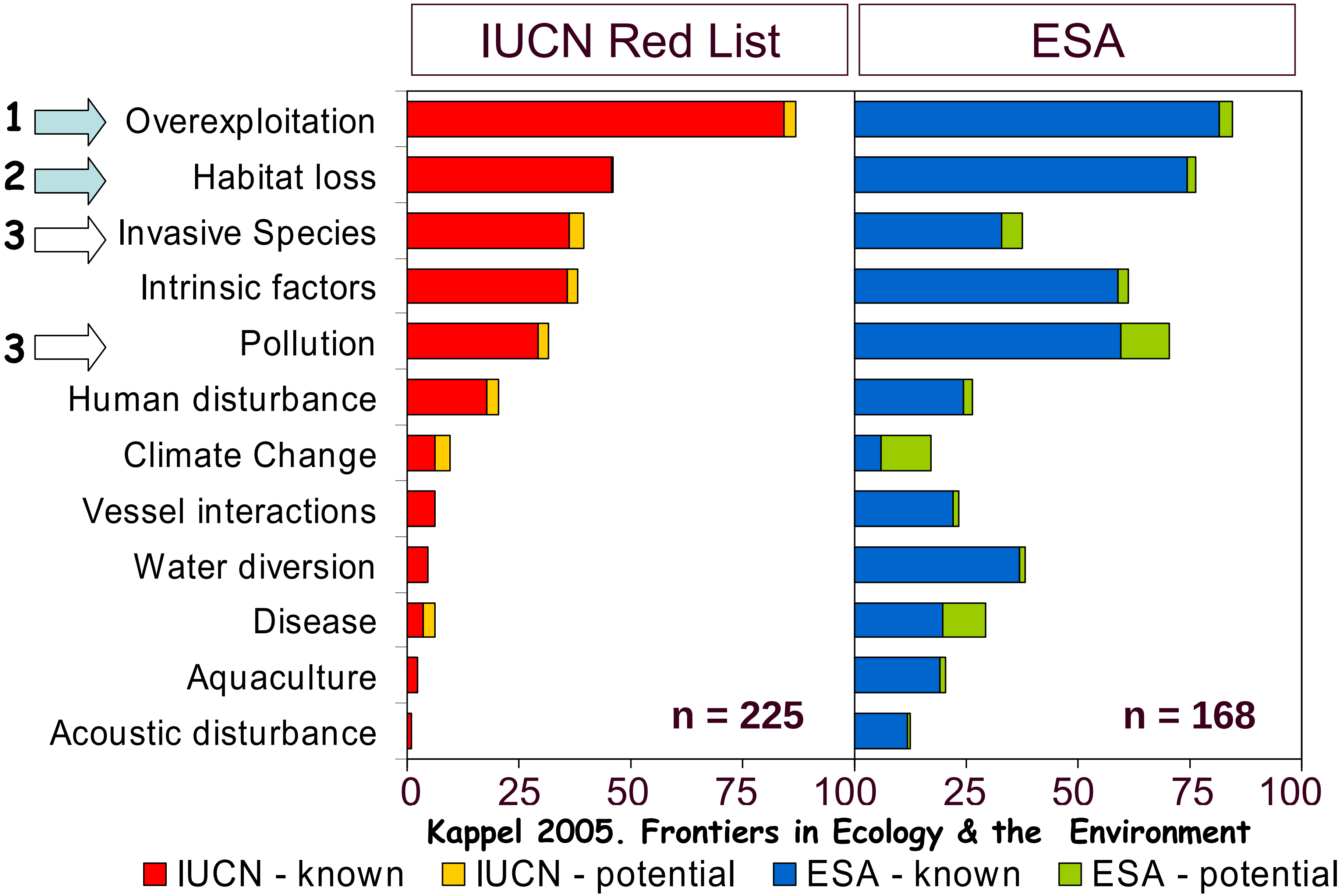
Source: Riebesell et al (2000) *Nature,* 407:364-367


8.4
8.3
8.2
8.1
8
7.9
7.8
7.7
7.6
pH
Oceanic pH
1800
2000
2050
2100
Danny et al. 2009
-25
-20
-15
-10
-5
0
5
time (million years before present)


1995
TROPIC OF CANCER
EQUATOR
TROPIC OF CAPRICORN
2100
Not corrosive
More corro
No data
2000
2100

Multiple stressors: cumulative impacts?

Marine species at risk from multiple threats:



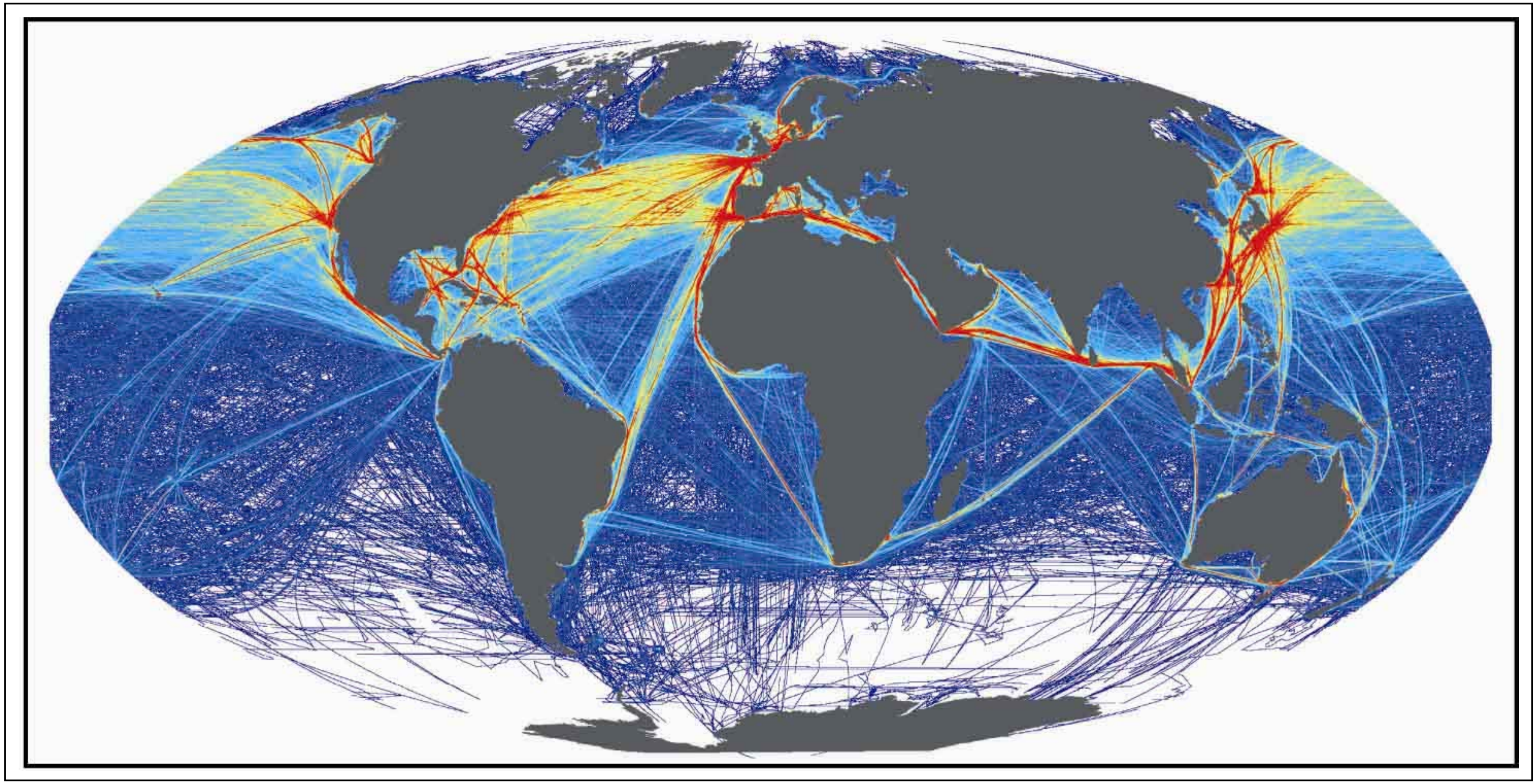
Kappel 2005. Frontiers in Ecology & the Environment

