Large Marine Ecosystems Assessment Methodology for the World's Coastal Zones During Climate Change

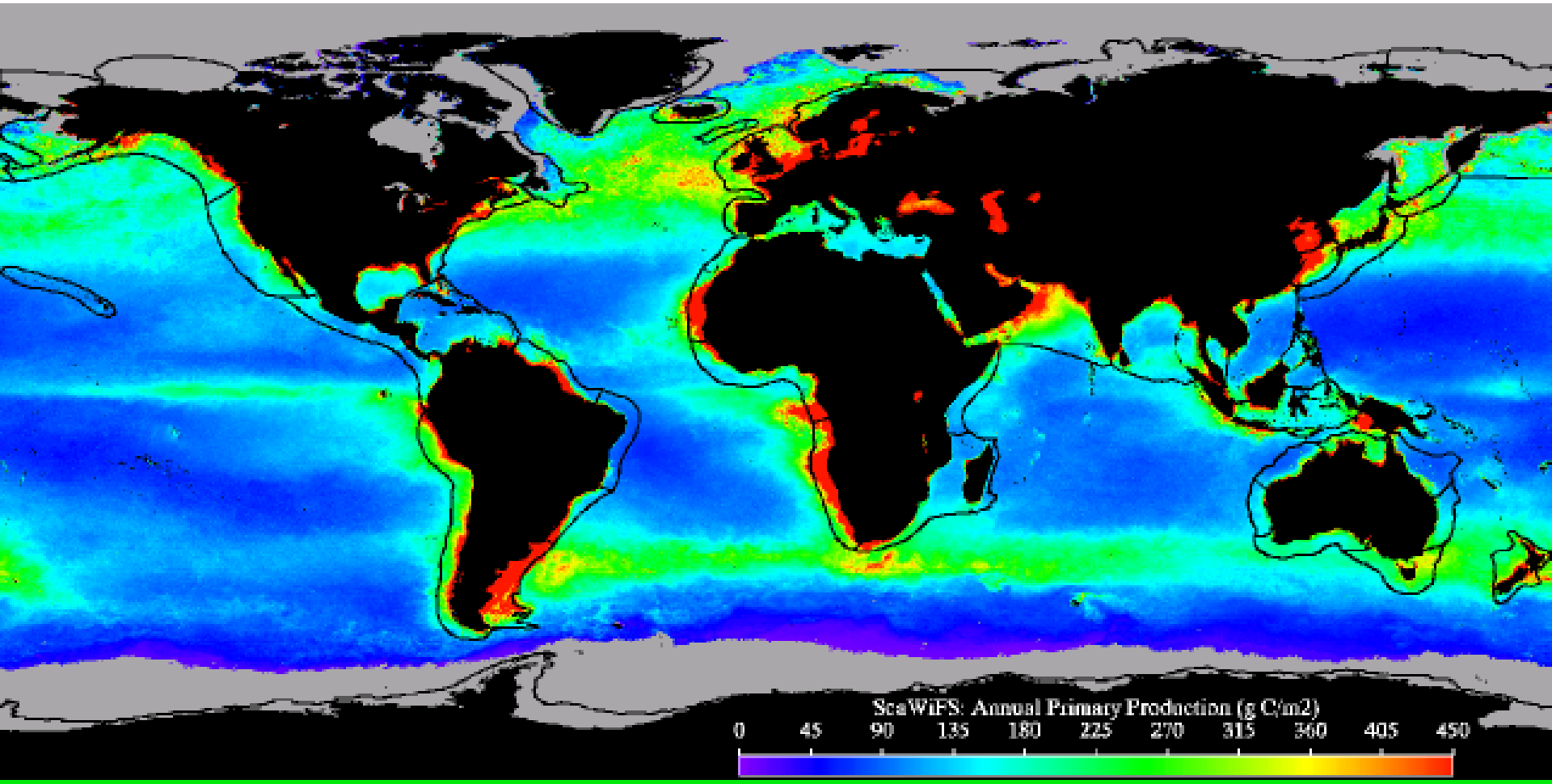
GOOS Africa/LMEs Workshop,
15-17 February 2010
Cotonou, Benin

Kenneth Sherman
NOAA National Marine Fisheries
Narragansett Laboratory
Narragansett, RI

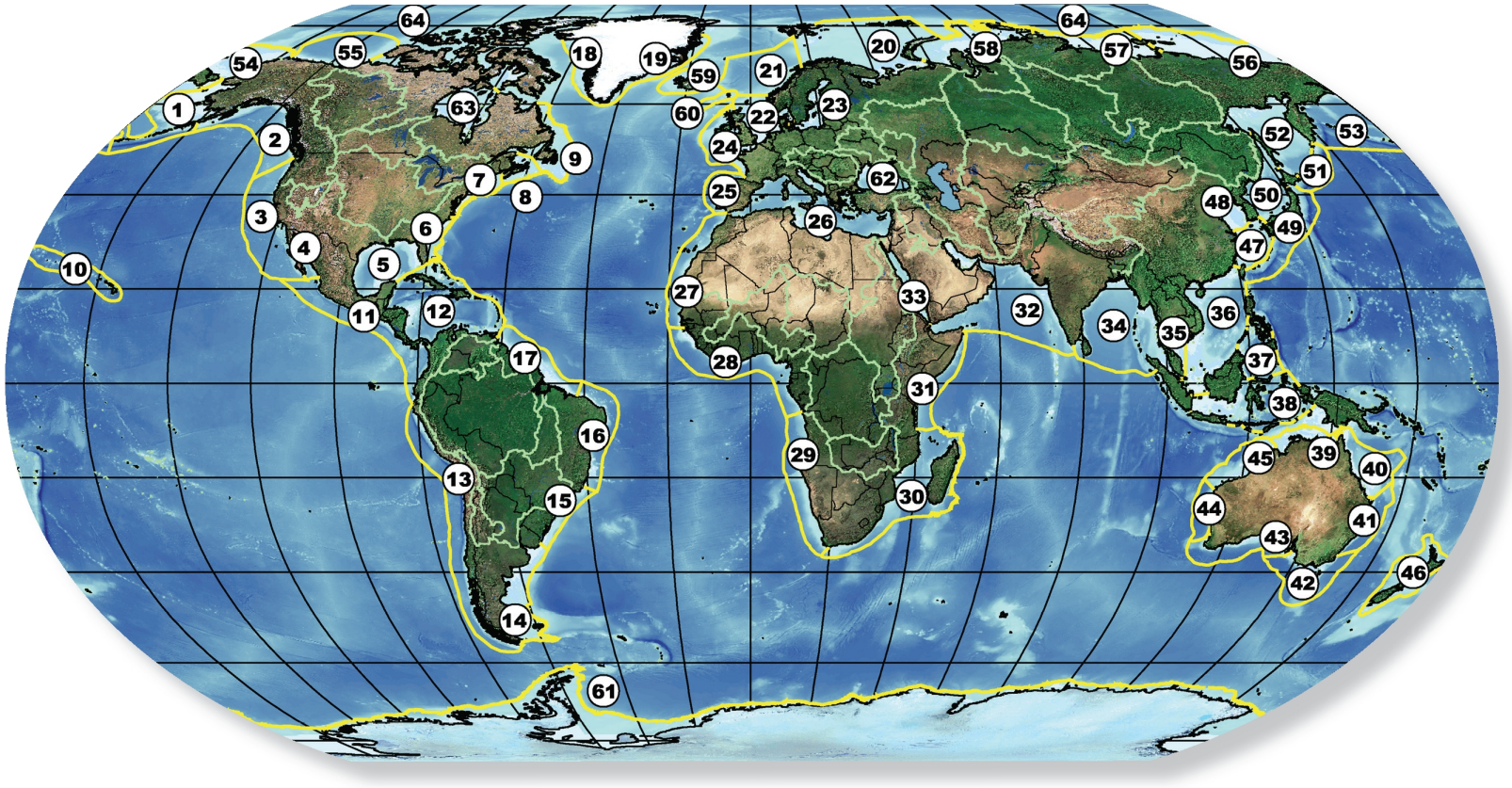
ECOLOGICAL CRITERIA USED TO DETERMINE AREAL EXTENT OF LMES:

- Bathymetry
- Hydrography
- Productivity
- Trophodynamics

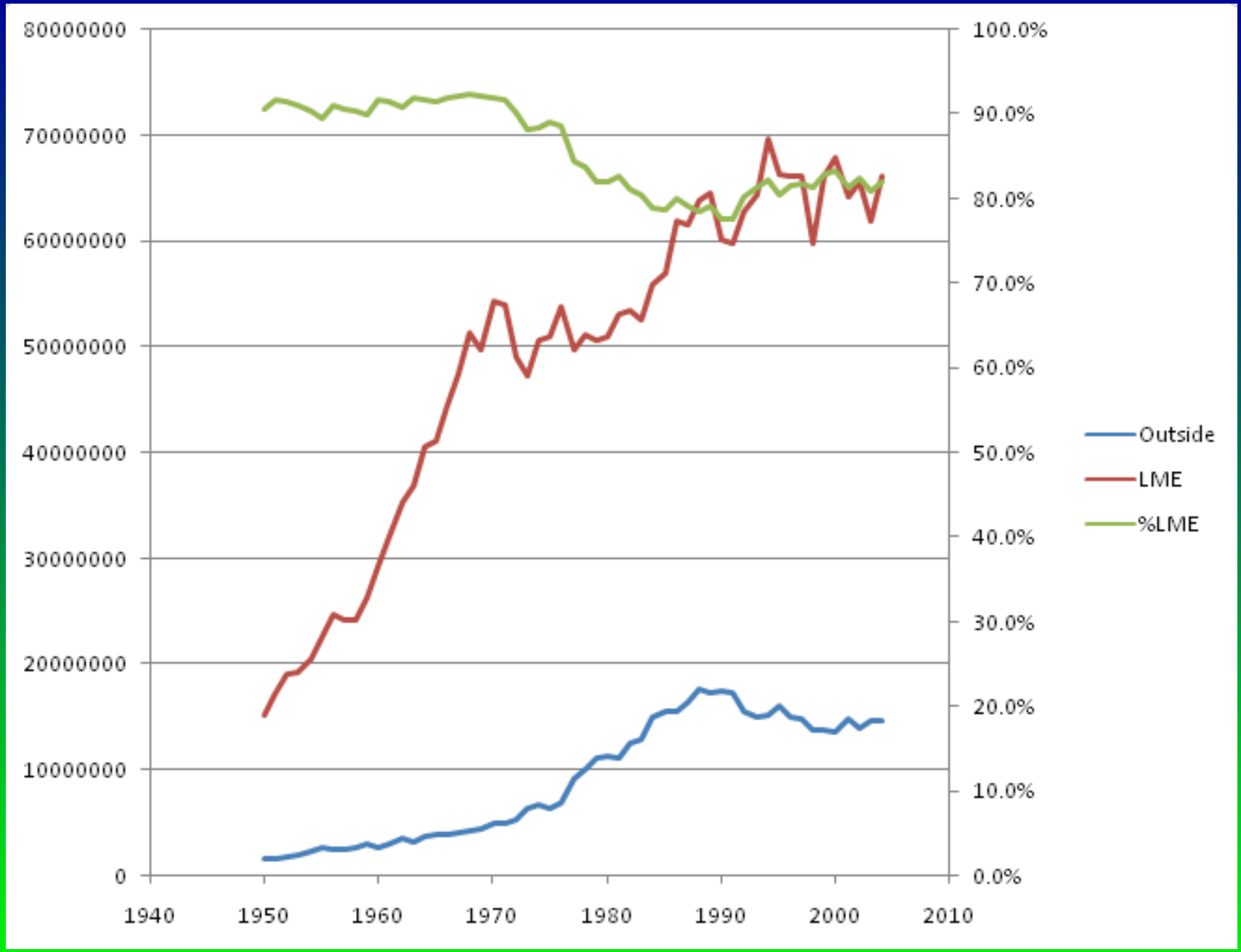
80% of the World's Fisheries Catches are produced in 64 Large Marine Ecosystems



Large Marine Ecosystems of the World and Linked Watersheds



1 East Bering Sea
2 Gulf of Alaska
3 California Current
4 Gulf of California
5 Gulf of Mexico
6 Southeast U.S. Continental Shelf
7 Northeast U.S. Continental Shelf
8 Scotian Shelf
9 Newfoundland-Labrador Shelf
10 Insular Pacific-Hawaiian
11 Pacific Central-American Coastal
12 Caribbean Sea
13 Humboldt Current
14 Patagonian Shelf
15 South Brazil Shelf
16 East Brazil Shelf
17 North Brazil Shelf
18 West Greenland Shelf
19 East Greenland Shelf
20 Barents Sea
21 Norwegian Shelf
22 North Sea
23 Baltic Sea
24 Celtic-Biscay Shelf
25 Iberian Coastal
26 Mediterranean Sea
27 Canary Current
28 Guinea Current
29 Benguela Current
30 Agulhas Current
31 Somali Coastal Current
32 Arabian Sea
33 Red Sea
34 Bay of Bengal
35 Gulf of Thailand
36 South China Sea
37 Sulu-Celebes Sea
38 Indonesian Sea
39 North Australian Shelf
40 Northeast Australian Shelf-Great Barrier Reef
41 East-Central Australian Shelf
42 Southeast Australian Shelf
43 Southwest Australian Shelf
44 West-Central Australian Shelf
45 Northwest Australian Shelf
46 New Zealand Shelf
47 East China Sea
48 Yellow Sea
49 Kuroshio Current
50 Sea of Japan
51 Oyashio Current
52 Okhotsk Sea
53 West Bering Sea
54 Chukchi Sea
55 Beaufort Sea
56 East Siberian Sea
57 Laptev Sea
58 Kara Sea
59 Iceland Shelf
60 Faroe Plateau
61 Antarctic
62 Black Sea
63 Hudson Bay
64 Arctic Ocean

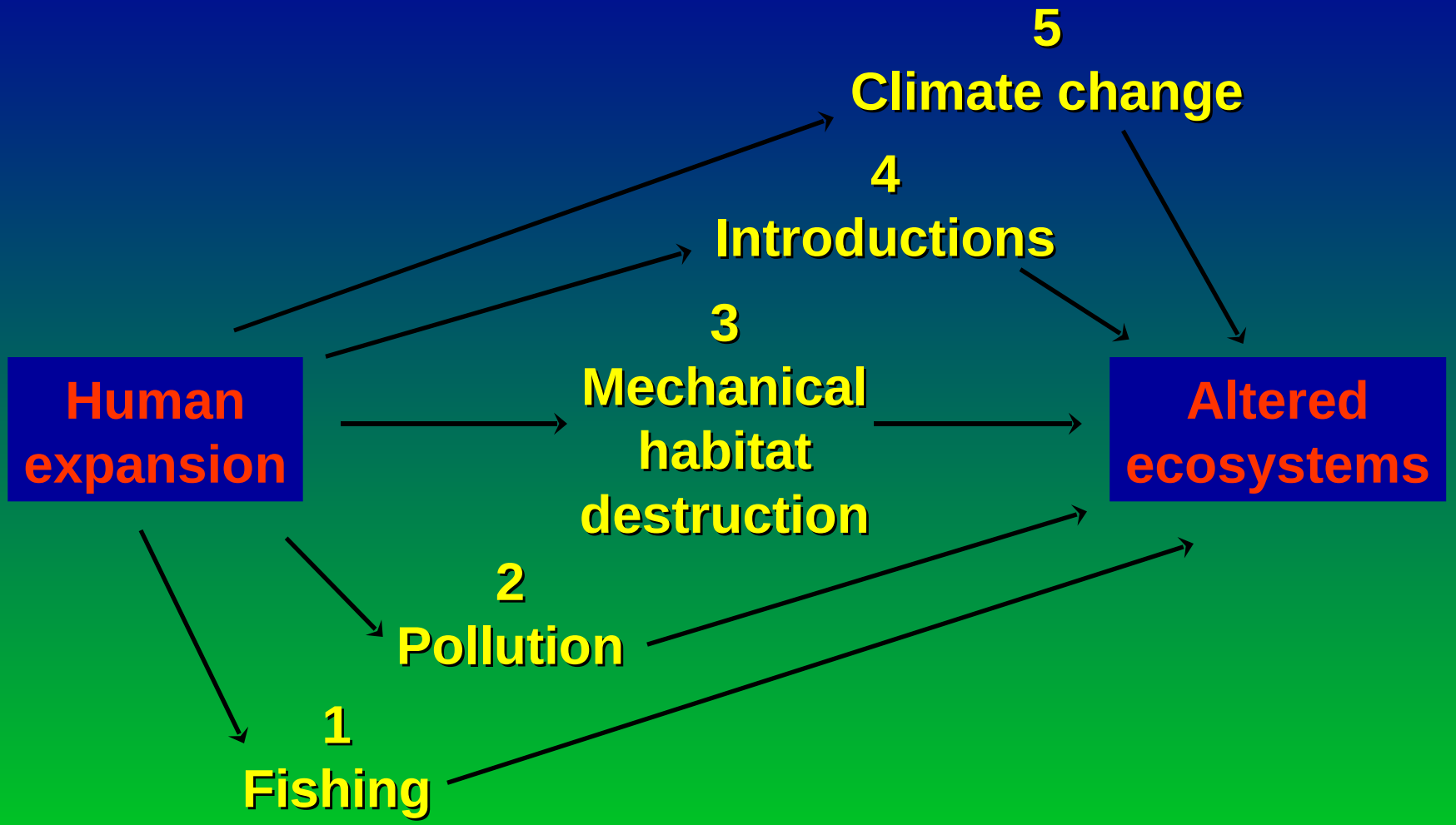


Courtesy of Villy Christensen, UBC, Fisheries Centre

ESTIMATED SOCIOECONOMIC VALUE OF LMEs

Goods and Services Contribute $12.6 Trillion Annually to the Global Economy

Costanza et al. , NATURE, Vol. 287/ 15 May 1997



"Then" .....➤

"Now"

(from Jackson *et al.*, *Science* vol. 293, 27 July 2001)

The Downward Spiral

Human activities are cumulatively driving the health of the world's oceans down a rapid spiral, and only prompt and wholesale changes will slow or perhaps ultimately reverse the catastrophic problems they are facing.

