PhD in Innovative Technologies and Sustainable Use of Mediterranean Sea Fishery and Biological Resources (FishMed-PhD)

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Indicators for sustainable fisheries: <u>a biological resources perspective</u>

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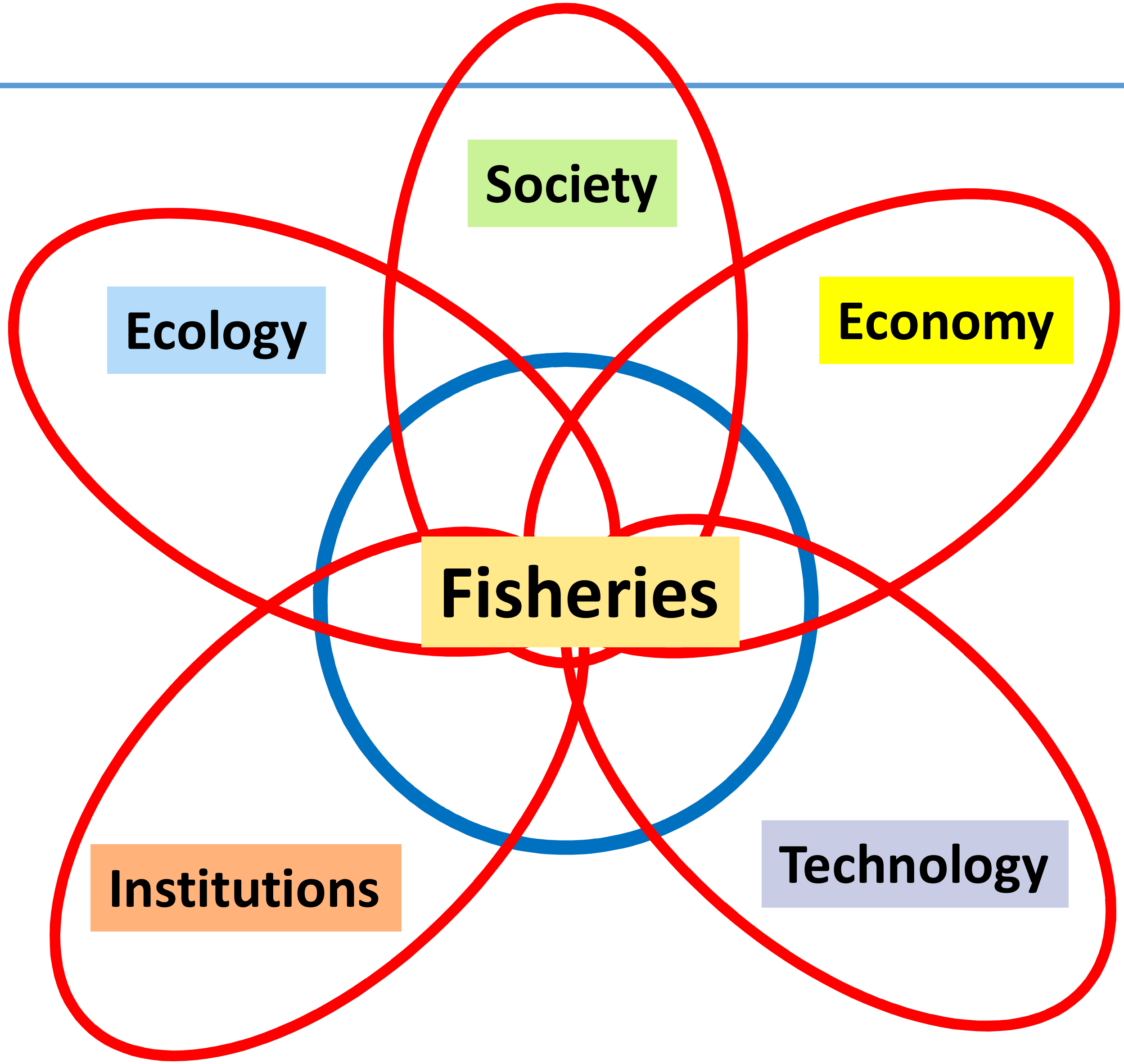
The five dimensions of fisheries



Main goals of the lecture

- Give information on **main kind of indicators**, both empirical and analytic, **their data sources** and their use **to assess the status of fishery resources;**

- Supply guidelines for the use of **threshold and trend of indicators** in the precautionary approach in fishery management

- Provide **pros and cons of different approaches** searching for biases, precision, robustness, sensitivity

- Furnish **advice on the suitability** of each approach in different cases of data availability, exploitation pattern, fleet structure, and species targets

- Present **some examples of use of indicators** to assess stock status **in the Mediterranean** with special attention to the Strait of Sicily

- Make some **final recommendations** when having to **choose indicators, models and reference points** to produce advices on fisheries resources

What is an INDICATOR?