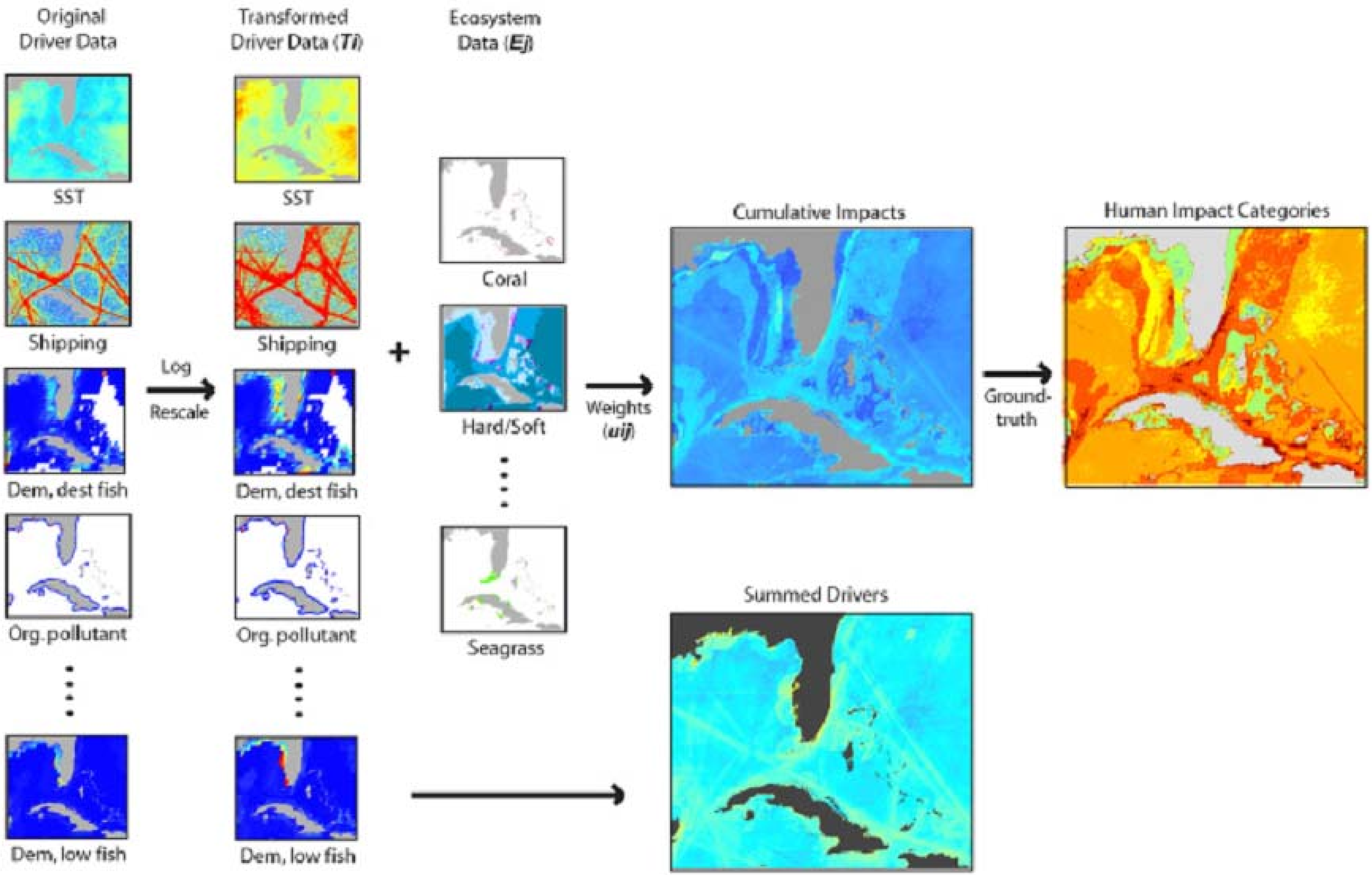
Halpern et al. Science 2008

Mapping Human Impacts

- Global data on 17 human activities or associated stressors
  - e.g., climatic stressors, fishing, pollution, invasive species…
- Global data on the distribution of 20 marine ecosystems
  - e.g., coral reefs, seagrass beds, seamounts
- Assess the vulnerability of each ecosystem to each stressor and defines weights accordingly