Jeremy Jackson, Scripps Institution of Oceanography / University of California, San Diego – Scripps News of 13 August 2008

SELECTED ECOSYSTEM-RELATED WSSD TARGETS AND PROGRAM OF IMPLEMENTATION (POI), Johannesburg, August 2002

- Land-based Sources of Pollution
  POI – Substantially reduce by 2006
- Ecosystem-based Approach
  POI – Introduce by 2010
- Marine Protected Areas
  POI - Designated Network by 2012
- Restoration and Sustainability of Fisheries
  POI – On an urgent basis and where possible to MSY by 2015

LMEs ARE GLOBAL CENTERS OF EFFORTS TO:

- **REDUCE** coastal pollution
- **RESTORE** damaged habitats
  (Coral reefs, mangroves, sea grasses)
- **RECOVER** depleted fishery stocks

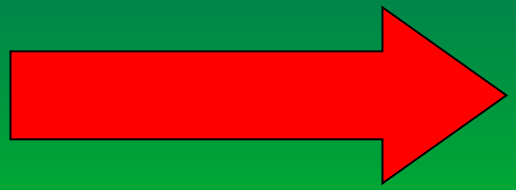
ECOSYSTEM MANAGEMENT: A PARADIGM SHIFT

FROM	TO
Individual species	**Ecosystems**
Small spatial scale	**Multiple scales**
Short-term perspective	**Long-term perspective**
Humans: independent of ecosystems	**Humans: integral part of ecosystems**
Management divorced from research	**Adaptive management**
Managing commodities	**Sustaining production potential for goods and services**

From:
Lubchenco J. 1994. The scientific basis of ecosystem manatement: Ecosystem management: Status and potential: 103rd Congress, 2d session, Committee Print. U.S. Government Printing Office, Superintendent of Documents. 33-39

GEF International Waters Operational Strategy

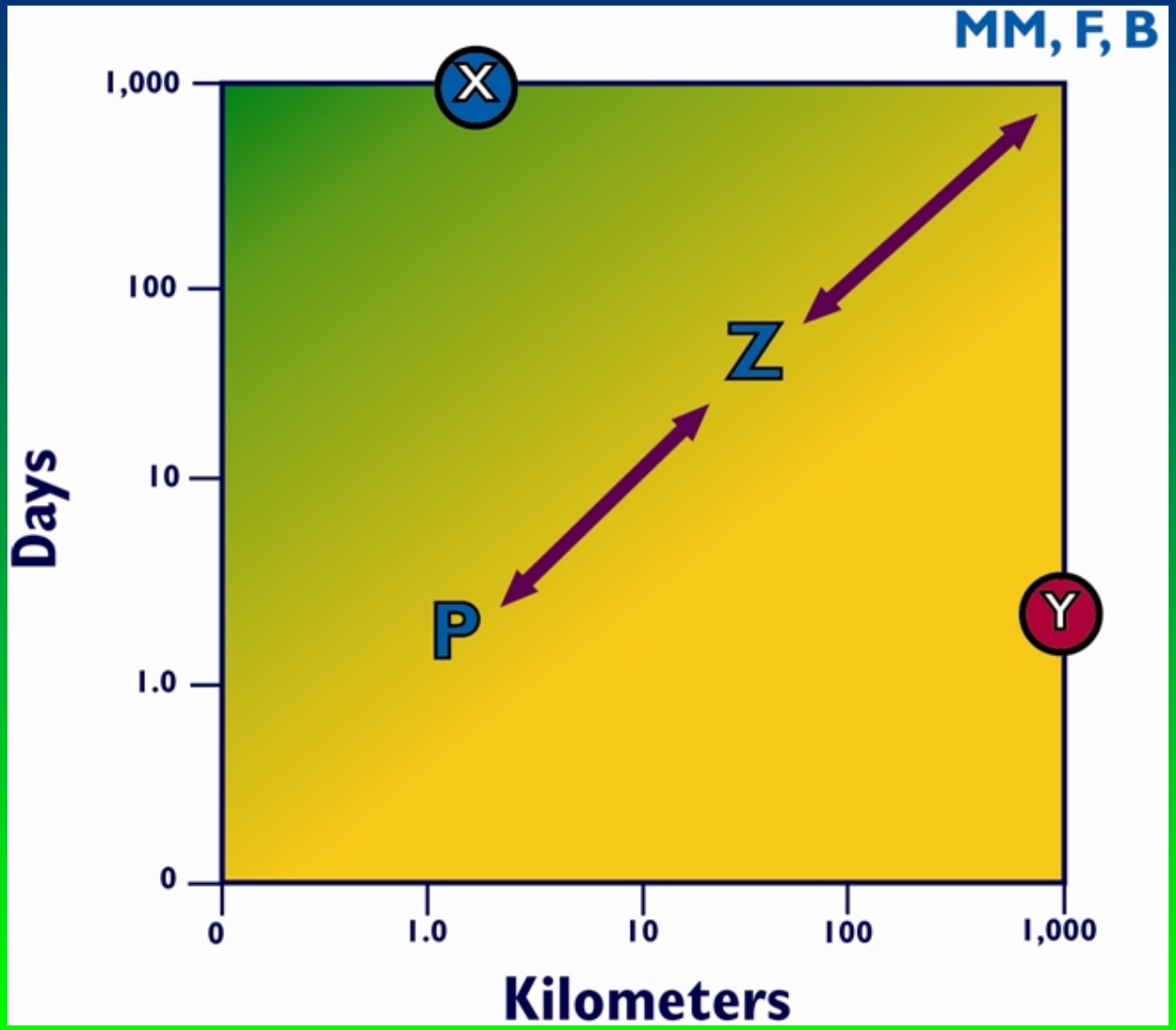
Supports New Paradigm



- **Ecosystem-based LME recovery and sustainability actions**

- **Transboundary Diagnostic Analyses (TDA) and Strategic Action Plan (SAP) priority actions**

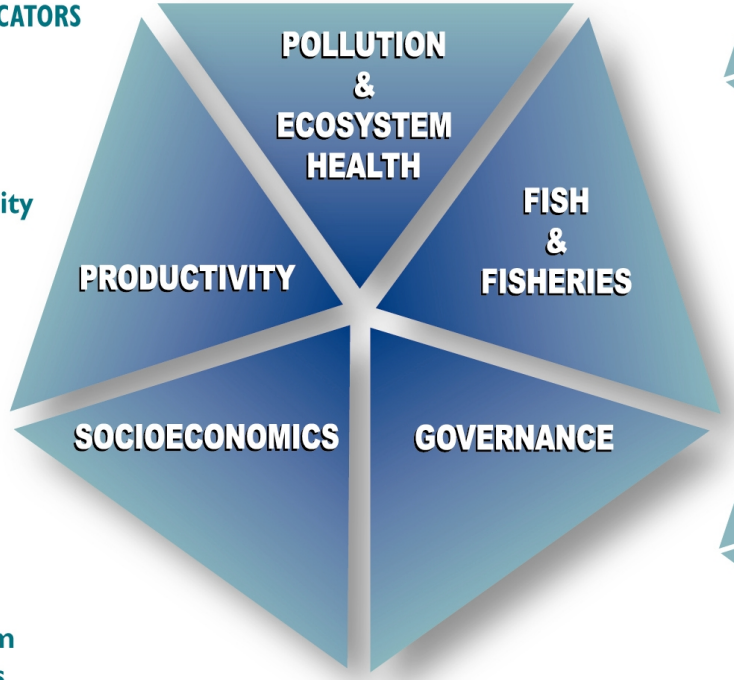
TEMPORAL AND SPATIAL SCALE RELATIONS FOR THE PELAGIC FOOD WEB



INDICATORS OF CHANGING STATES OF LARGE MARINE ECOSYSTEMS

5 MODULES WITH INDICATORS

Modular Assessments for Sustainable Development



PRODUCTIVITY MODULE INDICATORS
- Photosynthetic activity
- Zooplankton biodiversity
- Oceanographic variability
- Zooplankton biomass
- Ichthyoplankton biodiversity

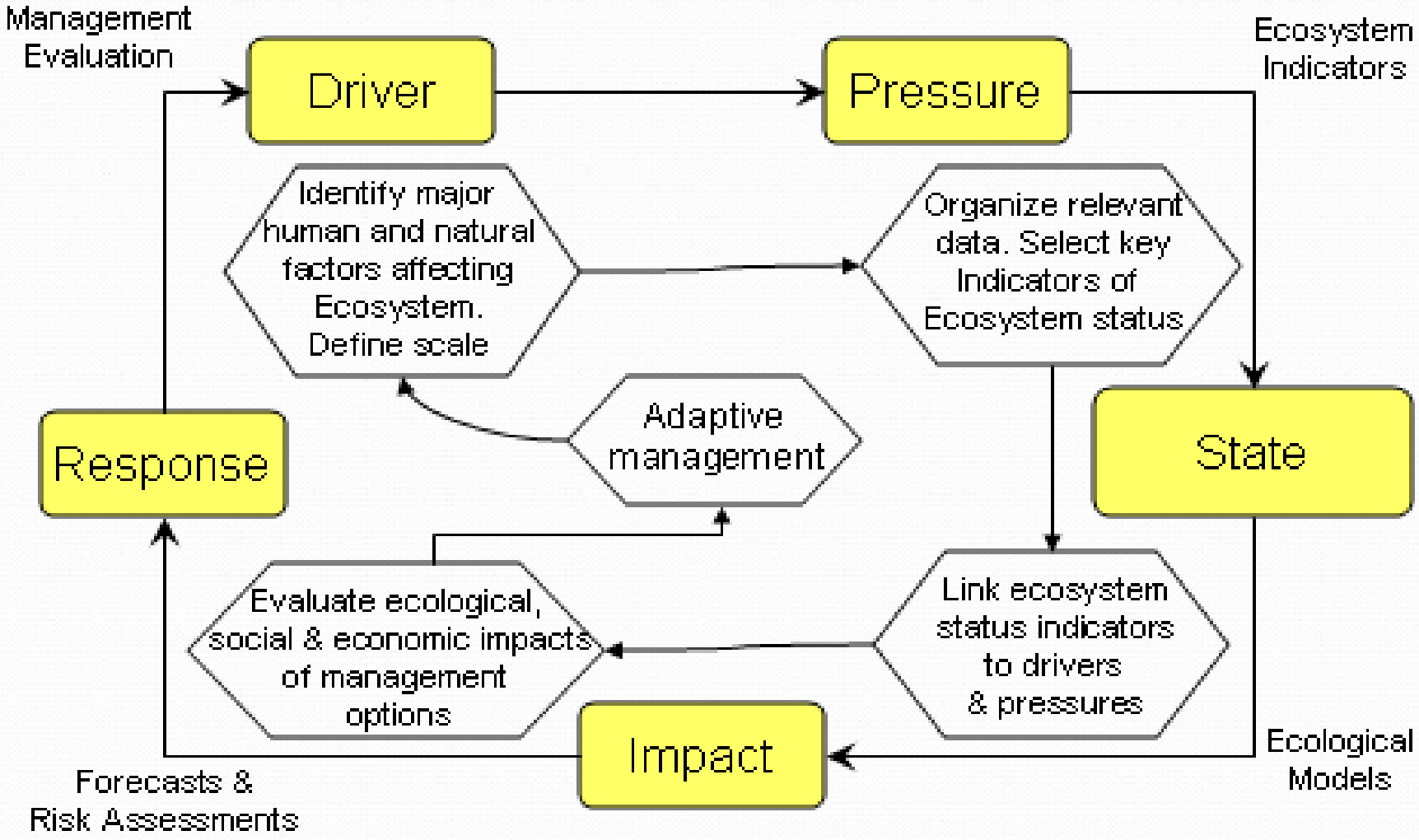
POLLUTION & ECOSYSTEM HEALTH MODULE INDICATORS
- Eutrophication
- Biotoxins
- Pathology
- Emerging disease
- Health indices
- Multiple marine ecological disturbances

SOCIOECONOMIC MODULE INDICATORS
- Integrated assessments
- Human forcing
- Sustainability of long-term socioeconomic benefits

FISH & FISHERIES MODULE INDICATORS
- Biodiversity
- Finfish
- Shellfish
- Demersal species
- Pelagic species

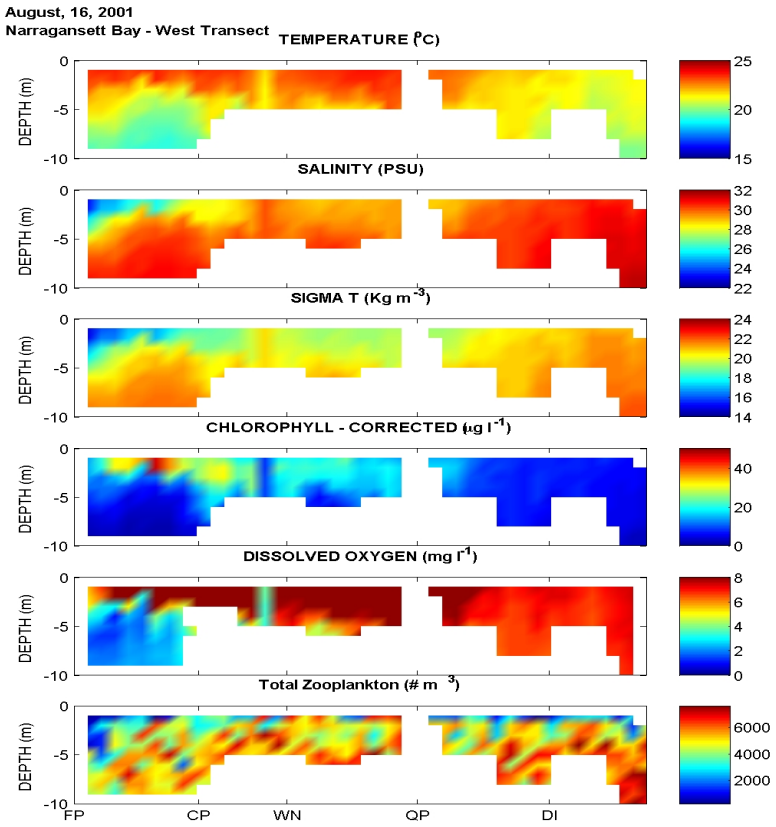
GOVERNANCE MODULE INDICATORS
- Stakeholder participation
- Adaptive management

Driver-Pressure-State-Impact-Response



From M. Fogarty et al. 2008

PRODUCTIVITY INDICATORS

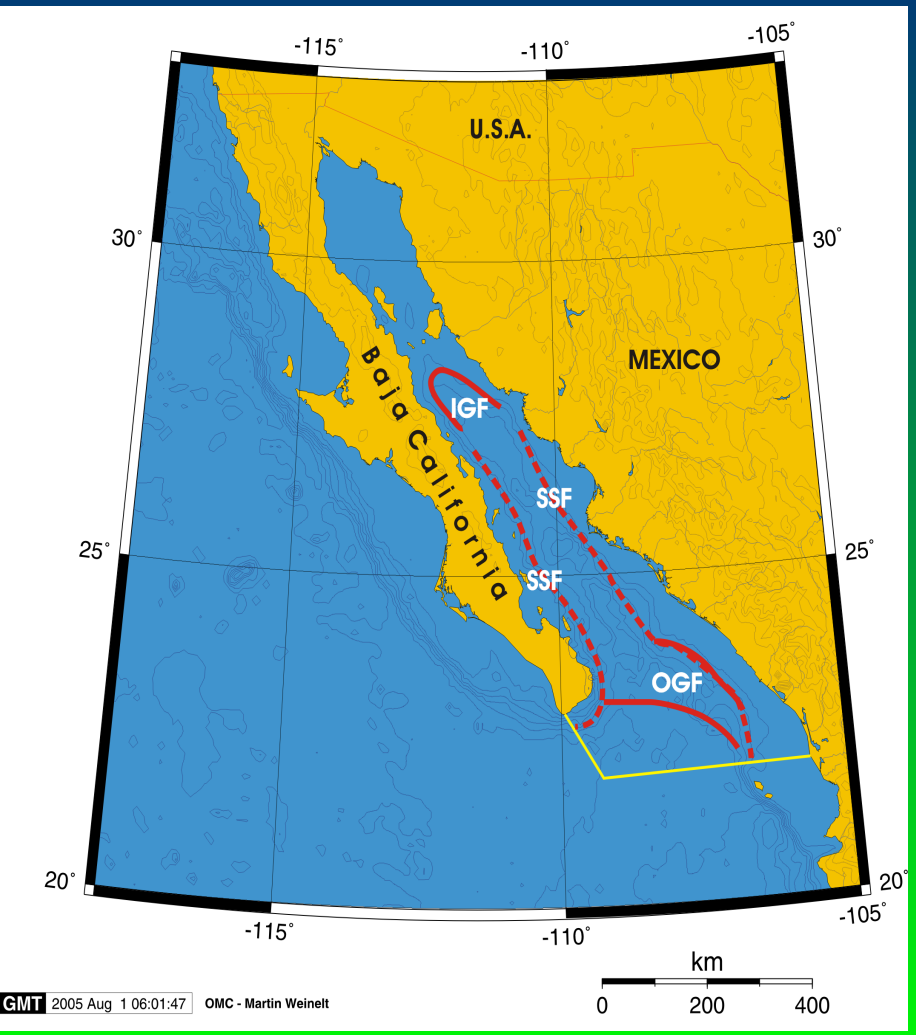


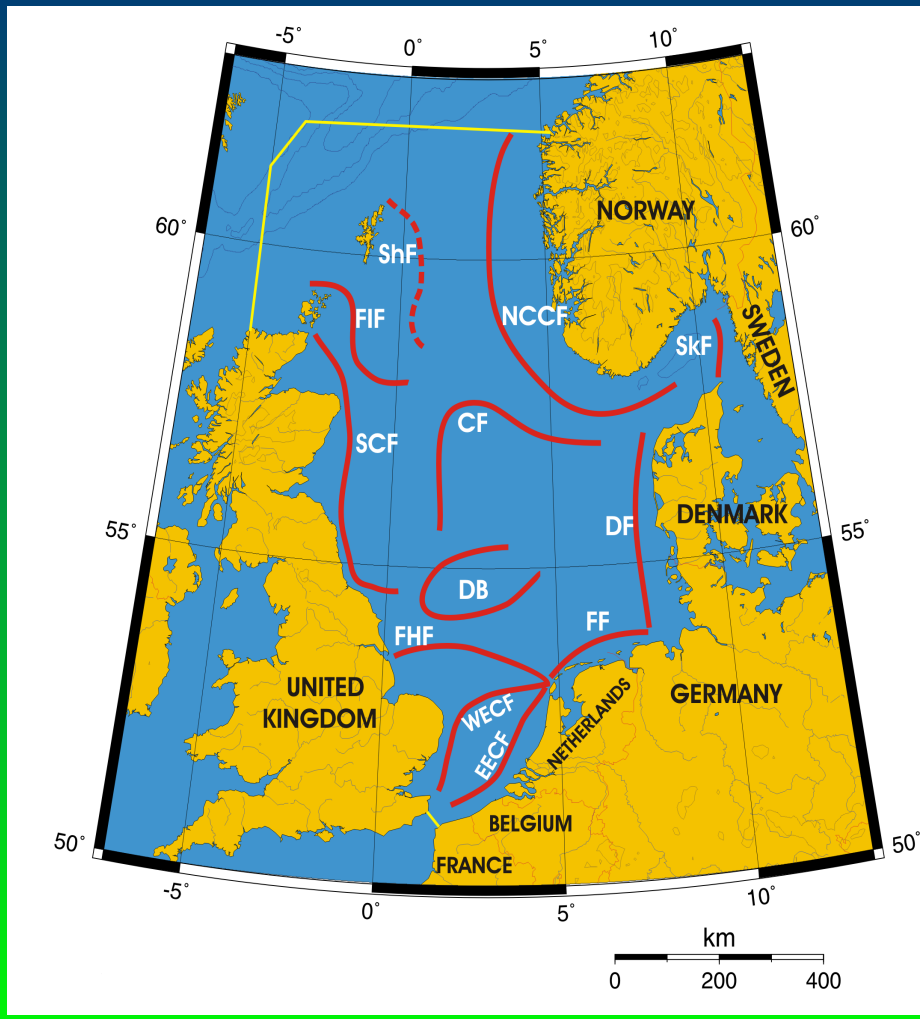
An undulating oceanographic recorder (above), towed behind a ship, is used to collect ecological parameters needed to assess the state of the marine ecosystem (left).

Productivity Indicators of changing ecosystem states

- Primary productivity and chlorophyll trends (1998-2006)
- LME fronts (temperature gradients)
- Sea Surface Temperatures (SST) profiles and anomalies (1957-2006 and 1982-2006) at the LME scale.

