The IndiSeas experience to evaluate and communicate the ecological status of exploited marine ecosystems using data-based indicators

and additions from food-web modelling exercises

Marta Coll
Institute of Marine Science (ICM-CSIC) &
Barcelona, Spain
mcoll@icm.csic.es

Yunne-Jai Shin
Lynne J. Shannon
Alida Bundy
Julia Blanchard
Didier Jouffre
Jason S. Link
Philippe Cury

Institut de Ciències del Mar
CSIC
Consejo Superior de Investigaciones Científicas

OUTLINE

IndiSeas

Background and General Approach
Selection of Indicators
Calculation of Indicators
Comparative Approach
Synthesis and Graphic Representation
Reaching the Public
What have we learned?

IndiSeas2

Objectives and General Approach
New Indicators

Food-web model-based indicators

Ecopath indicators
Ecosim indicators

IndiSeas: Background and General Approach

- Synthetic multispecies and ecosystem-based indicators needed to monitor and manage marine ecosystems

- Complement single-species-based fisheries management

- Progress towards an ecosystem-based approach to fisheries (EAF)

- 2005: **Follow-up to the SCOR/IOC Working Group** on Quantitative Ecosystem Indicators (2001-2004)

- **NoE EUR-OCEANS IndiSeas Working Group** to undertake a comparative study on EAF ecological indicators (2005-2010)

- Lead by **Yunne-Jai Shin, Lynne J. Shannon** and **Philippe Cury**

Shin and Shannon 2010. ICES JMS, Shin et al. 2010. ICES JMS

IndiSeas: Background and General Approach

- Selected a suite of **community- to ecosystem-level data-based indicators**

- Represented a minimum list of indicators that were **easy to calculate and agreed upon** with respect to several criteria

- Calculated the Indicators for **several exploited marine ecosystems** worldwide

- Developed comparative results to provide insights on the **relative current states and recent trends** of these ecosystems

Two important features:

We included **ecosystems that are normally excluded** from studies that require more complex indicators only applicable to data-rich situations

We involved **local experts** to help interpret results from each ecosystem

Shin and Shannon 2010. ICES JMS, Shin et al. 2010. ICES JMS

IndiSeas: Selection of Indicators

- **Examined and reviewed ecological indicators** to identify most suitable for evaluating ecosystem effects of fishing across ecosystem types

- Built a dashboard of indicators to evaluate the status of marine ecosystems in a **comparative framework**

- **Not development of new indicators**, but used specific criteria to select the most representative and practically achievable and meaningful set

- **Step-by-Step process**: define objectives of the WG and requirements of the indicators, identify potential indicators with literature review, determine screening criteria, rank the indicators

- **Criteria:** (i) data availability, (ii) ecological meaning, (iii) sensitivity to fishing, (iv) public awareness & (v) ecological objectives

Shin and Shannon 2010. ICES JMS, Shin et al. 2010. ICES JMS

IndiSeas: Selection of Indicators

- **Measurability**: data estimated routinely, so the potential data to calculate the indicators needed to be readily available across a range of marine ecosystems

- **Survey-based:** Indicators were mostly independent of the fishery in contrast to other comparative studies of fished ecosystems (model-derived or catch-based indicators)

- **Multi-institutional collaboration**: sharing scientific data and scientific diagnoses based on local expertise in each ecosystem investigated

Shin et al. 2010. ICES JMS

IndiSeas: Selection of Indicators

- **Ecological meaning**: reflected ecological processes occurring under fishing pressure and based on strong scientific and theoretical knowledge
- **Sensitivity**: were able to track ecosystem changes due to fishing, hence high correlation between trends in the indicator and in fishing pressure
- **Public awareness**: meaning and link of indicators with fishing widely and intuitively understood to avoid abstract ecological features

+ four ecological attributes to be linked with ecosystem health and management strategic priorities:

(i) Conservation of biodiversity

(ii) Maintenance of ecosystem stability and resistance to perturbation

(iii) Maintenance of ecosystem structure and functioning

(iv) Maintenance of resource potential

Shin et al. 2010. ICES JMS

IndiSeas: Selection of Indicators

Indicator	Ecological significance	Sensitivity	Measurability	Public awareness	Management objective[a]
Size-based indicators (Link, 2005; Rochet and Rice, 2005; Shin *et al.*, 2005)					
Mean length/weight in community	x	x	x	x	EF
Maximum length in community	x	x		x	
Mean maximum length in community	x	x		x	
Slope of size spectrum	x	x			
Slope of diversity size spectrum	x				
Proportion of large fish	x	x		x	
Proportion of large species	x	x	x	x	CB
Trophodynamic indicators (Cury *et al.*, 2005; Fulton *et al.*, 2005; Link, 2005; Pauly *et al.*, 2000)					
TL landings	x	x	x	x	EF
TL community	x	x	x	x	EF
Fishing-in-Balance index	x	x			
Proportion of predatory fish	x	x	x	x	CB
Pelagic to demersal fish biomass ratio	x	x	x		
Piscivorous to zooplanktivorous fish biomass ratio	x	x	x		
Species-based indicators (Degnbol and Jarre, 2004; Fulton *et al.*, 2004; Link, 2005; Rochet and Rice, 2005; Yemane *et al.*, 2005)					
Species richness	x			x	
Shannon and Hill's index of diversity	x		x		
K-dominance, ABC curves, *W*-statistic	x	x	x		
Ratio of endangered to unendangered species	x	x		x	
Ratio of target to non-target species	x		x	x	
Proportion of sustainably or under-/moderately exploited stocks	x	x	x	x	CB
Mean lifespan	x	x	x	x	SR

[a]CB, conservation of biodiversity; SR, maintaining ecosystem stability and resistance to perturbation; EF, maintaining ecosystem structure and functioning; RP, maintaining resource potential.

Shin et al. 2010. ICES JMS

IndiSeas: Selection of Indicators

Indicator	Ecological significance	Sensitivity	Measurability	Public awareness	Management objective[a]
Pressure indicators (Degnbol and Jarre, 2004; Fréon *et al.*, 2005; Fulton *et al.*, 2005)					
Overall fishing mortality rate	x	x	x	x	RP
Exploited fraction of ecosystem surface	x		x	x	
Mean distance of catches from the coast	x				
Catch rate by community	x	x			
Discard rate	x			x	
Biomass-related indicators (Blanchard and Boucher, 2001; Fulton *et al.*, 2005; Link, 2005; Rochet *et al.*, 2005)					
Total community biomass	x	x	x	x	RP
Coefficient of variation in biomass	x	x	x	x	SR

[a]CB, conservation of biodiversity; SR, maintaining ecosystem stability and resistance to perturbation; EF, maintaining ecosystem structure and functioning; RP, maintaining resource potential.

- During 2005-2008 the WG agreed on a suite of **eight ecological indicators**
- Six indicators of **State (S)** and six indicators of **Trend (T)**

Shin et al. 2010. ICES JMS

IndiSeas: Calculation of Indicators

Table 3. Summary of ecological indicators selected by the IndiSeas WG and the corresponding management objectives.

Indicators	Headline label	Used for State or Trend	Management objective[a]
Mean length	Fish size	S, T	EF
TL of landings	TL	S, T	EF
Precaution of under- and moderately exploited stocks	% healthy stocks	S	CB
Proportion of predatory fish	% predators	S, T	CB
Mean lifespan	Lifespan	S, T	SR
1/CV of total biomass	Biomass stability	S	SR
Total biomass of surveyed species	Biomass	T	RP
1/(landings/biomass)	Inverse fishing pressure	T	RP

[a]CB, conservation of biodiversity; SR, maintaining ecosystem stability and resistance to perturbation; EF, maintaining ecosystem structure and functioning; RP, maintaining resource potential.

- 2008-2009. Calculation of indicators with **standardized procedures**
- Current States (**2003-2005**) and recent Trends (**1980-2005** and **1996-2005**)
- All indicators defined to **decrease with increasing fishing** pressure

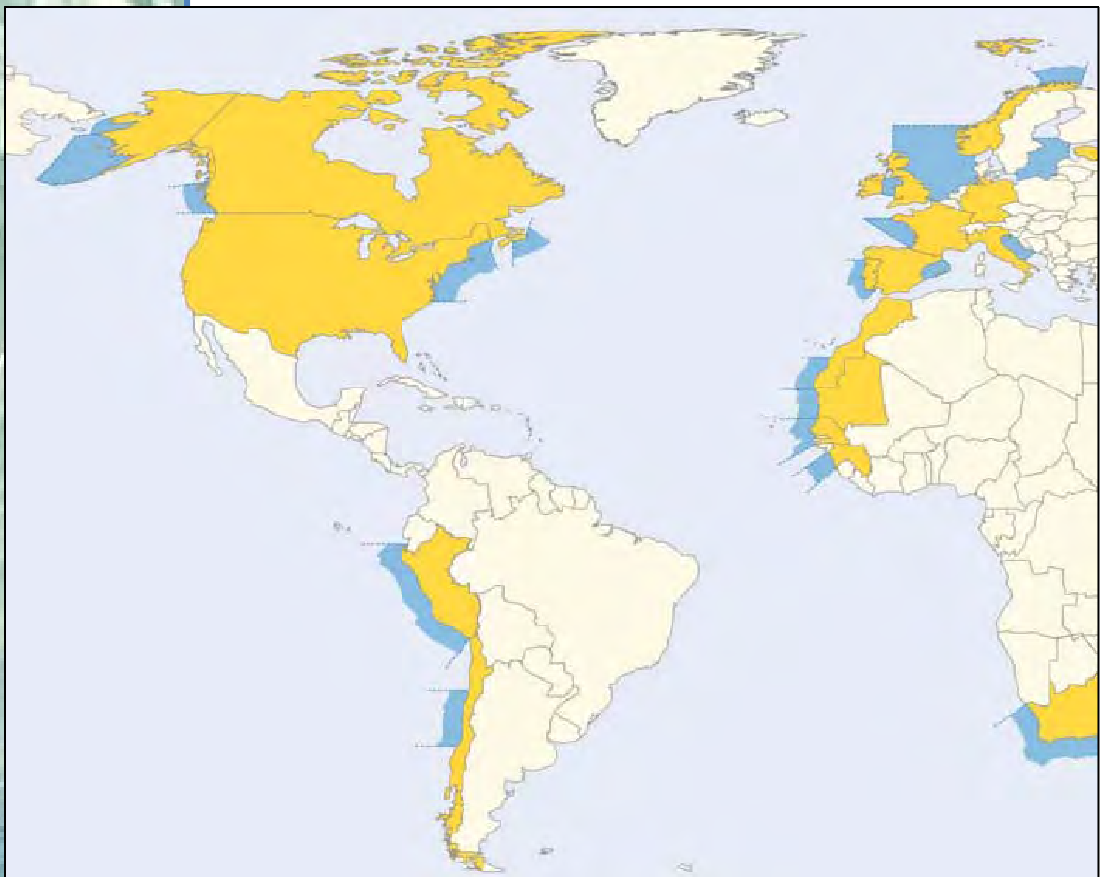
Shin et al. 2010. ICES JMS

IndiSeas: Calculation of Indicators

Indicators	Headline label	Source	Calculation, notations, units
Mean length of fish in the community	*fish size*	Fisheries Independent Surveys	$\overline{L} = \frac{\sum_i L_i}{N}$ (cm)
Mean life span of fish in the community	*life span*	Fisheries Independent Surveys	$\overline{LS} = \frac{\sum_S (age_{\max} B_S)}{\sum_S B_S}$ (y[-1])
Total biomass of species in the community	*biomass*	Fisheries Independent Surveys	*B* (tons)
Proportion of predatory fish in the community	*% predators*	Fisheries Independent Surveys	prop predatory fish= B predatory fish/B surveyed
TL landings	*trophic level*	Commercial landings and estimates of trophic level (empirical and fishbase)	$\overline{TL}_{land} = \frac{\sum_s TL_s \ Y_s}{Y}$
1/(landings /biomass)	*inverse fishing pressure*	Commercial landings	B/Y retained species
Proportion of under- and moderately exploited stocks	*% healthy stocks*	FAO data and local expertise	Number (under- þ moderately exploited stocks)/total number of stocks considered
1/CV total biomass	*Biomass stability*	Fisheries Independent Surveys	Mean(total biomass for the past 10 years)/s.d.(total biomass for the past 10 years)

Shin et al. 2010. ICES JMS

IndiSeas: Comparative Approach



- **19 ecosystems**
- **32 countries**
- Temperate, Tropical, Upwelling, and High latitude ecosystems
- Span different socioeconomic situations, and vary in ecosystem structure, environmental forcing, and exploitation histories

Shin et al. 2010. ICES JMS

IndiSeas: Comparative Approach

Coastal ecosystem	Geographic area	Type of ecosystem	Surrounding countries
Adriatic Sea (north-central)	Central Mediterranean	Temperate	Italy, Slovenia, Croatia, Bosnia-Herzegovina, Montenegro
Baltic Sea (central)	NE Atlantic	Brackish temperate	Germany, Estonia, Sweden, Poland, Russia, Lithuania, Latvia, Finland, Denmark
Barents Sea	NE Atlantic	High latitude	Norway
Bay of Biscay	NE Atlantic	Temperate	France
Benguela (southern)	SE Atlantic	Upwelling	South Africa
Bering Sea, Aleutian Islands	NE Pacific	High latitude	Alaska, USA
Canada coast (West)	NE Pacific	Seasonal upwelling	Canada
Catalan Sea (southern)	NW Mediterranean	Temperate	Spain
Guinean EEZ	East-central Atlantic	Upwelling	Guinea
Humboldt (northern)	SE Pacific	Upwelling	Peru
Humboldt (southern)	SE Pacific	Upwelling	Chile
Irish Sea	NE Atlantic	Temperate	Ireland, UK
Mauritanian EEZ	East-central Atlantic	Upwelling	Mauritania
Morocco (Sahara coastal)	East-central Atlantic	Upwelling	Morocco
North Sea	NE Atlantic	Temperate	UK, Norway, Denmark, Germany, Netherlands, Belgium
Portuguese EEZ	NE Atlantic	Upwelling	Portugal
Scotian Shelf (eastern)	NW Atlantic	Temperate	Canada
Senegalese EEZ	East-central Atlantic	Upwelling	Senegal
US coast (Northeast)	NW Atlantic	Temperate	United States

[a]MFA, FAO major fishing area; Div, FAO Division.

Shin et al. 2010. ICES JMS

IndiSeas: Comparative Approach

The WG developed and applied **different analyses and methodological approaches**:

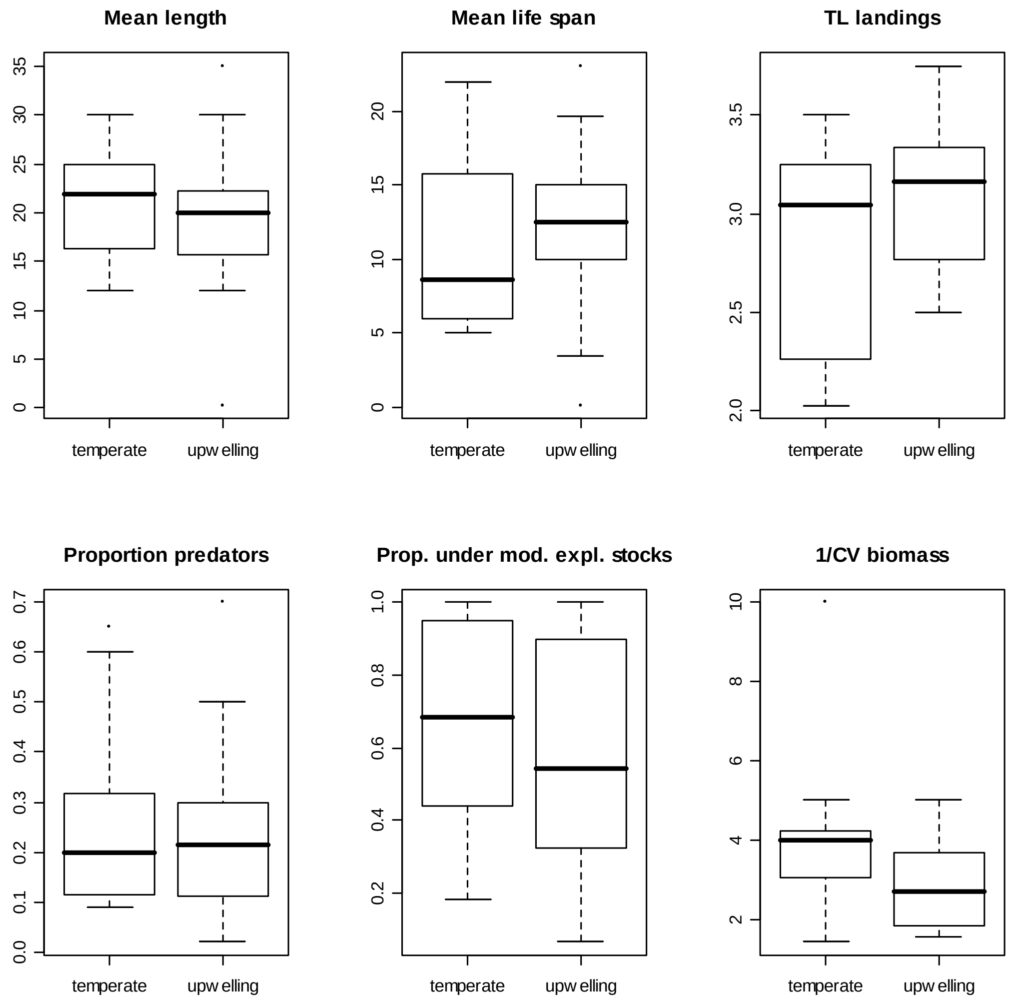
- **Comparison of S**, keeping in mind difficulty to establish reference points
- **Comparison of T,** with linear & non-linear approaches
- **Decision-tree** criteria to evaluate T
- **Ranking criteria** using both S and T
- **Environmental parameters** in comparison of S and T
- **Comparison of similar ecosystems**
- Investigation of how the **quality of trawl-based surveys** influence results

Special volume 67(4) of ICES Journal of Marine Science, 2010

IndiSeas: Comparative Approach

Can simple be useful and reliable? Using ecological indicators to represent and compare the states of marine ecosystems: Shin et al. 2010b.

- Can we directly compare ecosystems of different types by using a common set of indicators?
- Check whether reference levels for these indicators are similar across ecosystems
- Use of an expert survey of scientists to define reference levels (ecosystem overexploitation)