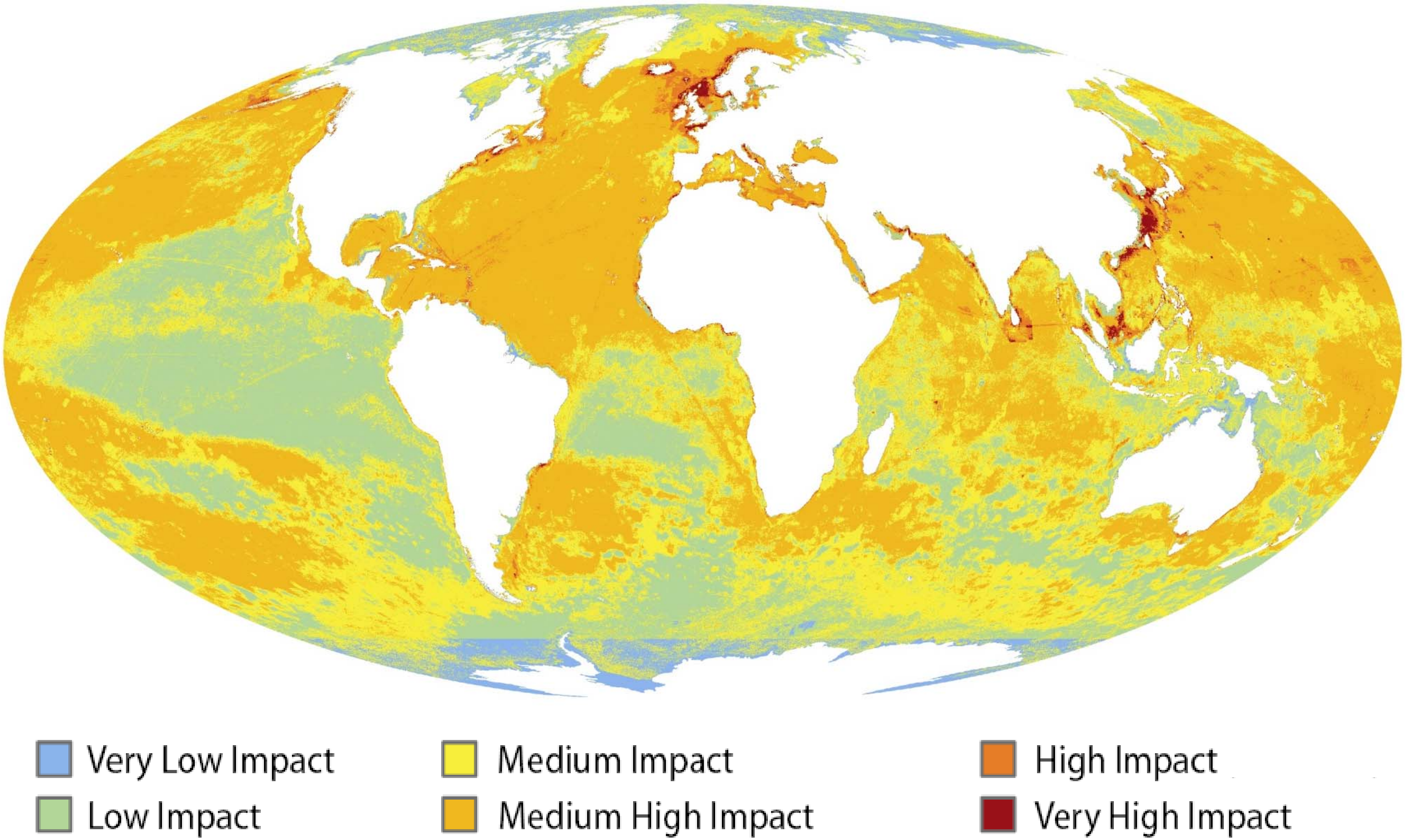
Commercial shipping and pollution, 1994





Original
Driver Data
Transformed
Driver Data (Ti)
Ecosystem
Data (Ej)
SST
SST
Shipping
Shipping
Dem, dest fish
Dem, dest fish
Org. pollutant
Org. pollutant
Dem, low fish
Dem, low fish
Log
Rescale
+
Coral
Hard/Soft
Seagrass
Weights
(uij)
Cumulative Impacts
Ground-
truth
Human Impact Categories
Summed Drivers

Global Cumulative Impact Map



Halpern et al. 2008. Science

Ecology Letters, (2008) 11: 1304–1315 doi: 10.1111/j.1461-0248.2008.01253.x

LETTER

Interactive and cumulative effects of multiple human stressors in marine systems

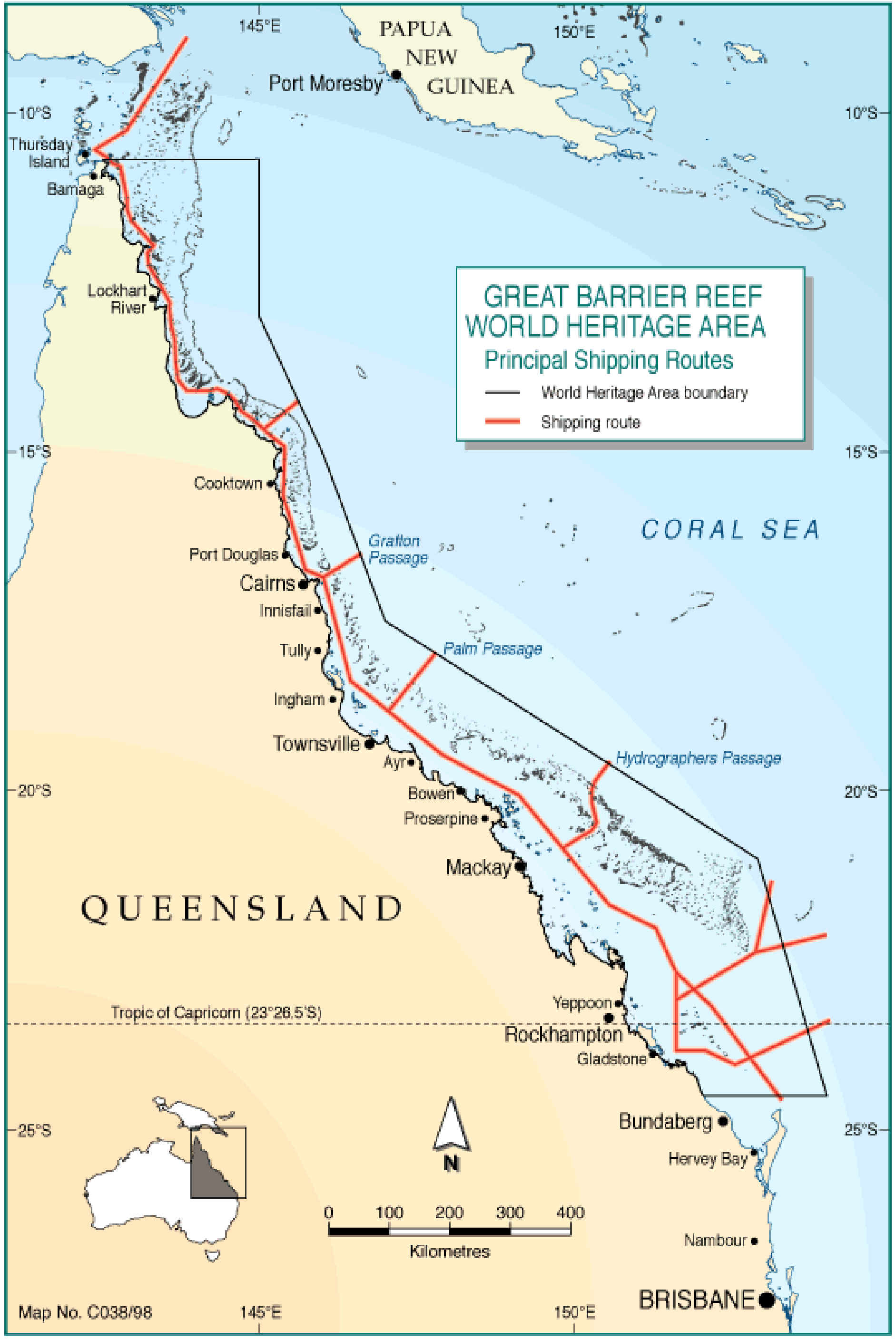
Caitlin Mullan Crain,[1,*] Kristy Kroeker[2] and Benjamin S. Halpern[3]
[1]*University of California, Santa Cruz and The Nature*