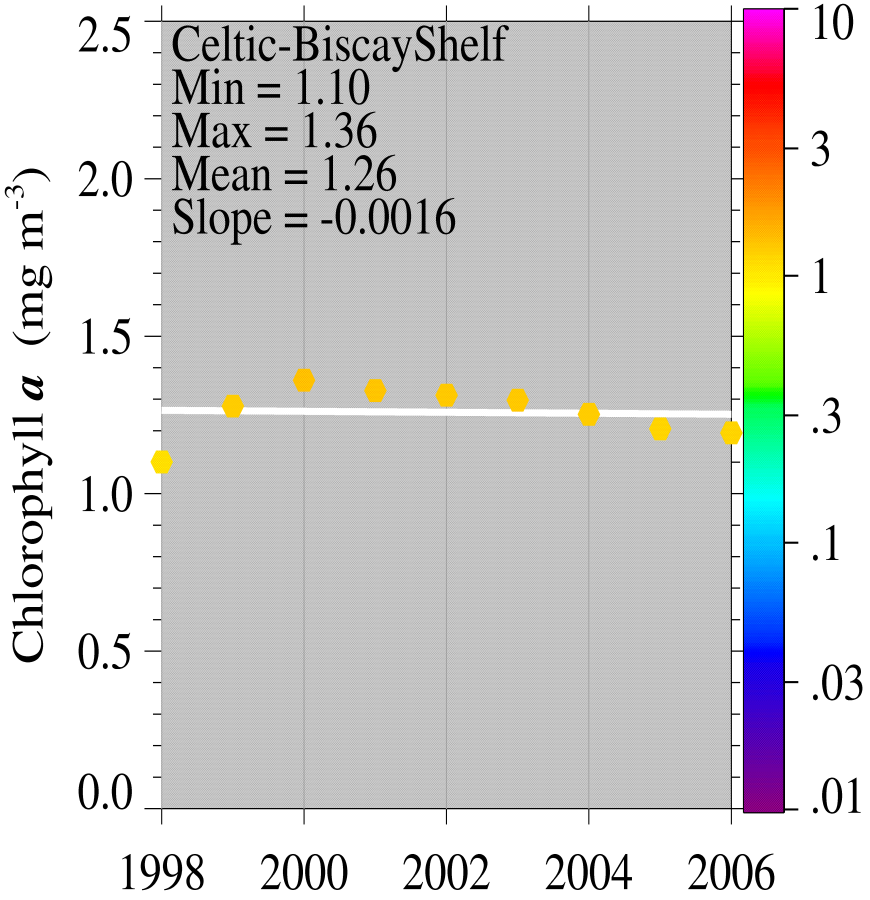
Frontal Maps: Gulf of California (left) and North Sea (right) LMEs

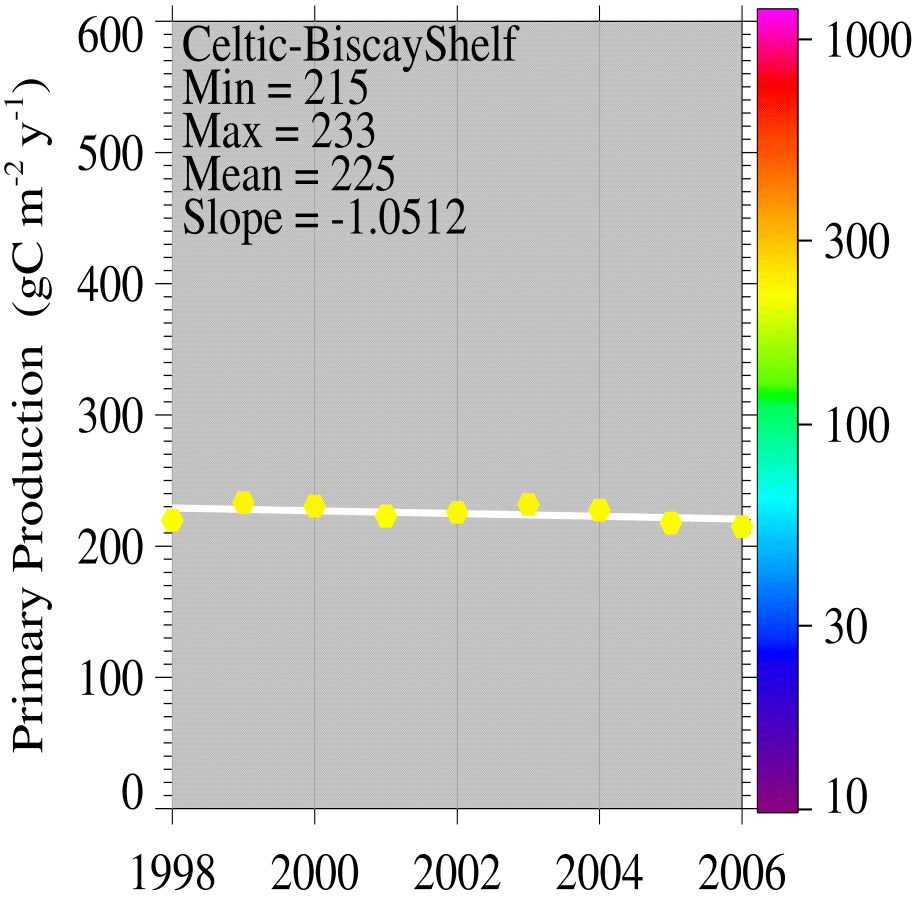




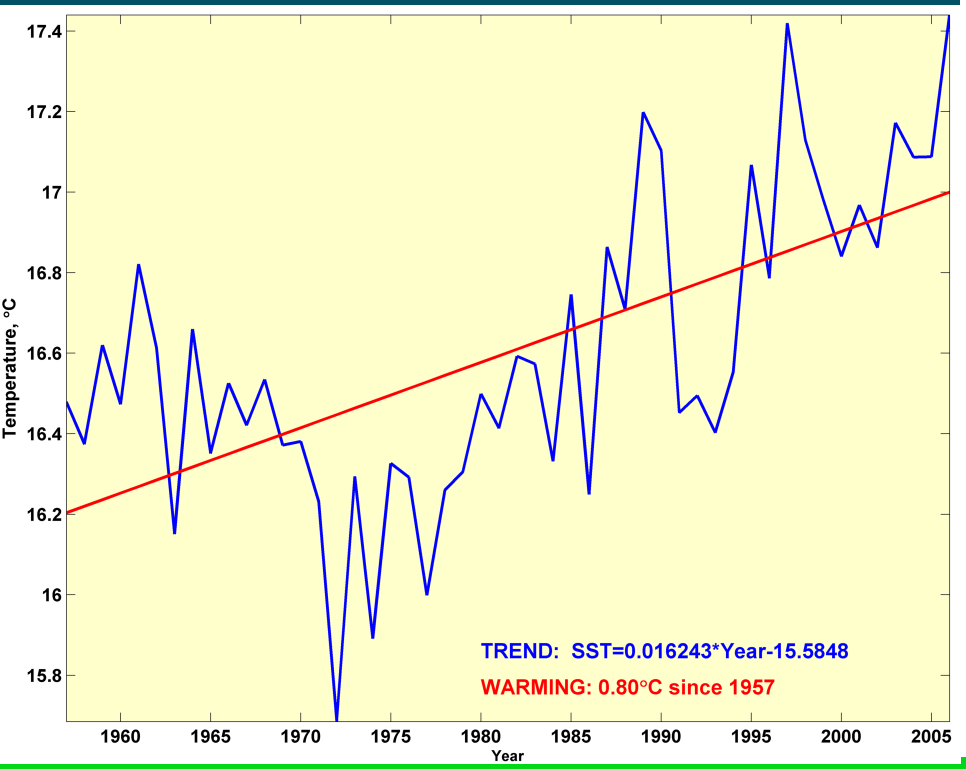
I. Belkin

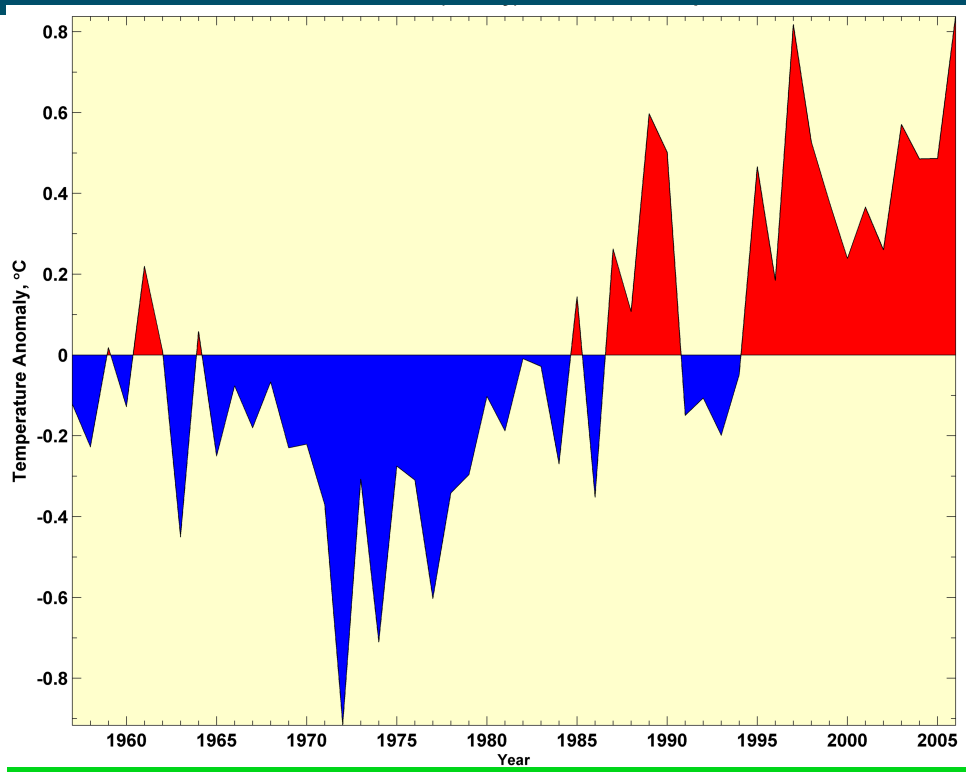
Celtic Biscay Shelf LME trends in chlorophyll (left) and primary productivity (right) (1998-2006)





Iberian Coastal LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology.





I. Belkin 2008

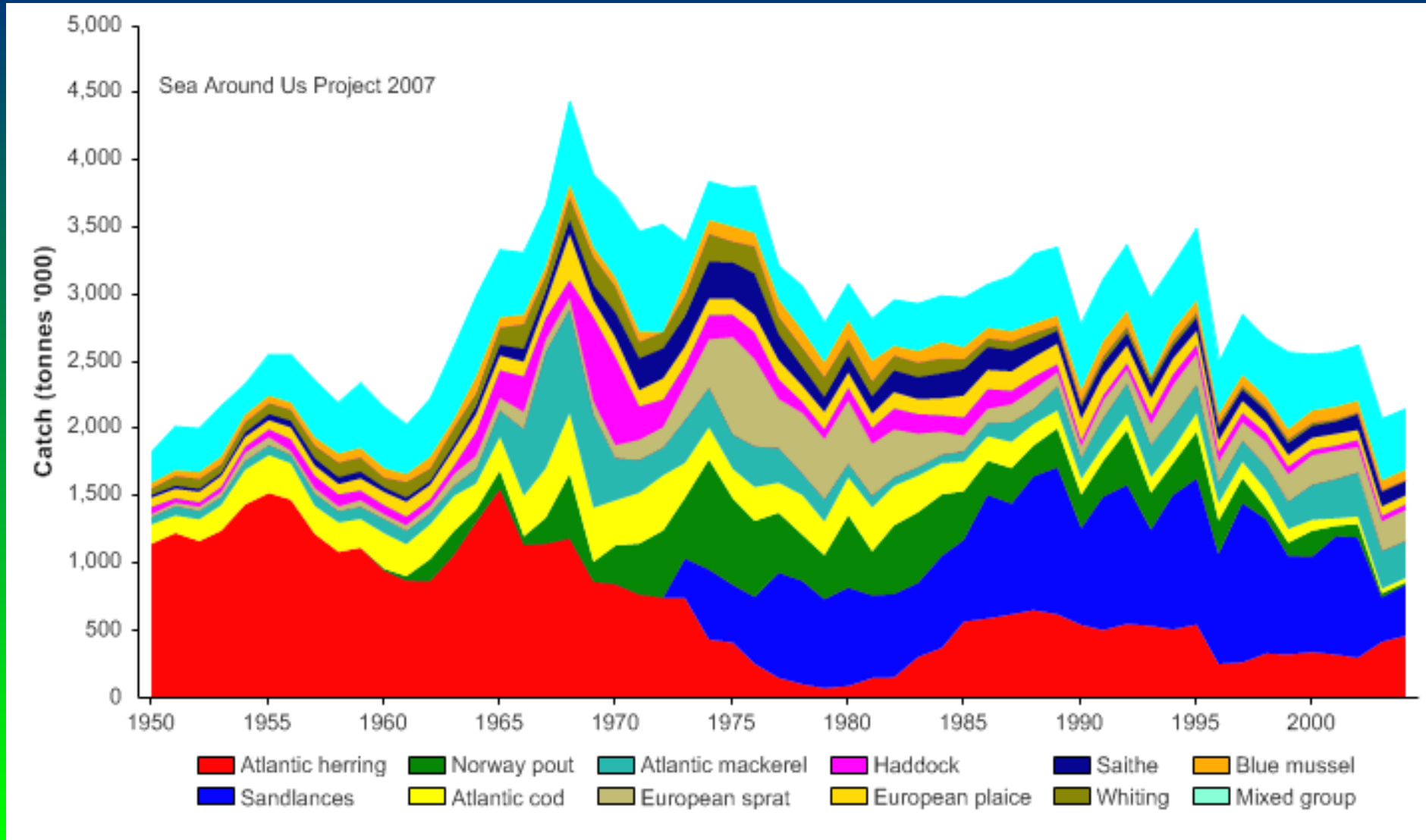
Fish and Fisheries Indicators

For each LME…

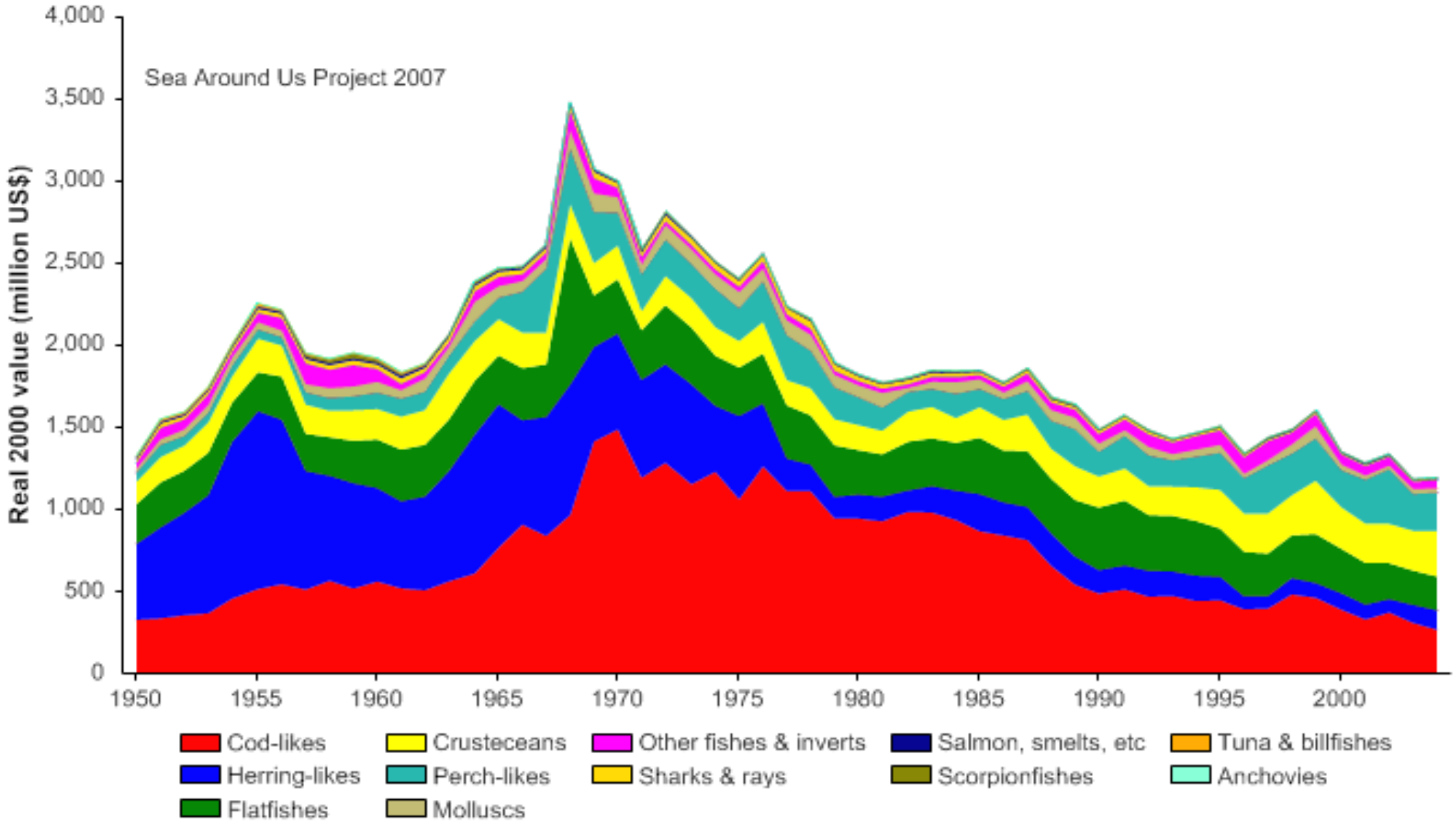
- **Mean annual total catch (1950-2004)**
- **Total value**
- **Primary Productioon Required (PPR) to sustain fisheries (“footprint”)**

Daniel Pauly, Villy Christensen, Sea Around Us

North Sea LME catch data
(Sea Around Us Project 2007)

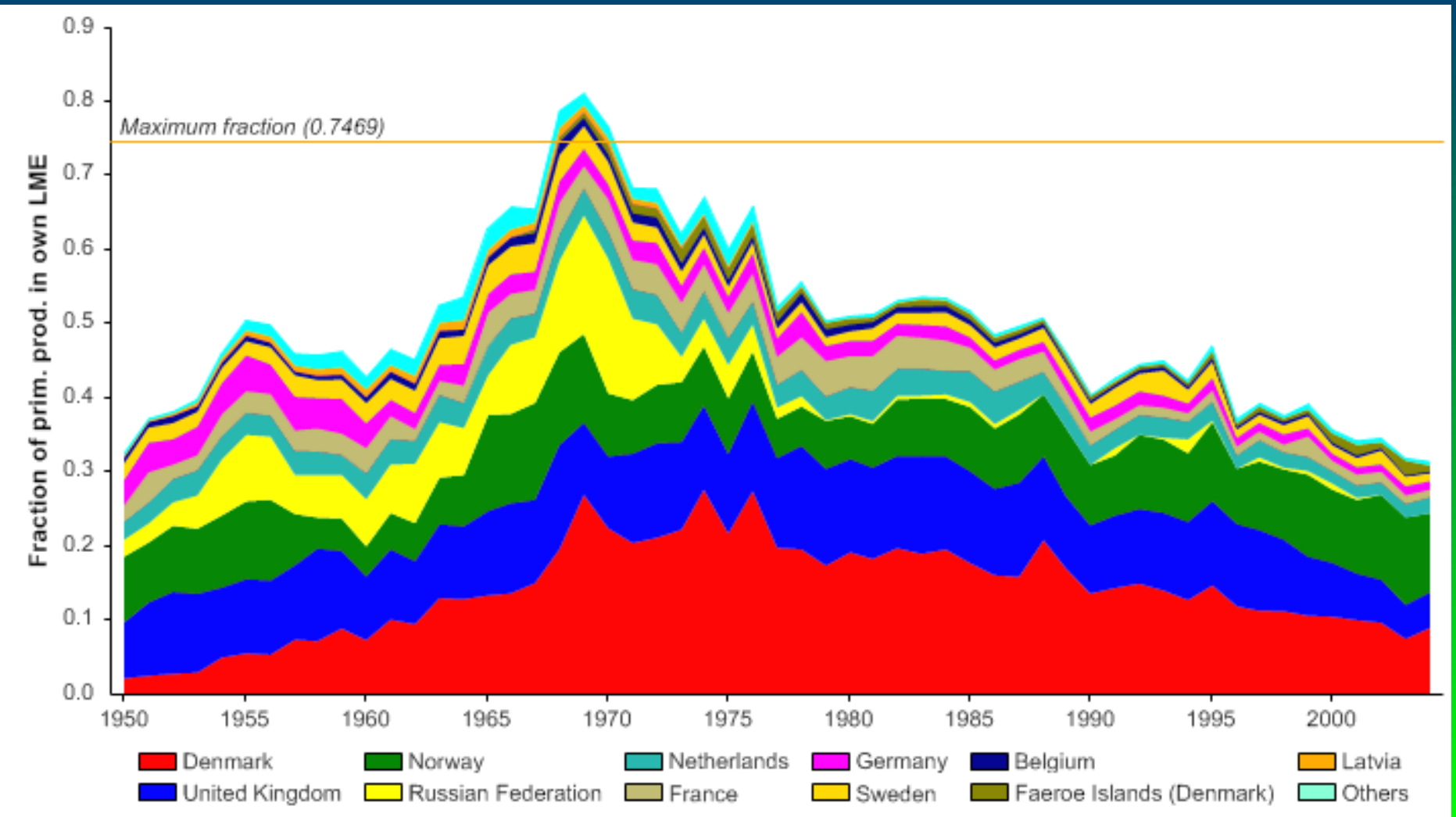


Value of reported landings in the North Sea LME by commercial groups (Sea Around Us 2007)



Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the North Sea LME

(Sea Around Us 2007).