IndiSeas: Comparative Approach

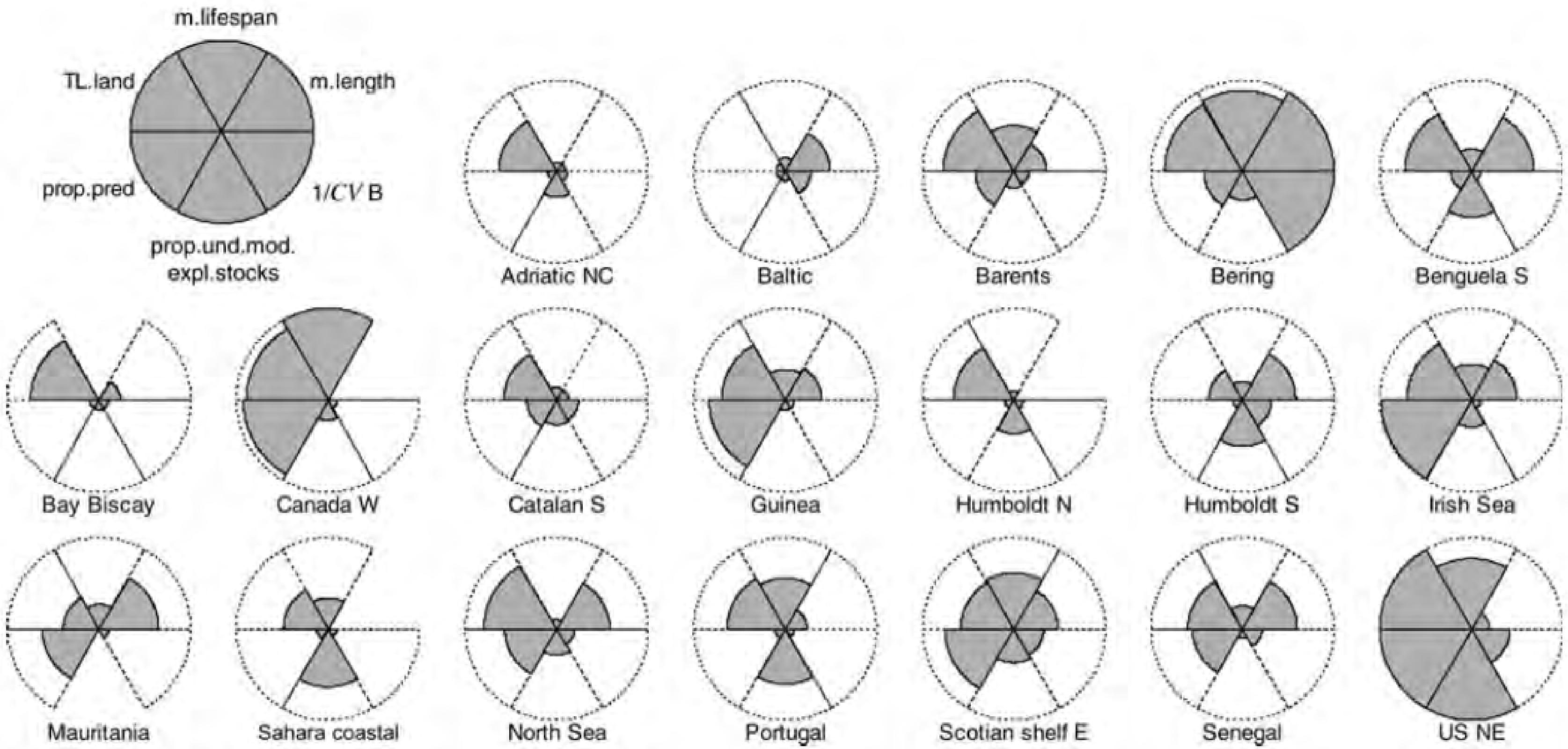


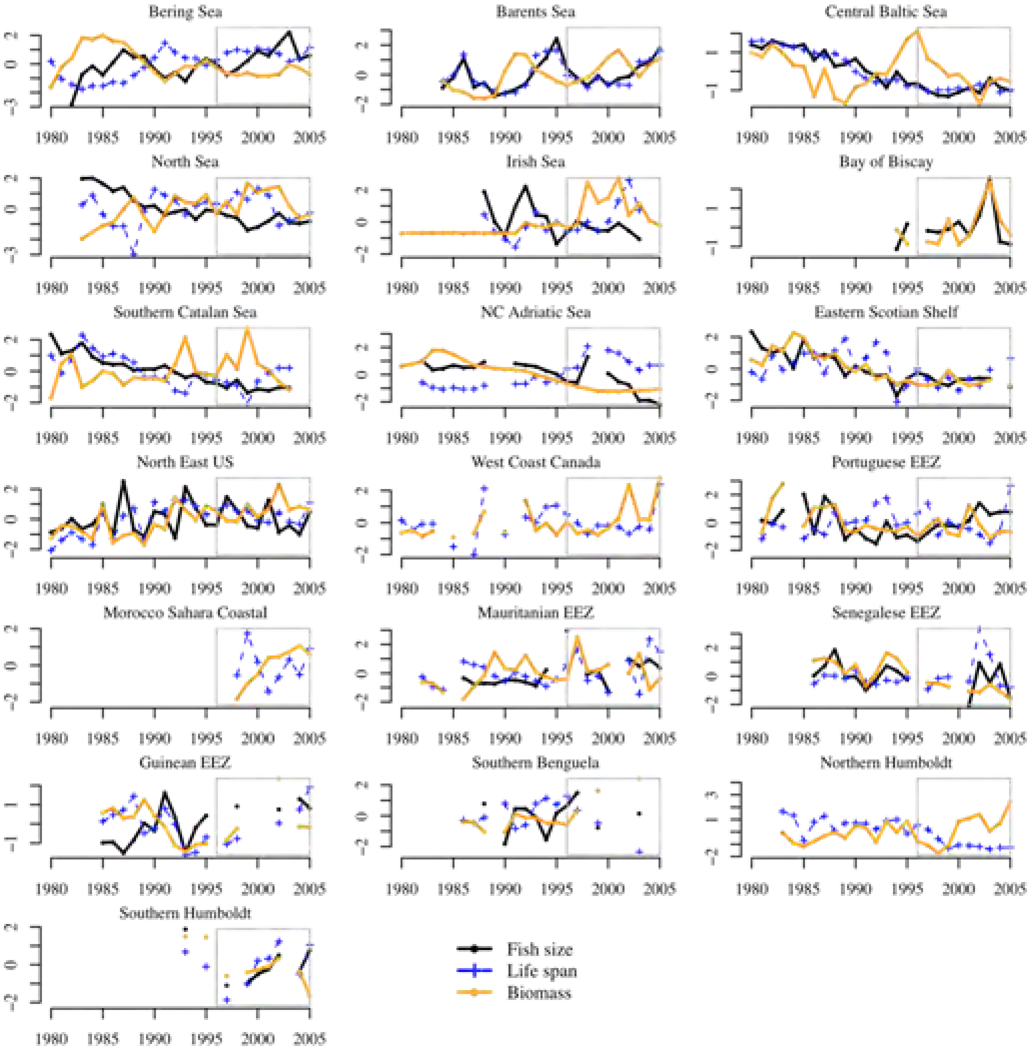
Figure 2. Pie diagrams representing present ecosystem states (2003–2005) using six ecological indicators: mean length, mean lifespan, TL of the landings, proportion of predatory fish, proportion of under- to moderately exploited species, and $1/CV$ biomass. Absence of the external border of a portion of the pie means that the corresponding indicator value was not available.

Shin et al. 2010b. ICES JMS

IndiSeas: Comparative Approach

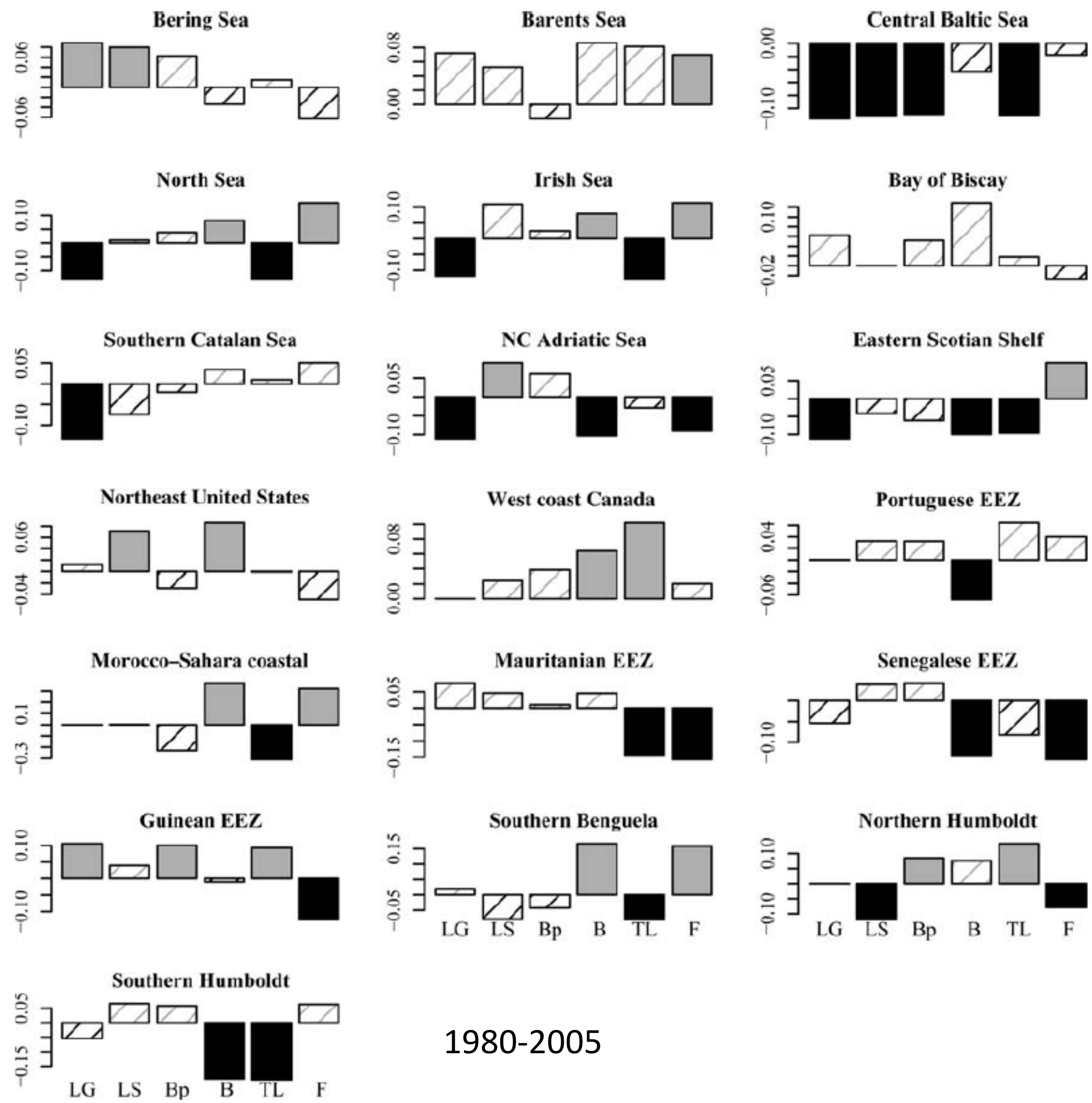
Trend analysis of indicators: a comparison of recent changes in the status of marine ecosystems around the world: Blanchard et al. 2010.

- Explore changes of indicators using both linear and non-linear statistical methods for quantifying T
- Compare and contrast T in indicators across ecosystems
- Address the redundancies and/or complementarities of indicators by looking at similarities in temporal dynamics



IndiSeas: Comparative Approach

- No consistent patterns in the redundancy of the indicators: each indicator provided complementary information
- Mixture of **+** and **-** directions of change including long and short time series
- Need to improve understanding of the responsiveness and performance of indicators



Blanchard et al. 2010. ICES JMS

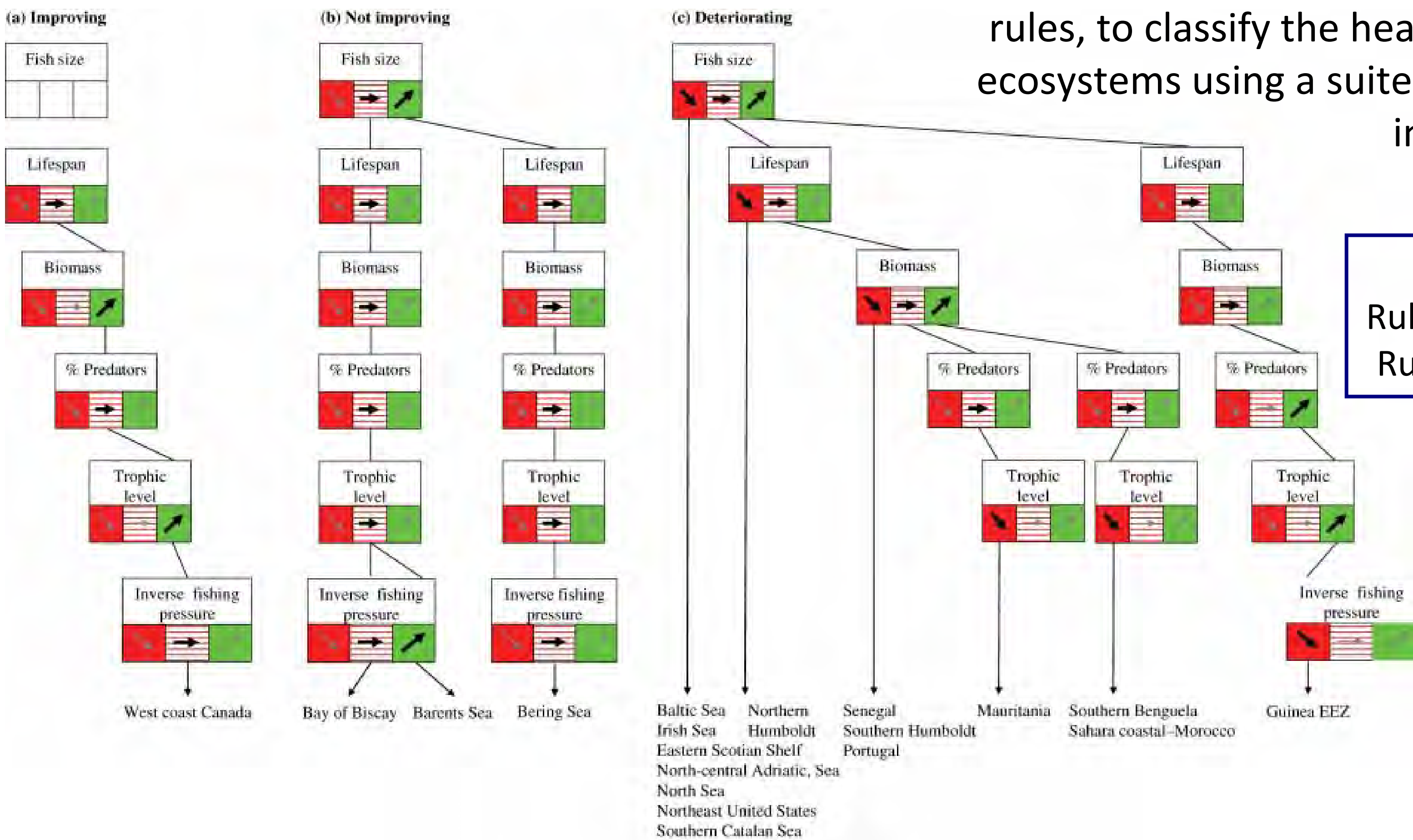
IndiSeas: Comparative Approach

The good(ish), the bad, and the ugly: a tripartite classification of ecosystem trends:

Bundy et al. 2010.

1980-2005

Application of a decision-tree framework, with associated decision rules, to classify the health of marine ecosystems using a suite of ecological indicators of T

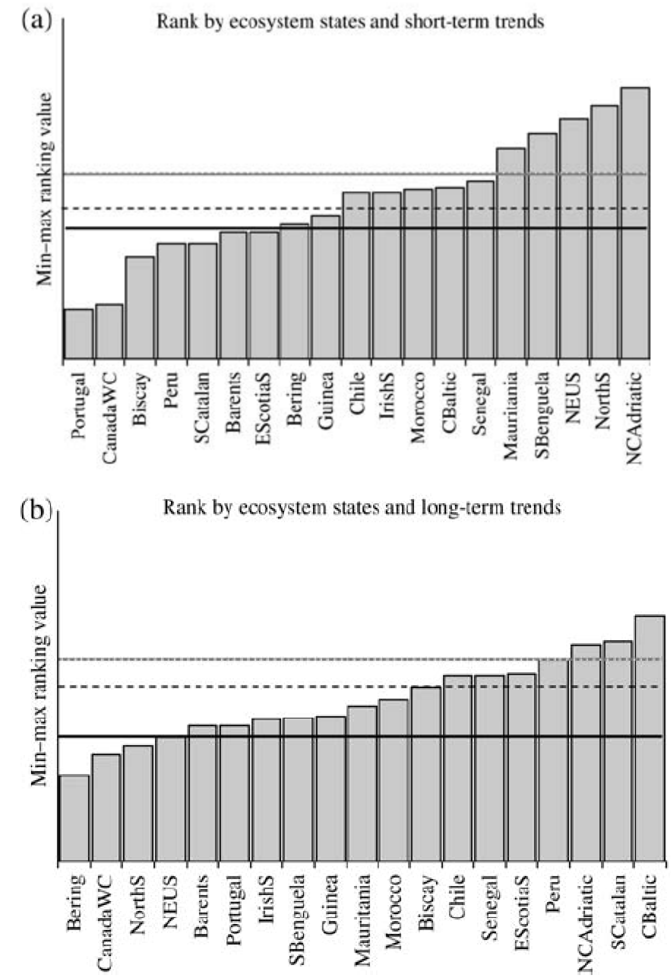


No T, +T, -T
Rule1: one (-) out
Rule2: 2(+) no (-)

IndiSeas: Comparative Approach

Ranking the ecological relative status of exploited marine ecosystems: Coll et al. 2010.

- S and T used to rank exploited ecosystems regarding fishing impacts
- Ecosystems classified into they were most, moderately, or least impacted (S), and they were becoming more or less impacted, or remaining stationary (T)
- Responses of ecological indicators to environmental and socio-economic explanatory factors were tested (BIO-ENV routine PRIMER)



IndiSeas: Comparative Approach

- Ranking with S and T differed because of differences in trends
- Nº of ecosystems classified as "unclear or intermediately impacted" increased with time, and the "less strongly impacted" and "more strongly impacted" were maintained
- Ecosystem type, enforcement, primary production, sea temperature, and fishing type were important variables explaining the ecological indicators

From long-term to short-term trends

Ecosystem	Situation
Barents Sea	U
Bay of Biscay	H → L
Bering Sea	L
Central Baltic Sea	H
Eastern Scotian shelf	H → L
Guinean EEZ	L → U
Irish Sea	U
Mauritania	U → H
Morocco	U
North Central Adriatic Sea	H
Northeastern US	L → H
North Sea	L → H
Northern Humboldt	H → L
Portugal EEZ	L
Senegal EEZ	H → U
Southern Benguela	U → H
Southern Catalan Sea	H
Southern Humboldt	H → U
West coast Canada	L

U, an unclear situation; L, lower impacts of fishing, i.e. a system classified as in a more lightly impacted by fishing situation; H, higher impacts, i.e. a more strongly impacted situation; → indicates that a system's classification changed when assessed over the long term (1980–2005, or for as long as there were data available for the system—see Link *et al.*, 2010, for lengths of the trends) relative to the short term (1996–2005).

Coll et al. 2010. ICES JMS

IndiSeas: Comparative Approach

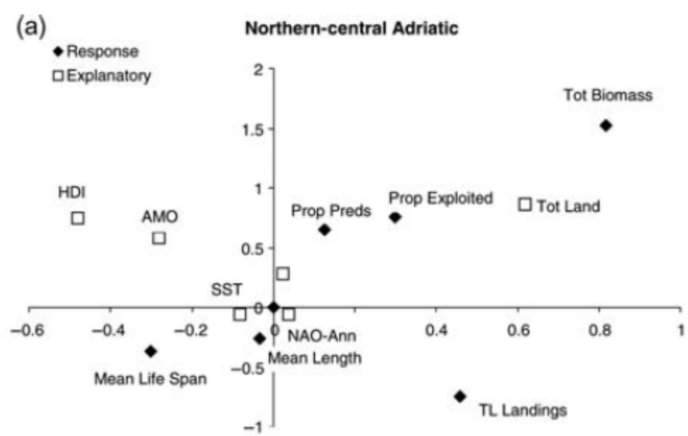
Relating marine ecosystem indicators to fishing and environmental drivers: an elucidation of contrasting responses: Link et al. 2010.

- Analysis of the specificity of S and T indicators, and key drivers: fishing and the environment
- Fishing (Landings) or human populations (HDI) were the primary drivers
- Environmental drivers were secondarily important, except mostly for upwelling systems

Table 2. Importance of ecosystem drivers across the 19 ecosystems resulting from the BV-STEP analysis. Black boxes are significant, grey boxes marginally significant. Blank cells indicate that an indicator was either not applicable to the particular ecosystem or did not emerge as having detected a relationship with the response indicators. AMO, Atlantic Multidecadal Oscillation Index; PDO, Pacific Decadal Oscillation; ENSO, *El Niño*–Southern Oscillation; SST, sea surface temperature; HDI, Human Development Index.

Drivers \ Ecosystems	Adriatic Sea	Baltic Sea	Barents Sea	Southern. Benguela	Bering	Biscay	Chile	Eastern Scotian Shelf	Guinea	Irish Sea	Mauritania	Morocco	North Sea	Perú	Portugal	Southern Catalan Sea	Senegal	US northeast	West coast Canada
AMO		black				grey			grey	black		black	black				black		
PDO					black														
ENSO							grey							black					black
Landings	black		black	black	black			black			grey				black		black	black	
SST		black	black			grey					grey		black			black			
HDI			black	black	black					black		black	black	black	black		black	black	

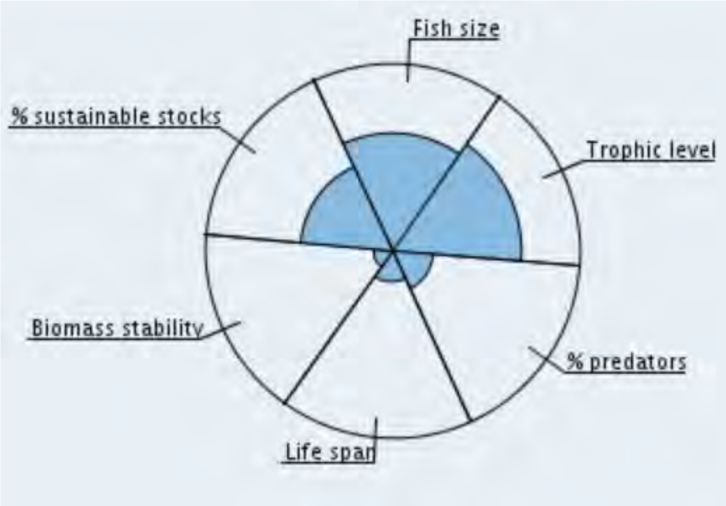
Canonical correlations



IndiSeas: Synthesis and Graphic Representation

- A special emphasis was given to conveying results clearly
- Images were ideal tools to convey the information from the suite of indicators regarding S and T

Pie diagrams for States (S)



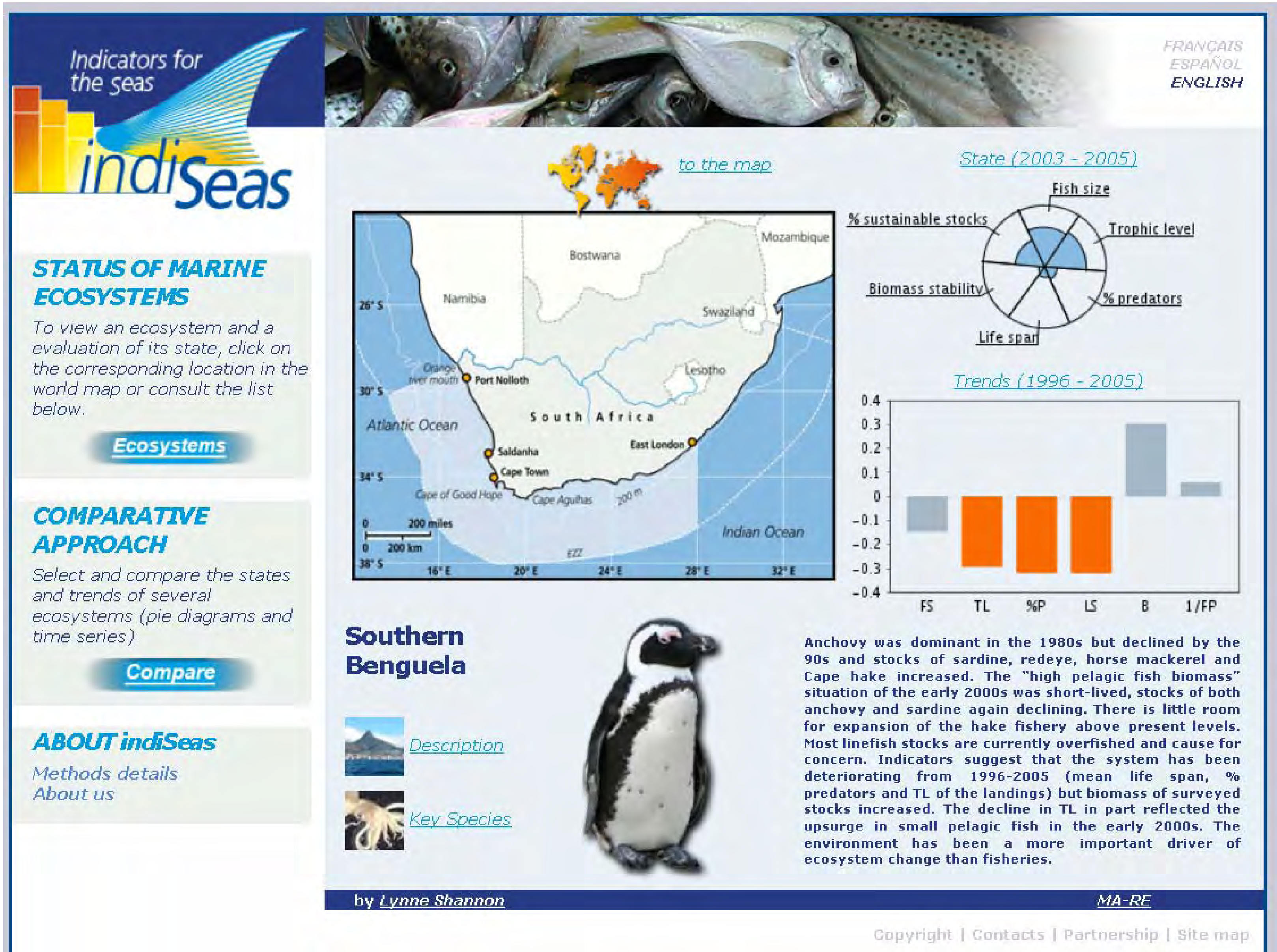
Bar plots for Trends (T)

IndiSeas: Reaching the public

www.indiseas.org

IndiSeas: Reaching the public

IndiSeas: Reaching the public



IndiSeas: Reaching the public

Indicators for the seas

indiSeas

FRANÇAIS
ESPAÑOL
ENGLISH

STATUS OF MARINE ECOSYSTEMS

To view an ecosystem and a evaluation of its state, click on the corresponding location in the world map or consult the list below.