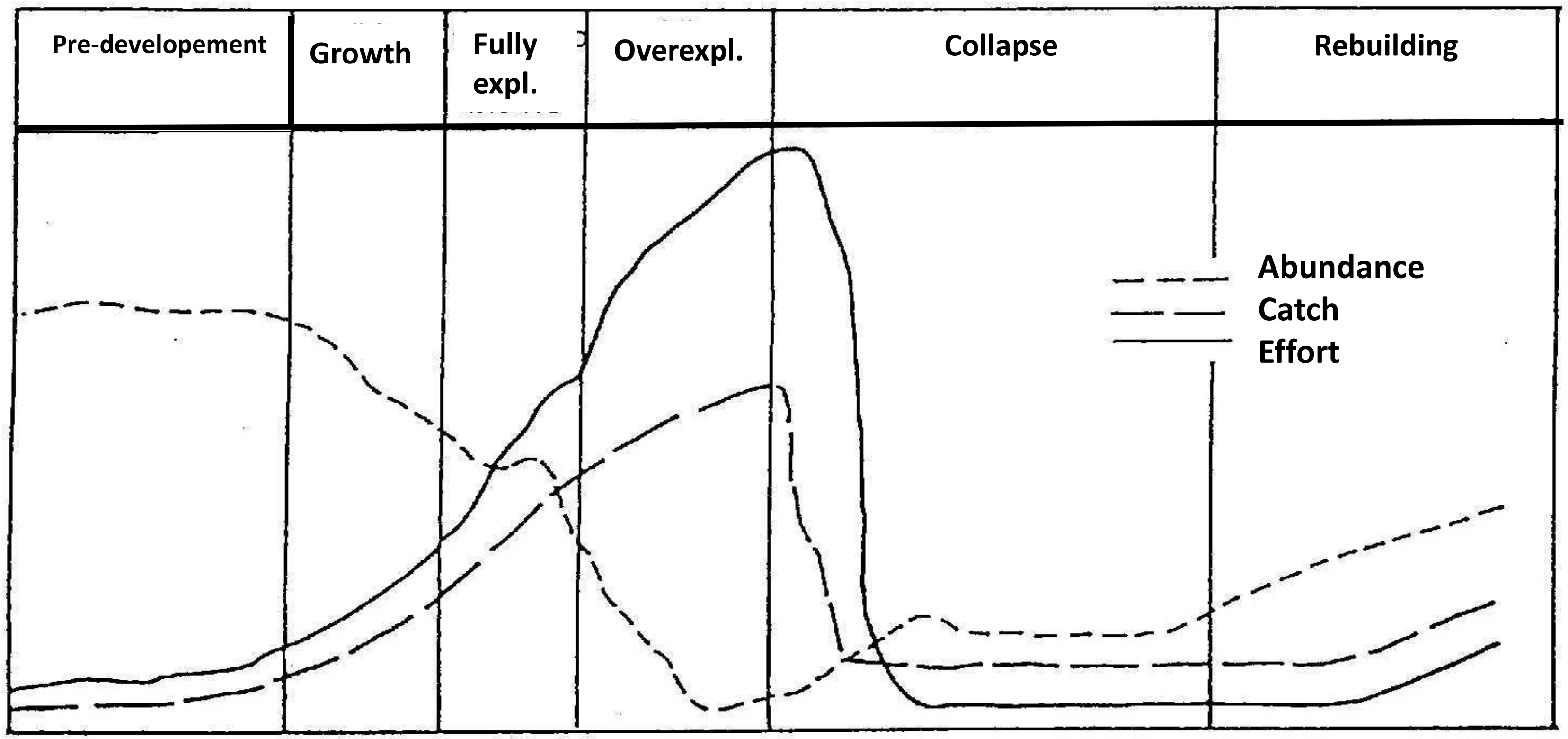
In general an **indicator** can be defined as a "**measurable characteristic**" of a system that shows what a **situation is like**.