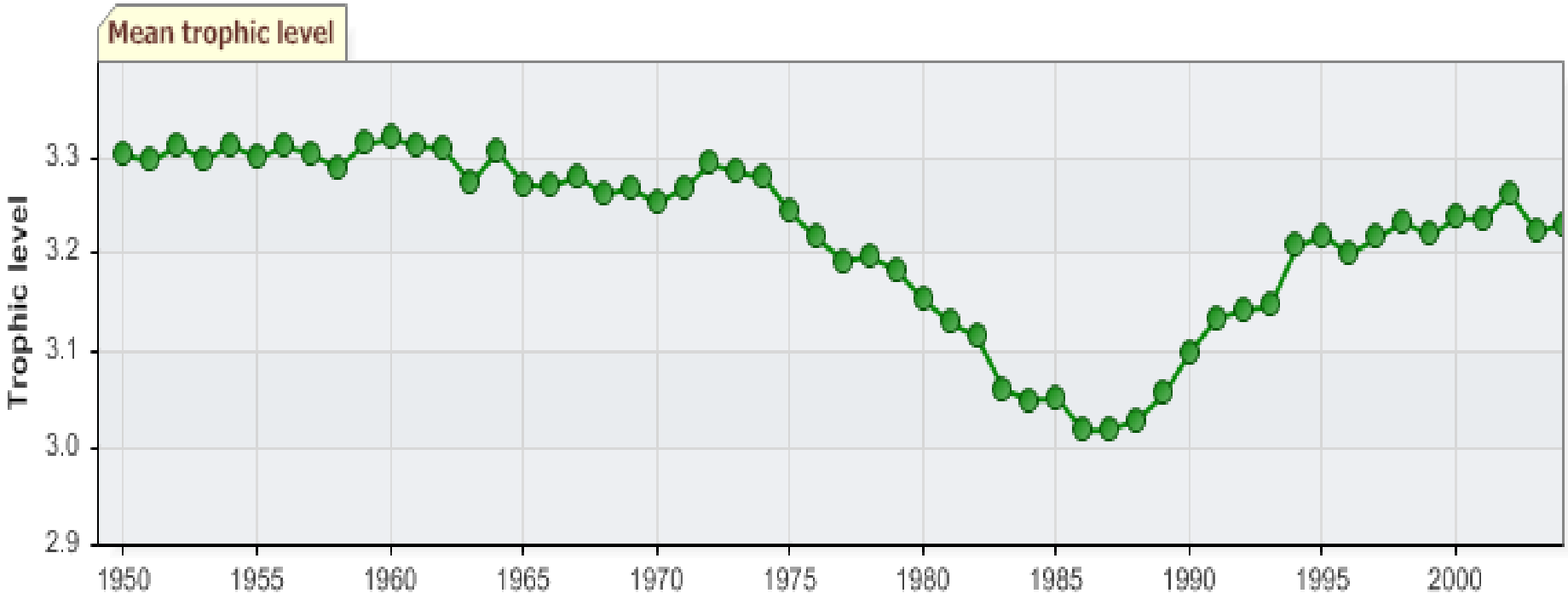
Fish and Fisheries Indicators

For each LME…

- **Mean annual trophic levels of fish catches and FiB**
- **Fisheries conditions relative to stock conditions (developing, fully exploited, over exploited, collapsed)**

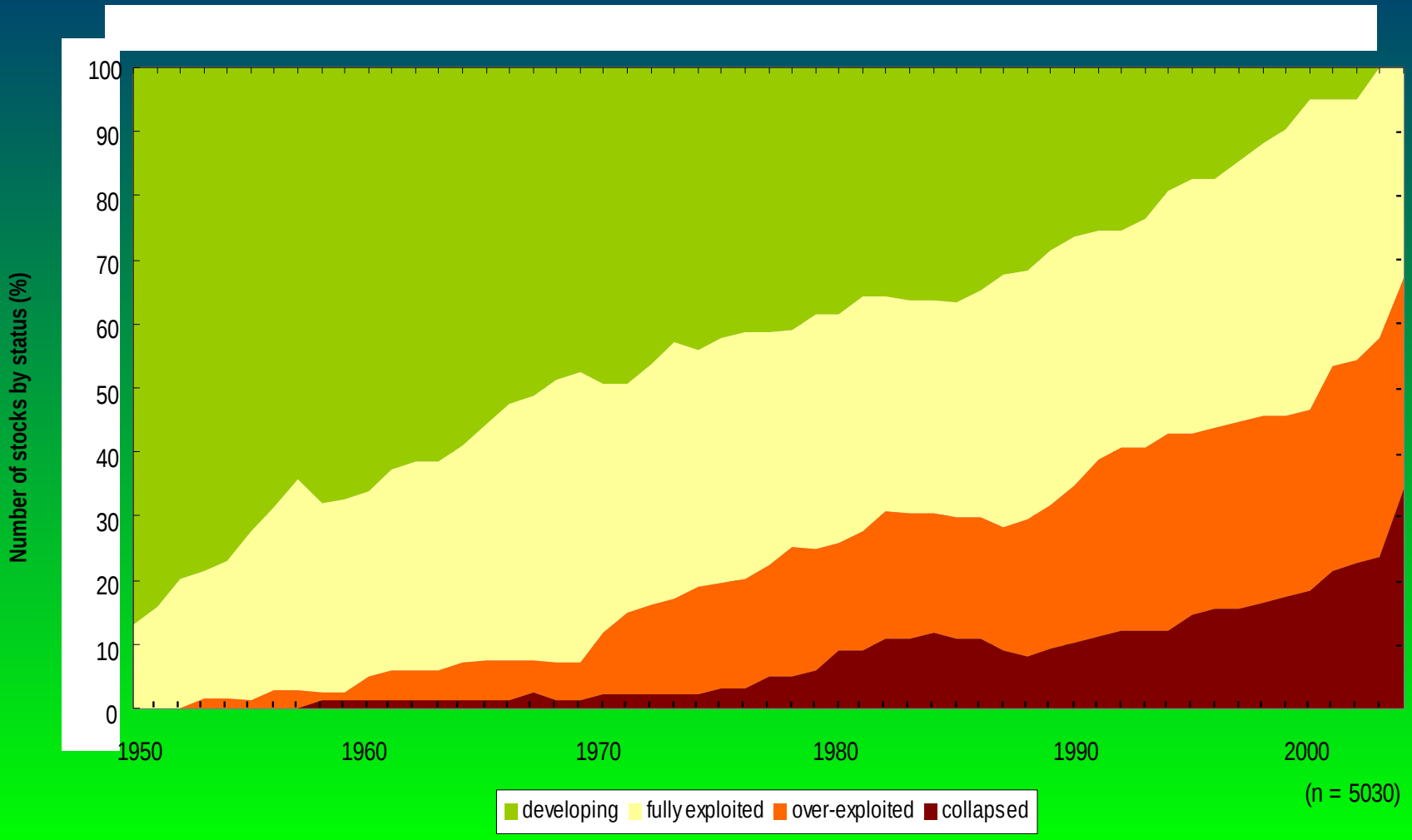
Daniel Pauly, Villy Christensen, Sea Around Us

Mean trophic level (i.e., Marine Trophic Index) in the Yellow Sea LME (Sea Around Us 2007).



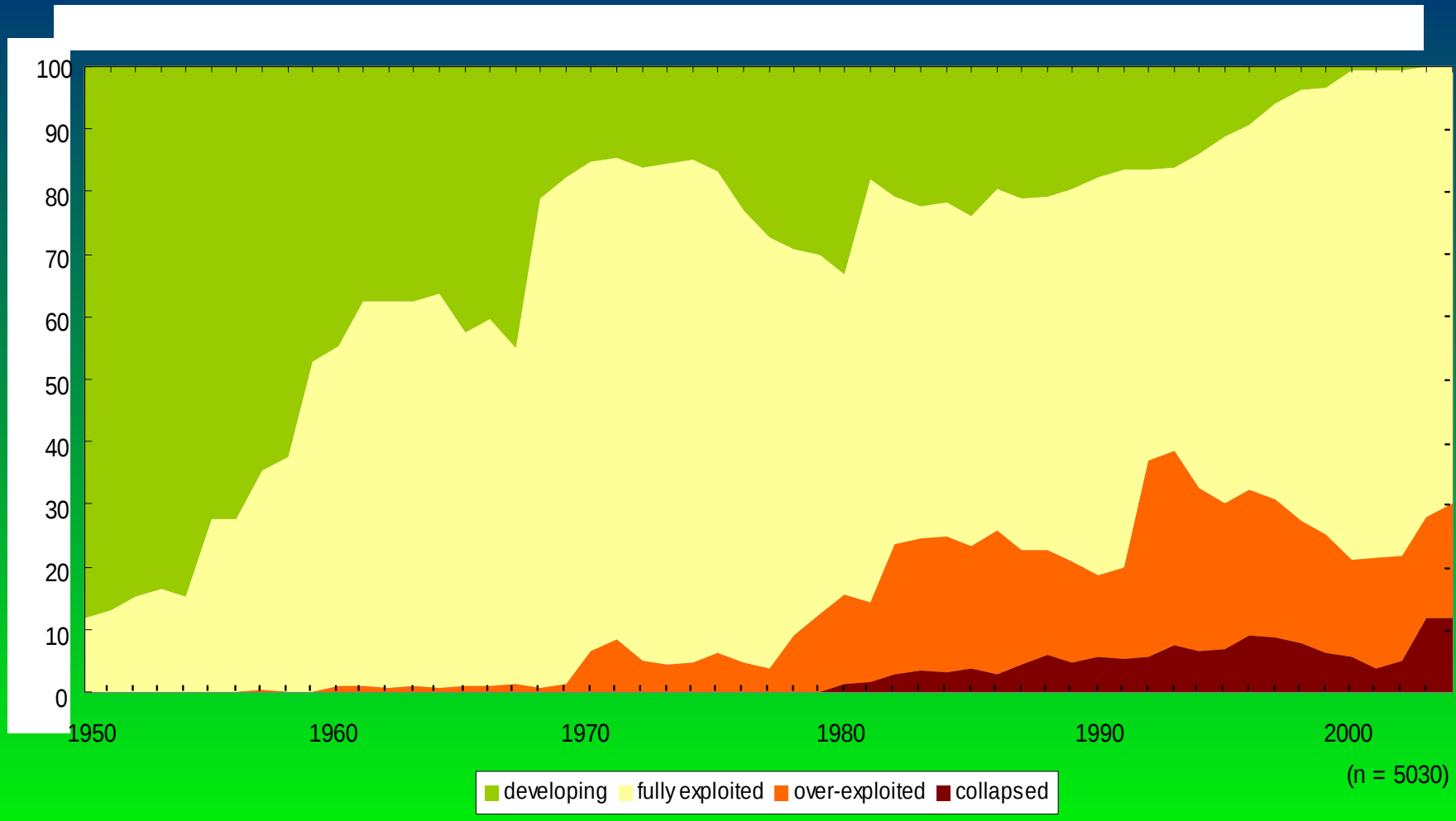
Yellow Sea LME:

The Stock-Catch Status Plot indicates that the number of the collapsed and overexploited stocks has been increasing, accounting for 60% of the commercially exploited stocks in the LME

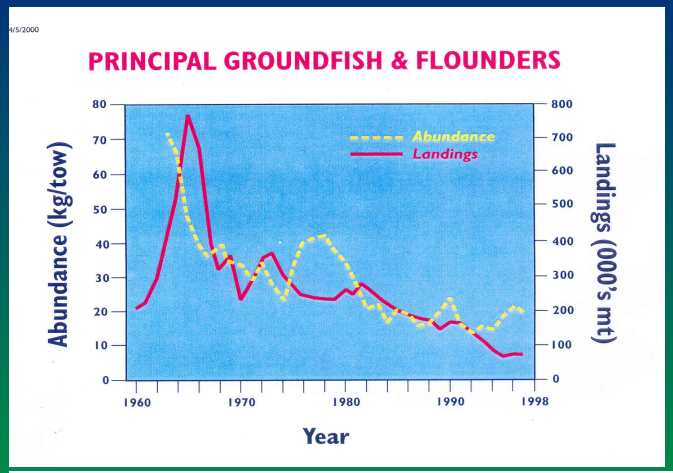


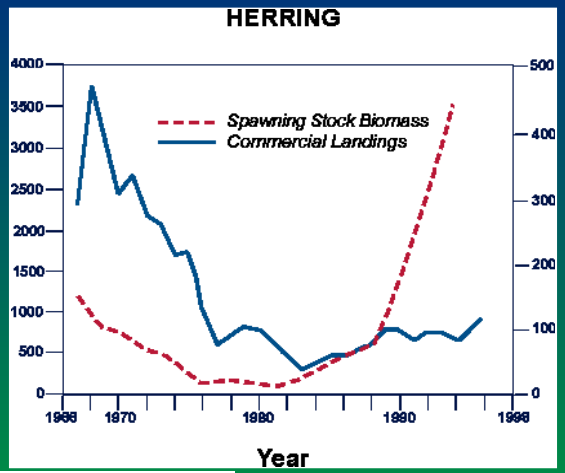
Yellow Sea LME:

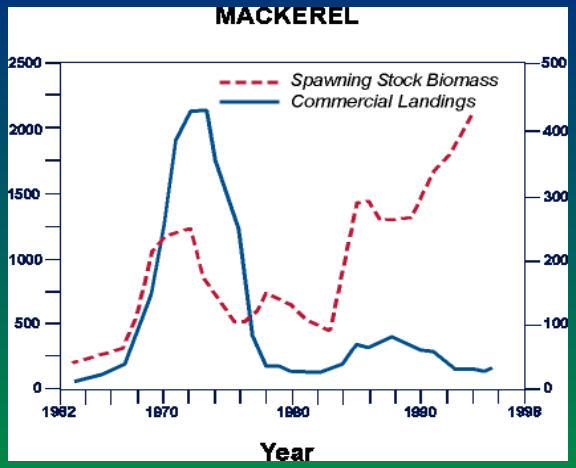
Stock-Catch Status Plots by catch biomass(1950-2004): 70% of the catch is still supplied by fully exploited stocks.

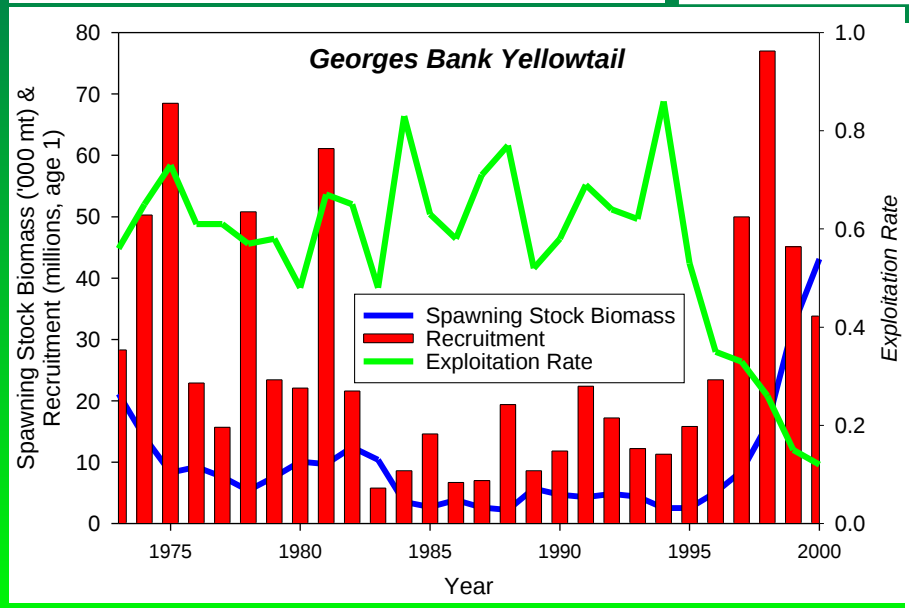


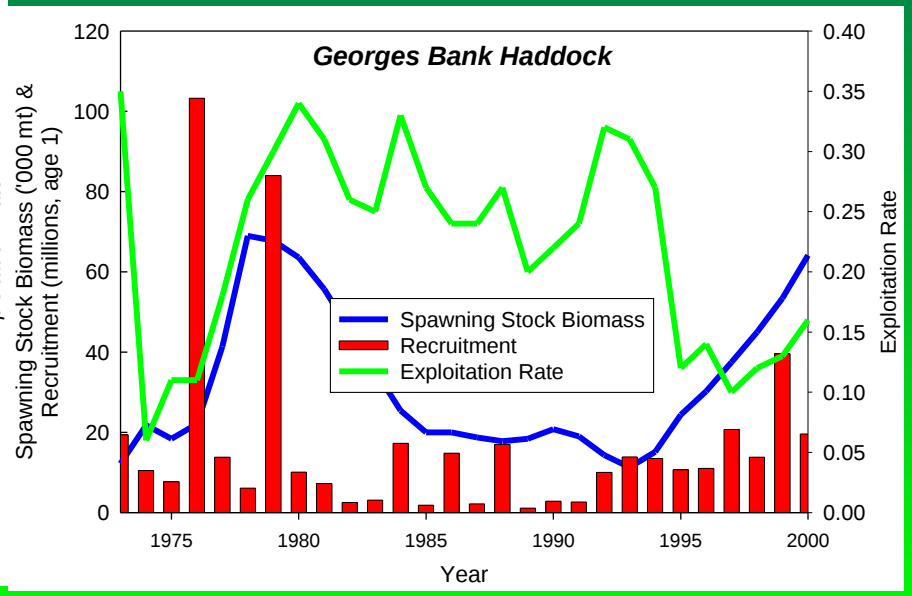
FISH AND FISHERIES INDICATORS

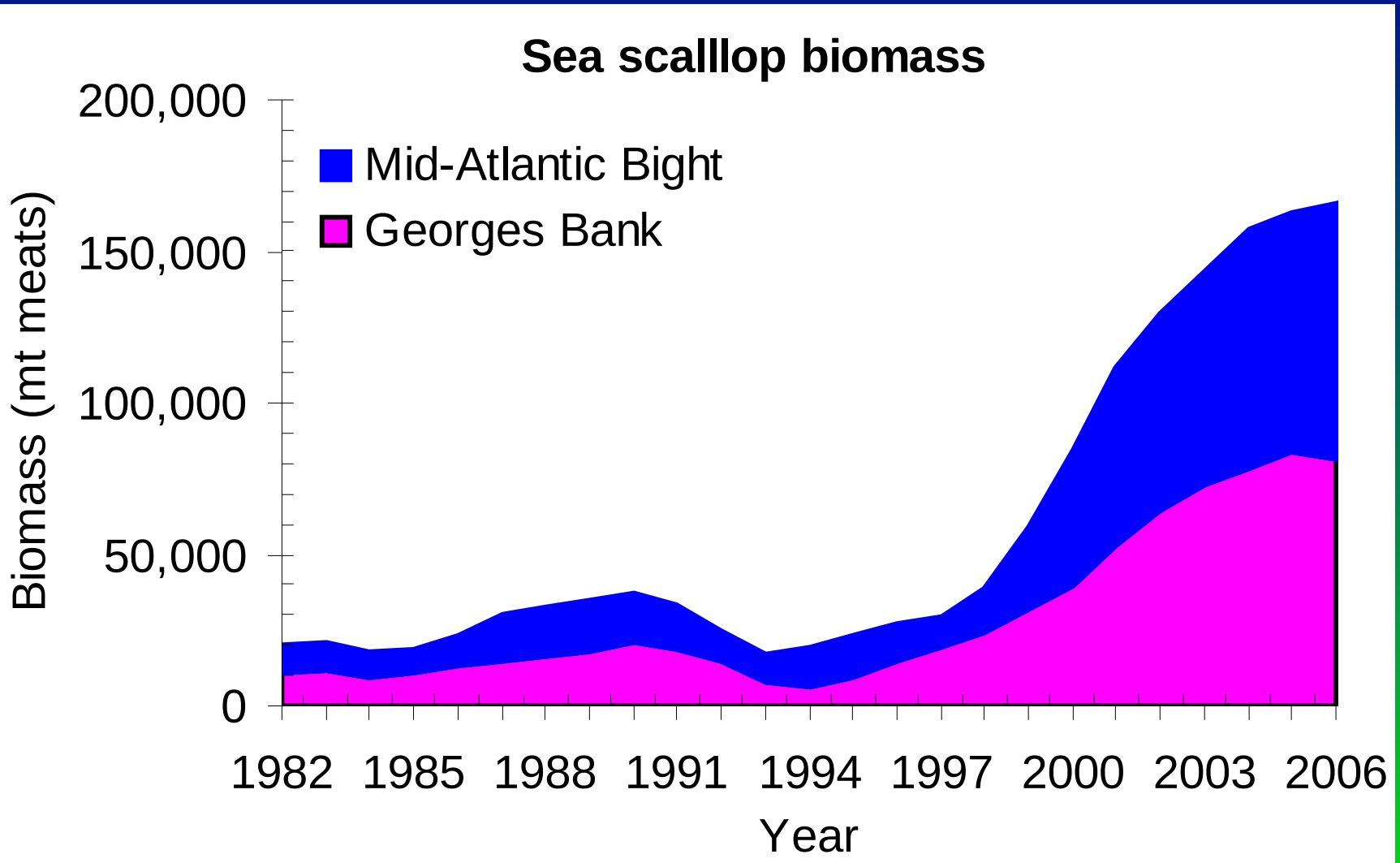











Sea scalllop biomass
200,000
150,000
100,000
50,000
0
Biomass (mt meats)
Mid-Atlantic Bight
Georges Bank
1982
1985
1988
1991
1994
1997
2000
2003
2006
Year