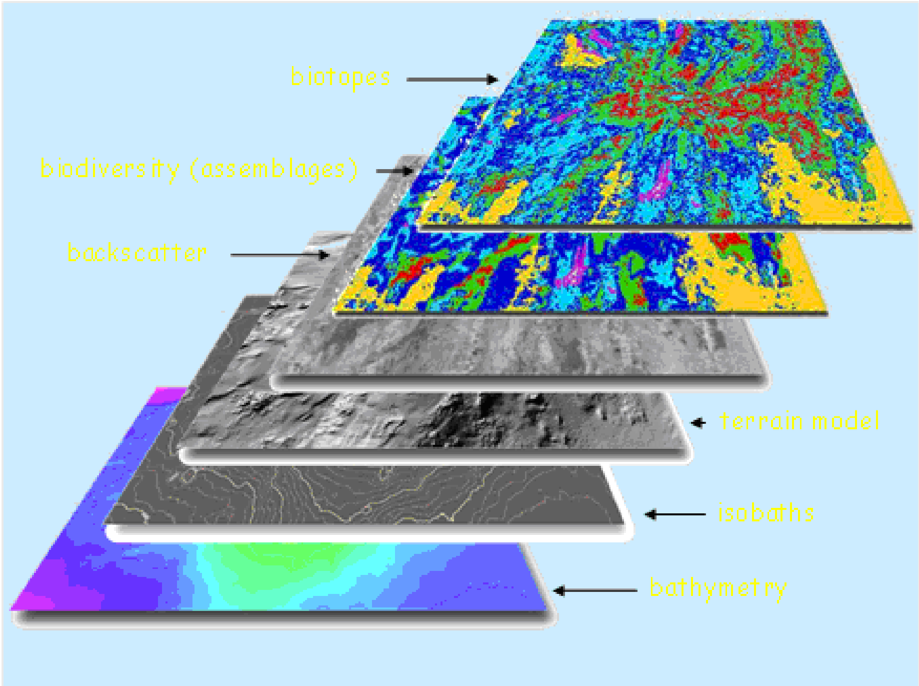
Abstract
Humans impact natural systems in a multitude of ways, yet the cumulative effect of multiple stressors on ecological communities remains largely unknown. Here we synthesized 171 studies that manipulated two or more stressors in marine and coastal systems and found that cumulative effects in individual studies were additive (26%), synergistic (36%), and antagonistic (38%). The overall interaction effect across all

interactions. Given that most studies were performed in laboratories where stressor effects can be carefully isolated, these three-stressor results suggest that synergies may be quite common in nature where more than two stressors almost always coexist. While

What can we do?

Ocean Zoning





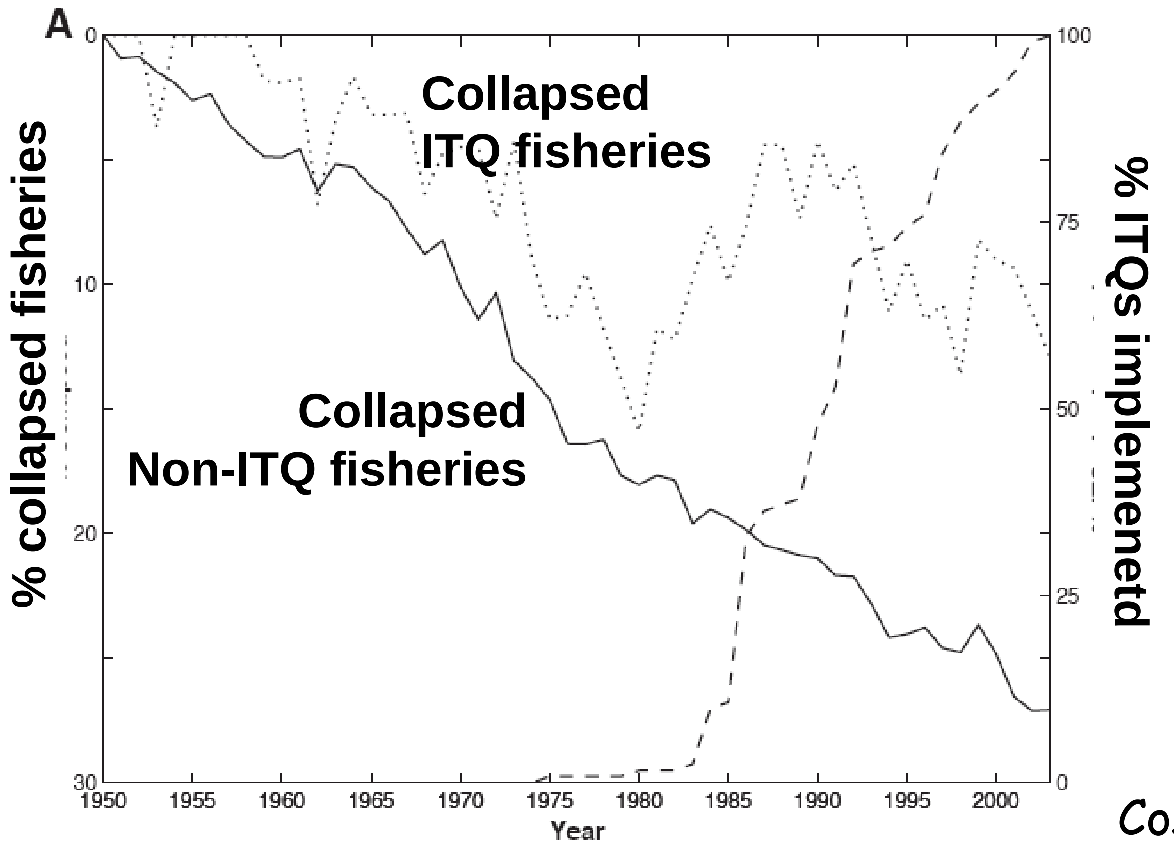
Promote Sustainable Fishery Management

- **eliminate incentive for fleet expansion**
- **provide incentives to reduce the competitive nature of fisheries**