Ecosystems

COMPARATIVE APPROACH

Select and compare the states and trends of several ecosystems (pie diagrams and time series)

Compare

ABOUT indiSeas

Methods details
About us

to the map
to the ecosystem

Southern Benguela

Overview of the ecosystem and its fisheries

Lion's Head, and Cape Town waterfront from harbour entrance to Table Bay. © Obie Oberholster

Geographic Area

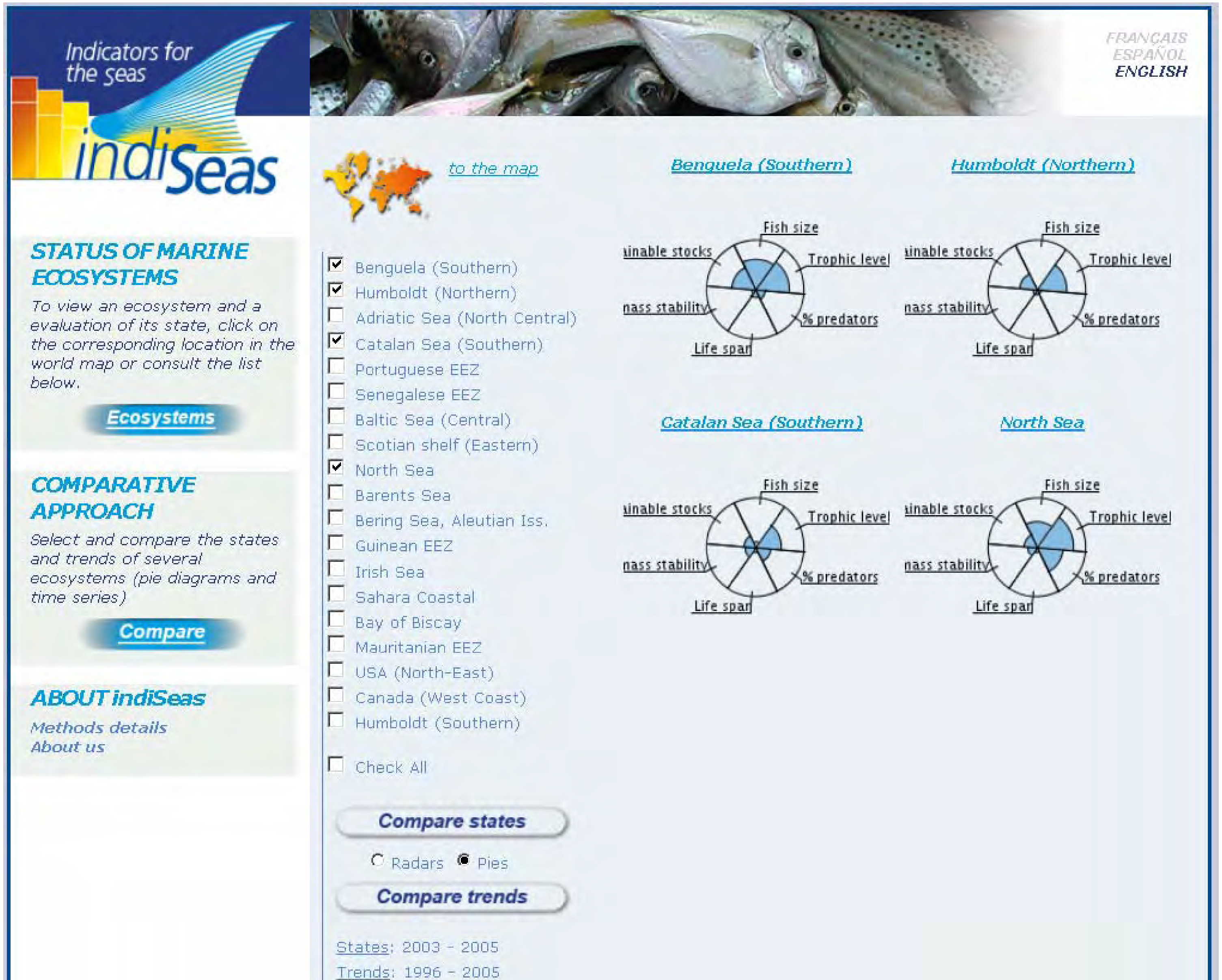
The Benguela is an upwelling system that may be subdivided into two oceanographic sub-systems. The northern Benguela is considered to extend south of the Angola-Benguela front located between 14 and 16oS, southwards to the permanent upwelling cell located in the vicinity of Lüderitz, Namibia (26oS). The latter is believed to provide a barrier to the north-south migration of some fish stocks, such as anchovy and sardine. However, the conventional division between northern and southern sub-systems is the Namibian-South African border at the Orange River Mouth (29oS). For scientific and fisheries management purposes, the southern Benguela ecosystem is generally assumed to extends from the Orange River Mouth (29oS) to East London (28oE), offshore to approximately the 500-m depth contour, covering an area of 220 000 km2.

FAO Fishing Areas: [47.1.6 ; 47.2.1]

Environment

The southern Benguela sub-system is unique because it includes the upwelling region along the south-western coast of Africa, but also extends over the Agulhas Bank and along the south coast. For this reason, the demersal and benthic components of the southern Benguela ecosystem are more abundant and play a more important role than in most other upwelling systems. The complex life cycles of many marine species off South Africa, which have spawning, nursery and feeding grounds in both the upwelling area off the west coast and on the Agulhas Bank or south coast, at different times of the

IndiSeas: Reaching the public



IndiSeas: Reaching the public

IndiSeas: What have we learned?

- A **set of indicators is helpful** in establishing a diagnosis of the status of exploited ecosystems
- A **comparative approach** enables greater understanding of the driving mechanisms of exploited marine ecosystems
- The **simple, yet rigorous, and often available indicators** of IndiSeas provide good perspective of ecosystem status and the impacts of fishing, and **complement more specific or rich-data assessments**
- Need of **local experts** to interpret results

Advantages and disadvantages

States: easier to calculate, but less informative and difficult to compare
Long-term trends: more informative, fully comparable, but data challenge
Short-term trends: data available, but less informative
Decision tree: provides diagnosis applicable for management, but previous classification needed
Ranking: complete picture of S and T, but weighting method needed
Drivers: informative and necessary

IndiSeas: What have we learned?

- Some consistent patterns observed across ecosystems, methods and indicators (state or trend) for long term trends:

  6 ecosystems identified as deteriorating/impacted

  2 ecosystems identified as less impacted/non-deteriorating

  3 ecosystems identified as improving or highly ranked

  8 ecosystems with mixed results due to difference in methodologies

- Results using short term T were more variable, but there were consistent patterns across 8 ecosystems. Most showed a prominence of primary human driver and of secondary environmental driver

- General evaluation indicates an **overexploitation state and declining trends** in several marine ecosystems
- **Fishing** is a prominent driver, **environment** follows, depending on local conditions
- Indicators expected to decrease with increasing fishing, but they do **not vary exclusively in response to fishing**, so need to consider multiple drivers of change

IndiSeas2
Objectives and General Approach

Synthesis of IndiSeas results

Future developments

- Add **marine ecosystems** to the comparison
- **Complement** the suite of indicators and **update** them to 2010
- Complement available indicators with additional indicators not necessarily available for all the ecosystems (e.g. discards) and **model-derived indicators**
- Importance of considering **environmental indicators** as synergistic or antagonistic drivers of ecosystem dynamics
- Need to further work on indicators' **thresholds and reference points**
- Need to assess the **responsiveness** of indicators to specific management

IndiSeas2: Objectives and General Approach

The **main objective of IndiSeas2** is to refine the evaluation and communication of the ecological status of marine ecosystems subject to multiple drivers (climate, fishing) in a changing world in support of an EAF

IndiSeas2 WG aims to:

(i) Update the ecological set of IndiSeas indicators and expand the range of ecosystems included

(ii) Include biodiversity and conservation-based (**Marta Coll & Lynne Shannon**), environmental (**Jason Link & Larry Hutchings**) and socioeconomic indicators (**Alida Bundy & Ratana Chuenpagdee**)

(iii) Further explore and test the set of indicators with development of new methods (integration, reference levels, test responsiveness and performance, and modeling) (**Steve Mackinson & Yunne Shin – Julia Blanchard & Jake Rice**)

IndiSeas2 is lead by **Yunne-Jai Shin, Lynne J. Shannon** and **Alida Bundy**

IndiSeas2: New Indicators on biodiversity and conservation-based issues

- Two of IndiSeas indicators were selected specifically to measure the impacts of fishing on the ecological attribute "Conservation of functional diversity":

  Proportion of predatory fish

  Proportion of underexploited stocks

- IndiSeas2 will include a set of indicators that can quantify the broader biodiversity and conservation risks in ecosystems

- **Step-by-step process**: define objectives of the group, requirements of the indicators, identify potential indicators with literature review, and determine screening criteria

- The set of new indicators will be **small**, **simple**, **available** and **rigorous**

- **Criteria:** data availability, ecological meaning, sensitivity to fishing, and public awareness, under a comparative approach framework

The indicators under consideration

In collaboration with Lynne J. Shannon

INDICATORS CHOSEN BY THE GROUP:
% Predatory fish in the catch
% Healthy stocks (FAO data and experts)
Proportion of all exploited species with declining biomass
Intrinsic vulnerability index of the catch -- W. Cheung and colleagues (FishBase)
Relative abundance (or biomass) of flagship species
Areas not impacted by mobile bottom gear
Marine Trophic Index -- D. Pauly and colleagues (CBD)
Mean trophic level of the community
Total (commercial) Invertebrates / Total catch or biomass
Discard rate
OTHER INDICATORS THAT WERE DISCUSSED:
Total fish / Total catch or biomass
% Depleted commercial taxa
Number of critically endangered, endangered, vulnerable or near threatened species (IUCN criteria)
Threat indicator for fish species -- N. Dulvy and colleagues (using IUCN criteria)
Endemic or rare (fish) species in the catch
Proportion of fish species included in the catch or total taxonomic groups (families, orders)
Total surface area of the ecosystem formally protected from fishing, or closed to fishing
% Catch that is coming from highly bottom impacting fleets / the total catch
% Catch that is coming from bottom trawl-beam trawl and dredges / the total catch
Piscivorous fish / planktivorous fish catch or biomass ratios
Seagrass, mangrove or oyster/mussel banks extent or coral reef condition

The indicators under consideration

Criteria of **ecological meaning, sensitivity to fishing, data availability**, **and public awareness**

INDICATORS CHOSEN BY THE GROUP:

Biodiversity/conservation-based indicators	Ecological significance	Sensitivity	Measurability (%)	Public awareness
% Predatory fish in the catch	x	x	100	x
% Healthy stocks	x	x	100	x
Proportion of all exploited species with declining biomass	x	x	88	x
Intrinsic vulnerability index of the catch	x	x	100	x
Relative abundance (or biomass) of flagship species	x	x	88	x
Areas not impacted by mobile bottom gear	x		88	x
Marine Trophic Index	x	x	100	x
Mean trophic level of the community	x	x	76	x
Total (commercial) Invertebrates / Total catch or biomass	x	x	94	x
Discard rate	x	x	94	x

In collaboration with Lynne J. Shannon

The indicators under consideration

The decision so far…

IndiSeas1:
- % Predatory fish in the community (State & Trend)
- % of under-and moderately exploited stocks (State)

New indicators:
- % of exploited species with declining biomass (State)
- Intrinsic vulnerability index of the catch (State)
- Relative abundance (or biomass) of flagship species (Trend)
- Marine Trophic Index (of landings, Trend)

Complementary:
- TL of surveyed community to complement MTI and TLc
- Discard (% or discard rate)

Food-web model-based indicators

Species / Ecological groups indicators

Biomass, Production and Consumption ratios
Indicators of fishing impact: F/Z, PPR, TLc
Trophic level
Mixed trophic impact analysis
Keystone species
Total trophic flows, transfer efficiencies
Ecosystem development (Odum; Ulanowicz)

Food web / Ecosystem emergent properties

Single species indicators

Population indicators

Community-based indicators

Ecosystem indicators

- Ecosystem structure
- Ecosystem functioning
- Fishing and environmental impacts
- Biodiversity and conservation-based

Food-web modelling

Due to human activities, important changes may have occurred in marine food webs

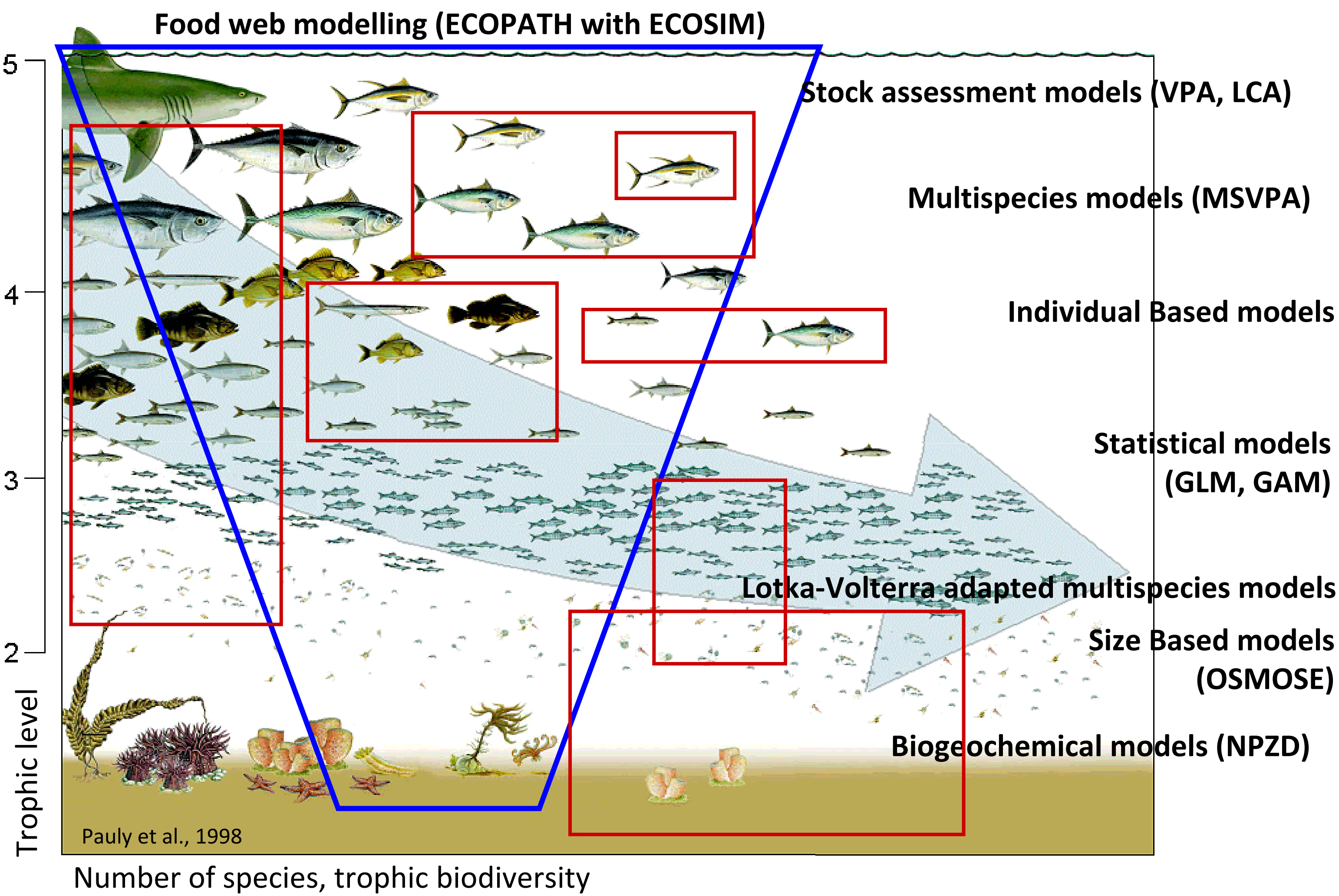
Intense exploitation

Introduction of exotic species

Climatic changes

Habitat modification

Pollution & nutrient enrichment



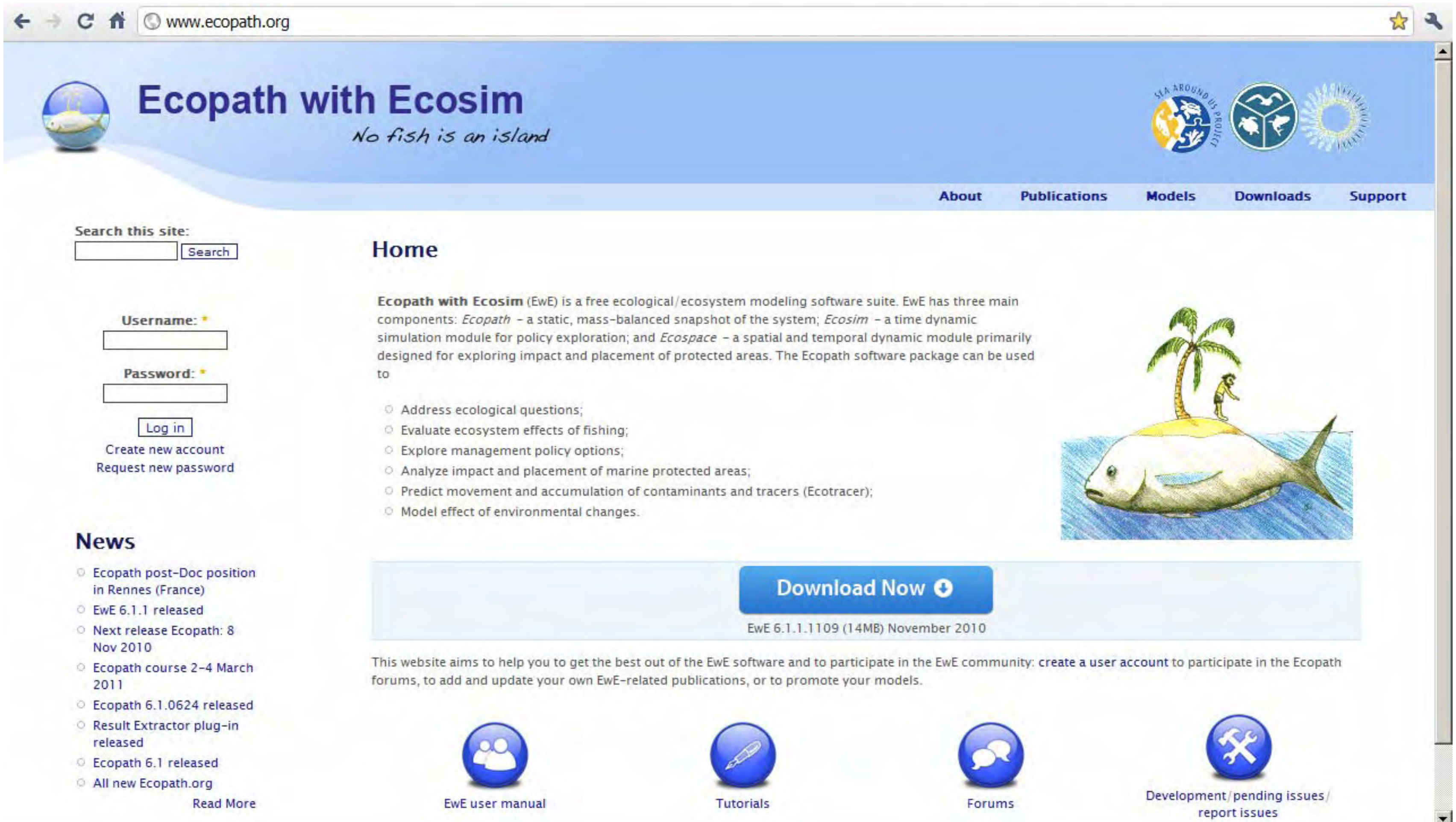
Plaganyi 2007. Models for an Ecosystem Approach to Fisheries . FAO

Graph design: Daniel Pauly; Artist: Rachel Atanacio

EwE Food-web modelling

Ecopath with Ecosim – EwE – www.ecopath.org

Worldwide applied tool for the description of ecosystem structure and functioning (mainly marine), for theoretical analysis of food webs, and for investigating various ecological issues in an EAF context



EwE Food-web modelling

(1) ECOPATH: mass balance static routine (0D, NO time dynamics)

(2) ECOSIM: time dynamic (0D)

(3) ECOSPACE: time dynamic and spatially explicit (2D)

Polovina, J. J. (1984) Model of a Coral-Reef Ecosystem .1. the Ecopath Model and Its Application to French Frigate Shoals. *Coral Reefs*, **3**, 1-11.