Methodology for Assessing the Changing States of the World's LMEs During Climate Change PART II

Pollution and Ecosystem Health
Indicators

The US Environmental Protection Agency's seven pollution and ecosystem health Indicators:

(water quality, dissolved oxygen, coastal habitat, eutrophic condition, sediment quality, benthic index, fish tissue contaminants)

POLLUTION AND ECOSYSTEM HEALTH INDICATORS

Indicators:

- *Water Clarity*
- *Dissolved Oxygen*
- *Coastal Wetland Loss*
- *Eutrophic Condition*
- *Sediment Contamination*
- *Benthic Index*
- *Fish Tissue Contaminants*
- *Multiple Marine Ecological Disturbances*

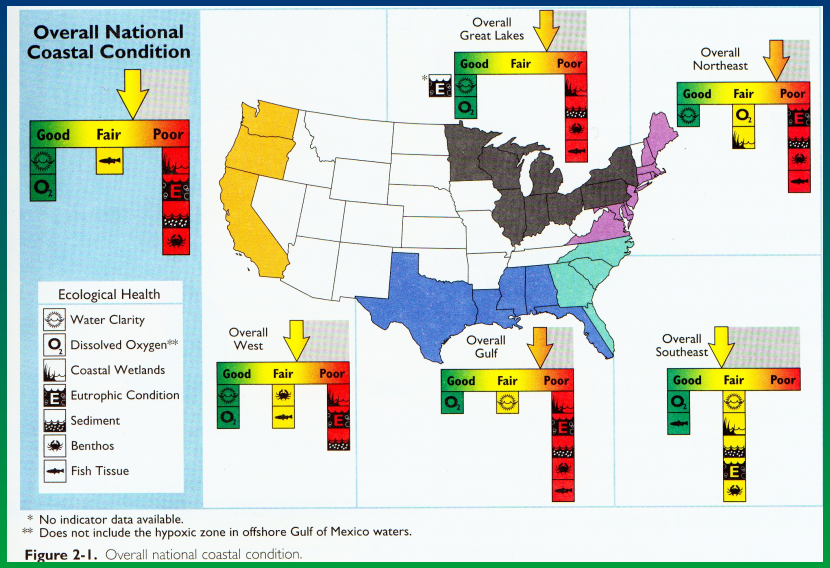
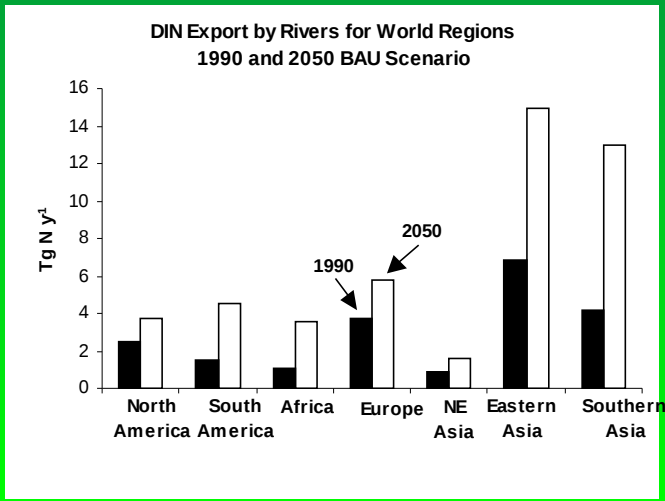
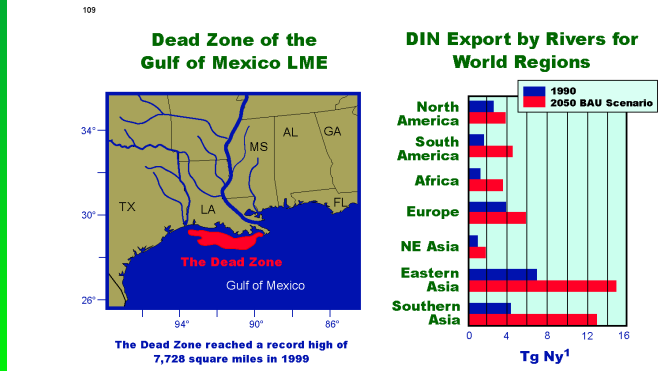


Figure 2-1. Overall national coastal condition.





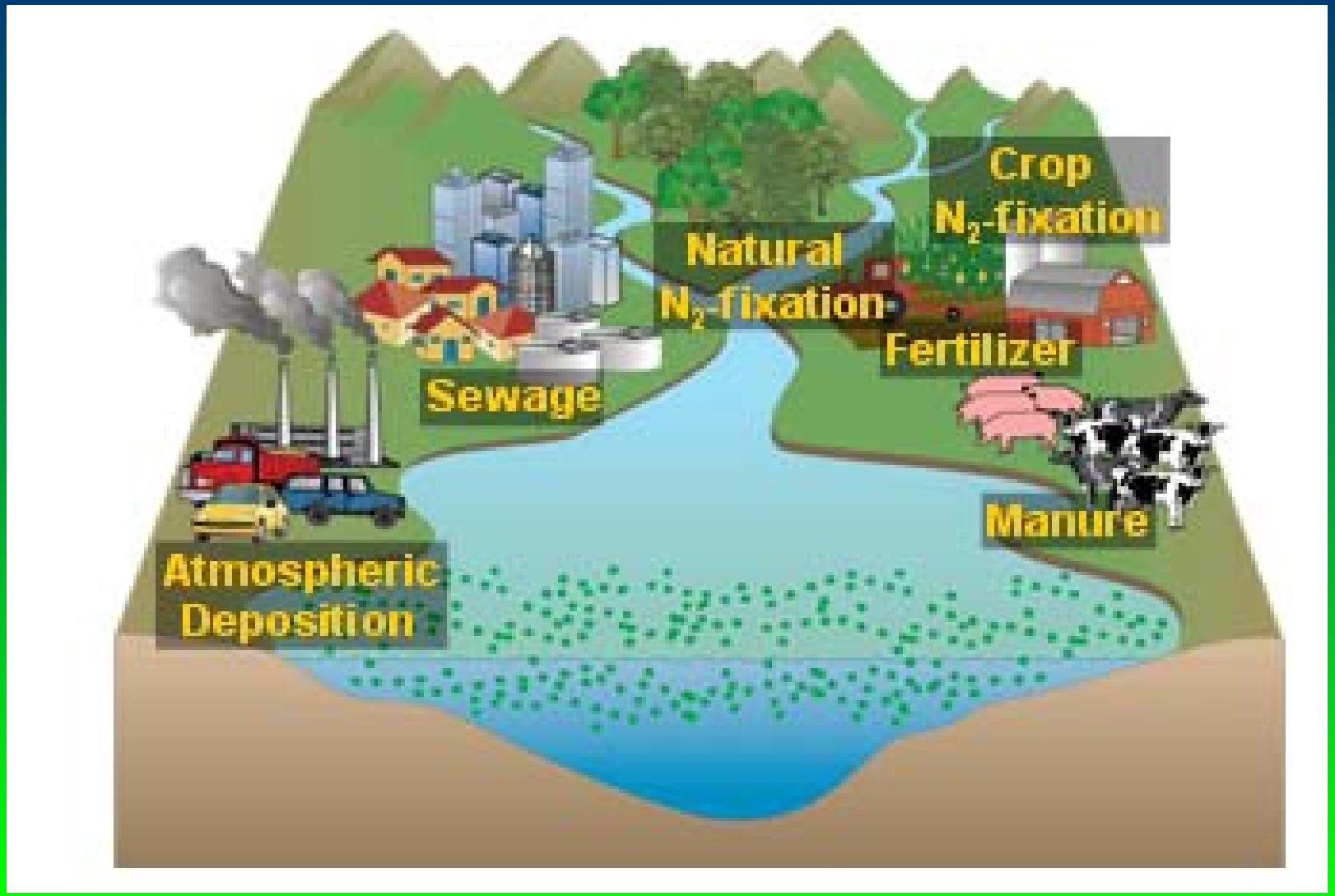
Pollution and Ecosystem Health: nutrient over-enrichment indicators

A Watershed perspective:

- Nutrient export model (Sybil Seitzinger);
- Nitrogen and Phosphorus export to coastal systems;
- Contribution of N sources in watersheds to model-predicted DIN river export to the coastal zone of each continent.

Watershed schematic of nitrogen inputs and transport to coastal systems

(University of Maryland Center for Environmental Science)



Global NEWS Model

Nutrient Sources

Natural
- N_2-Fixation
- P Weathering

Anthropogenic
- Non-Point
  - Fertilizer (by crop type)
  - N_2-fixation - crops
  - Atmos. Dep. N
  - Manure (by animal species)
- Point
  - Sewage (pop.; treatment level)

Hydrology & Physical Factors

Global Watersheds
- Water Runoff
- Precip. Intensity
- Land-use
- Slope

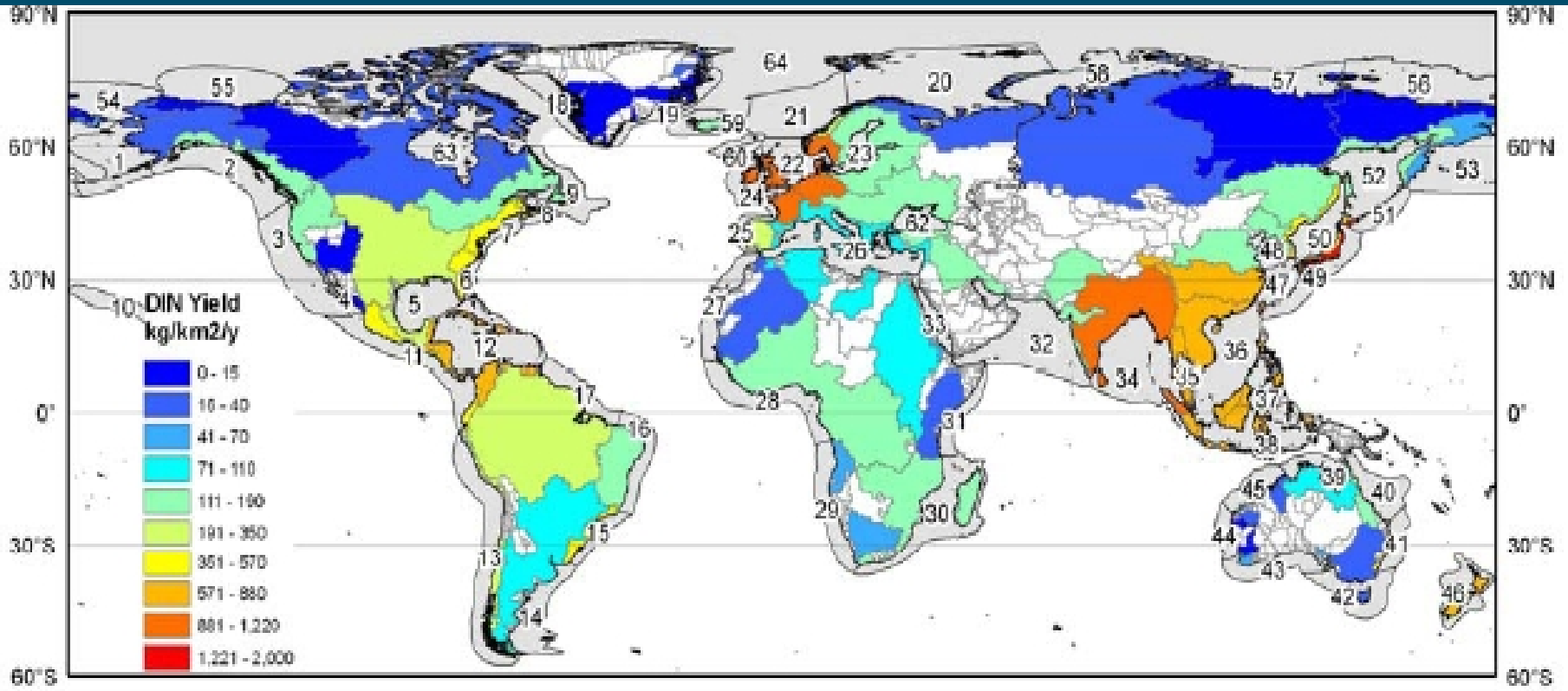
In-River N & P Removal

Rivers & Reservoir
- Consumptive Water Use

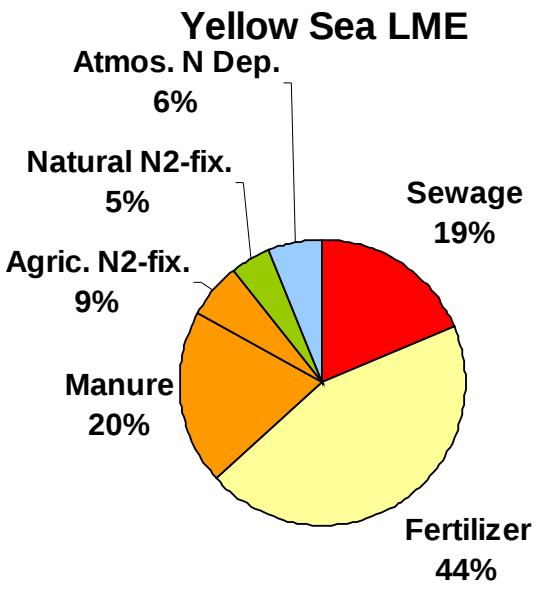
>5000 watersheds globally

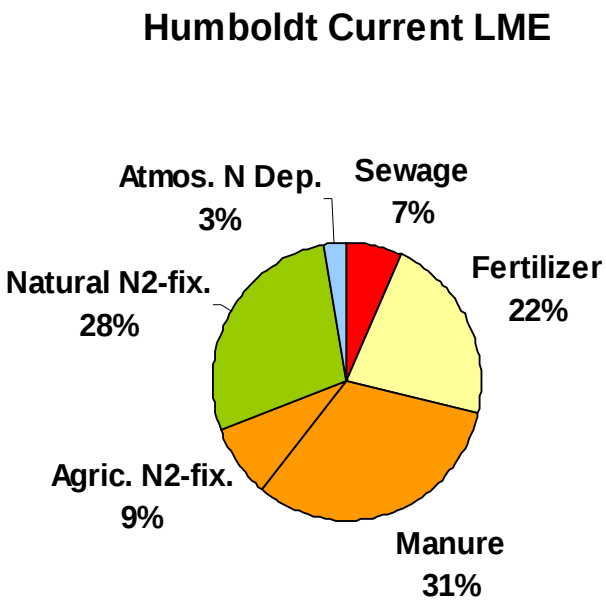
DIN yield from land-based sources to LMEs predicted by the NEWS DIN model.

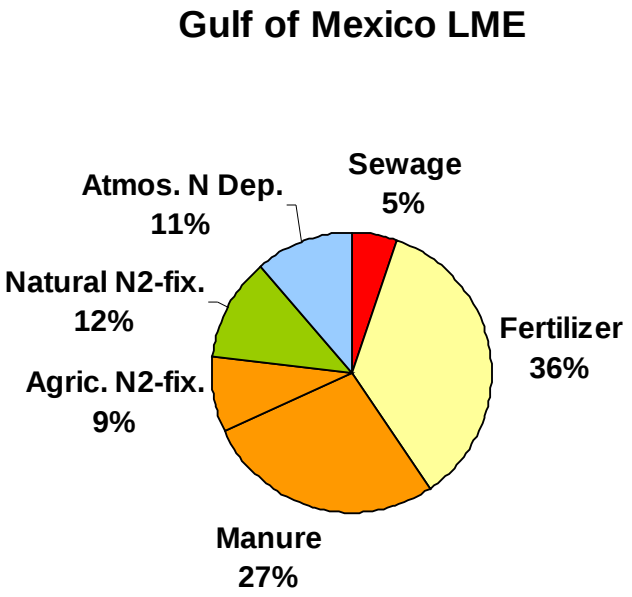
Watersheds discharging to LMEs are grey; watersheds with zero coastal discharge are white.



Source attribution of DIN export predicted by the NEWS DIN model to the Yellow Sea, Humboldt Current and Gulf of Mexico LMEs

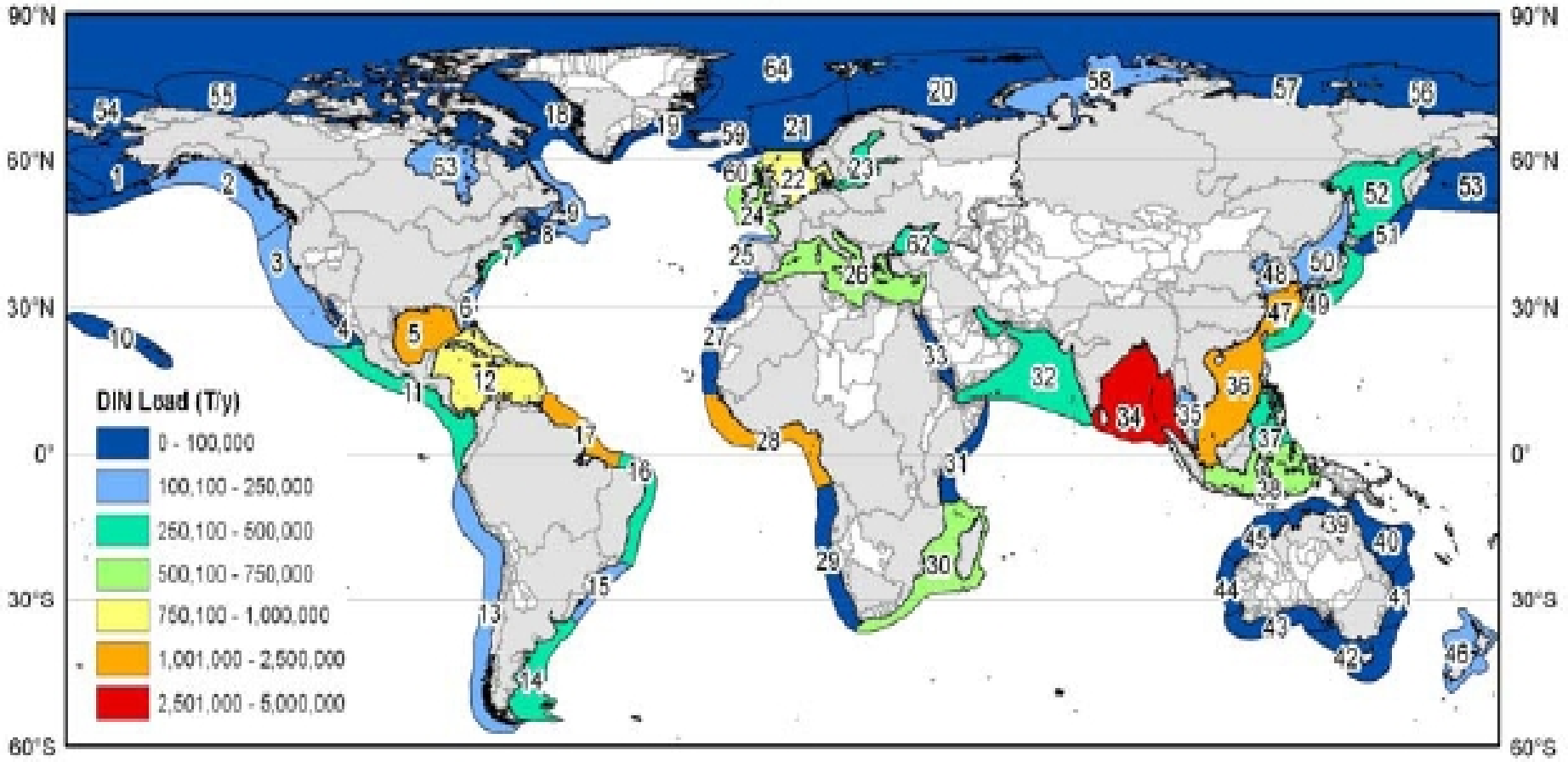






Pollution & Ecosystem Health Indicators:

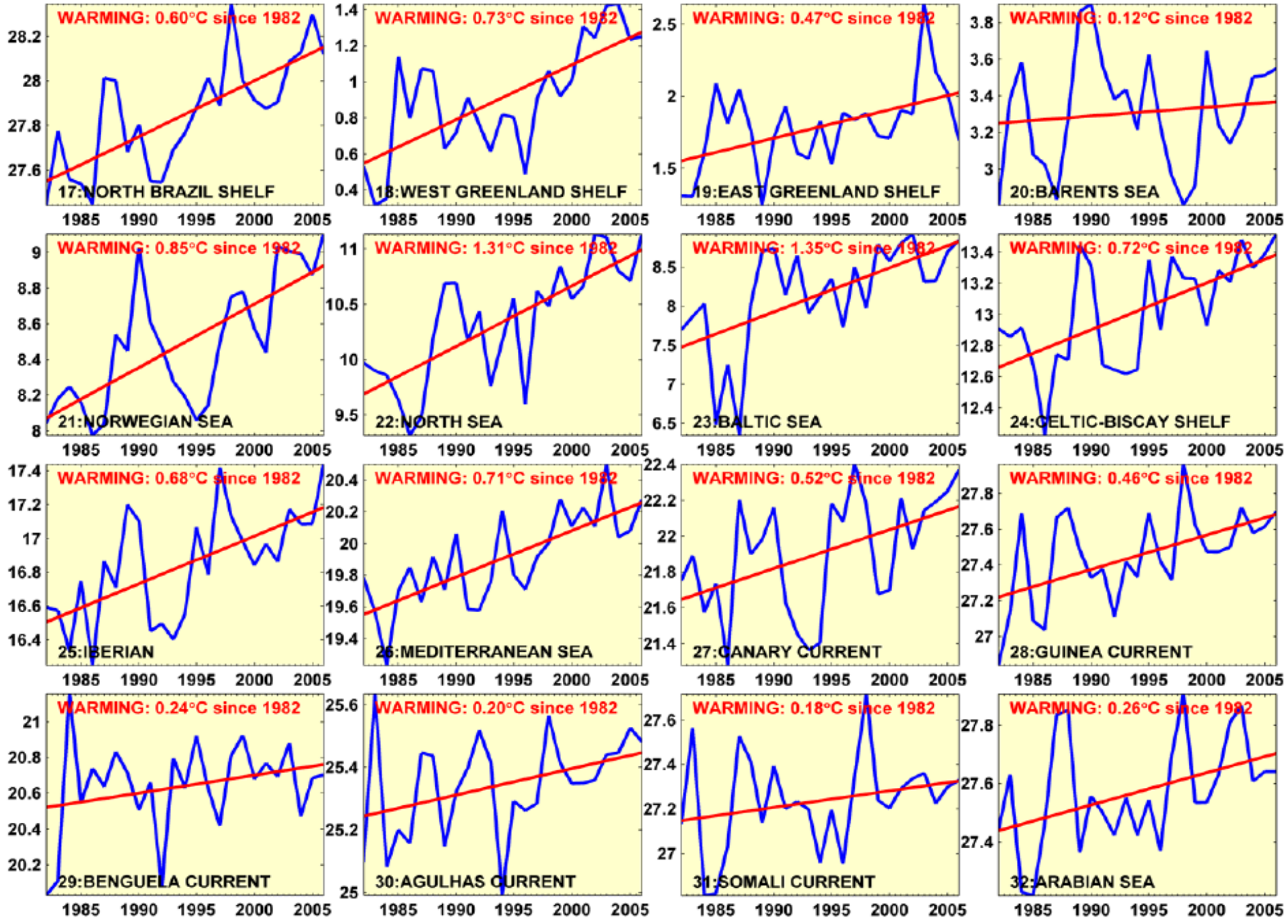
DIN load from land-based sources to LMEs predicted by the NEWS DIN model. Watersheds discharging to LMEs are grey; watersheds with zero coastal discharge are white.



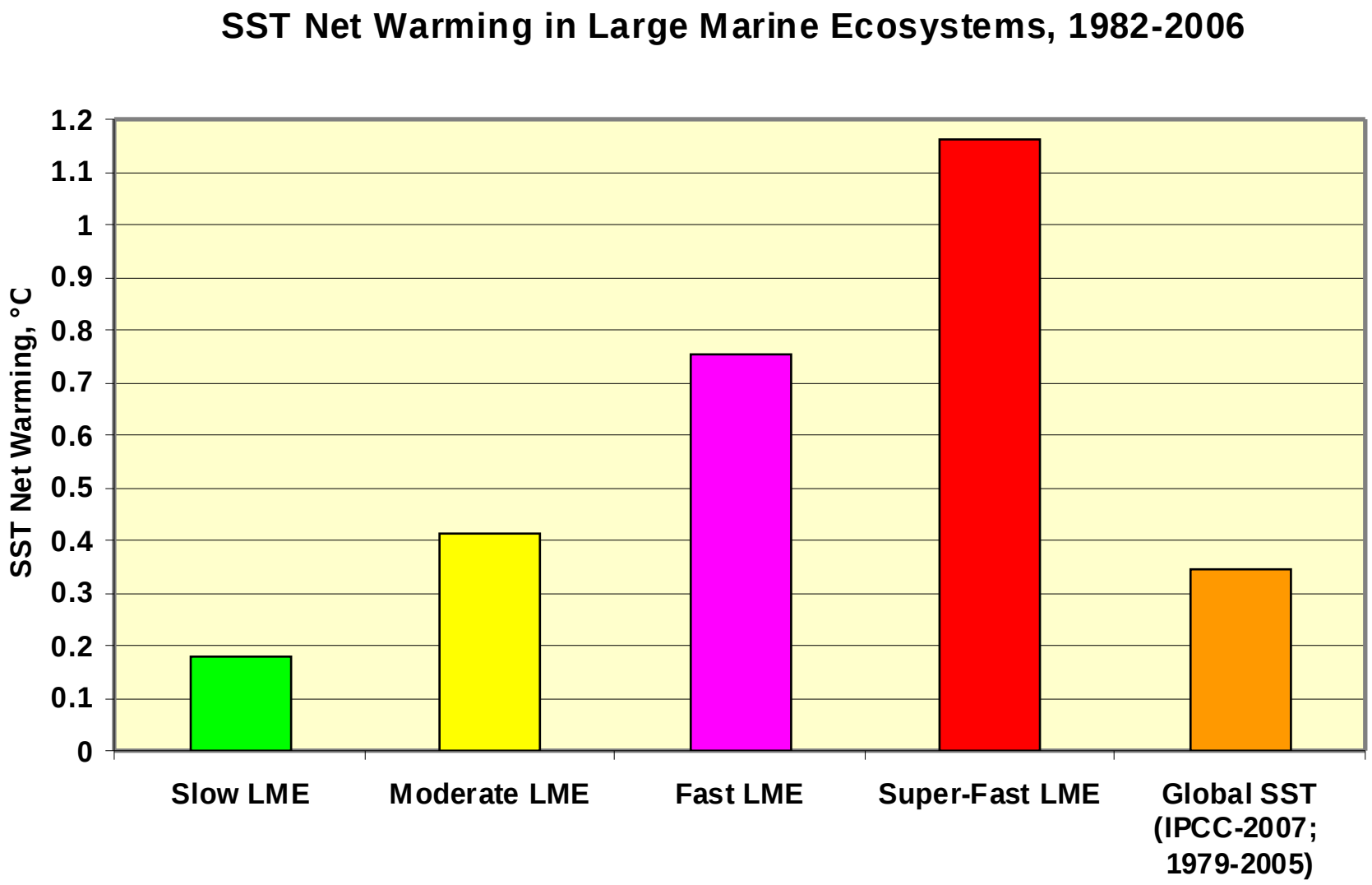
Regular Assessments of:

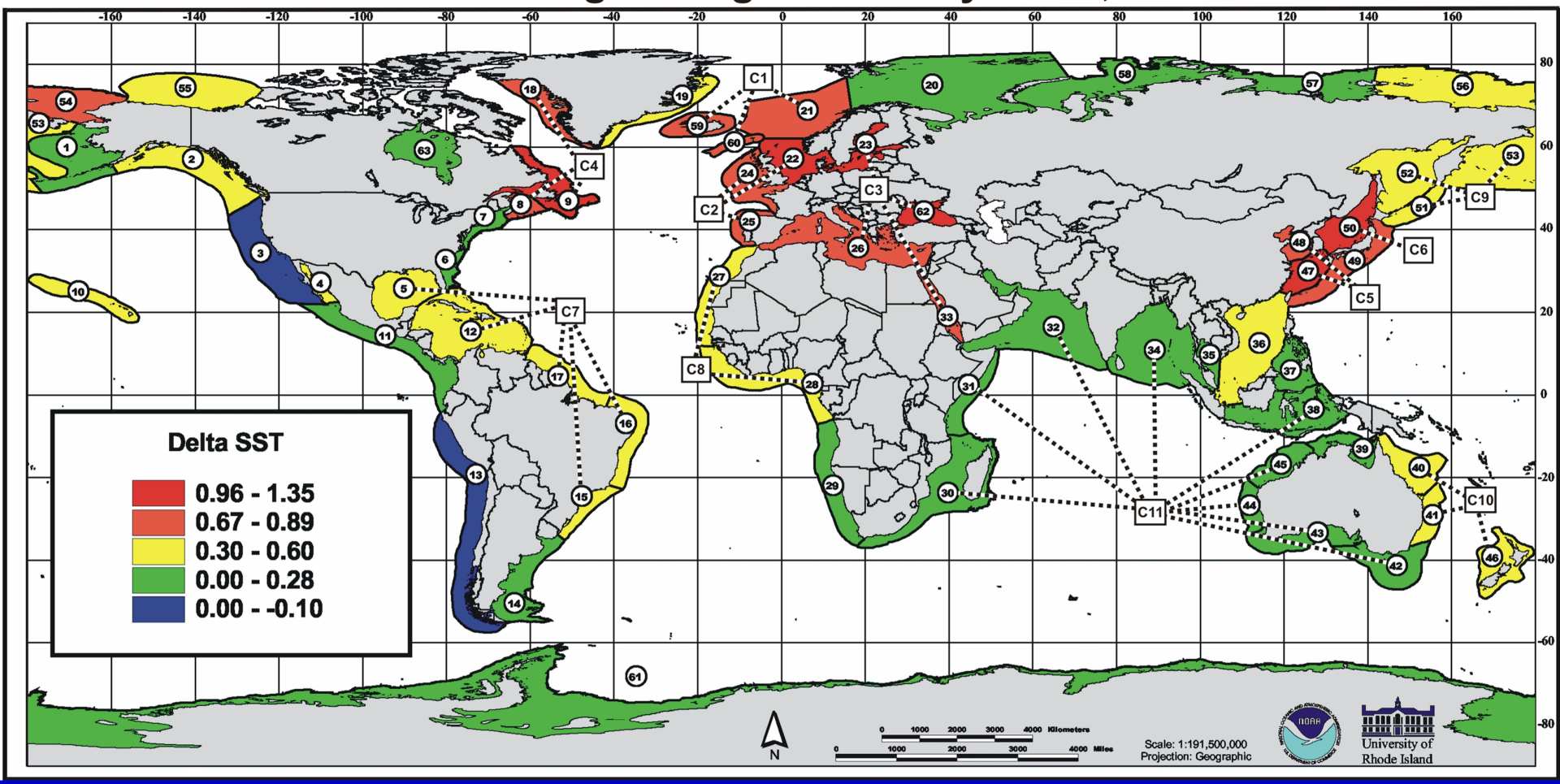
- Acidification
- Biogeochemical flux
- Multiple Marine Ecological Disturbances

Climate Warming Adaptation Movement


WARMING: 0.60°C since 1982
17:NORTH BRAZIL SHELF
WARMING: 0.73°C since 1982
18:WEST GREENLAND SHELF
WARMING: 0.47°C since 1982
19:EAST GREENLAND SHELF
WARMING: 0.12°C since 1982
20:BARENTS SEA
WARMING: 0.85°C since 1982
21:NORWEGIAN SEA
WARMING: 1.31°C since 1982
22:NORTH SEA
WARMING: 1.35°C since 1982
23:BALTIC SEA
WARMING: 0.72°C since 1982
24:CELTIC-BISCAY SHELF
WARMING: 0.68°C since 1982
25:IBERIAN
WARMING: 0.71°C since 1982
26:MEDITERRANEAN SEA
WARMING: 0.52°C since 1982
27:CANARY CURRENT
WARMING: 0.46°C since 1982
28:GUINEA CURRENT
WARMING: 0.24°C since 1982
29:BENGUELA CURRENT
WARMING: 0.20°C since 1982
30:AGULHAS CURRENT
WARMING: 0.18°C since 1982
31:SOMALI CURRENT
WARMING: 0.26°C since 1982
32:ARABIAN SEA
1985 1990 1995 2000 2005

Climate Warming and Fisheries Biomass Yields





Warming Clusters of LMEs in Relation to SSTs, 1982-2006:

FAST WARMING:

C1 Northern European Cluster; C2 Southern European; C3 Semi-Enclosed European Seas; C4 of the NW Atlantic; C5 Fast Warming East Asian LMEs; C6 Kuroshio Current and Sea of Japan/East Sea LMEs.

MODERATE WARMING:

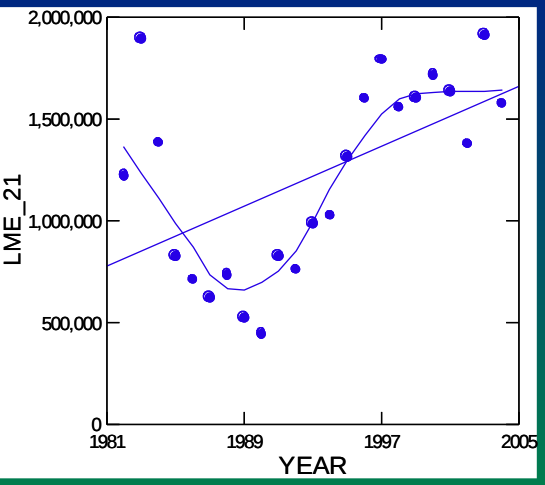
C7 Western Atlantic LMEs; C8 Eastern Atlantic LMEs; C9 NW Pacific LMEs; C10 SW Pacific LMEs. Several Non-Clustered, Moderate Warming LMEs: NE Australia, Insular Pacific Hawaiian, Gulf of Alaska, Gulf of California; South China Sea, East Greenland Shelf;

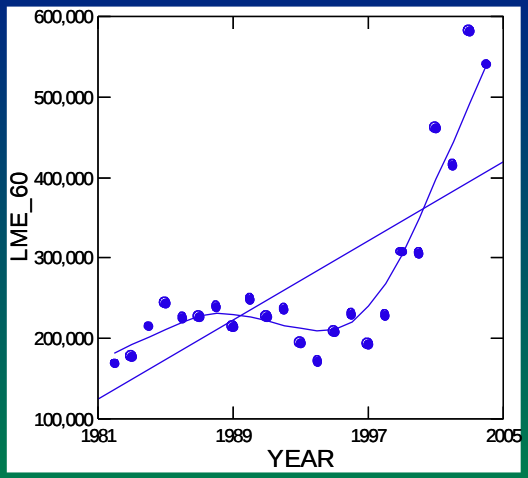
SLOW WARMING:

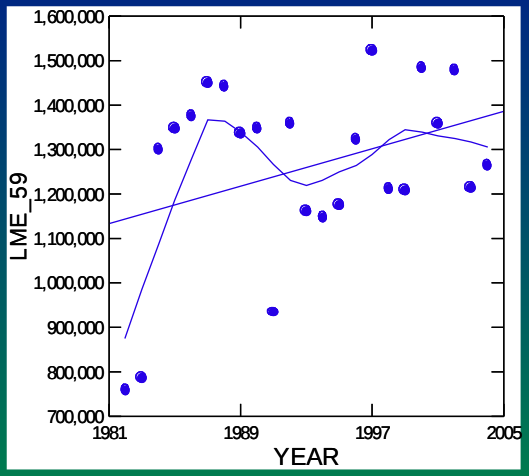
C11 Indian Ocean and Adjacent Waters.

Non-clustered, Slow Warming LMEs include the U.S. Northeast Shelf, the U.S. Southeast Shelf, the Barents Sea, East Bering Sea; Patagonian Shelf, Benguela Current and Pacific Central American Coastal LMEs.

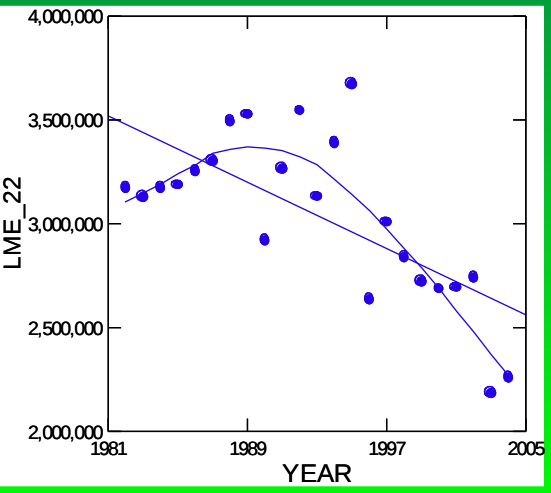
Fisheries biomass yield trends (metric tons) in fast warming cluster 1: Norwegian Sea (LME 21), Faroe Plateau (LME 60), and Iceland Shelf (LME 59).

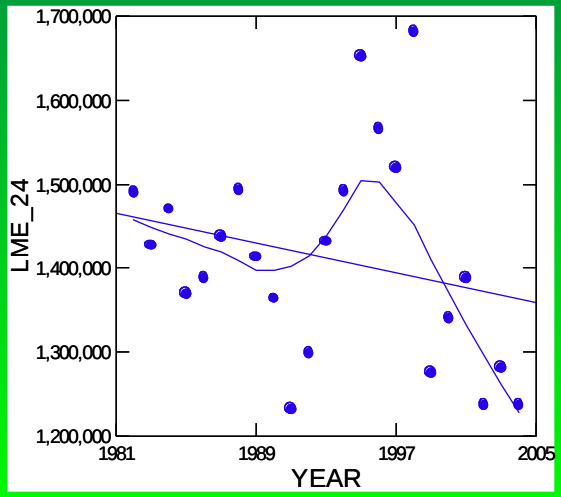


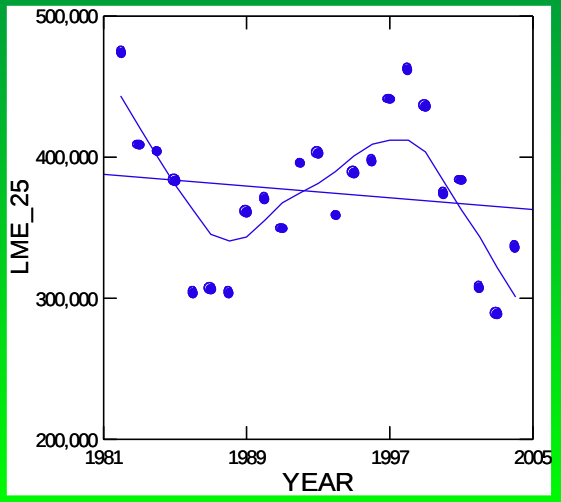


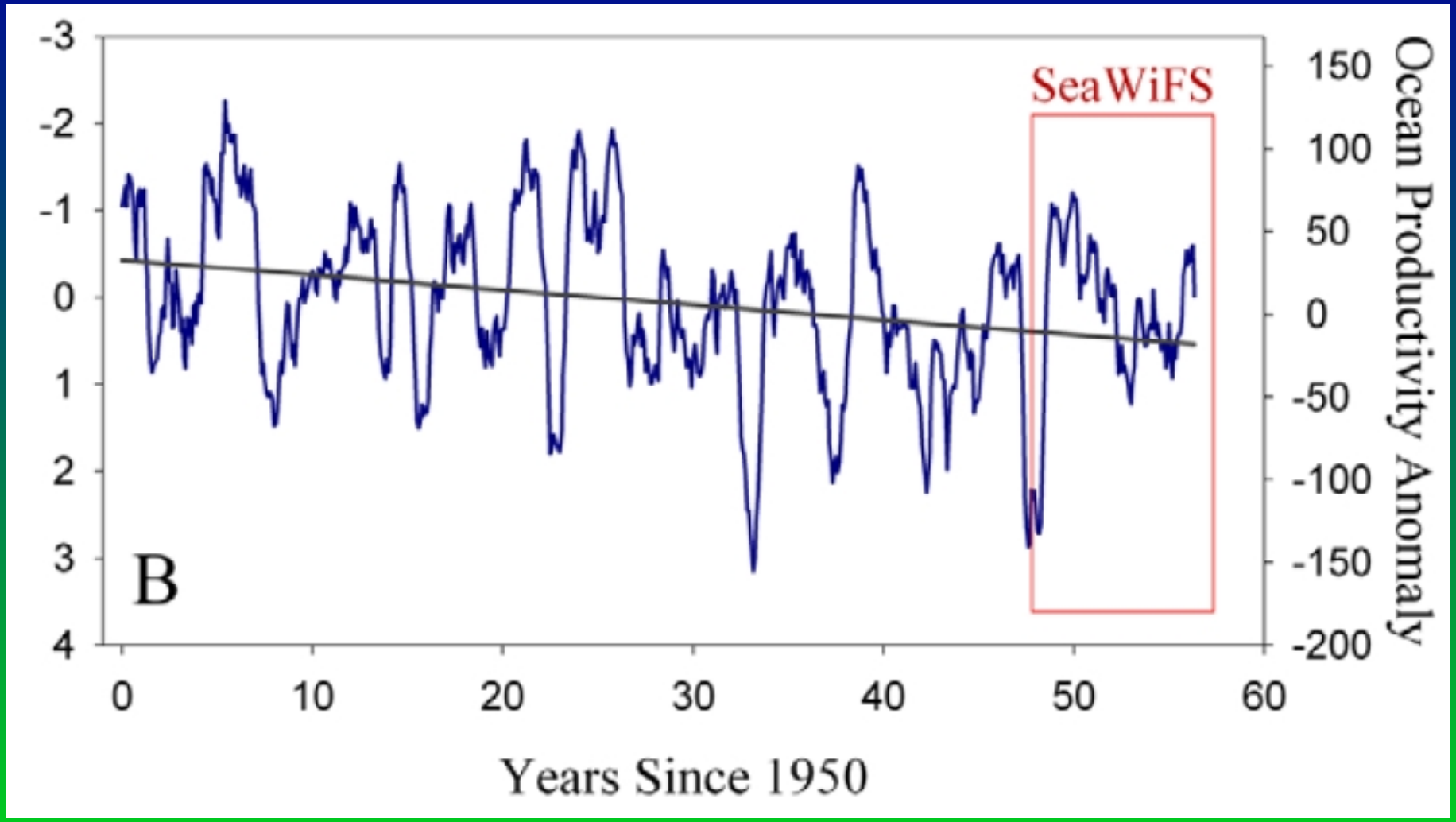


Fisheries biomass yield trends (metric tons) in fast warming cluster 2: North Sea (LME 22), Celtic Biscay (LME 24) and Iberian Coastal (LME 25)