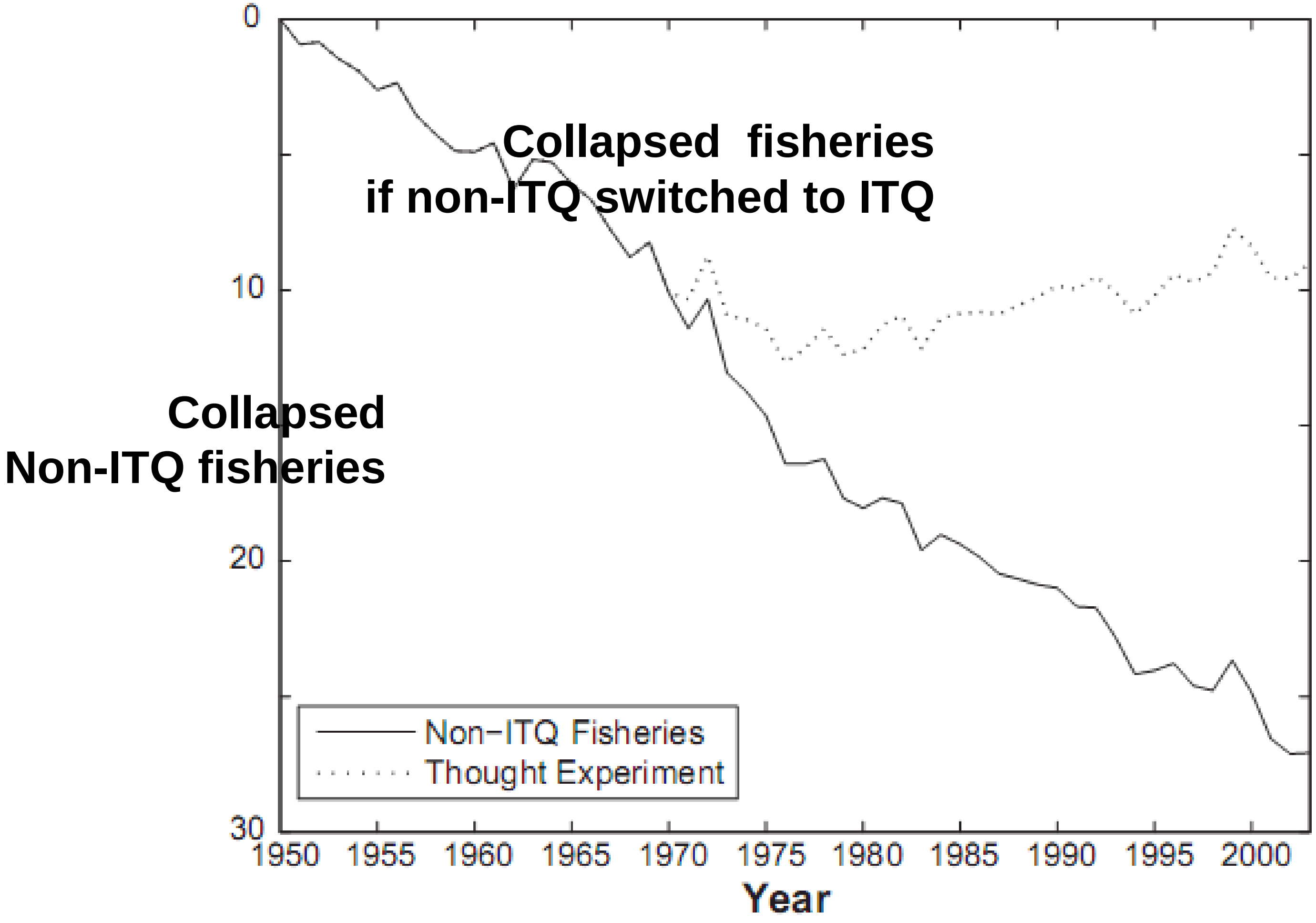
  - **Moving to sustainability by learning from <u>successful fisheries</u>**
    (Hilborn, AMBIO 2007)
  - **Reinterpreting the state of fisheries and their management**
    (Hilborn ECOSYSTEMS 2007)
  - **Incentive based approaches to sustainable management**
    (Quentin et al. CJFAS 2006)

Small- scale fisheries based on property rights

- Trajectories of collapse with and without ITQ management: implementation of catch shares halts trends for collapse



Costello et al. 2008. Science



Costello et al. (Science 2008)

Are Marine Reserves part of the optimal solution?

- Benefits of MR
  - To protect marine habitat from different forms of anthropogenic disturbance
  - To serve as "biological insurance policy" for future generations against imperfect knowledge
  - To protect species from overexploitation

Evidence of MPA benefits for target species is quite robust

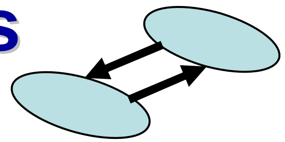
- **Meta-analysis**
  - **Molloy et al. 2008. *Biological Conservation*.**
    - **Links between sex change and fish densities in marine protected areas.**
  - **Claudet et al. 2006, *Biological Conservation*.**
    - **Assessing the effects of marine protected area (MPA) on a reef fish assemblage in a northwestern Mediterranean marine reserve: Identifying community-based indicators**
  - **Worm et al. 2006. *Science.***
    - **Impacts of biodiversity loss on ocean ecosystems services**

Not so much about fishery benefits of MPA implementation

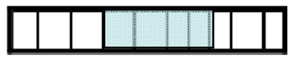
- **Goñi 2008. Spillover from six western Mediterranean marine protected areas: evidence from artisanal fisheries**
- **Yet, theoretical analyses provides conflicting outcomes:**
  - **MPA fishery management no better or <u>worse</u> than Traditional Management:**
    - **Shipp (2003), Hilborn et al. 2006, Walter et al. 2007, McGilliard & Hilborn (2008), Hart & Sissenwine (2009), etc.**
  - **MPA equal or <u>better</u> than traditional management**
    - **Sanchirico et al. (2006), White et al. (2008), Kaplan et al. (2009), De Leo and Micheli (in preparation), etc.**

MPA-fishery models are no better than the assumptions they are based on..

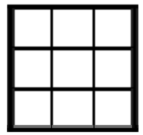
- Single-species, metapopulation models



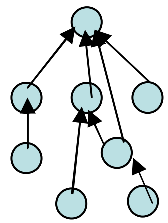
  - Sanchirico et al. (2006): two-pacth model
- Single-species, spatially explicit models



  - 1-D: Hilborn et al. (2006) + …, Kaplan et al. (2009)



  - 2-D: Stefansson and Rosember (2004, 2005)
- Multi-species a-dimensional models



  - Species interaction (Micheli et al. 2004)
  - Ecopath+ Ecosim (Pauly et al. ICES JMS 2000)
- Multi-species spatially explicit models:
  - Ecospace
  - Coupled physical-ecological models with trophic interactions (Atlantis)

- **Key-words**
  - Spatial connectivity
  - Network of MPA

- **Critical aspects needing further investigations**
  - MPA spacing
  - Habitat heterogeneity
  - Type of existing fishery regulations (TAC vs. single owner management)
  - Fishermen behavior
  - Environmental Stochasticity
  - Shot term vs. long term performances
  - Population Size-Structure
  - Multi-species fishery
  - Species interactions and trophic cascades