In **fisheries** an **indicator** could be define as **a variable** for a given criterion **which fluctuations** reveals **changes** in **key attributes** linked with fishery sustainability in the ecosystem (by Garcia and Staples, 2000)

A more parsimonious definition could be "**any kind of variable or combination of variables"** allowing the **quantitative** description of the **dynamics** of exploited population and fisheries performances" (by myself)

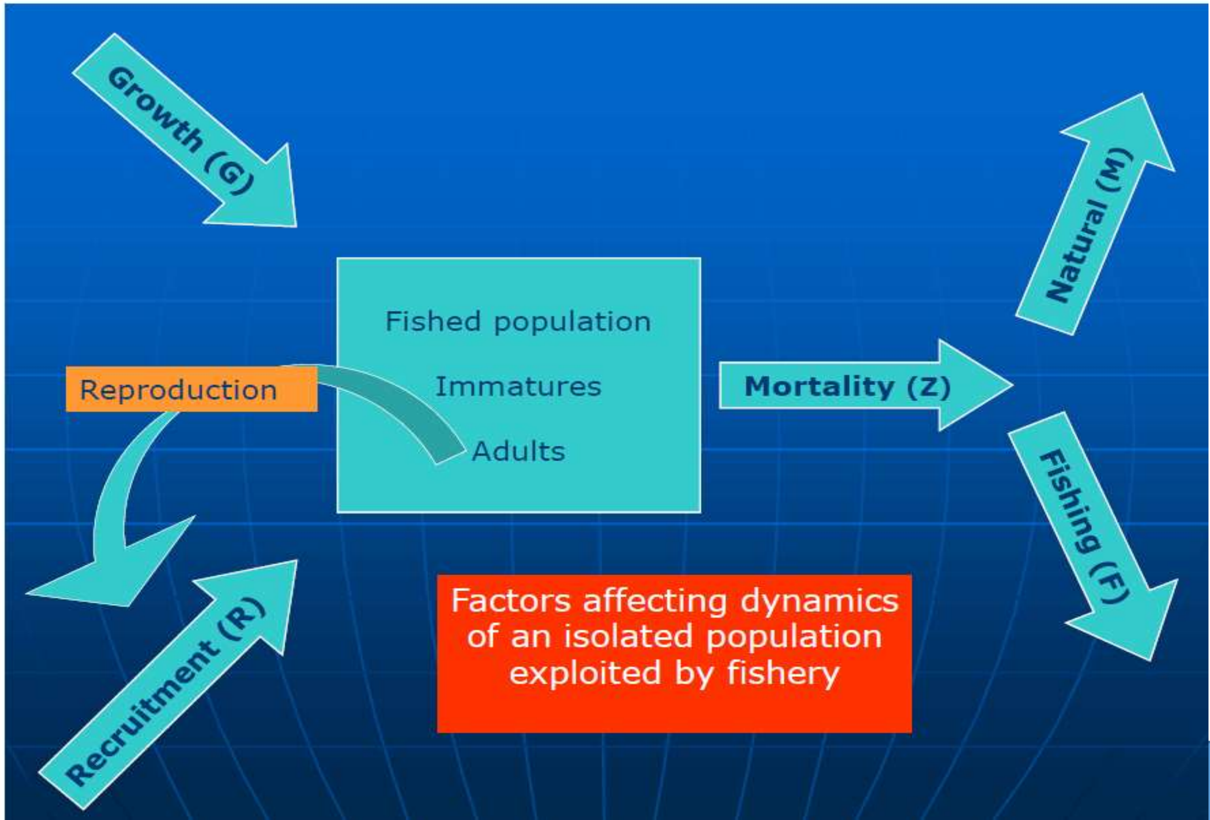
What are you getting into if you do not manage capture processes?