Christensen, V. & Pauly, D. (1992) ECOPATH II - A software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, **61**

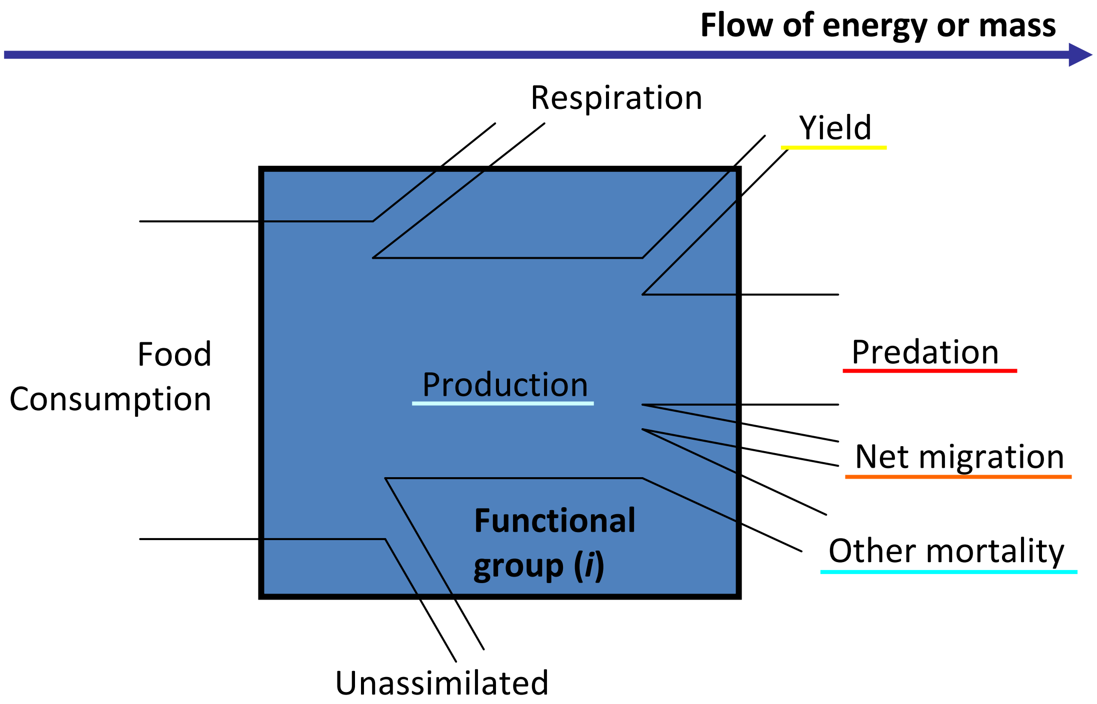
Christensen, V. & Pauly, D. (1993) *Trophic models of aquatic ecosystems*, edn. ICLARM Conference Proceedings

Walters, C., Christensen, V. & Pauly, D. (1997) Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. *Reviews in Fish Biology and Fisheries*, **7**, 139-172.

Walters, C., Pauly, D. & Christensen, V. (1999) Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *Ecosystems*, **2**, 539-554

Christensen, V. & Walters, C. (2004) Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling*, **72**, 109-139

Ecopath - Mass balance modelling



Assumptions

MASS BALANCE: For each compartment *i* (species or functional groups) a balance is set up between consumption and all productions

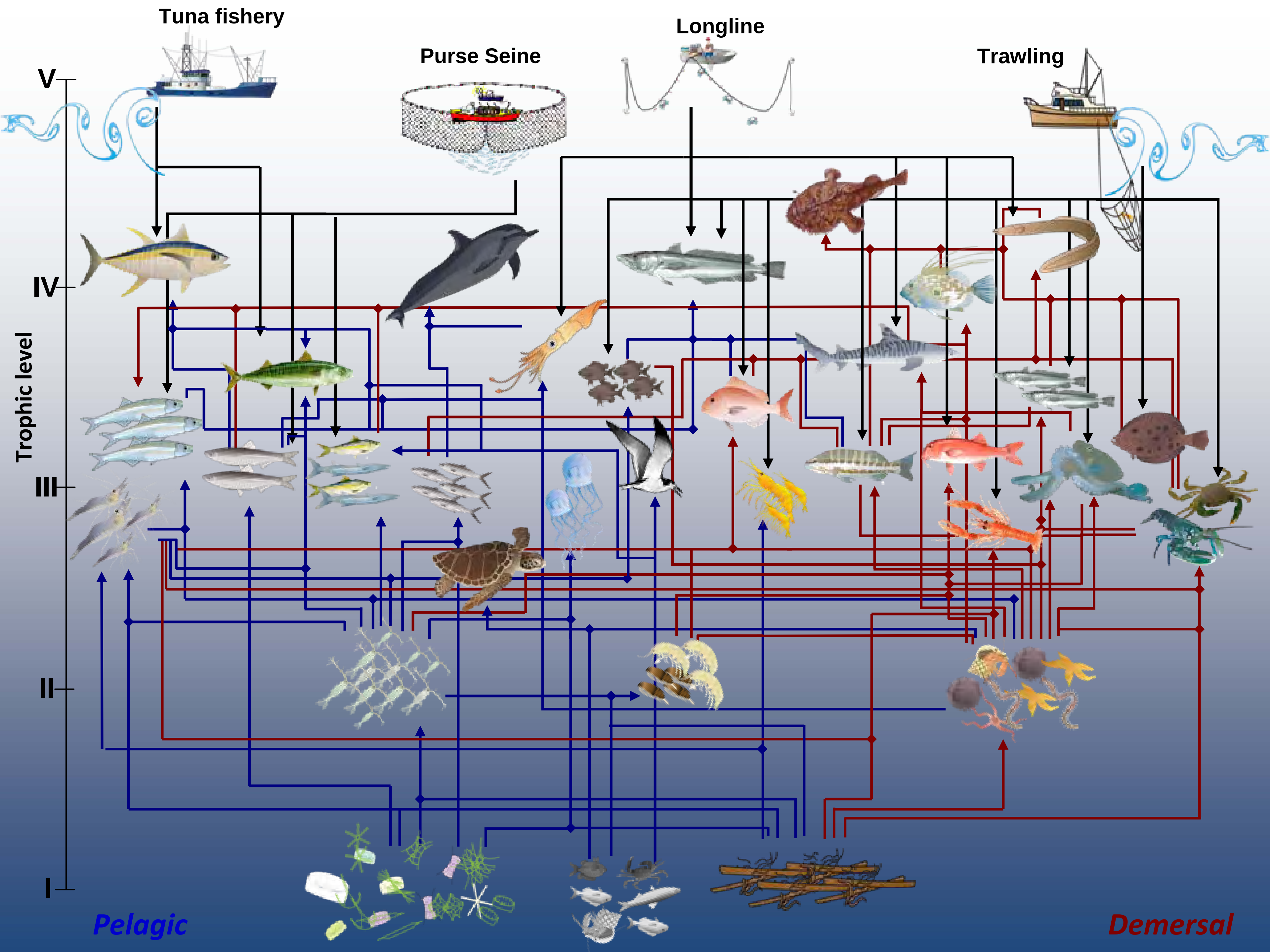
STATIC SNAPSHOT:
- **Biomass average**
- **Ratios as annual average**

Bi Biomass
P/Bi Specific Production
Q/Bi Specific Consumption
DCji Fraction of prey (i) in diet of predator (j)
BAi Biomass Accumulation
Yi Catch
EEi production used within the system
1- *EEi* is the unexplained mortality

$$\left(\frac{Q}{B}\right)_i \cdot B_i = \left(\frac{P}{B}\right)_i \cdot B_i + R_i + UN_i$$

$$\left(\frac{P}{B}\right)_i \cdot B_i = \sum_{Pred\_j=1}^{n} \left(\frac{Q}{B}\right)_j \cdot B_j \cdot DC_{ij} + E_i + Y_i + BA_i + \left(\frac{P}{B}\right)_i \cdot B_i \cdot (1 - EE_i)$$

Polovina, J.J. 1984. Coral Reefs, 3:1-11; Pauly et al. 2000. ICES J. Mar. Sci., 57: 697-706; Christensen and Walters. 2004. Ecol. Model., 172(2-4): 109-139

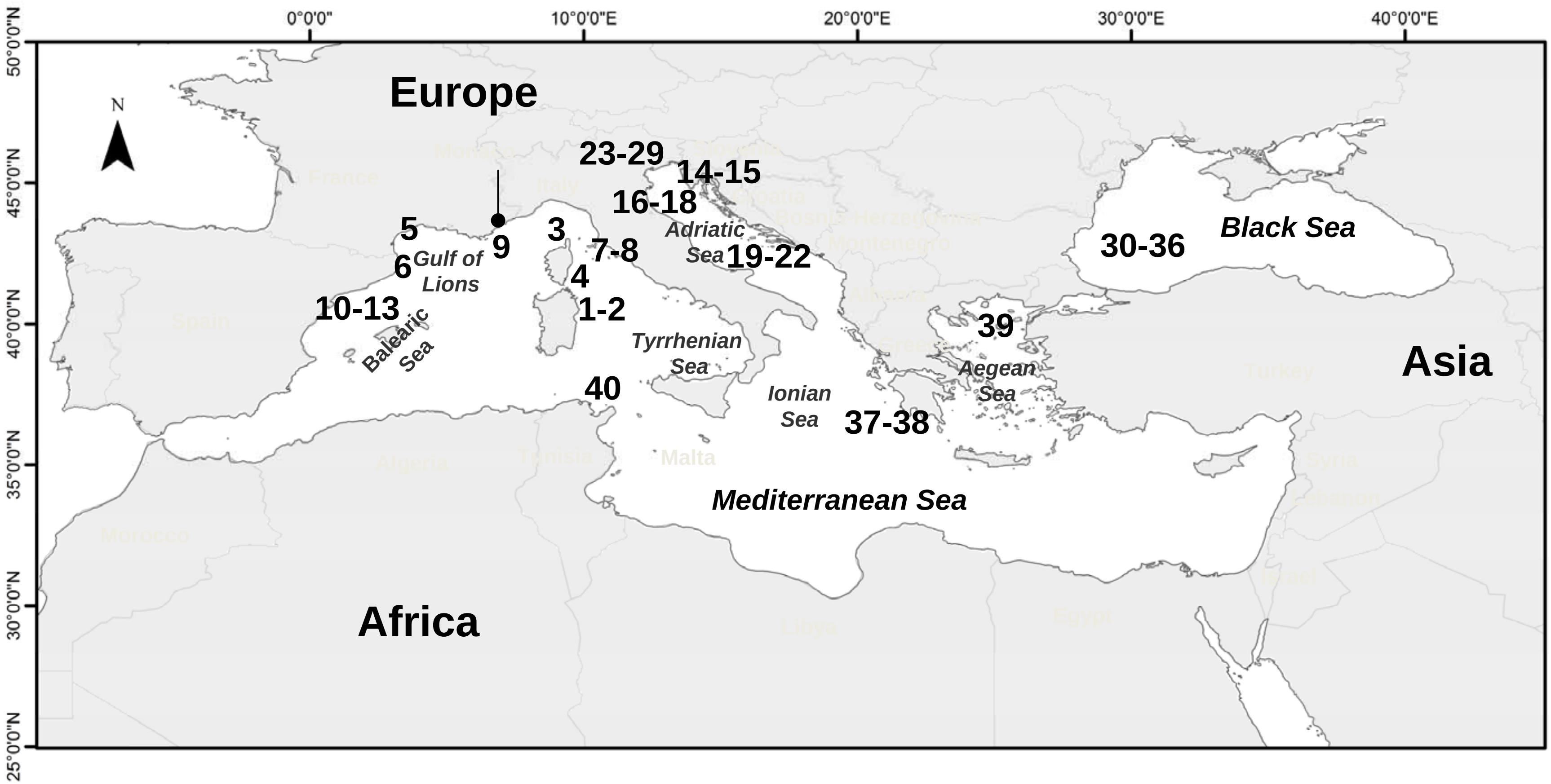

Tuna fishery
Purse Seine
Longline
Trawling
V
IV
III
II
I
Trophic level
Pelagic
Demersal

Ecopath applications

L. Morissette PhD 2007. Ecosystem models constructed from 1984 to 2007 with Ecopath. A total of **393 models** are shown on the map, 316 in marine habitats, 71 in rivers, lakes or reservoirs, and 6 terrestrial ecosystems.