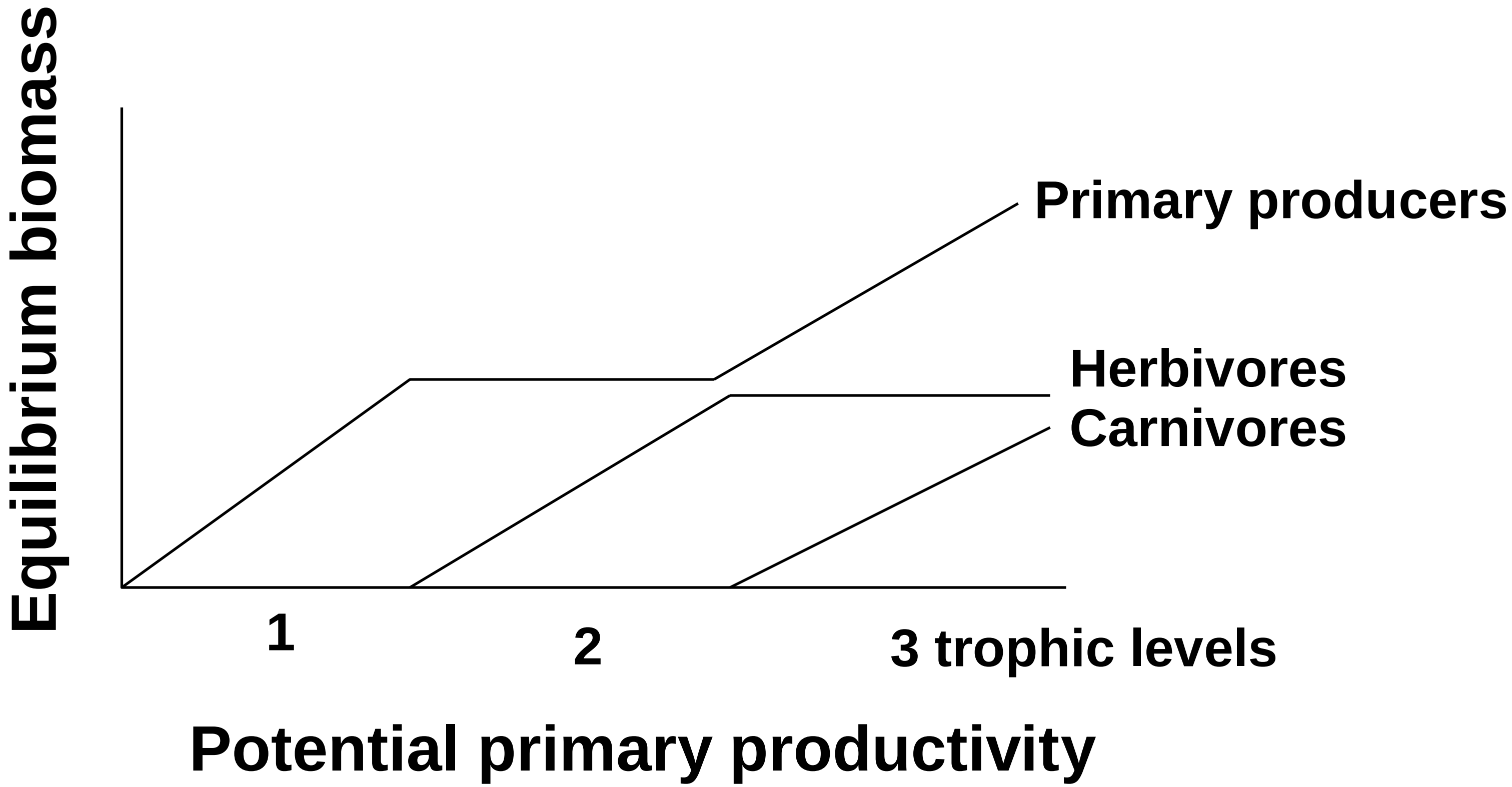
Conclusion

- Evidence of significant alteration of marine ecosystem and food web structure and interactions
- Creating effective incentives for conservation of marine resources and ecosystems and addressing the cumulative impacts of multiple stressors present major challenges
  - Multiple co-occurring stressors
  - Cross-scale issues
    - High variation in responses of individual species but general trends in responses of trophic structure and loss of diversity, function and services
  - Socio-economic components
- Provide assessment of ecosystems services and set priorities accordingly

Tomorrow two case studies

- **Importance of large spanwer protections in MPA**
- **Conservation and management of the european eel *Anguilla anguilla***

Bottom-up/top-down control: the trophic cascade



Caribbean coral reef food web: strength of interactions (Bascompte et al. 2005)

- **249 species and species groups, 3,313 interactions**

- **Measure of per capita interaction strength: proportion of prey biomass consumed per unit predator biomass per day**

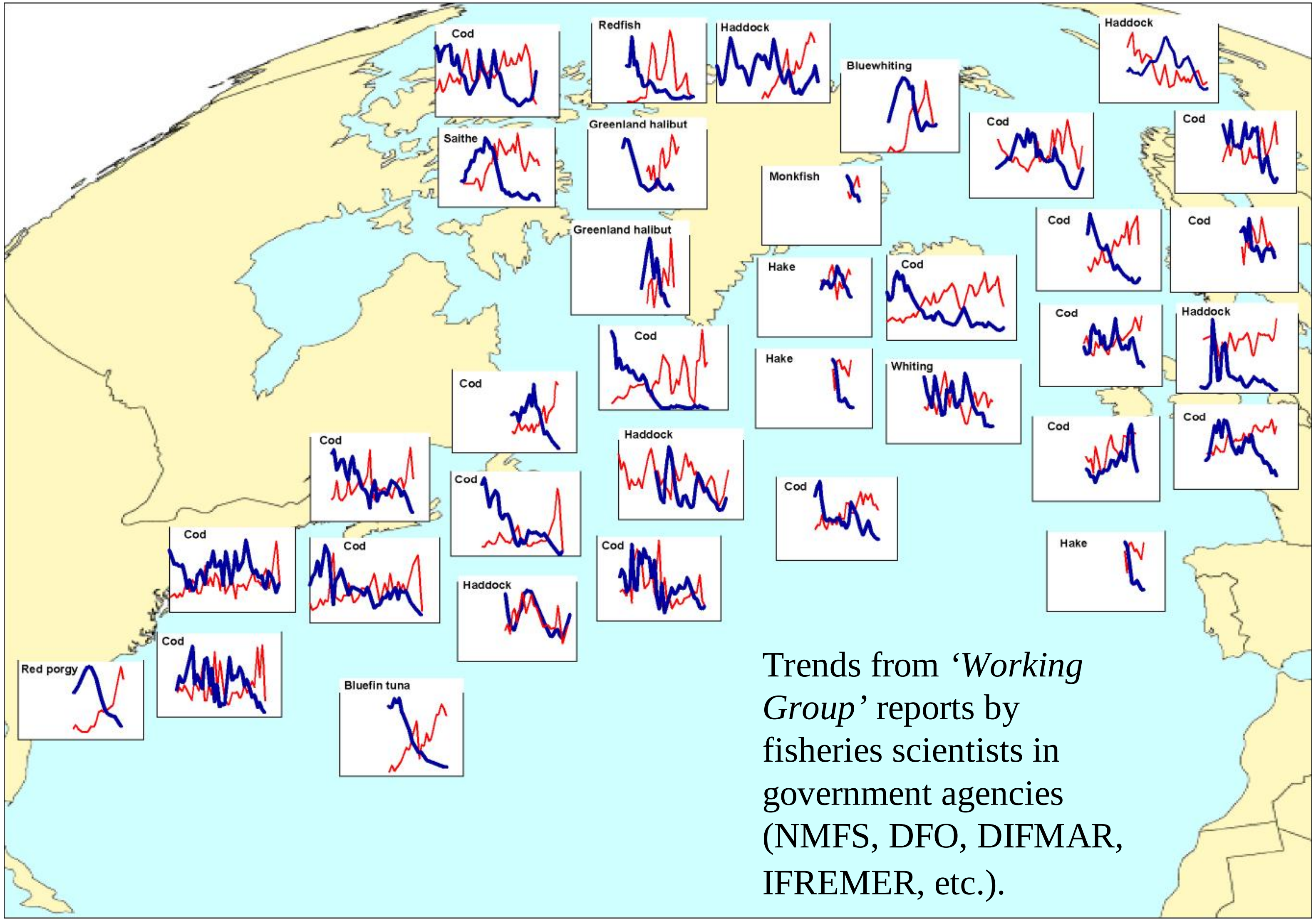
Caribbean coral reef food web: strength of interactions (Bascompte et al. 2005)