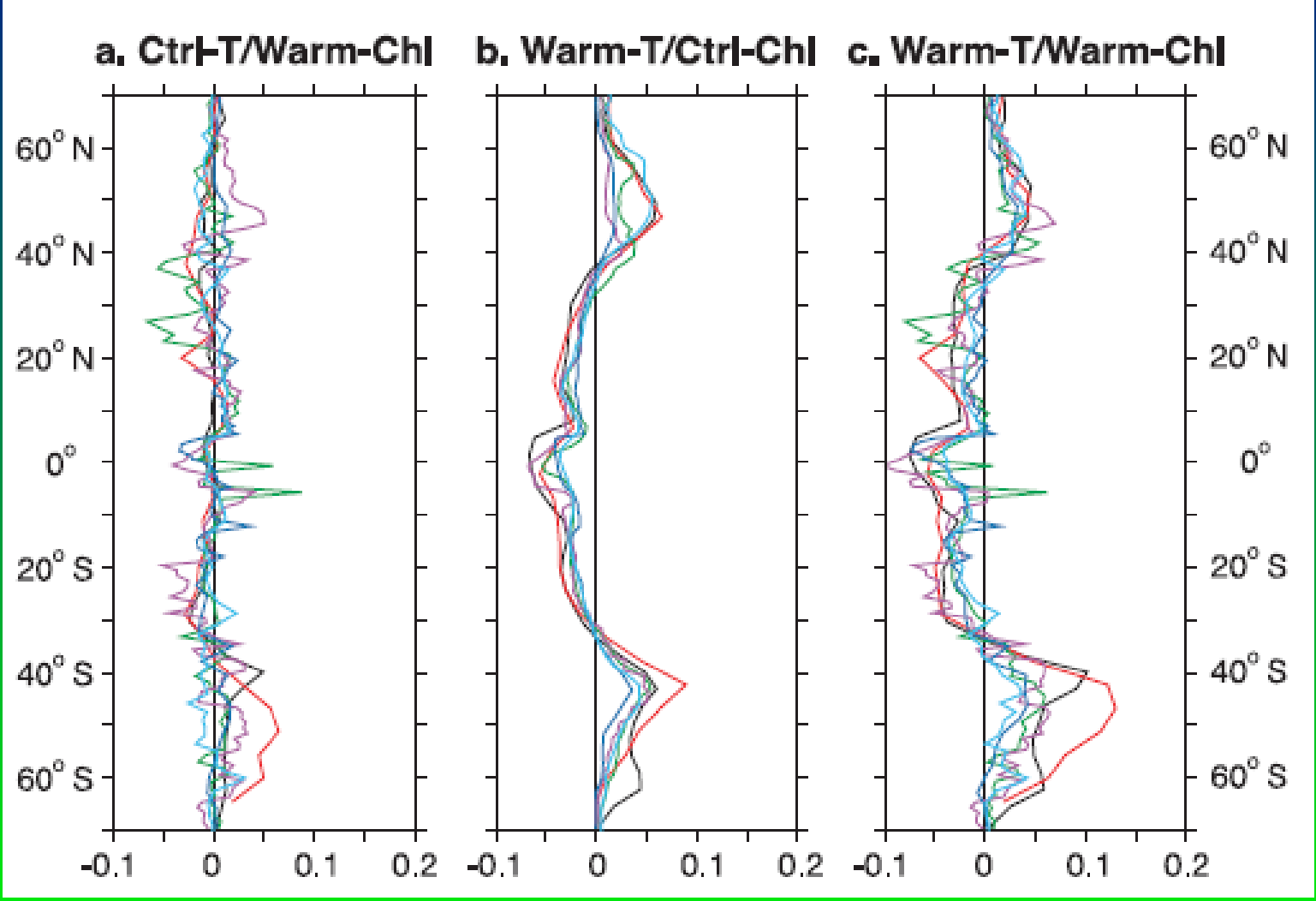






From Behrenfeld et al. 2007

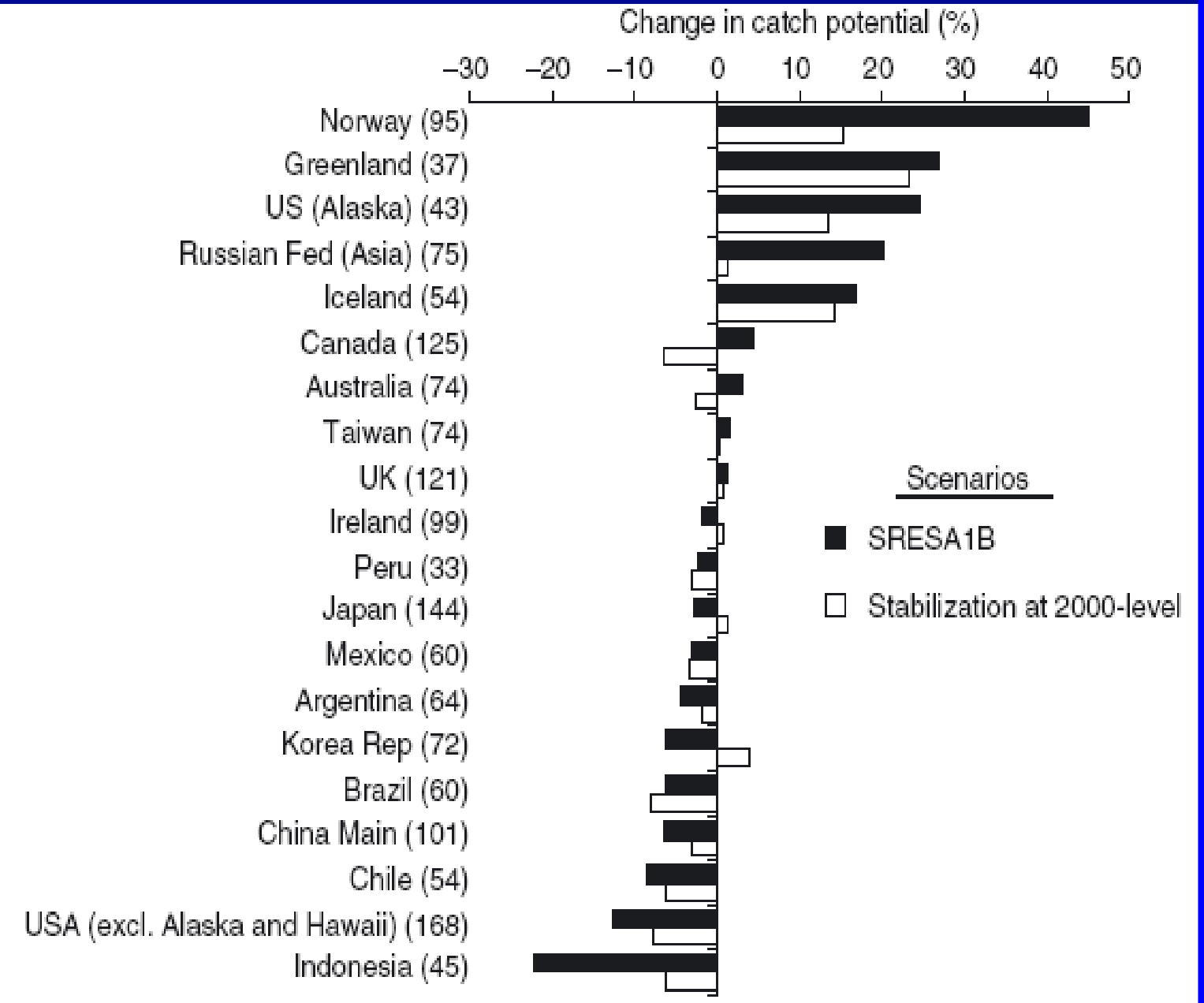
Estimated 2040 – 2060 primary production change (Pg-C deg^{-1} yr^{-1})



From Behrenfeld et al. 2007

- Six different coupled climate models
- Ocean biological responses to climate warming from industrial revolution to 2050
- Marginal sea-ice biome area decreases 42% (N) and 17% (S)
- Expansion of low production permanently stratified ocean by 4% (N) to 9.4% (S)
- Subpolar gyre biome expands 16% (N) and 7% (S)
- Stratification decreases nutrient supply and thus productivity in permanently stratified oceans
- Stratification, extended growing season, and sea ice retreat enhance production at high latitudes
- Significant shifts in community composition

"Tidbits" from Behrenfeld, Sarmiento and others. 2004

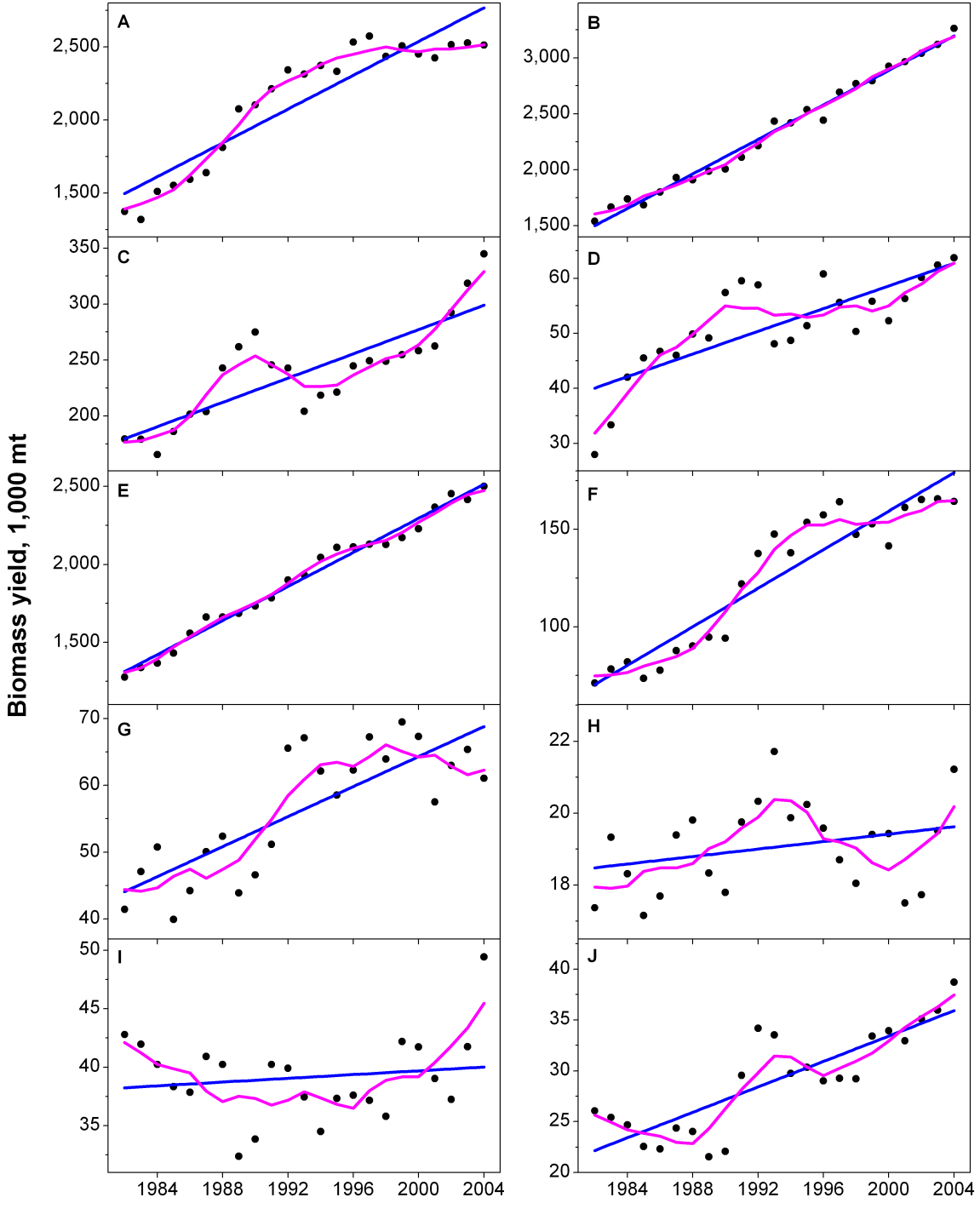


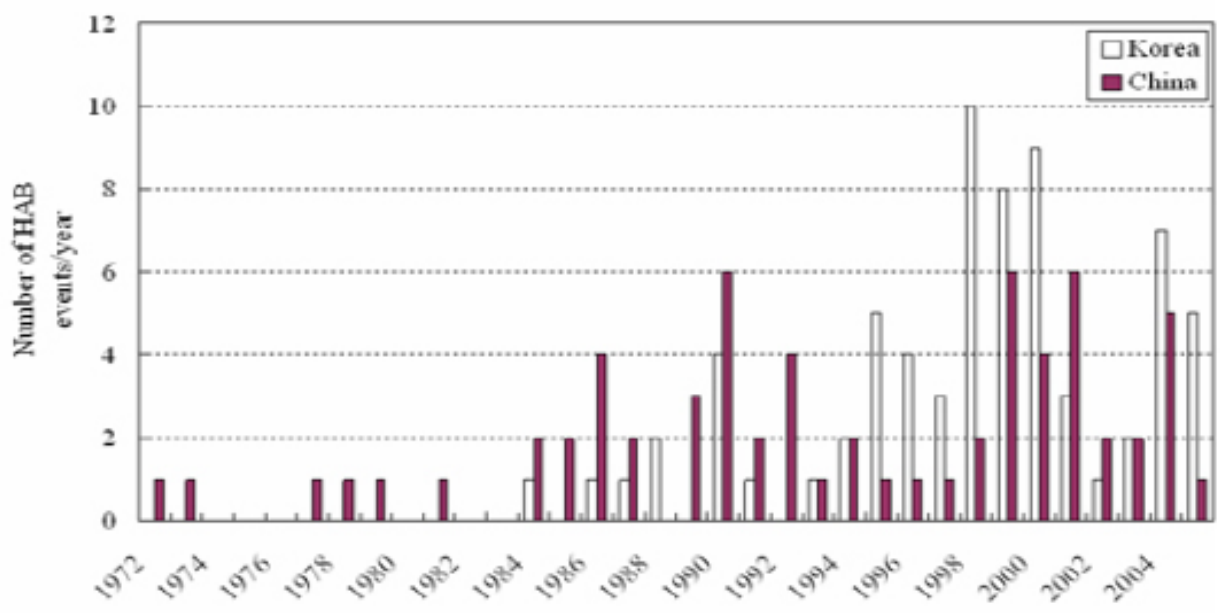
Projected changes in 10-year averaged maximum catch potential from 2005 to 2055 by the 20 Exclusive Economic Zone regions with the highest catch in the 2000s. The numbers in parentheses represent the numbers of exploited species included in the analysis.

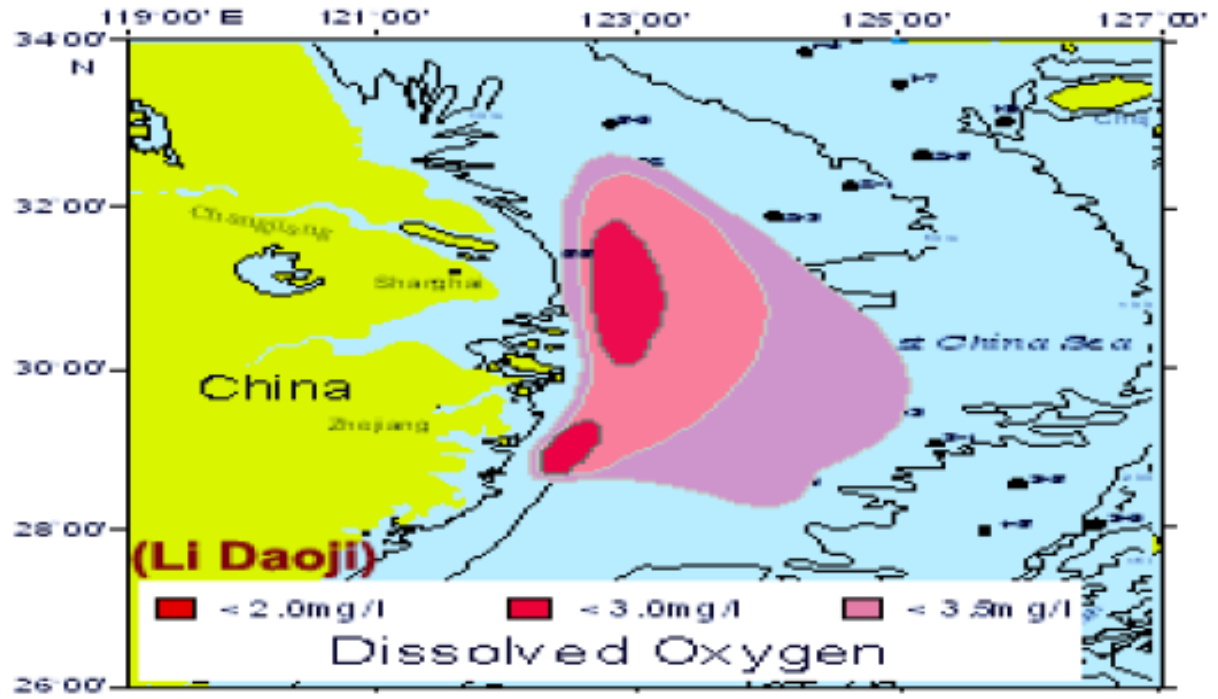
Cheung et al. Global Change Biology, 2009

CAP AND SUSTAIN

Comparative dynamics of fisheries biomass yield in the slow warming Indian Ocean and adjacent LMEs (see cluster C11 in Figure 6): Arabian Sea, LME 32 (A); Bay of Bengal, LME 34 (B); Agulhas Current, LME 30 (C); Somali Current, LME 31 (D); Indonesian Sea, LME 38 (E); North Australia, LME 39 (F); Northwest Australia, LME 45 (G); West-Central Australia, LME 44 (H); Southwest Australia, LME 43 (I); and, Southeast Australia, LME 42 (J). Linear regression is shown as blue trend line, adjacent averaging smoothing is shown as magenta trend line.







. Serious eutrophication, harmful algal blooms and dead zones in coastal areas.