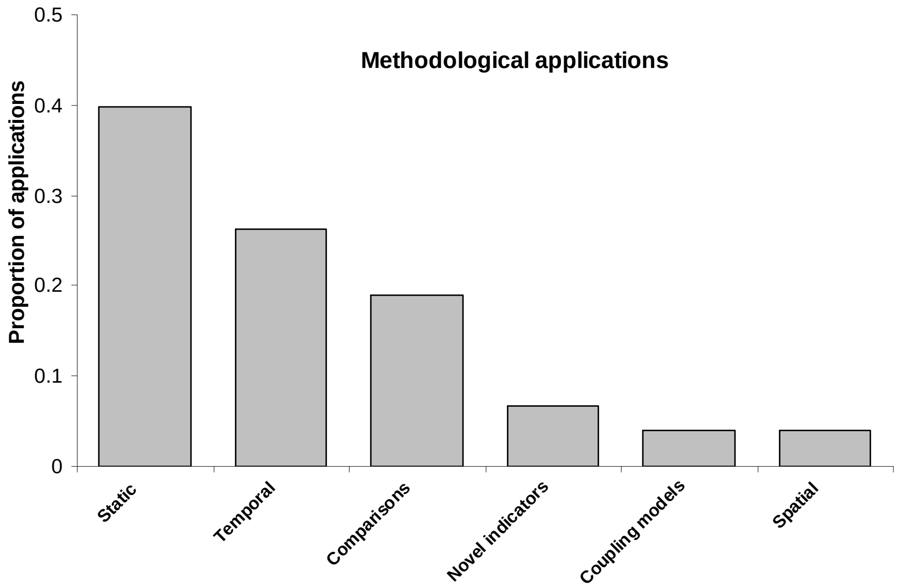
Mediterranean Ecopath applications

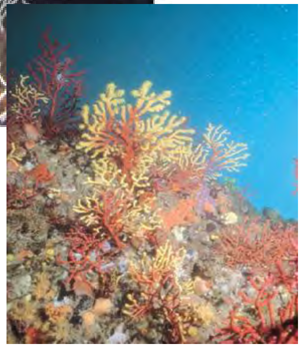
Comparative approach

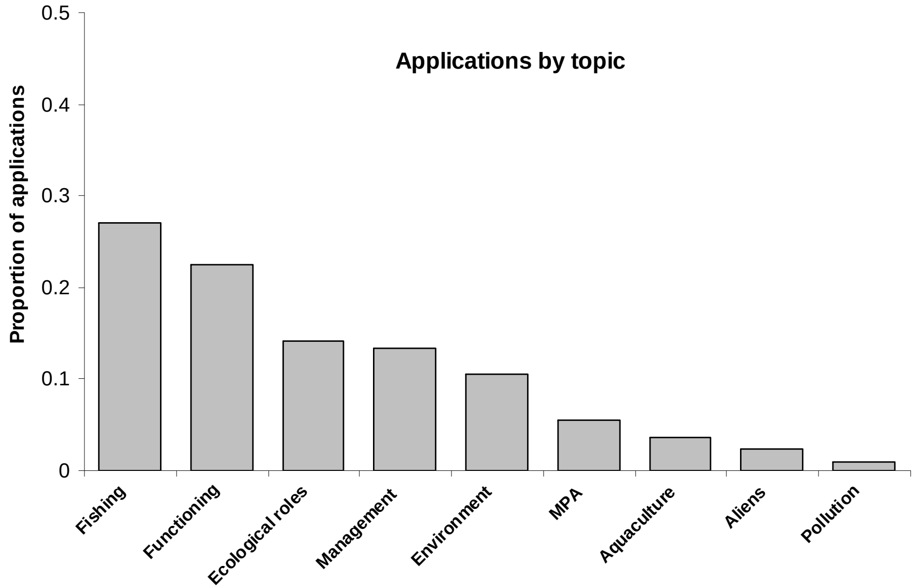


Coll & Libralato, 2011. Fish and Fisheries

Applications by method and by topic



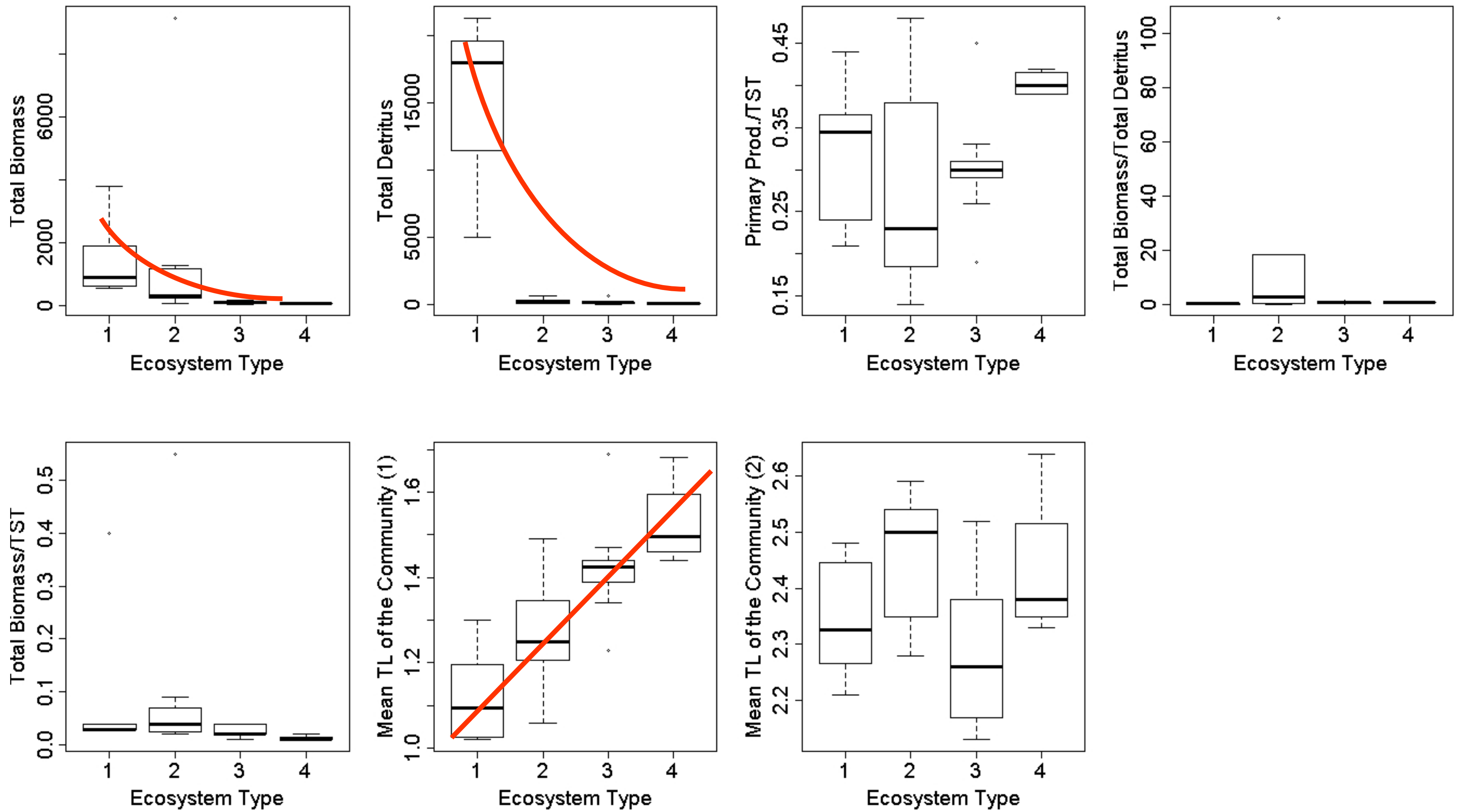




Coll & Libralato, 2011. Fish and Fisheries

Ecosystem indicators by ecosystem type

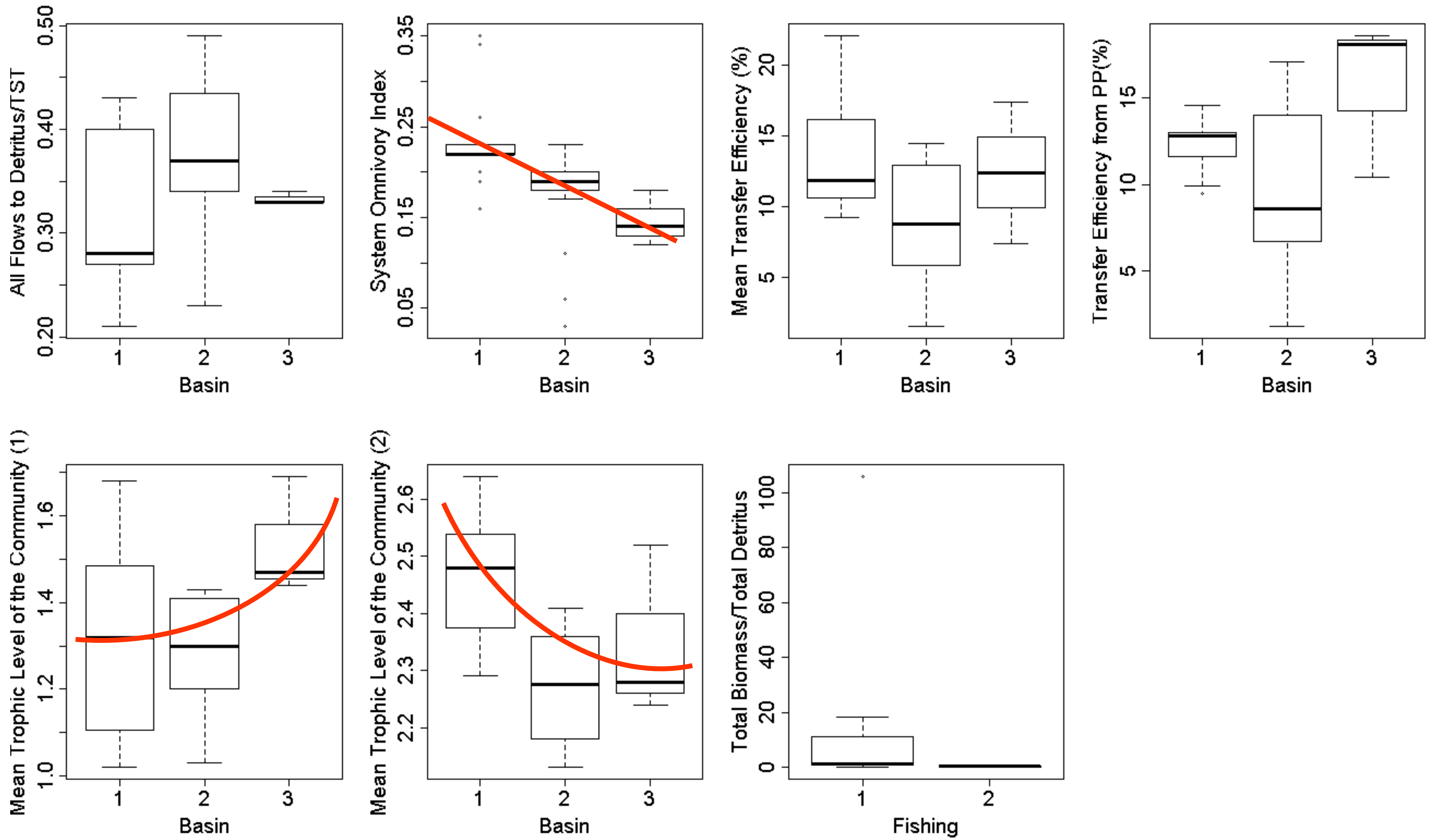
Ecosystem type: 1 = lagoon, 2 = coastal areas, 3 = continental shelf, 4 = continental shelf and slope



Coll & Libralato, 2011. Fish and Fisheries

… by basin and exploitation

Basin: 1 = North-Western, 2 = North-Central, 3 = North-Eastern



Fishing: 1 = none/slight fishing, 2 = high fishing

Coll & Libralato, 2011. Fish and Fisheries

Comparison of Ecopath models and SIA

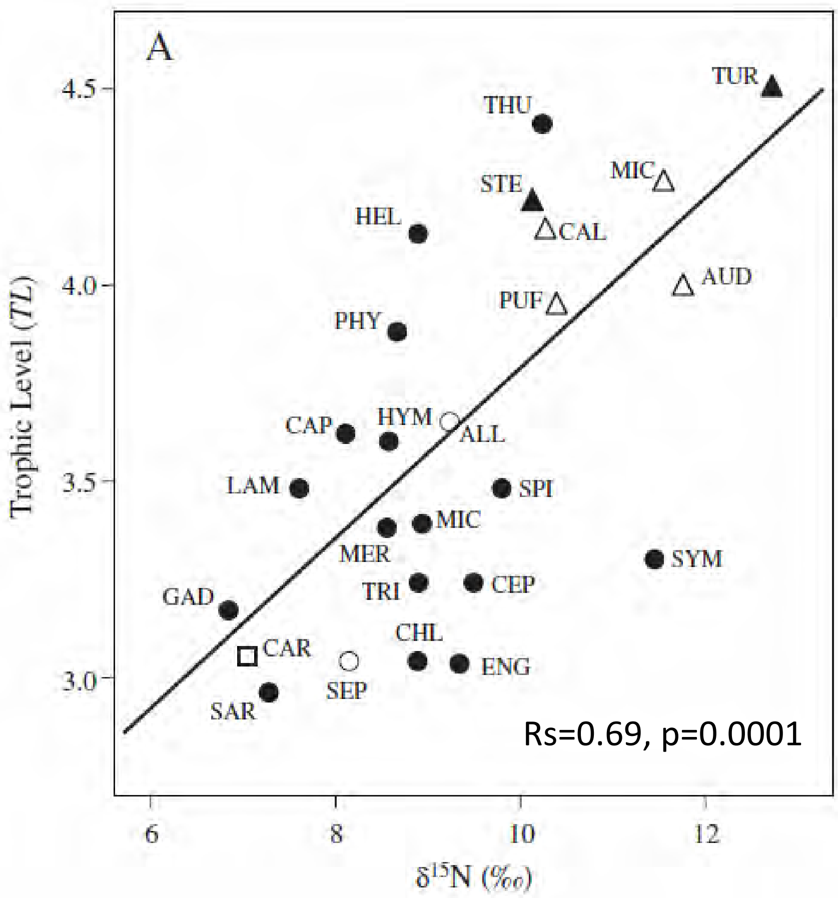
To depict the **trophic position** (trophic level and δ15N values) and **trophic width** (omnivory index and total isotopic area) of several species of fish, cephalopods, cetaceans, seabirds and one sea turtle

Table 1
Trophic level (*TL*, mean±sd) and trophic width estimators, total area (*TA*) and omnivory index (*OI*), for fish, cephalopods, seabirds, cetaceans and marine turtles from the South Catalan Sea (NW Mediterranean). The source of the stable isotope and the sample sizes for each species (n) are also indicated. ND = No data available.

Species	*TL*	*OI*	*TA*	n	Source
Fish					
Anchovy *Engraulis encrasicolus* (ENG)	3.05 ± 0.01	0	0.18	9	(Navarro et al., 2009)
Blackbelly rosefish *Helicolenus dactylopterus* (HEL)	4.14 ± 0.26	0.19	0.12	10	Present study
Blotched picarel *Spicara flexuosa* (SPI)	3.49 ± 0.35	0.35	0.08	9	(Navarro et al., 2009)
Blue whiting *Micromesistius poutassou* (MIC)	3.40 ± 0.41	0.46	0.14	9	(Navarro et al., 2009)
Bluefin tuna *Thunnus thynnus* (THU)	4.42 ± 0.32	0.11	ND	2	(Cardona et al., 2007)
Boarfish *Capros aper* (CAP)	3.65 ± 0.28	0.22	0.12	10	Present study
European hake *Merluccius merluccius* (MER)	3.39 ± 0.61	1	0.07	9	Present study
Glasshead grenadier *Hymenocephalus italicus* (HYM)	3.61 ± 0.24	0.32	0.05	6	Present study
Greater forkbeard *Phycis blennoides* (PHY)	3.89 ± 0.05	0.01	0.03	9	(Navarro et al., 2009)
Jewel lanternfish *Lampanyctus crocodilus* (LAM)	3.49 ± 0.35	0.35	0.18	8	Present study
Sardine *Sardina pilchardus* (SAR)	2.97 ± 0.27	0.21	1.01	9	(Navarro et al., 2009)
Poor cod *Trisopterus minutus* (TRI)	3.25 ± 0.51	0.71	0.21	10	Present study
Red bandfish *Cepola macrophthalma* (CEP)	3.25 ± 0.30	0.25	0.53	9	Present study
Shortnose greeneye *Chlorophthalmus agassizi* (CHL)	3.05 ± 0.01	0	0.01	5	Present study
Silvery cod *Gadiculus argenteus* (GAD)	3.18 ± 0.37	0.38	1.01	9	(Navarro et al., 2009)
Tonguesole *Symphurus nigrescens* (SYM)	3.31 ± 0.45	0.56	0.08	8	(Navarro et al., 2009)
Cephalopods					
Common bobtail *Sepieta oweniana* (SEP)	3.08 ± 0.29	0.24	0.06	9	Present study
Common squid *Allotheuthis subulata* (ALL)	3.66 ± 0.53	0.77	0.45	6	(Navarro et al., 2009)
Cetaceans					
Bottlenose dolphin *Tursiops truncatus* (TUR)	4.51 ± 0.50	0.25	ND	7	(Borell et al., 2006)
Striped dolphin *Stenella coeruleoalba* (STE)	4.22 ± 0.26	0.07	ND	5	(Cardona et al., 2007)
Seabirds					
Audouin's gull *Larus audouinii* (AUD)	4.01 ± 0.95	0.91	2.44	107	(Navarro et al., 2010)
Balearic shearwater *Puffinus mauretanicus* (PUF)	3.96 ± 1.02	1.05	1.35	145	(Navarro et al., 2009)
Yellow-legged gull *Larus michahellis* (MIC)	4.27 ± 0.93	0.87	ND	23	(Ramos et al., 2009)
Marine turtle					
Loggerhead sea-turtle *Caretta caretta* (CAR)	3.06 ± 0.79	0.63	ND	27	(Revelles et al., 2007)

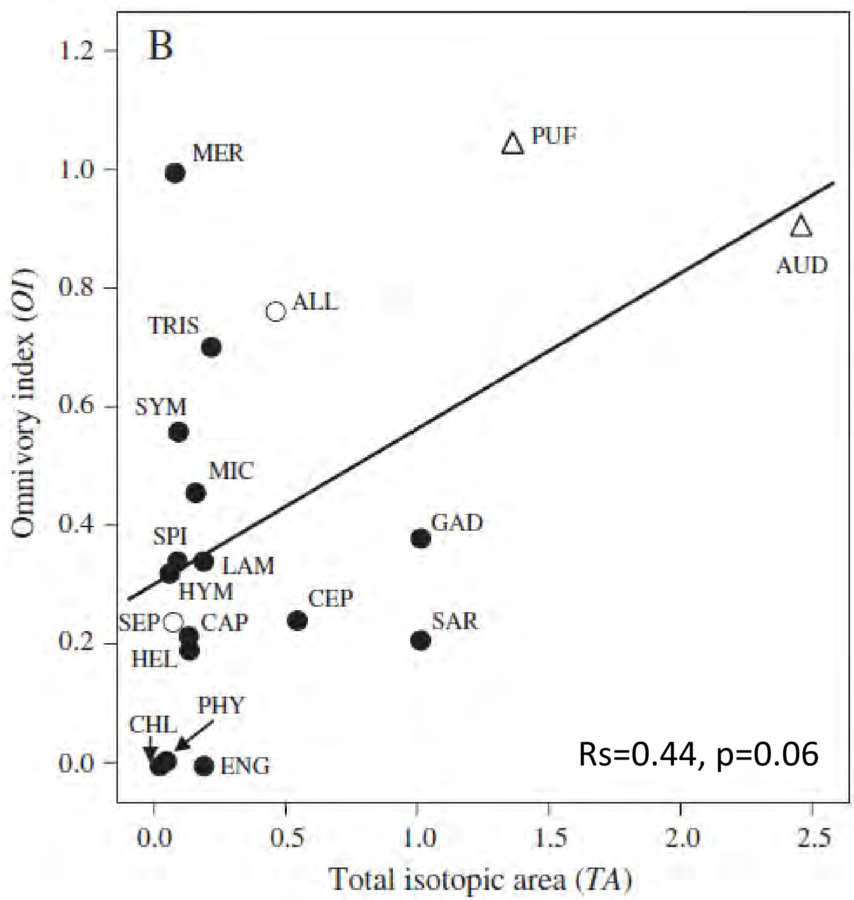
Navarro et al. 2011. JEMBE

Comparison of Ecopath models and SIA



The trophic level (mean) calculated with the Ecopath model and the δ15N values (mean)

Omnivory index (OI) calculated with Ecopath model with the total isotopic area (TA) calculated with the isotopic values for fish, cephalopods, seabirds, cetaceans, and marine turtles

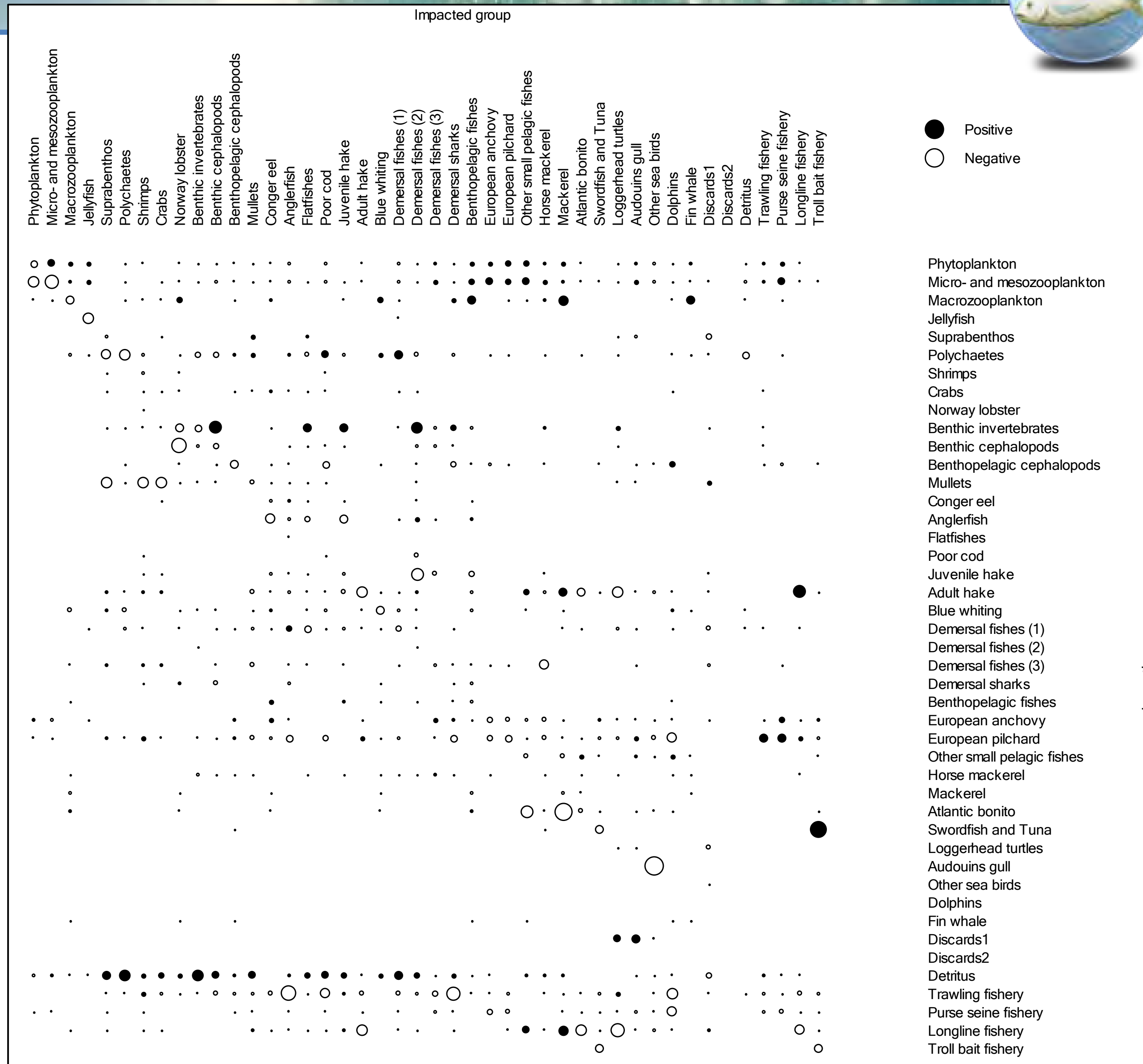


Navarro et al. 2011. JEMBE

Identification of keystone functional groups

Mixed Trophic Impact Analysis

$$MTI_{ij} = DC_{ij} - FC_{ji}$$



Identification of keystone functional groups

Keystone species are defined as relatively low biomass species with disproportionate high effects on the food web

The overall impact:

$$\varepsilon_i = \sqrt{\sum_{j \neq i}^{n} m_{ij}^2} \qquad p_i = \frac{B_i}{\sum_k B_k}$$

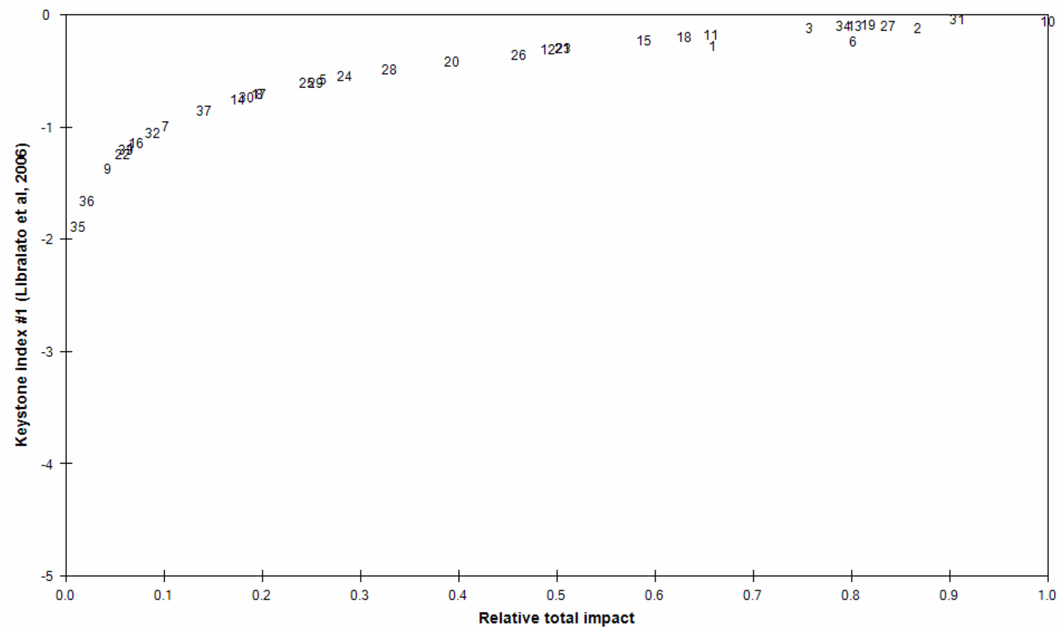
Keystone species (KS ≥ 0)

$$KS_i = \log[\varepsilon_i \cdot (1 - p_i)]$$

Key dominant groups (KD ≥ -0.7)

$$KD_i = \log[\varepsilon_i \cdot p_i]$$

Relative total impact & Keystoneness: **key species**



Identification of keystone functional groups

Keystone species are defined as relatively low biomass species with disproportionate high effects on the food web

The overall impact:

$$\varepsilon_i = \sqrt{\sum_{j \neq i}^{n} m_{ij}^2} \qquad p_i = \frac{B_i}{\sum_k B_k}$$

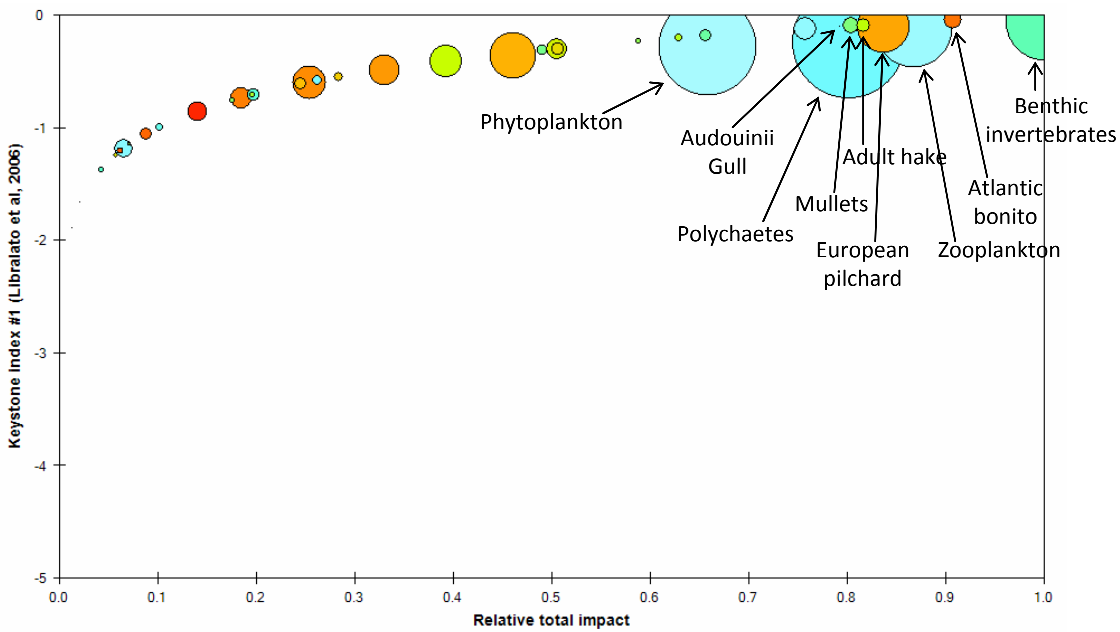
Keystone species (KS ≥ 0)

$$KS_i = \log[\varepsilon_i \cdot (1 - p_i)]$$

Key dominant groups (KD ≥ -0.7)

$$KD_i = \log[\varepsilon_i \cdot p_i]$$

Relative total impact & Keystoneness: **key species**



Libralato et al. 2006. Ecological Modelling

Identification of keystone functional groups

Keystone species are defined as relatively low biomass species with disproportionate high effects on the food web