Schematized cycle of a **unmanaged** fishery (from Hilborn & Walters, 1992 – modified)

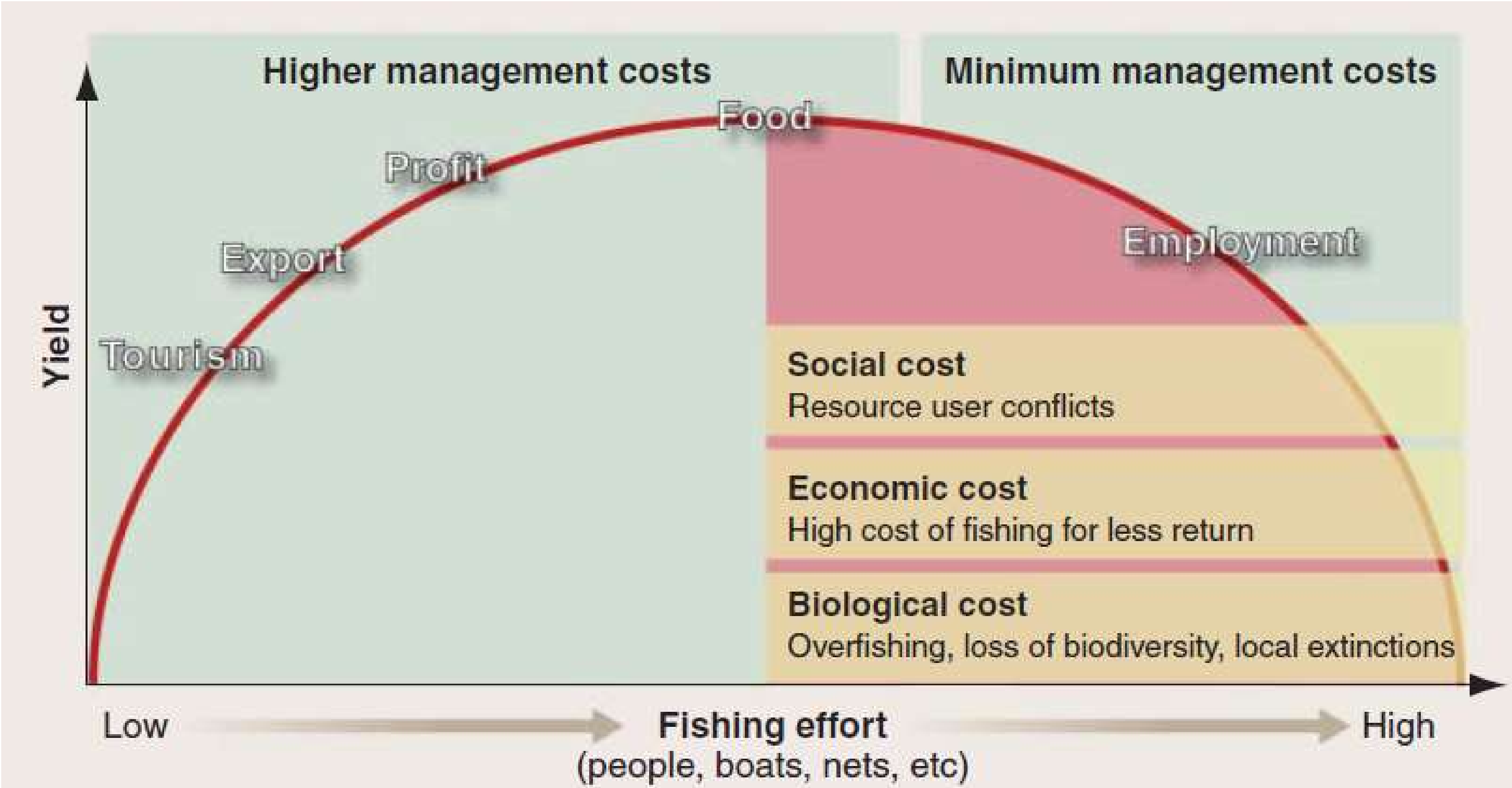


The dynamics of a fish stock

The biomass of fish stock at any time depends upon the biomass of the stock at time before plus variation due to **natural and fishing mortality**, **recruitment of juveniles**, **growth of already recruited fish**, immigration and emigration.