- Few strong interactions in matrix of weak interactions (confirms previous results)

- Most strong interactions chains (3 trophic levels) have sharks at the top

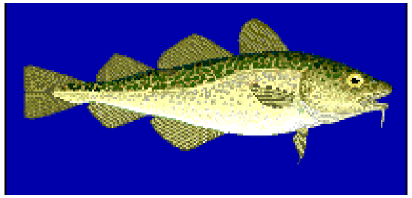
- Removal of sharks triggers trophic cascades?

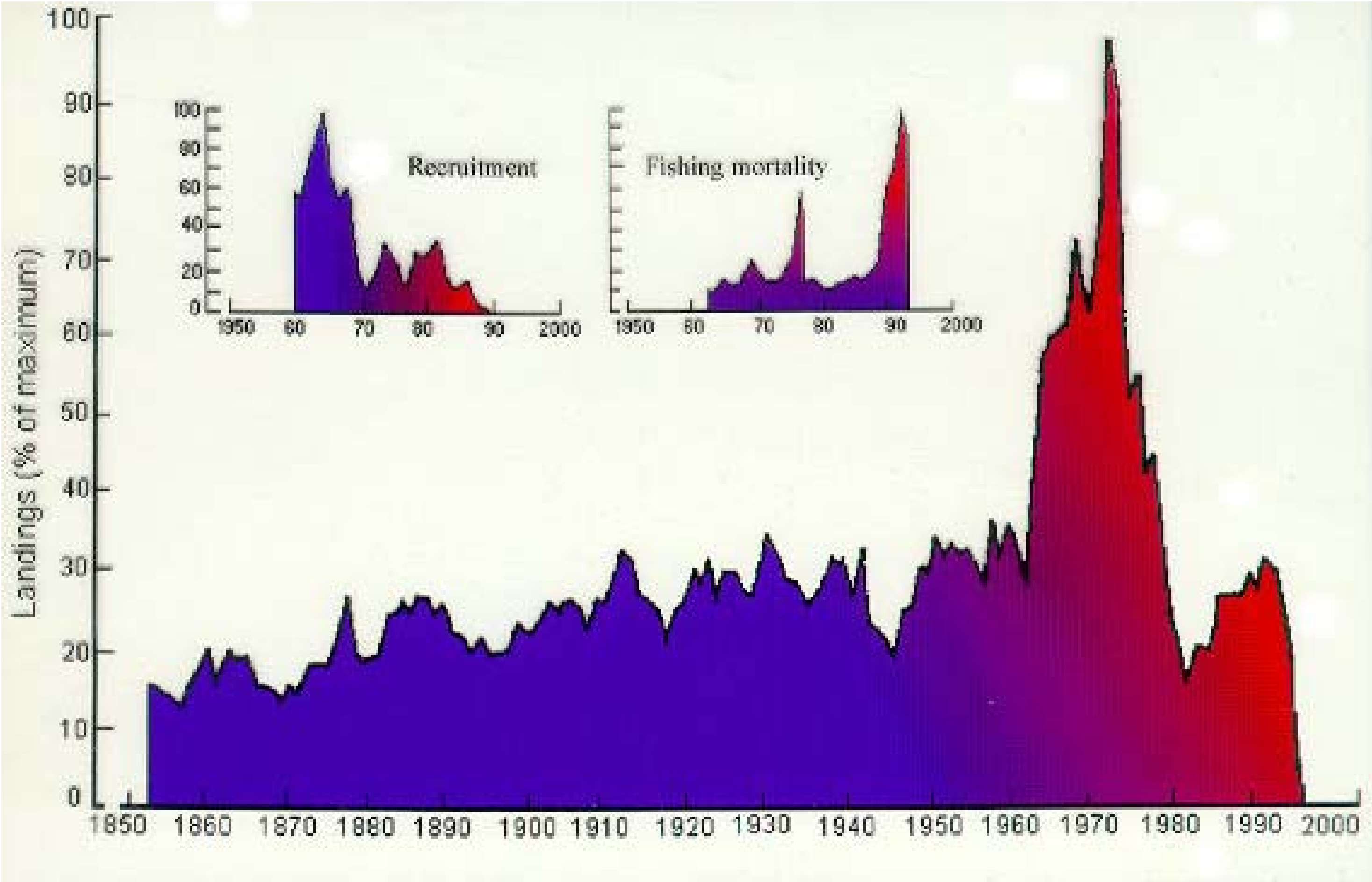
trends in biomass (blue) and fishing mortality (red) from single-species assessments in the North Atlantic.