The overall impact:

$$\varepsilon_i = \sqrt{\sum_{j \neq i}^{n} m_{ij}^2} \qquad p_i = \frac{B_i}{\sum_k B_k}$$

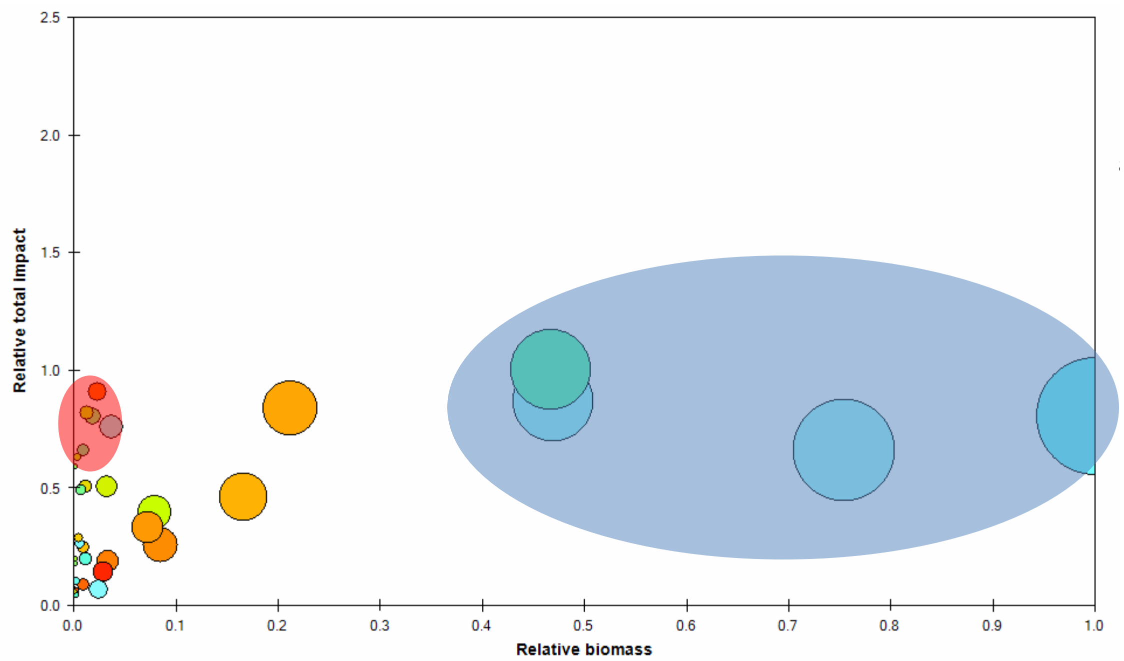
Keystone species (KS ≥ 0)

$$KS_i = \log[\varepsilon_i \cdot (1 - p_i)]$$

Key dominant groups (KD ≥ -0.7)

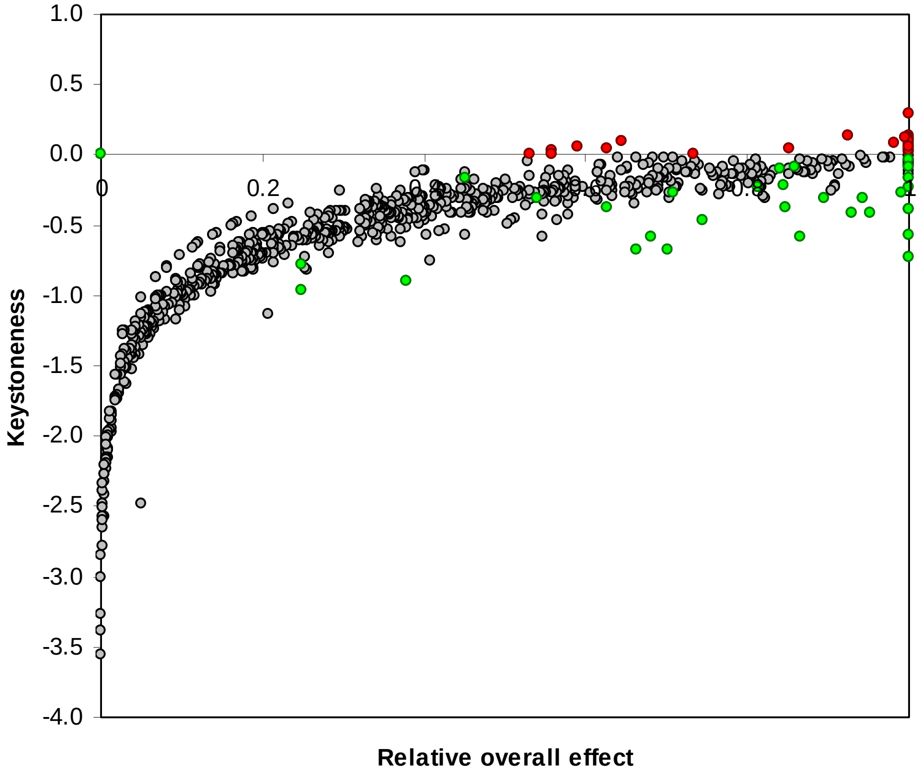
$$KD_i = \log[\varepsilon_i \cdot p_i]$$

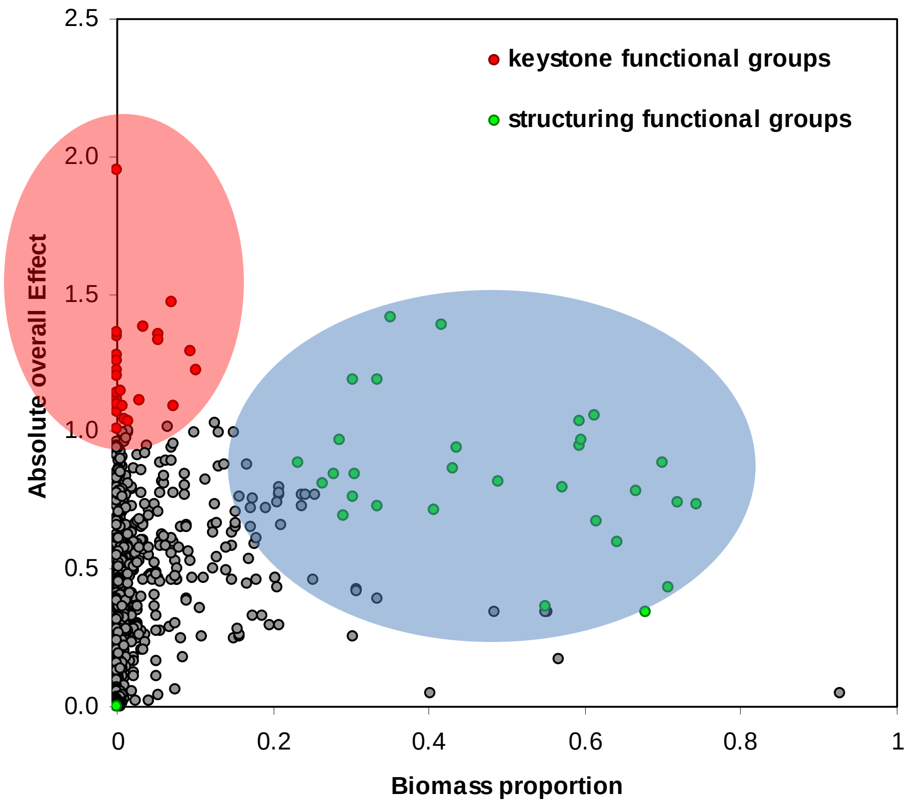
Relative total impact & Keystoneness: **key species**



Libralato et al. 2006. Ecological Modelling

Identification of keystone functional groups



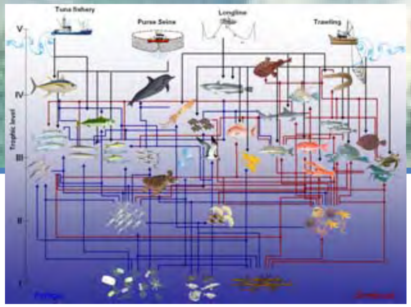


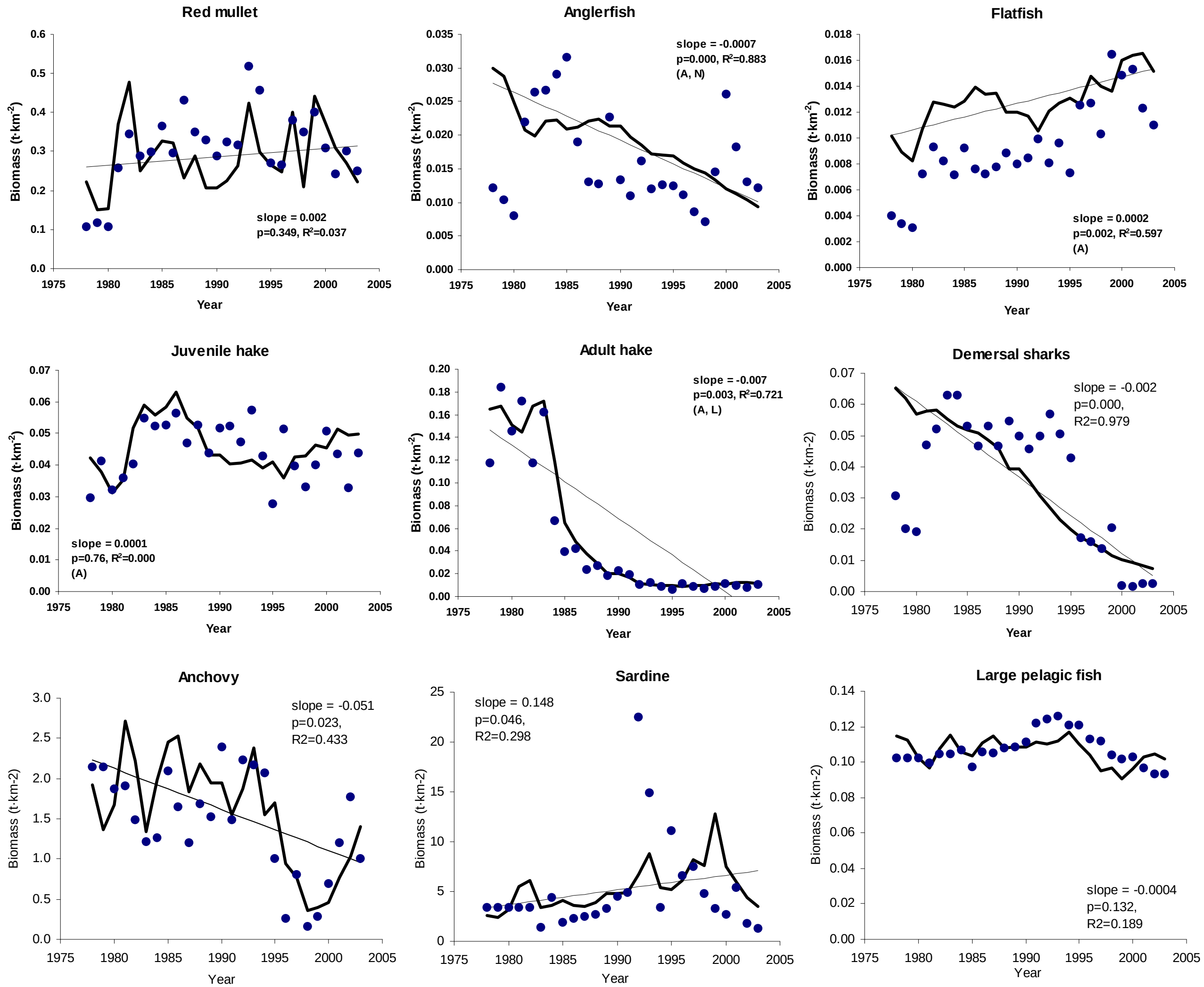
Fished ecosystem models (N = 627): **2%** identified keystone groups; **4%** structuring groups

Non-fished (or slightly fished) ecosystems (N 188): **6%** identified keystone groups; **4%** structuring

Coll & Libralato, 2011. Fish and Fisheries

Indicators from Ecosim





Fishing effort

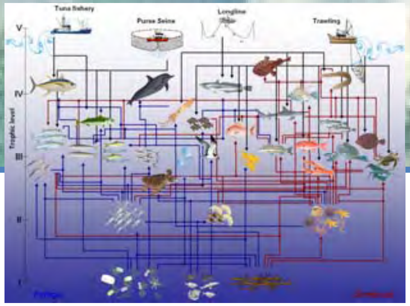
Environment

SST

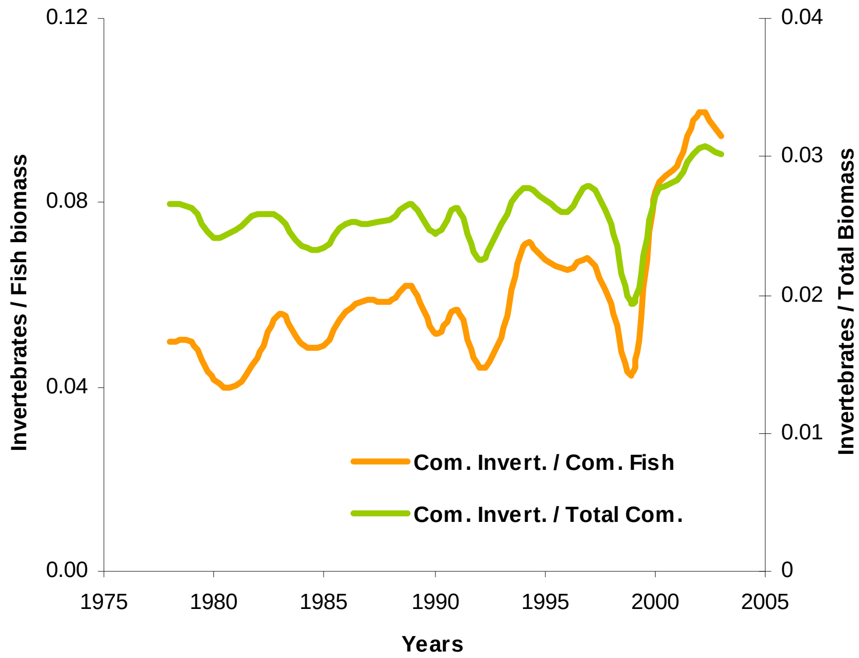
PP

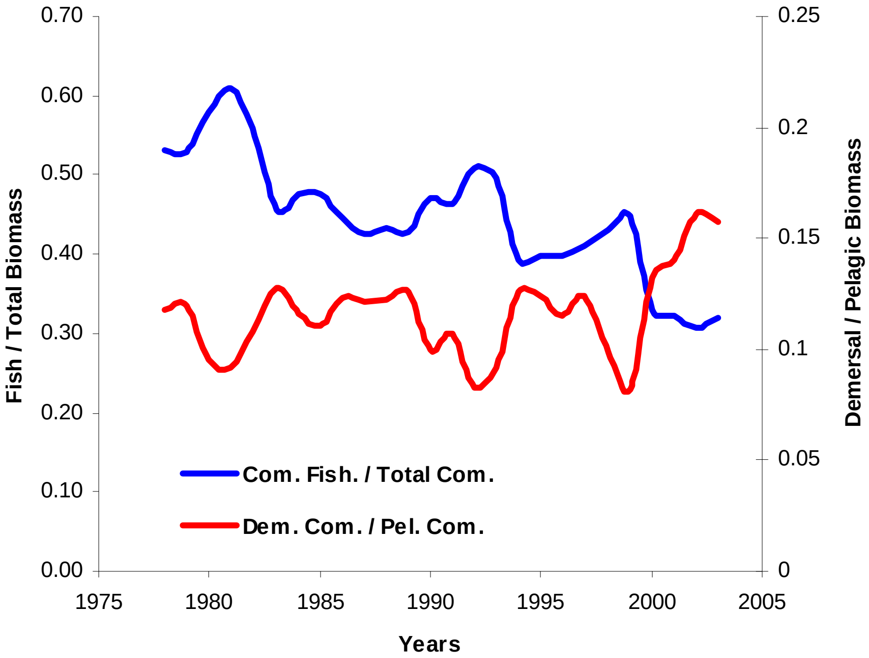
Coll et al. 2006. JMS, 2008. Ecological Modelling

Indicators from Ecosim

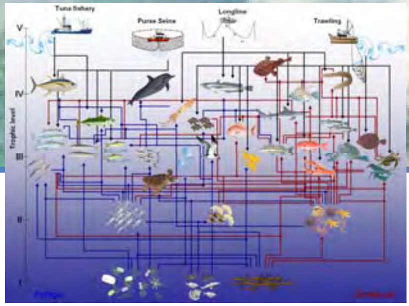


- Commercial Invertebrates / Commercial fish Biomass & Catch
- Commercial Invertebrates / Total Commercial Biomass & Catch
- Commercial Fish / Total Commercial Biomass & Catch
- Demersal Commercial / Pelagic Commercial Biomass & Catch





Indicators from Ecosim



IndiSeas2

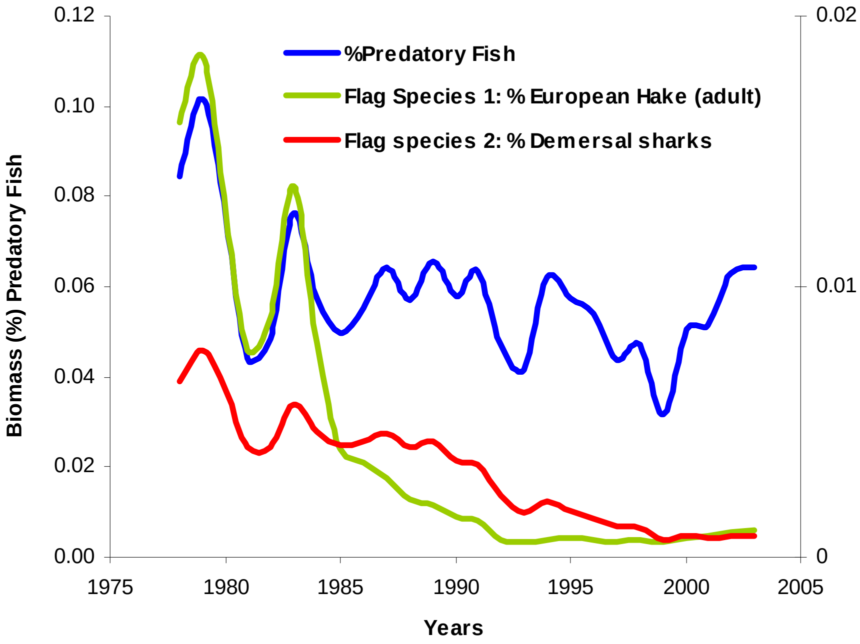
% Predatory fish in the community (State & Trend)

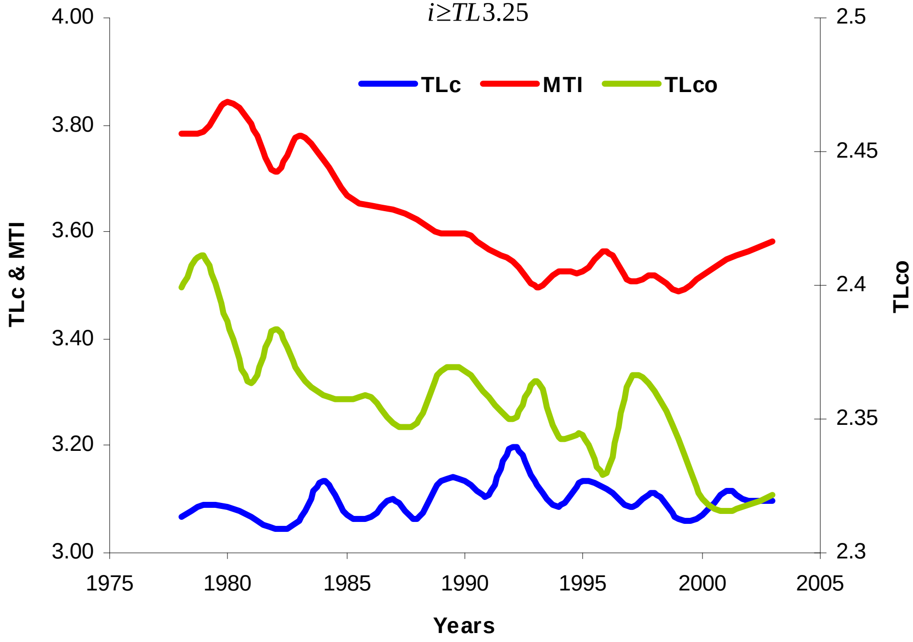
Relative abundance (or biomass) of flagship species (Trend)

Marine Trophic Index (of landings; Trend)

TL of surveyed community to complement MTI and TLc (Trend)