The "classical" sustainable yield pattern of a single species varying with effort and the fishery management dilemma

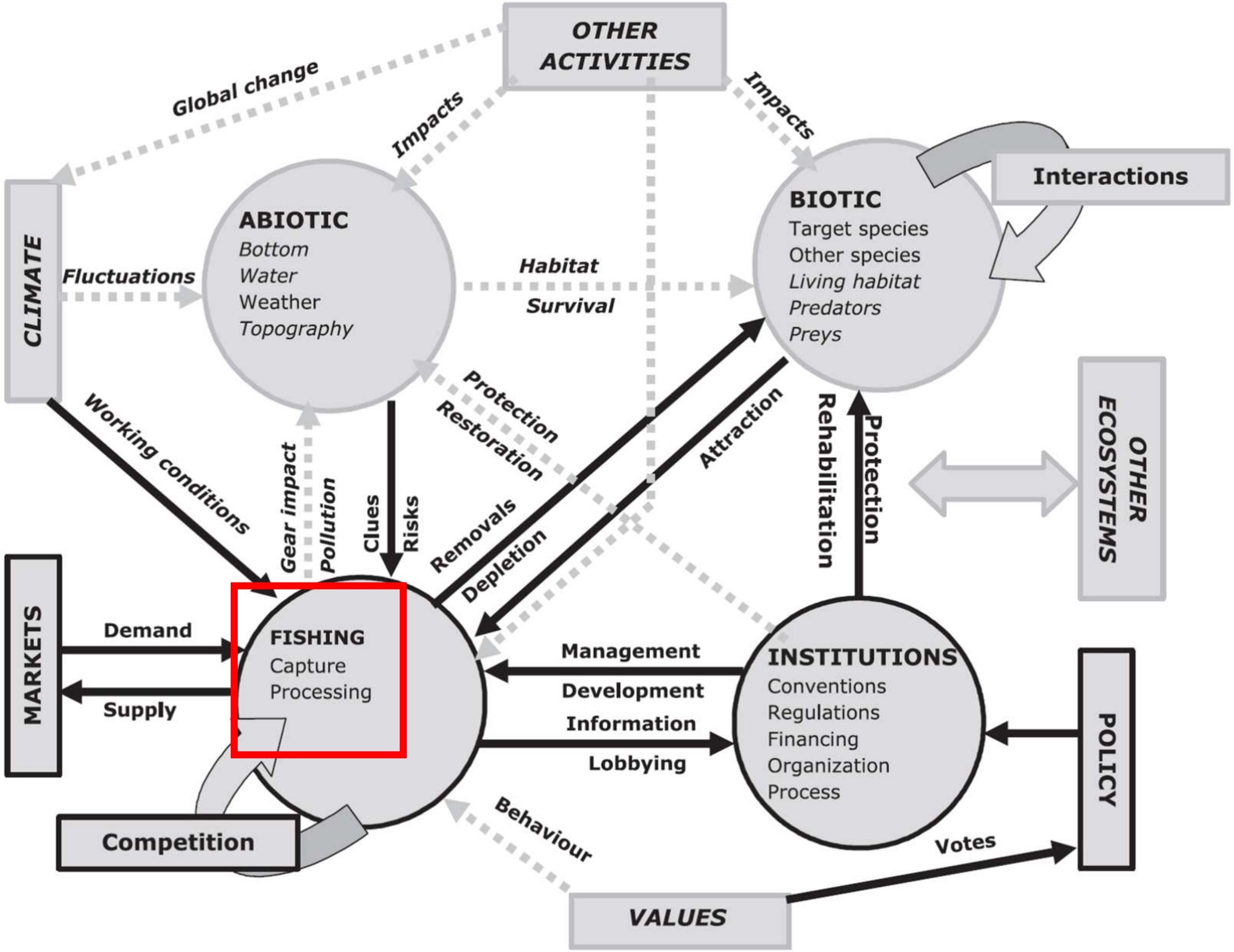


(by **Beddington et al., 2007**)

Ecosystem components and interactions addressed by EAFM

Elements in black and bold specify the conventional fishery management approach

Elements in grey and italics represent elements to add for EAFM



(by Garcia & Cochrane, 2005)

Why fishery indicators are useful and how they can be classified

Indicators are useful to:

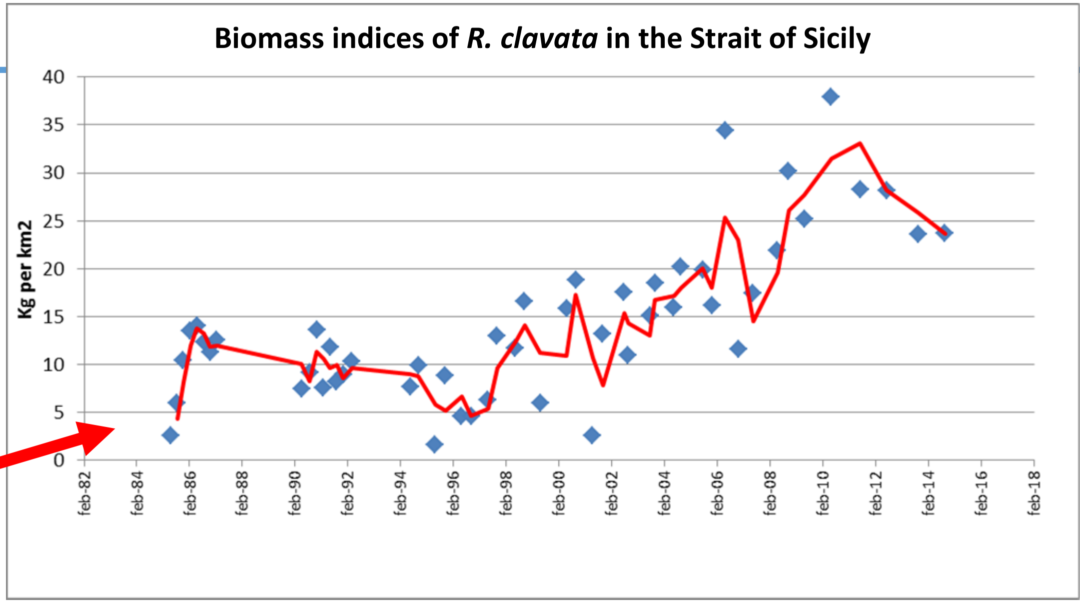
- **Describe**
  - the **State** of the ecosystem
  - the **Pressure** affecting ecosystems
  - the **Response** of managers
- **Support management** decision making
- **Track progress** towards meeting management **objectives**
- **Communicate** to a non specialist audience

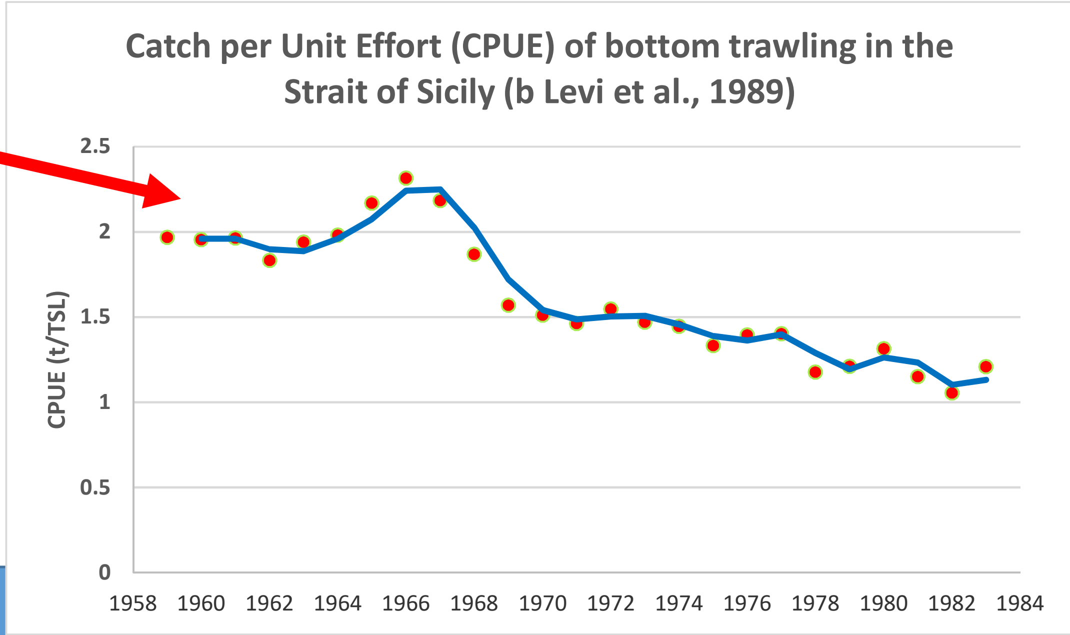
Different kind of indicators for inferring possible state of the fishery can be distinguished in:

- **Stock status indicators**: abundance, demography, spatial distribution, morphometric and genetic for stock unity identification purpose
- **Socio-economic indicators**: value of production, level of subsidies, level of employment, balance of trade, level of investment, fisher demography, processing, marketing and support-industry, community-dependence and fisher social status
- **Ecosystem indicators**: structure and functioning of ecosystem supporting fisheries, environmental factors
- **Others**……

What are the main indicators of fish stock dynamics?