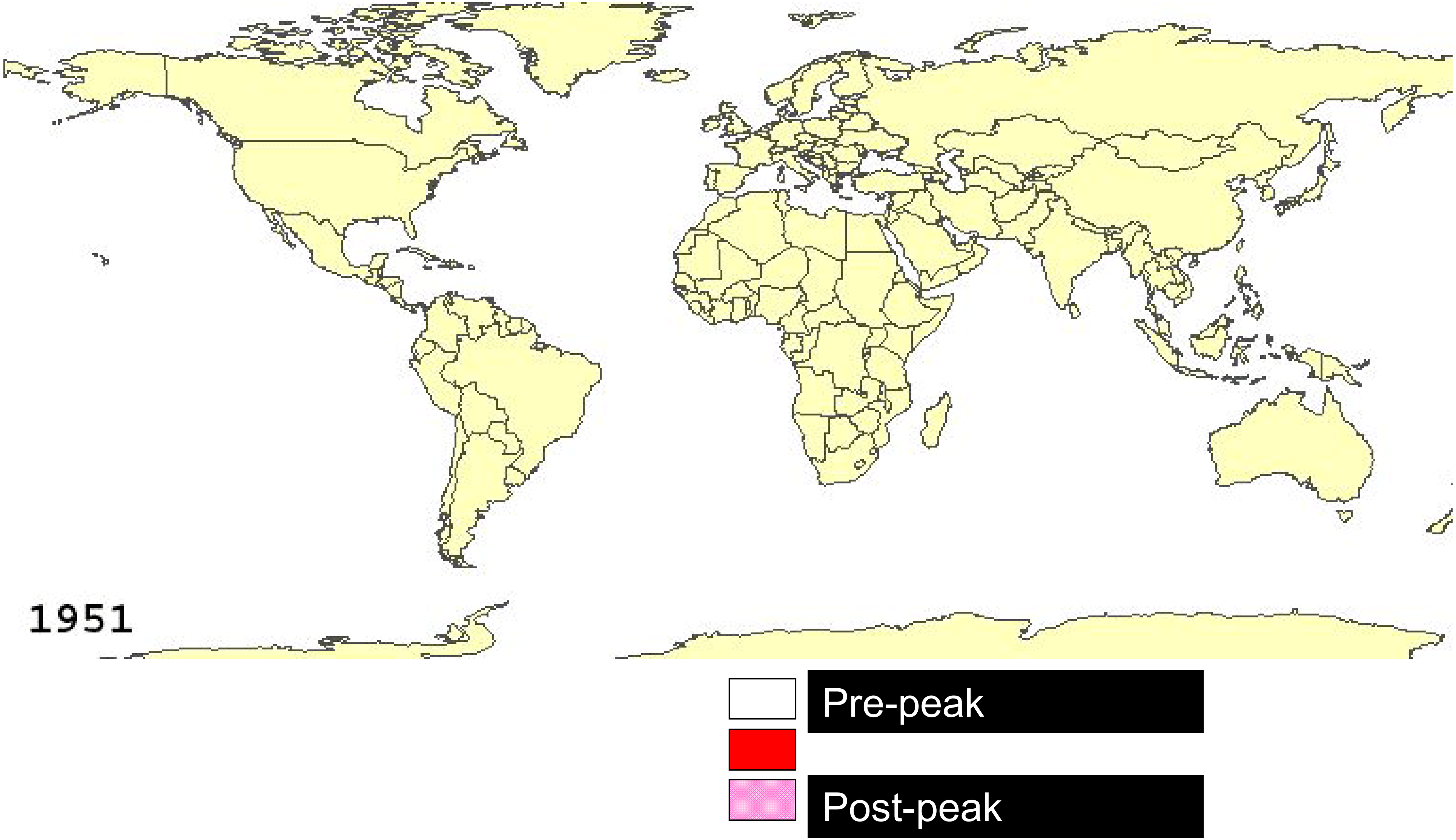
Trends from *'Working Group'* reports by fisheries scientists in government agencies (NMFS, DFO, DIFMAR, IFREMER, etc.).

A typical story: Northern cod

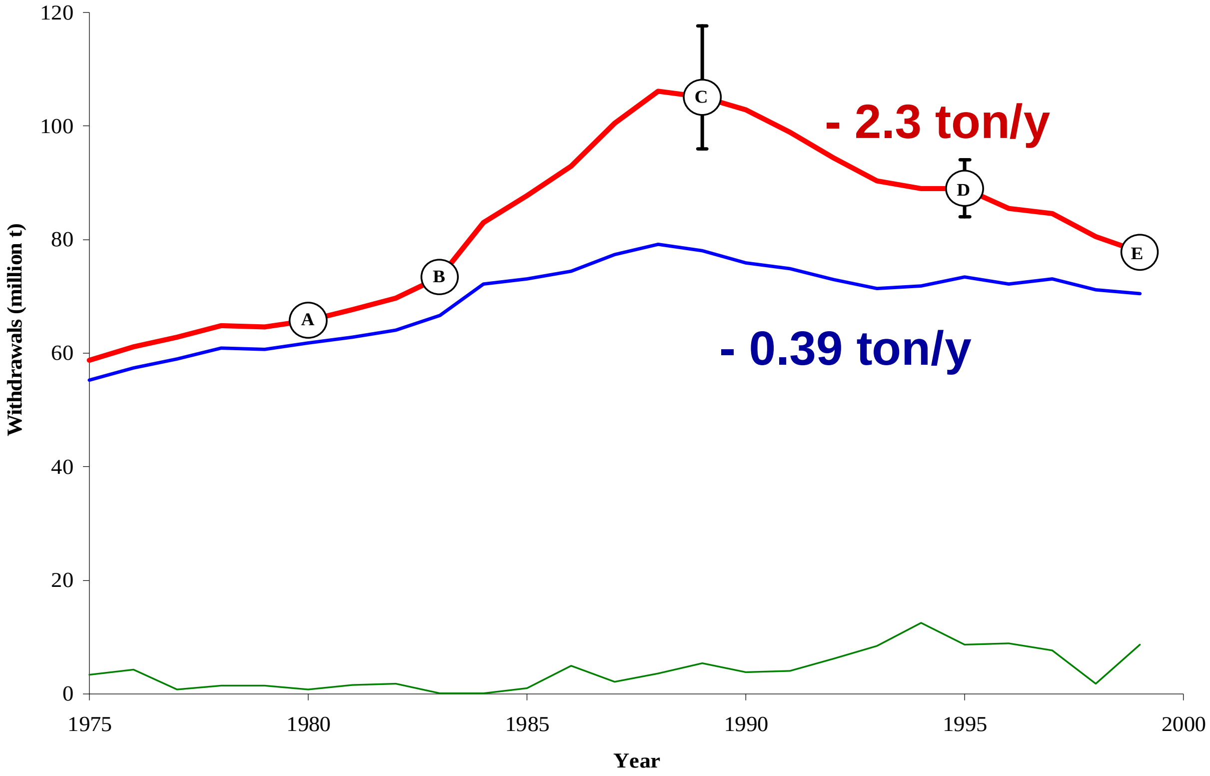




And it goes on!


1951
Pre-peak
Post-peak

The decline is even stronger if one considers discarded fish (in red). This was not mentioned by FAO when the last estimate (dot E; 7-8 million tonnes was released).



Zeller and Pauly (2005)

BENEFITS / FISHERY	LARGE-SCALE	SMALL-SCALE
Number of fishers employed	about 2 million	over 12 million
Annual catch of marine fish for human consumption	about 29 million tons	about 24 million tons
Capital cost of each job on fishing vessels	$30,000 – $300,000	$25 – $2,500
Annual catch of marine fish for industrial reduction to meal and oil, etc.	about 22 million tons	Almost none
Annual fuel oil consumption	14–19 million tons	1–3 million tons
Fish caught per ton of fuel consumed	2–5 tons	10–20 tons
Fishers employed for each $1 million invested in fishing vessels	5–30	500–4,000
Fish and invertebrates discarded at sea	16–40 million tons	None