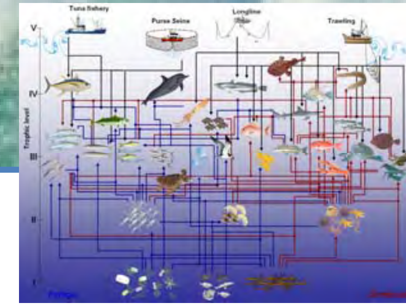
$$MTI = \sum_{i \geq TL3.25} \left(TL_i \cdot Y_i / Y \right)$$

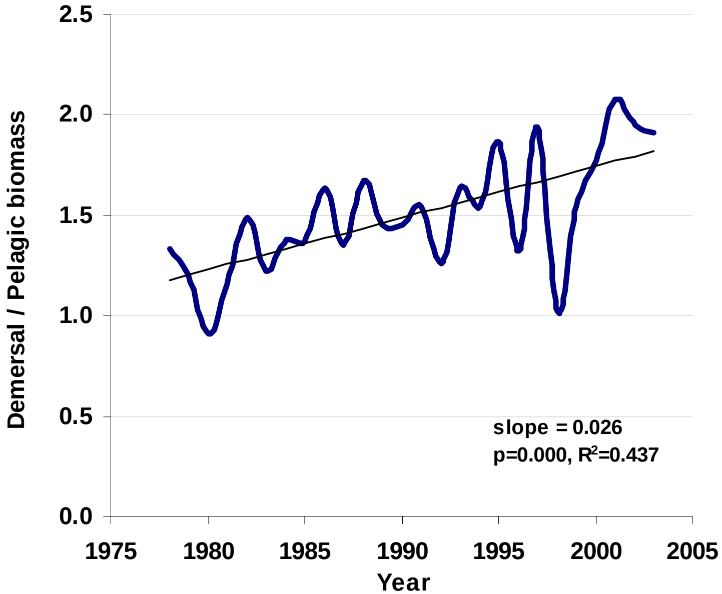


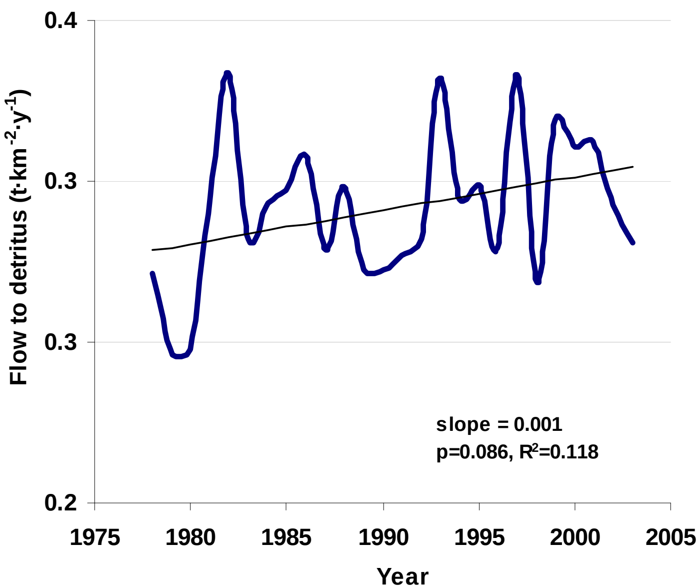


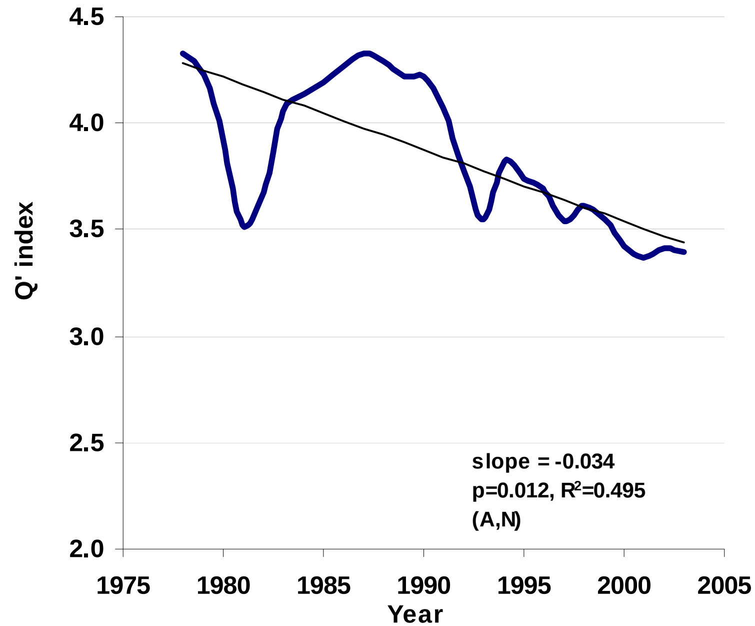
Coll et al. 2008. Ecological Modelling

Indicators from Ecosim







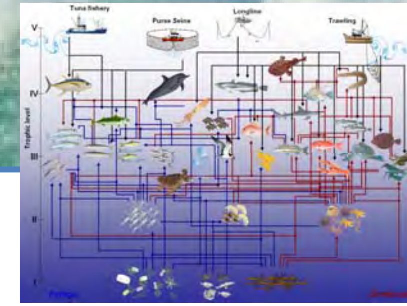


$$Q' = \frac{0.8 \cdot S}{\log\left(R_2 / R_1 \right)}$$

(Kempton & Taylor 1976, Ainsworth & Pitcher 2006)

Coll et al. 2008. Ecological Modelling

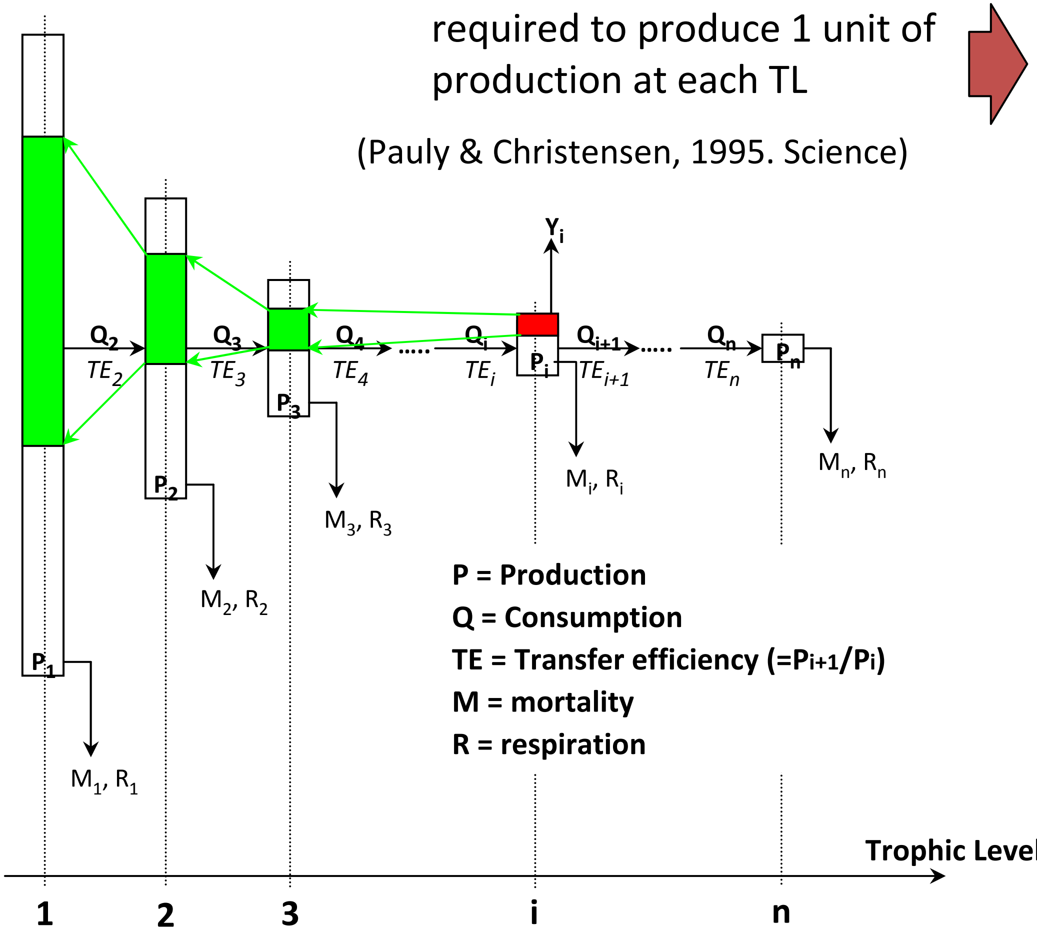
Indicators from Ecosim

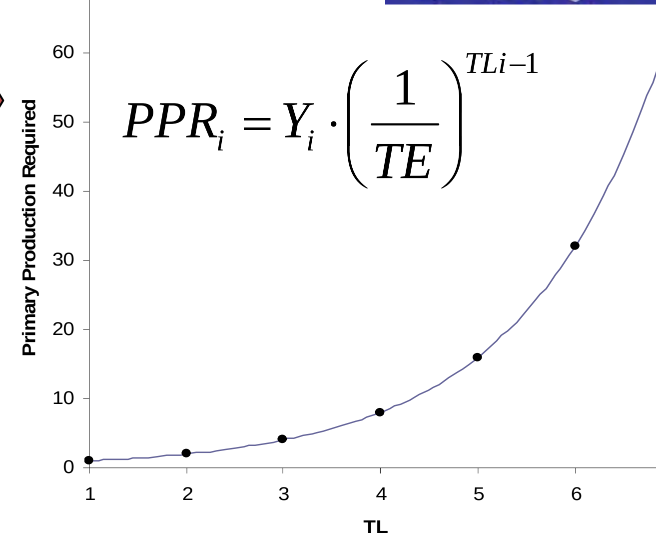


Primary Production Required

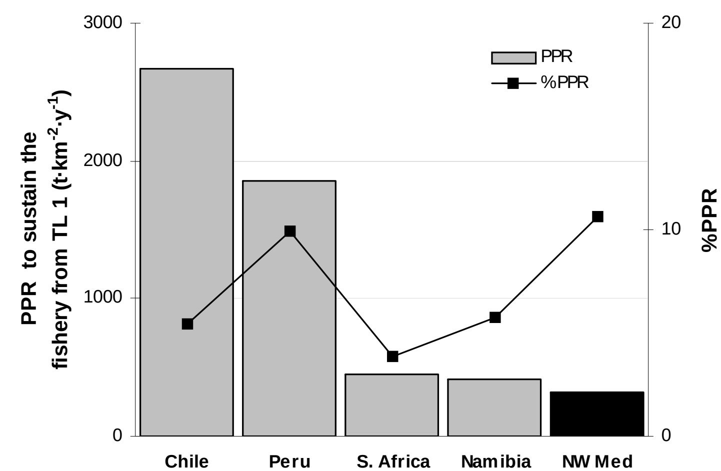
Amount of primary production required to produce 1 unit of production at each TL

(Pauly & Christensen, 1995. Science)



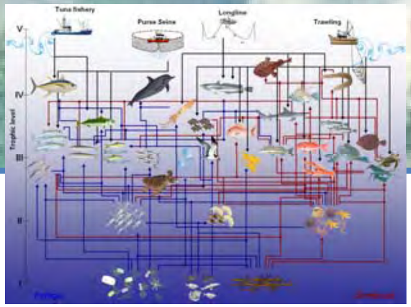


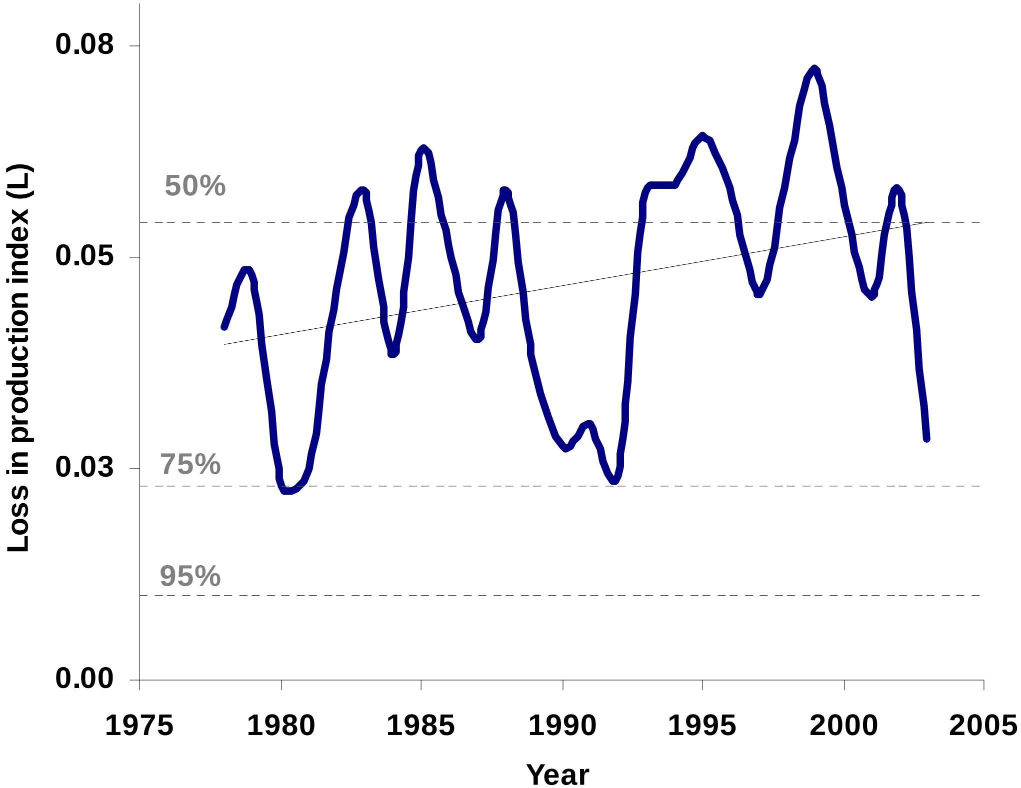
$$PPR_i = Y_i \cdot \left(\frac{1}{TE}\right)^{TLi-1}$$



Coll et al. 2006. Ecological Modelling

Indicators from Ecosim





Loss in production index

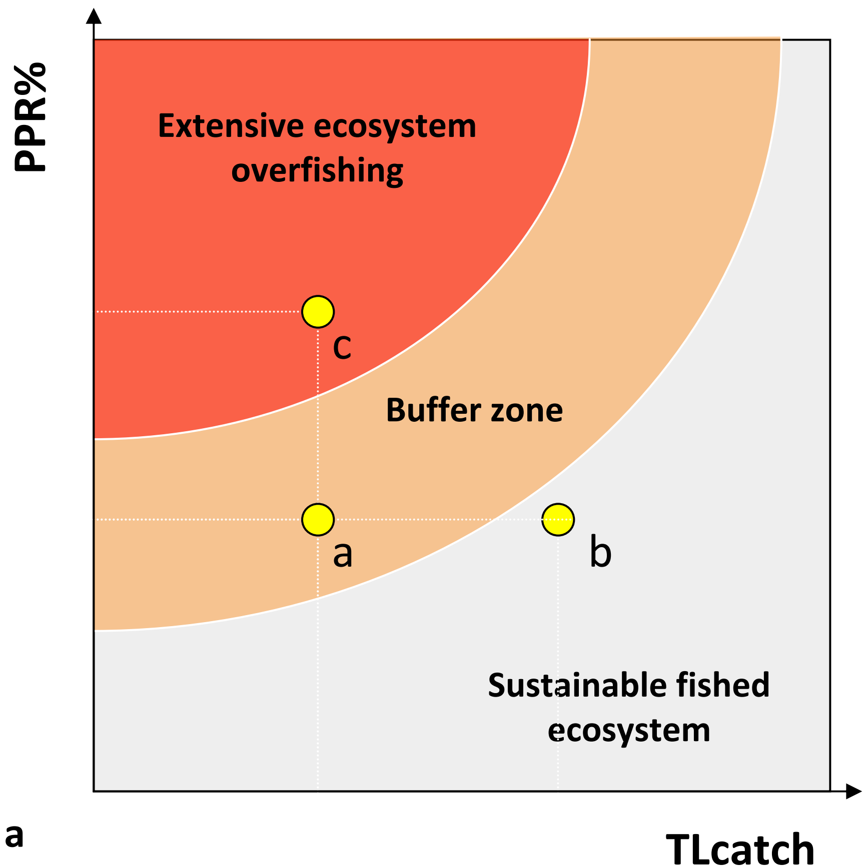
$$L = -\frac{1}{PP \cdot \ln TE} \cdot \sum_{i}^{m} \left(PPR_i \cdot TE^{TLi-1} \right) \cong -\frac{PPR \cdot TE^{TLc-1}}{PP \cdot \ln TE}$$

Libralato et al. 2008. MEPS, Coll et al. 2008. PLoS ONE

New Index of Ecosystem Overfishing

Idea for a new index based on:

- Simple ecological theory
- Data and input information easy to get
- Broadly applicable
- With possibility to identify REFERENCE VALUES



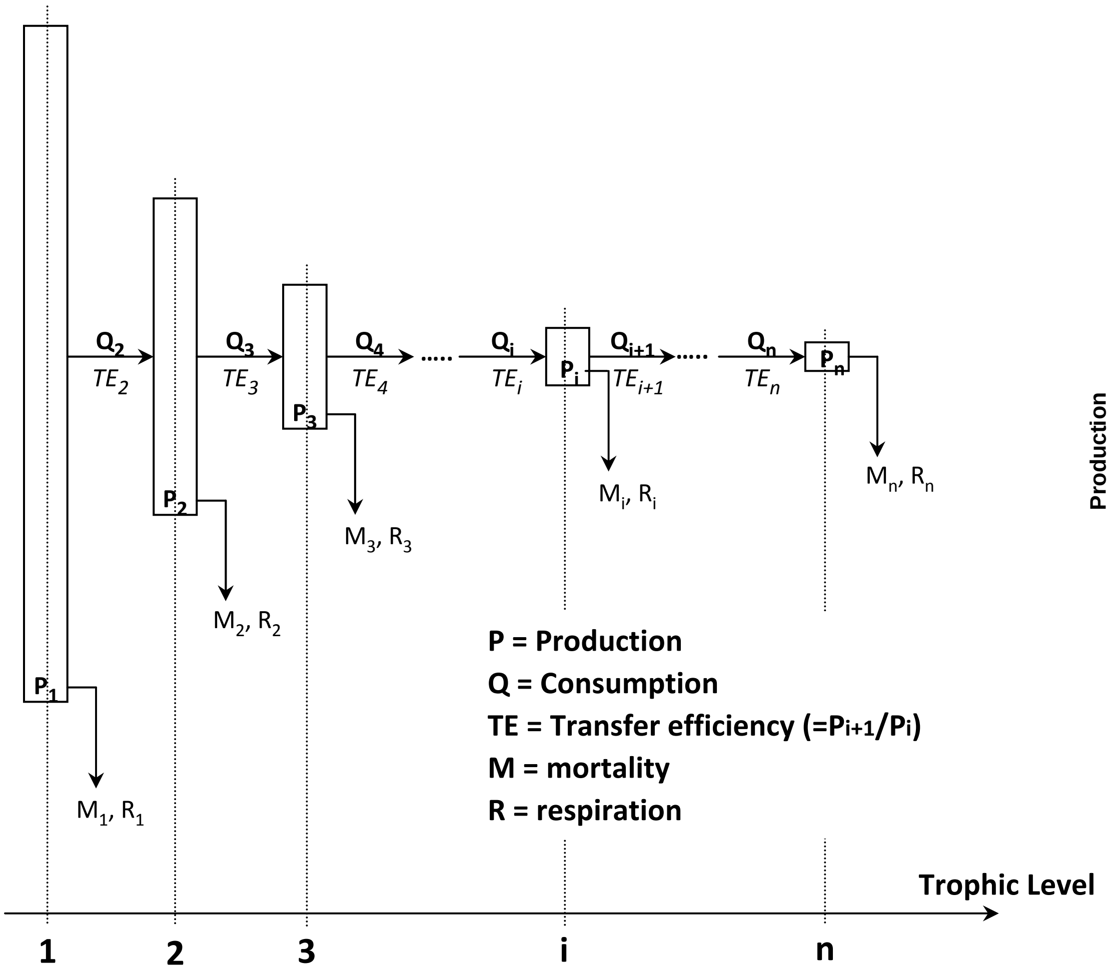
Basics of the new idea

b is intrinsically less disrupting than **a**

c is more disrupting than **a**

Tudela, Coll, Palomera 2005. ICES JMS

The Energy Flow…

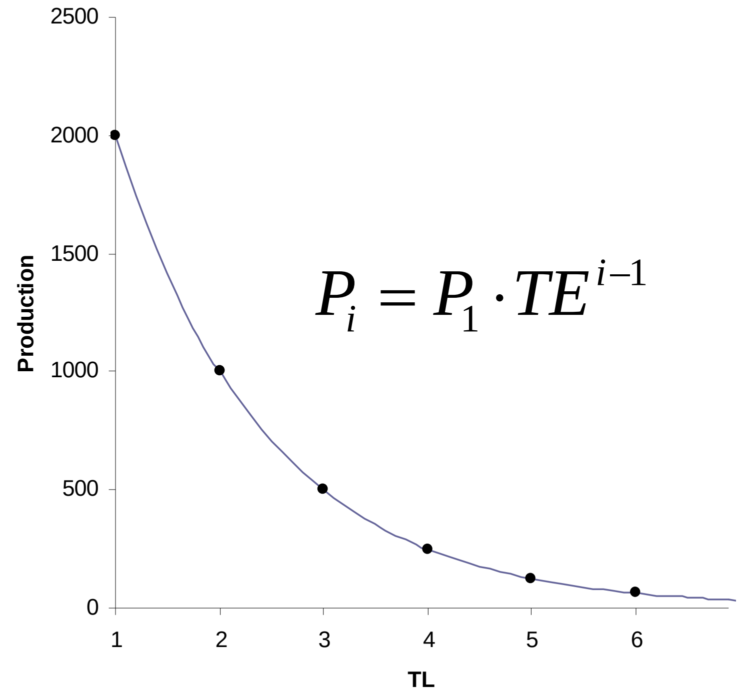


$$P_2 = P_1 \cdot TE_2$$

$$P_3 = P_2 \cdot TE_3 = \left(P_1 \cdot TE_2\right) \cdot TE_3$$

….