Nutrient overenrichment and climate warming contribute to dead zone in the YSLME

Q. Tang, 2009, Figure 6

Yellow Sea Large Marine Ecosystem Management

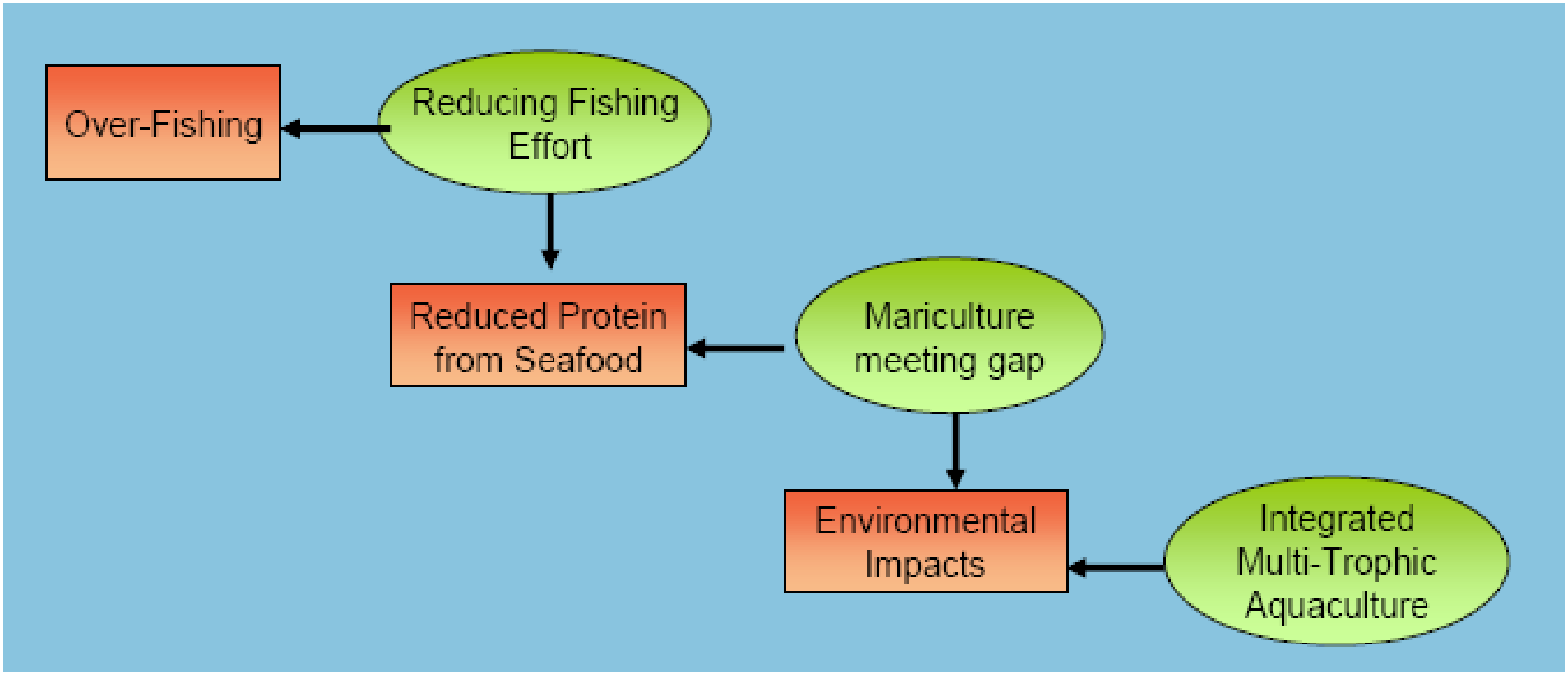


Figure 1. Logical considerations of management implementation

Walton and Jiang 2009, fig.1

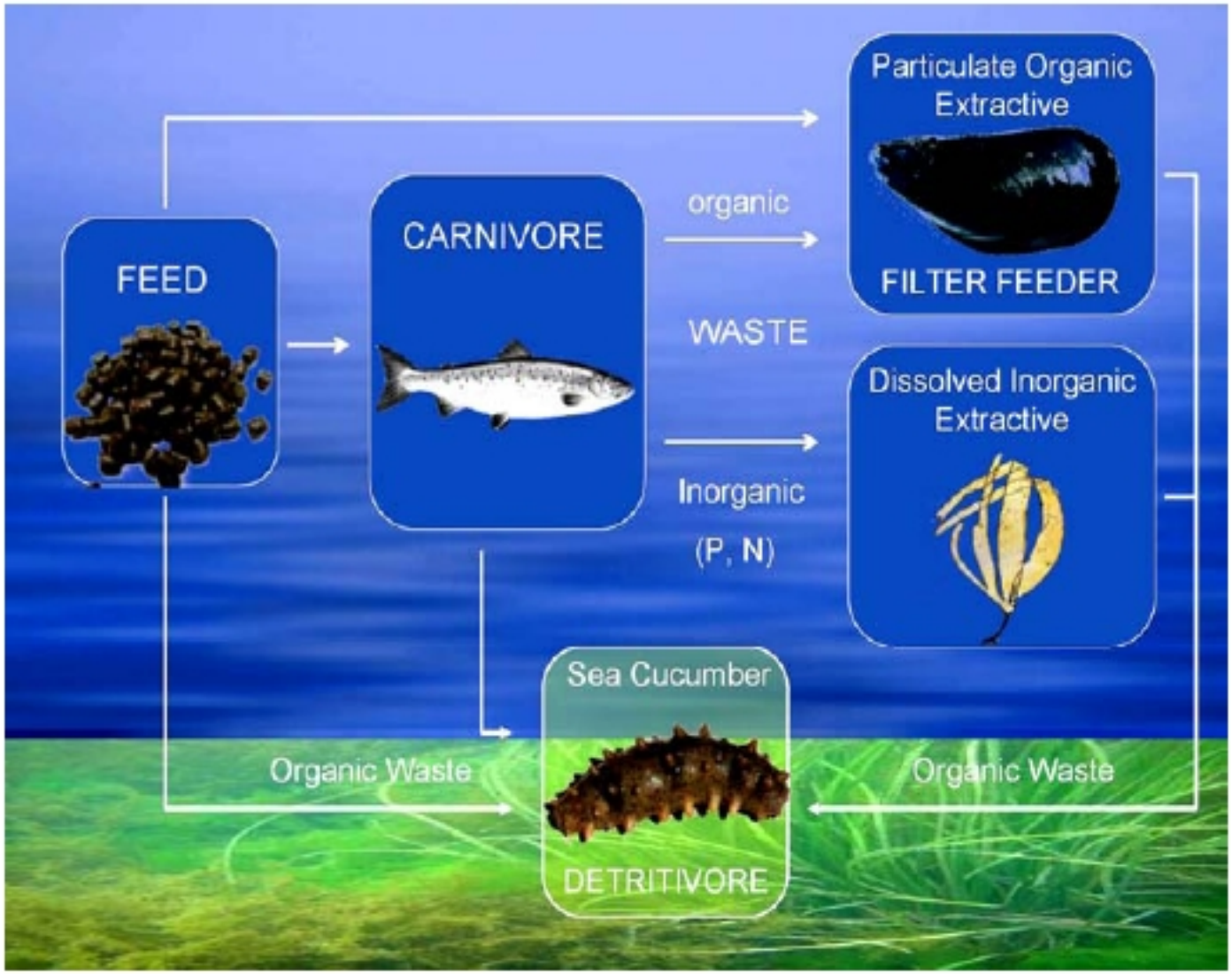
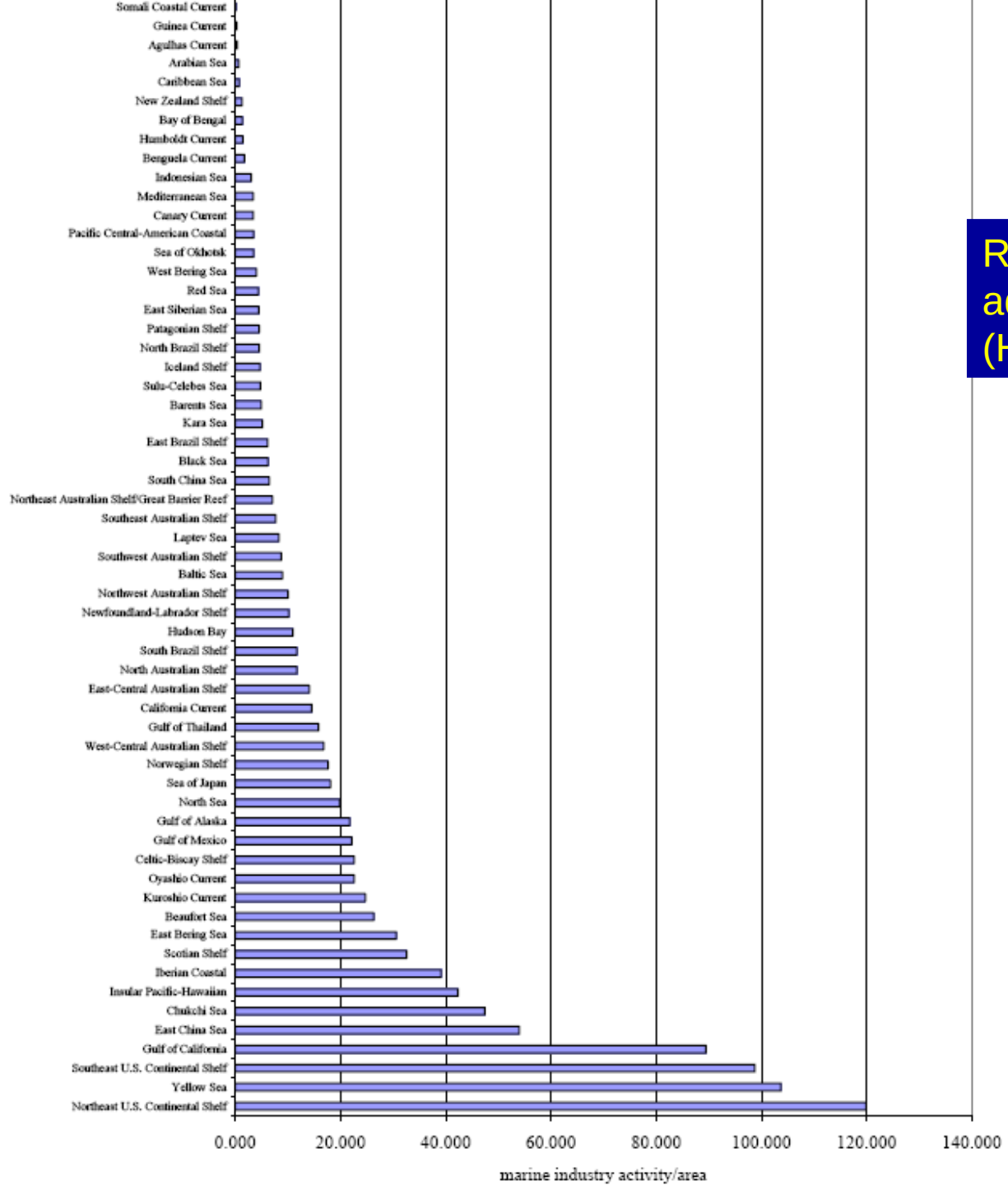


Figure 4. IMTA concept: The particulate waste in the water column is removed by filter feeding bivalves, while the portion that ends on the seafloor is utilised by sea cucumbers. The dissolved inorganic nutrients (N, P & CO_2) are absorbed by the seaweed that also produces oxygen, which in turn is used by the other cultured organisms. Modified from (Fang et al. 2009)

Walton and Jiang 2009, fig. 4

Ranking of LMEs by Area-adjusted Marine Industry Activity (Hoagland and Jin 2006)



Additive and Integrative Layering toward Governance

PLANNING ACTIONS

1. Transboundary Diagnostic Analysis (TDA) – provides consensus priorities from analysis and ranking of water-related resources issues, their environmental and socioeconomic impacts, immediate and root causes and possible remedies

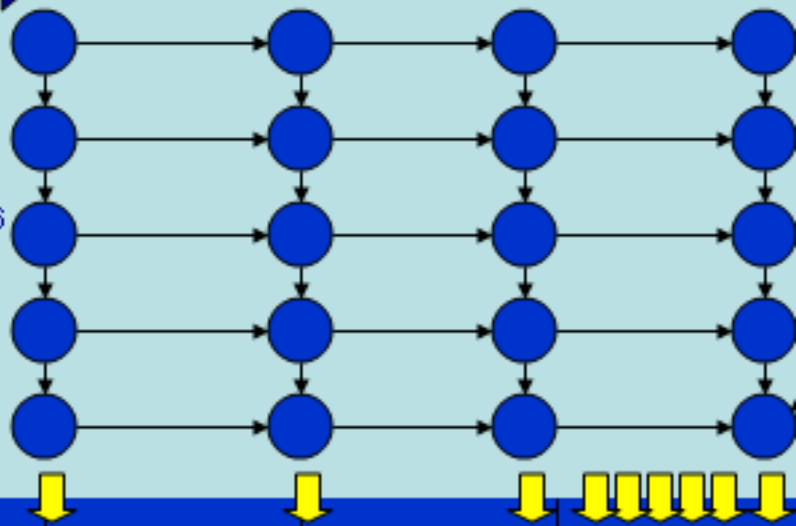
2. Strategic Action Program (SAP) – provides national and regional commitments to policy, legal and institutional reforms, and investments to remedy root causes of priority transboundary issues identified in TDA

IMPLEMENTATION ACTIONS

3. Ecosystem-based assessment and management strategy for TDA and SAP

- 3.1 Productivity indicators and assessments
- 3.2 Fish and fisheries indicators and assessments
- 3.3 Pollution and ecosystem health indicators and assessments
- 3.4 Socioeconomic indicators and assessments
- 3.5 Governance indicators and assessments

Integrated Ecosystem-Based, Assessment and Adaptive Management

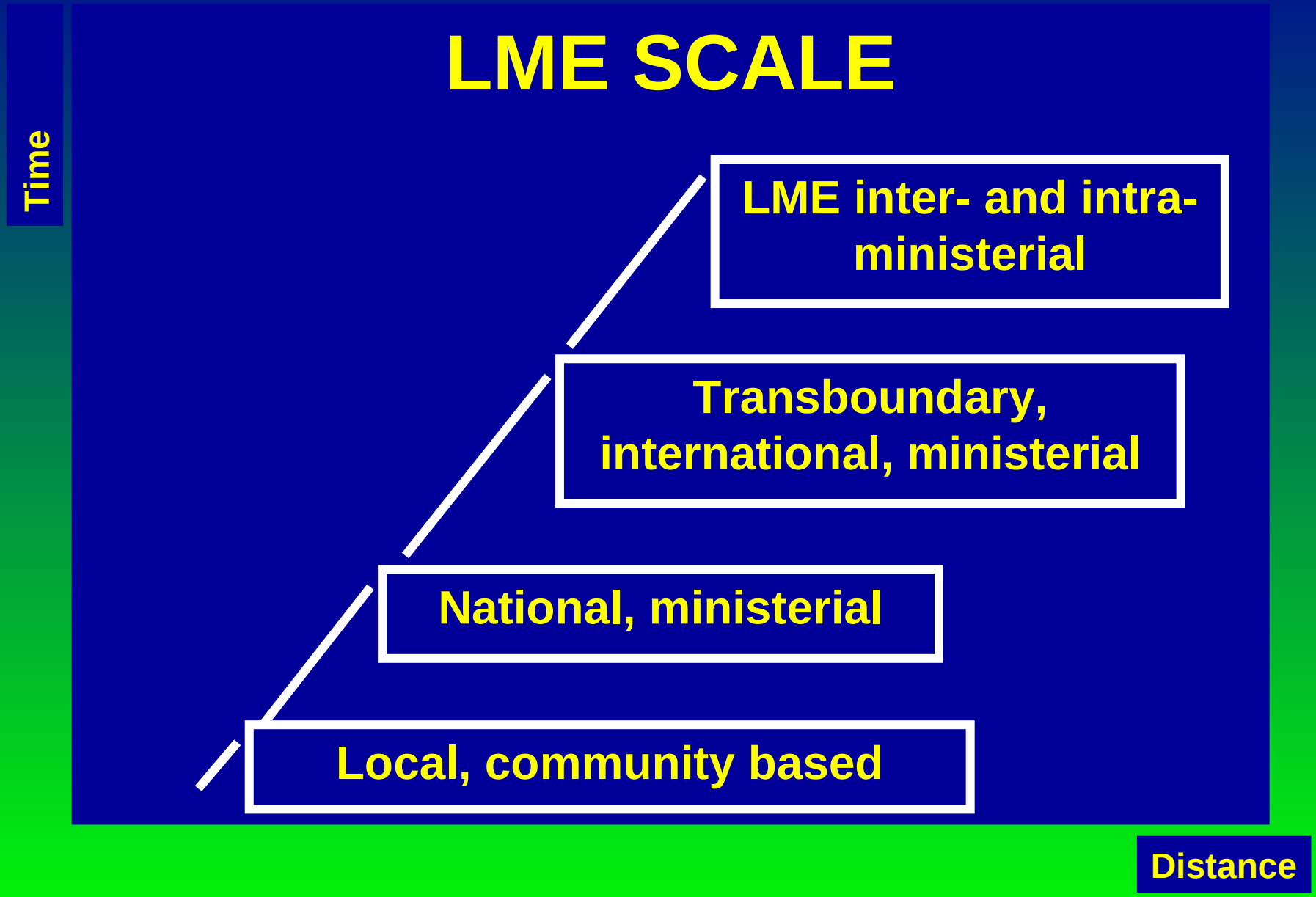


Year 1	Year 2	Year 3	Year 4	Years 5-10
	Assessments & Management Actions	Assessments & Management Actions	Assessments & Management Actions	Toward Self-financing Assessments and adaptive management

DEVELOPING COUNTRIES AT WORK TO OPERATIONALIZE THE GLOBAL SCALE APPLICATIONS OF THE LME APPROACH:

- Implementing the 5 Module approach
- 16 international GEF-funded LME projects in Africa, Asia, Latin America and eastern Europe
- Level of funding: $2.5 billion
- Partnership of 5 UN agencies
- NOAA provides scientific and technical support
- Hands on participation of 2,500 LME experts and practitioners

LME SCALE


Time
LME inter- and intra-ministerial
Transboundary, international, ministerial
National, ministerial
Local, community based
Distance

Engaging with partners

- 5 UN Agencies
  - UNDP
  - UNEP
  - UNIDO
    FAO
  - IOC UNESCO
- 2 NGOs
  - IUCN
  - WWF
- 2 Global Financial Institutions
  - Global Environment Facility
  - World Bank

Upward Spiral

- Tertiary waste water treatment to reduce excessive nutrient input to the Baltic Sea LME and east Asian Seas
- Reduction of fishing effort in the Yellow Sea,
- Successfully introducing an ecosystem based LME TDA and SAP to 110 countries (greater than 50% of world's nations)
- Successfully established the World's first Commission for the BCLME

Benguela CURRENT COMMISSION

On the road to implementing an ecosystem approach to the management of Benguela Current Large Marine Ecosystem by Angola, Namibia and South Africa.

BCLME
Benguela Current Large Marine Ecosystem Programme

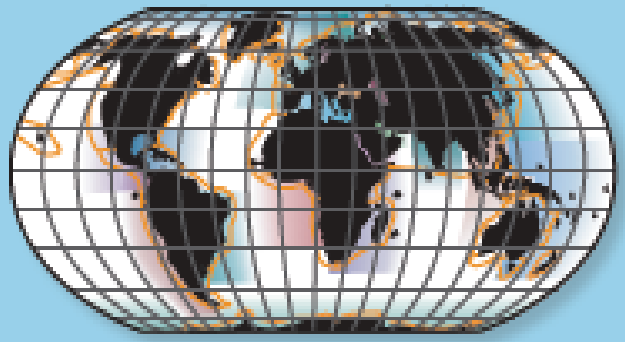
The Benguela Current Commission represents the world model for successfully operationalizing the ecosystem-based approach to the assessment and management of LME goods and services for the people of Angola, Namibia and South Africa

CONCLUSIONS

- Socioeconomic benefits of $12.6 trillion annually in economic activity based on coastal ocean goods and services are at risk.
- The 5-module science-based metrics support an upward spiral toward ecosystem recovery activities by governments and developing nations
- Additional GEF financial support is required for governments to support 10,000 LME practitioners, to adapt to the effects of climate warming, reduce habitat loss, designate and manage marine protected areas, control nutrient overenrichment and recover depleted fisheries.

The UNEP Large Marine Ecosystem Report

A Perspective on Changing Conditions in LMEs of the World's Regional Seas



UNEP Regional Seas Report and Studies No. 182

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Regional Seas

GPA