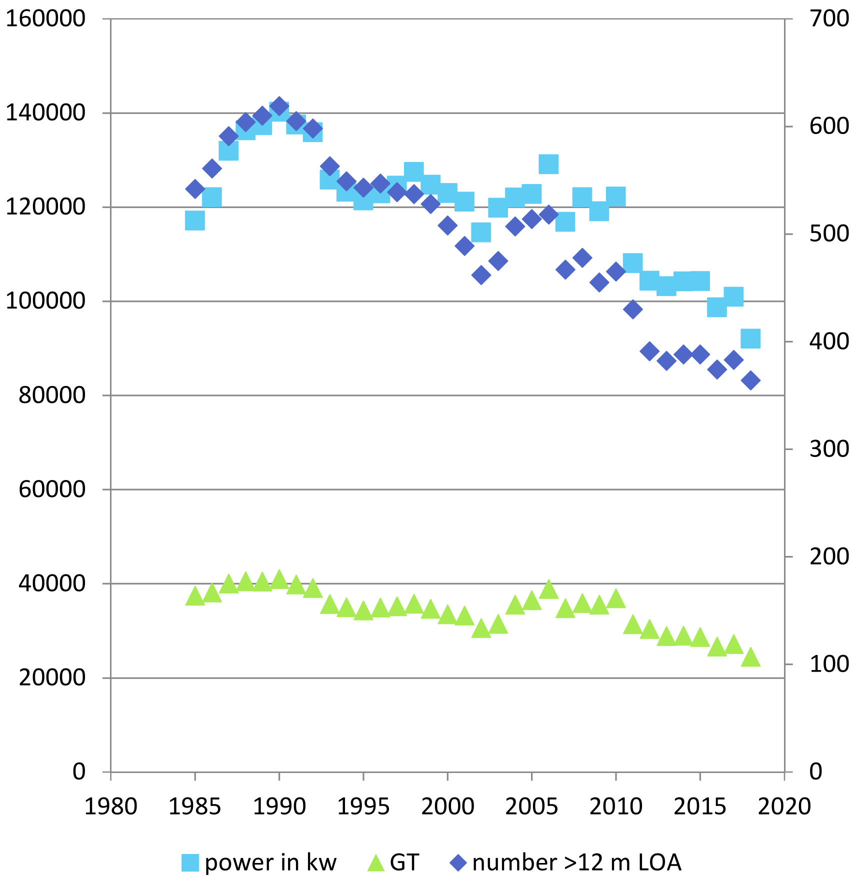
The most common **empirical or data based indicators of stock status** are **abundance indices** obtained by scientific surveys or **catch per unit effort** obtained by monitoring commercial catches