$$P_i = P_1 \cdot TE_2 \cdot TE_3 \cdot \ldots . \cdot TE_i$$

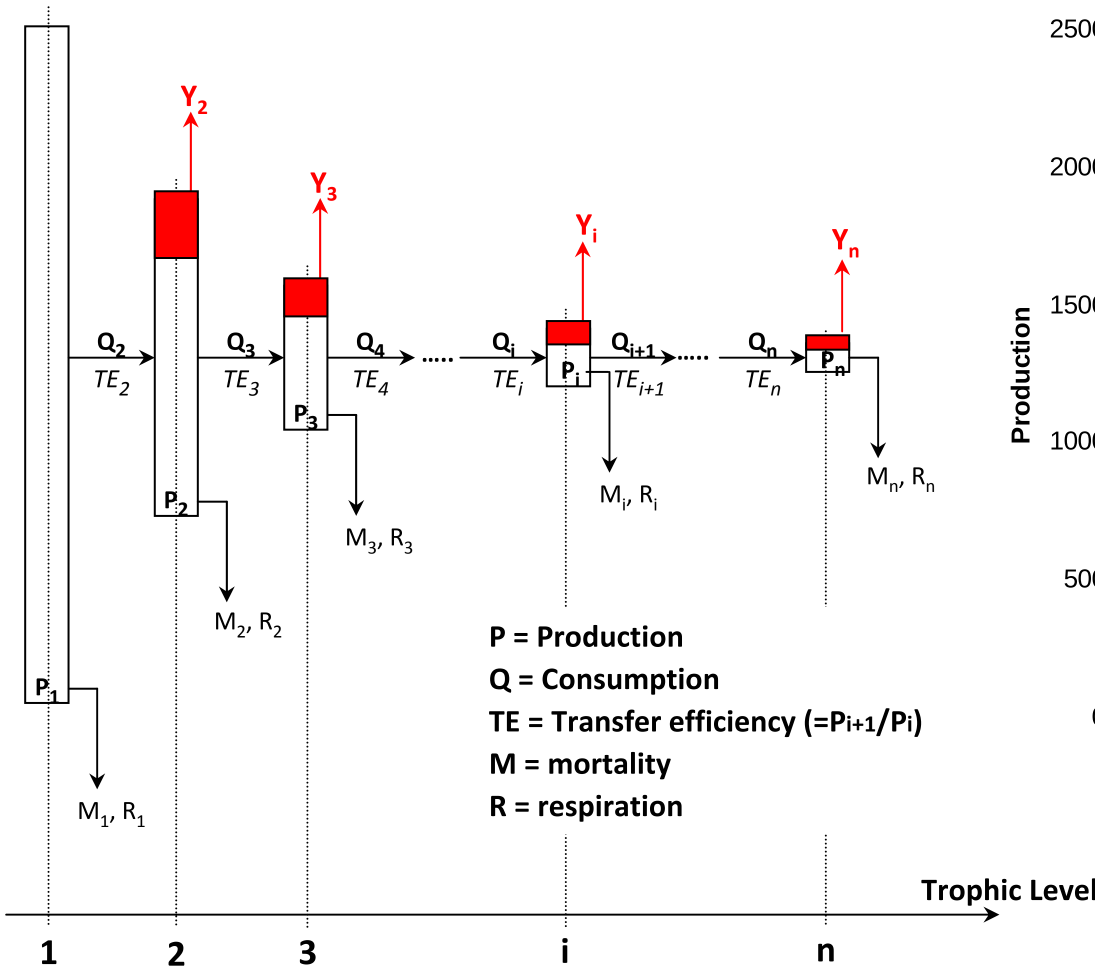


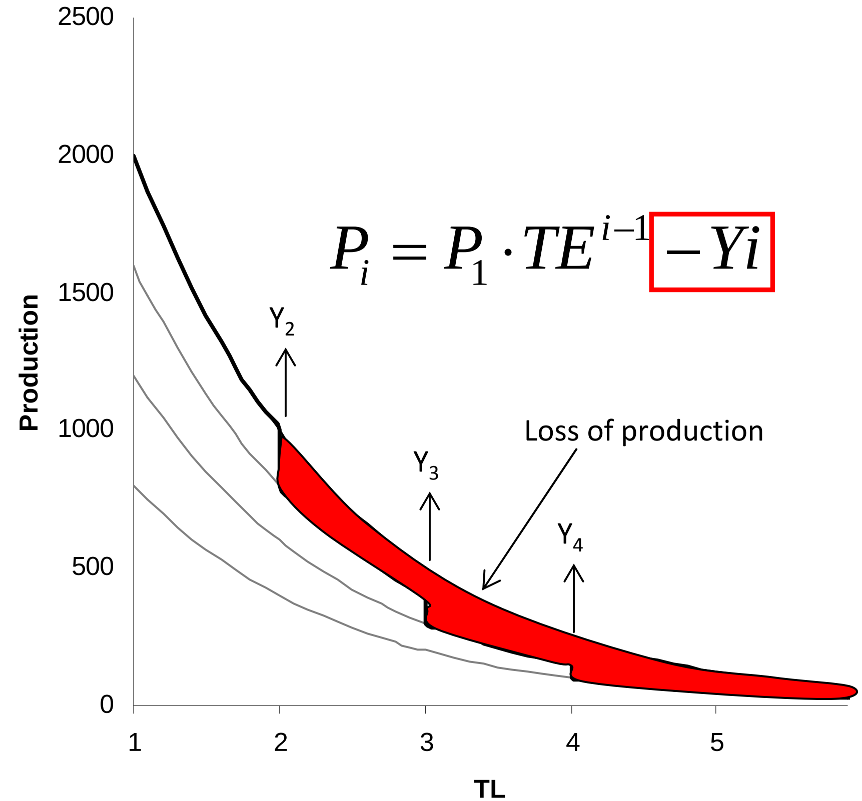
$$P_i = P_1 \cdot TE^{\,i-1}$$

If all the TE_i can be assumed equal to a general characteristic of the ecosystem TE

Libralato et al. 2008. MEPS

The Exploited Energy Flow





The loss in production is used as a proxy for quantifying the disruption of the ecosystem due to fishing exploitation

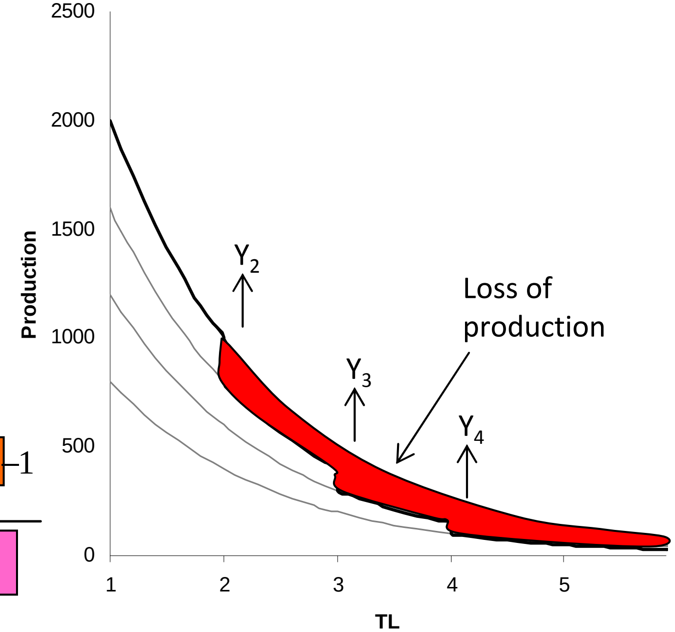
Libralato et al. 2008. MEPS

New Index of Ecosystem Overfishing

$$L = -\frac{PPR_i}{PP} \cdot \frac{TE^{TLi-1}}{\ln TE}$$

In case of multi-target fisheries (m species):

$$L = -\frac{1}{PP \cdot \ln TE} \cdot \sum_{i}^{m} \left(PPR_i \cdot TE^{TLi-1} \right) \cong -\frac{PPR \cdot TE^{TLc-1}}{PP \cdot \ln TE}$$



PPR of the catches

TL of the catches

PP of the exploited ecosystem

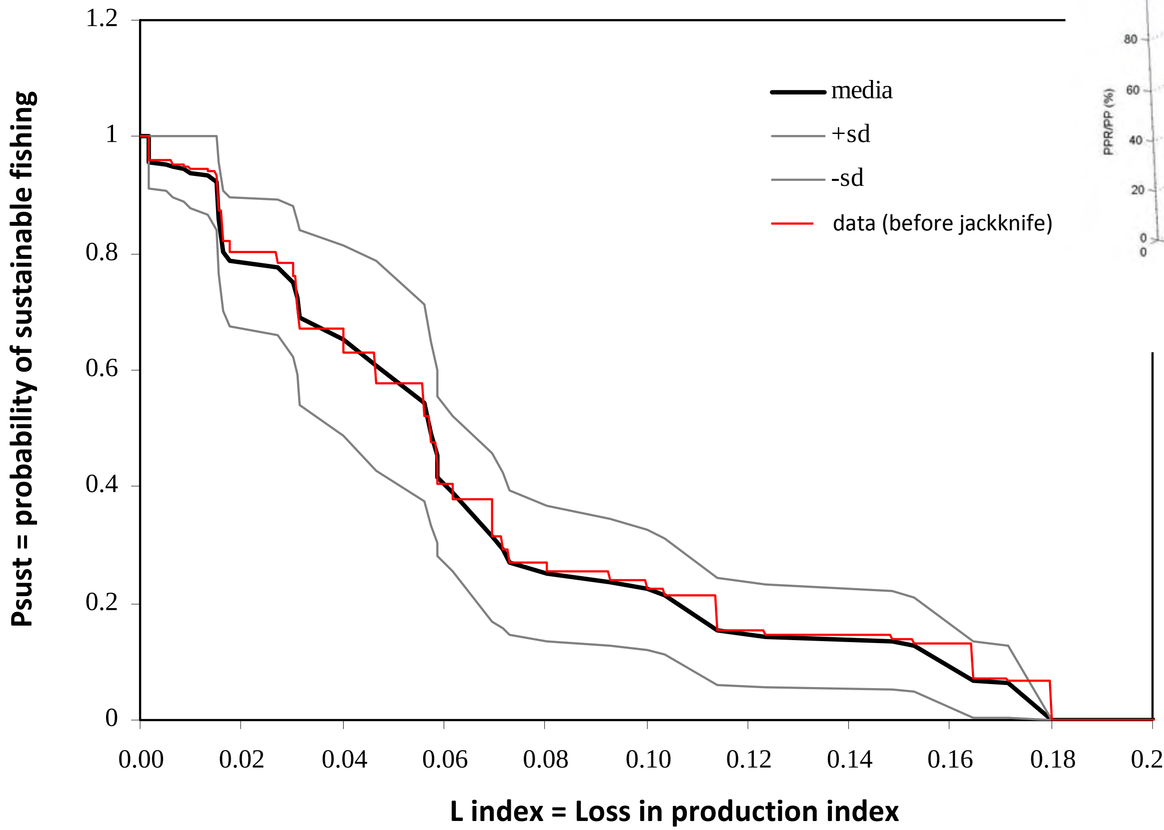
TE of ecosystem

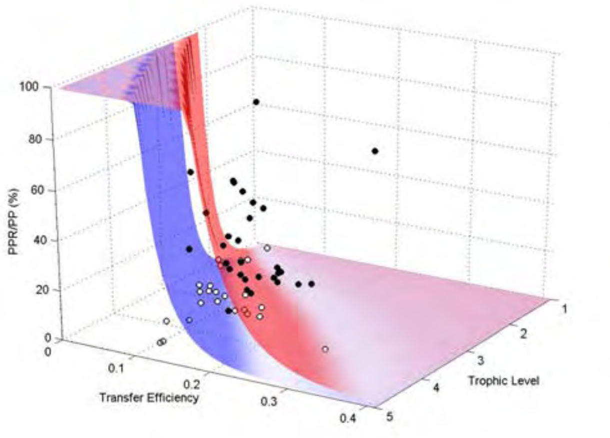
Estimates of the index for
1- Local diet studies and catch statistics
2- Food web models
3- catch data and literature diet

Libralato et al. 2008. MEPS

New Index of Ecosystem Overfishing

$$p_{sust}(L) = \frac{P(L_2 > L)}{P(L_2 > L) + P(L_1 < L)}$$



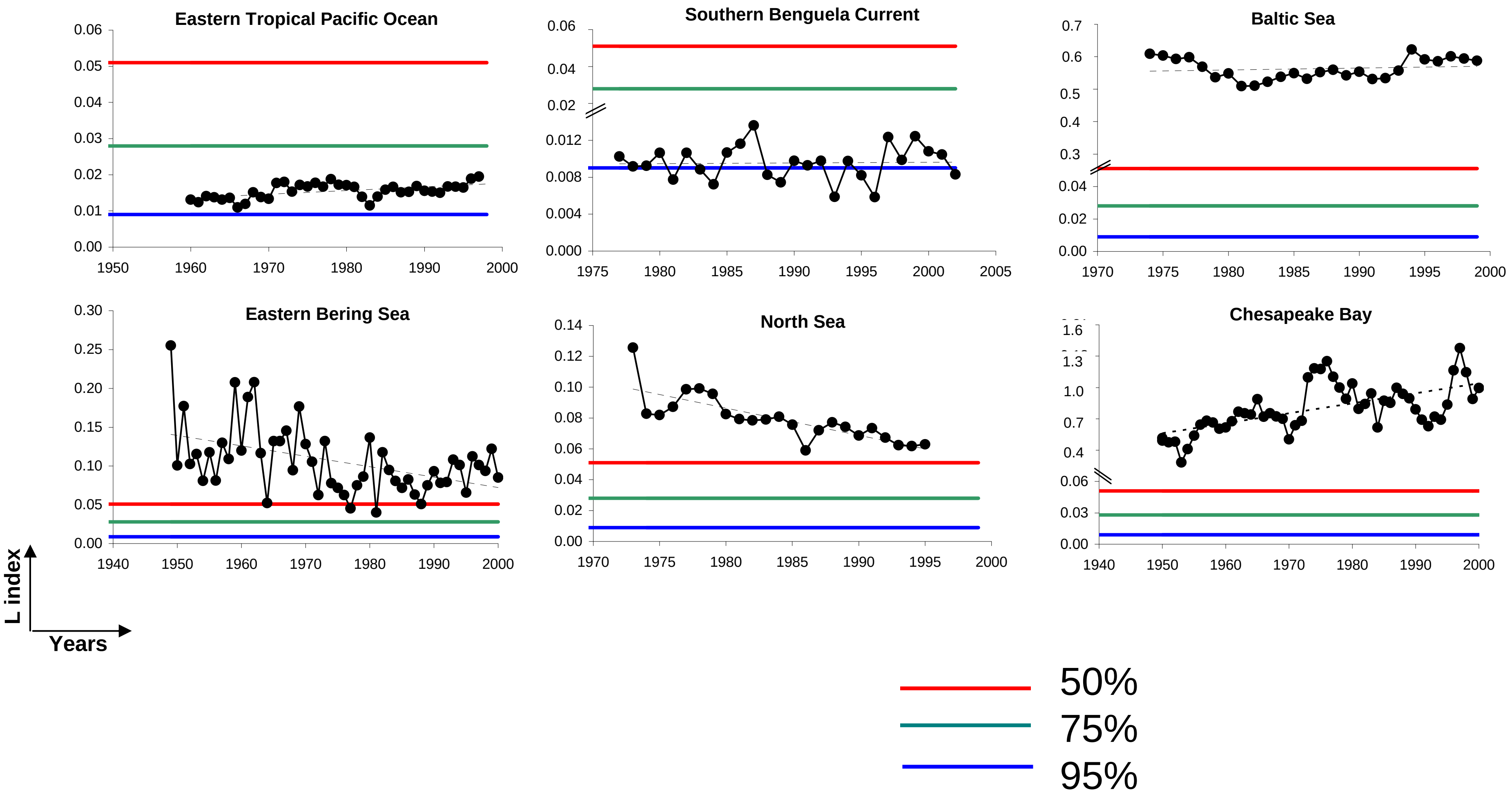


Bootstrap and jackknife analysis: to define confidence intervals

Libralato et al. 2008. MEPS

New Index of Ecosystem Overfishing

Temporal dynamic models fitted to time series of data (FC, UBC)



Libralato et al. 2008. MEPS

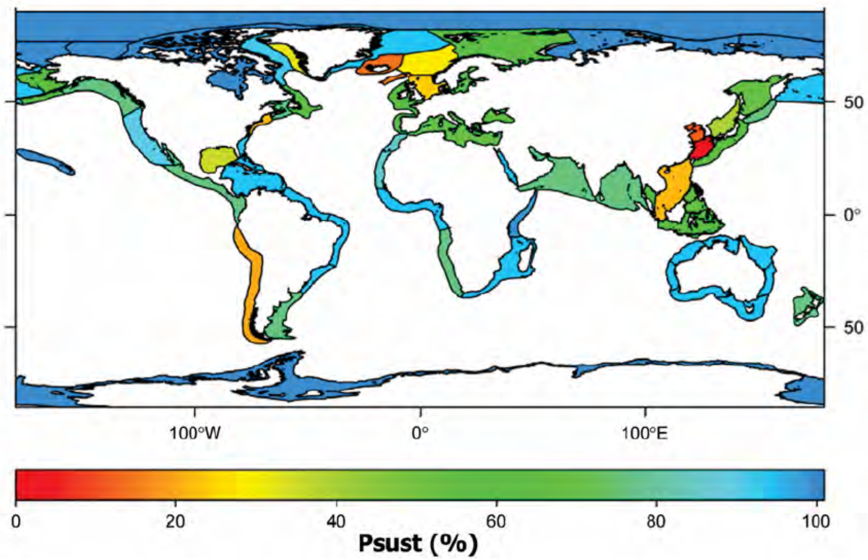
Global Evaluation of Overfishing

OPEN ACCESS Freely available online — PLoS one

Ecosystem Overfishing in the Ocean

Marta Coll[1,2]*, Simone Libralato[3], Sergi Tudela[4], Isabel Palomera[1], Fabio Pranovi[5]

1 Institut de Ciències del Mar, ICM-CSIC, Passeig Marítim de la Barceloneta, Barcelona, Spain, 2 Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada, 3 Istituto Nazionale di Oceanografia e di Geofisica Sperimentale–OGS, Sgonico-Zgonik, Italy, 4 World Wide Fund for Nature, WWF, Mediterranean Programme Office, Barcelona, Spain, 5 Dipartimento di Scienze Ambientali, Università Ca' Foscari, Venezia, Italy

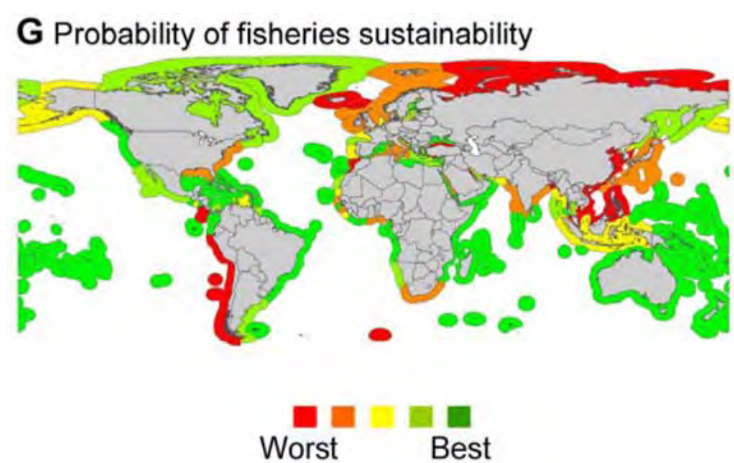


OPEN ACCESS Freely available online — PLoS BIOLOGY

Management Effectiveness of the World's Marine Fisheries

Camilo Mora[1,2]*, Ransom A. Myers[2†], Marta Coll[2,3], Simone Libralato[4], Tony J. Pitcher[5], Rashid U. Sumaila[6], Dirk Zeller[6], Reg Watson[6], Kevin J. Gaston[7], Boris Worm[2]

1 Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, United States of America, 2 Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada, 3 Institut de Ciències del Mar, ICM-CSIC, Passeig Marítim de la Barceloneta, Barcelona, Spain, 4 Istituto Nazionale di Oceanografia e di Geofisica Sperimentale–OGS, Sgonico-Zgonik, Italy, 5 Peter Wall Institute for Advanced Studies, University of British Columbia, Vancouver, British Columbia, Canada, 6 Sea



Some remarks…

- A **set of indicators is helpful** in establishing a diagnosis of exploited ecosystems
- A **comparative approach** enables greater understanding of the driving mechanisms
- **Simple data-base available indicators** provide good perspective of ecosystem status
- Can be **complemented** with more specific indicators (modelling-based or rich-data assessments)
- Need to take into account **multiple drivers of marine ecosystems** (fishing, environment)
- Need to look at **different components** (populations, communities, ecosystems, commercial, non-commercial)
- Involvement of **local experts** to interpret results
- Investigate indicators' **responsiveness** to management, **thresholds** and **reference points**

THANKS!

Acknowledgements to:

IndiSeas leading group Yunne-Jai Shin, Lynne Shannon, Philippe Cury & Alida Bundy

IndiSeas participants

Villy Christensen & Jeroen Steenbeek

Sergi Tudela, Isabel Palomera and Fabio Pranovi