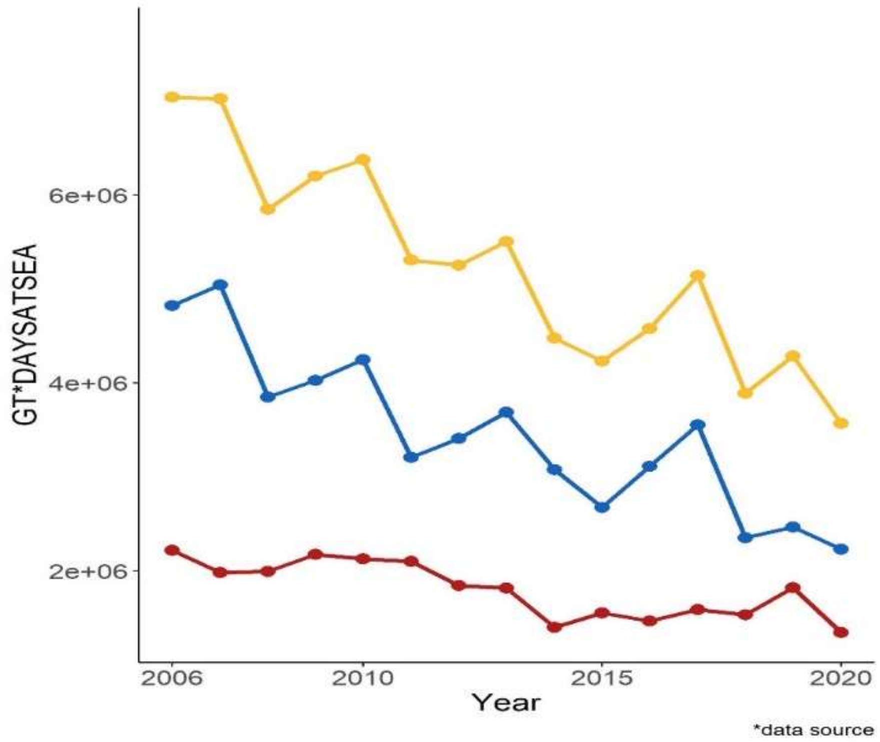


The most common empirical indicators of fishing pressure on exploited stocks are fishing capacity or fishing effort

The fishing capacity of trawler fleet in the Strait of Sicily as the size and power

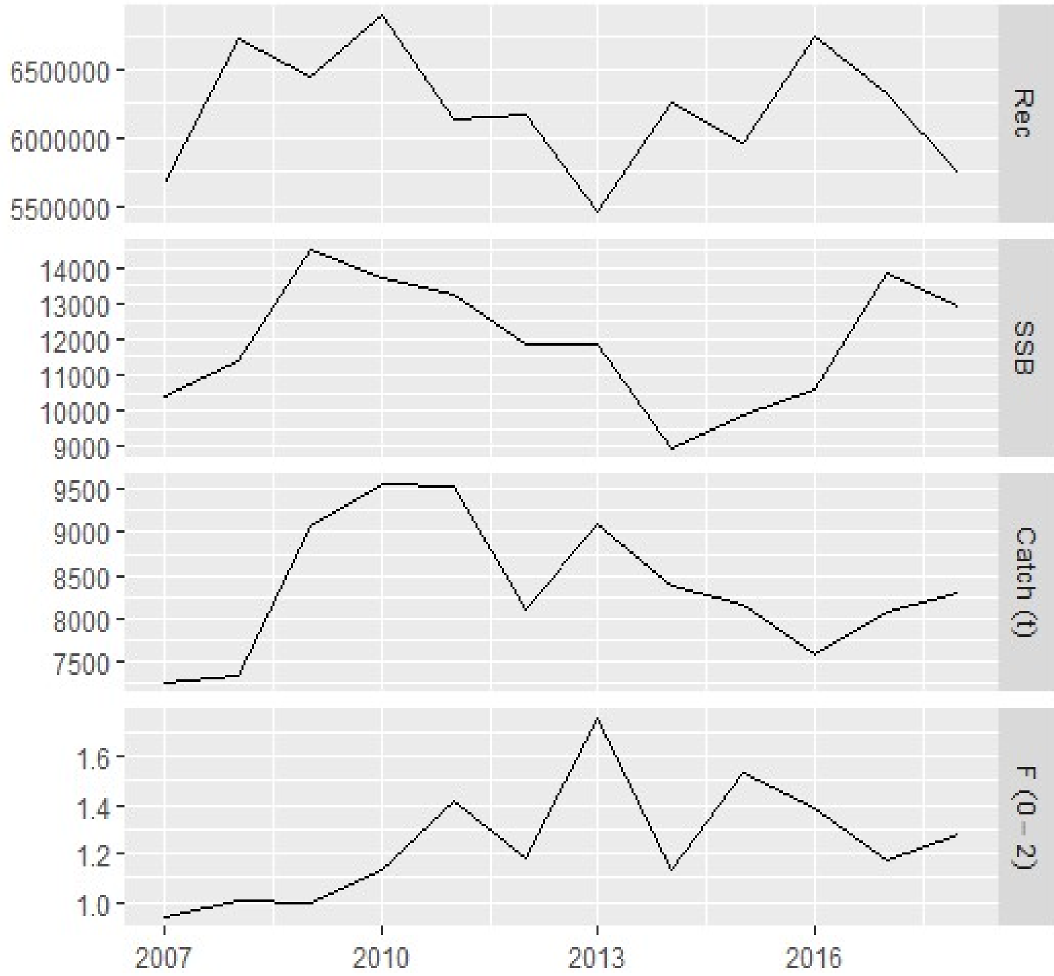


The fishing effort of trawler fleet in the Strait of Sicily as the product of capacity time activity



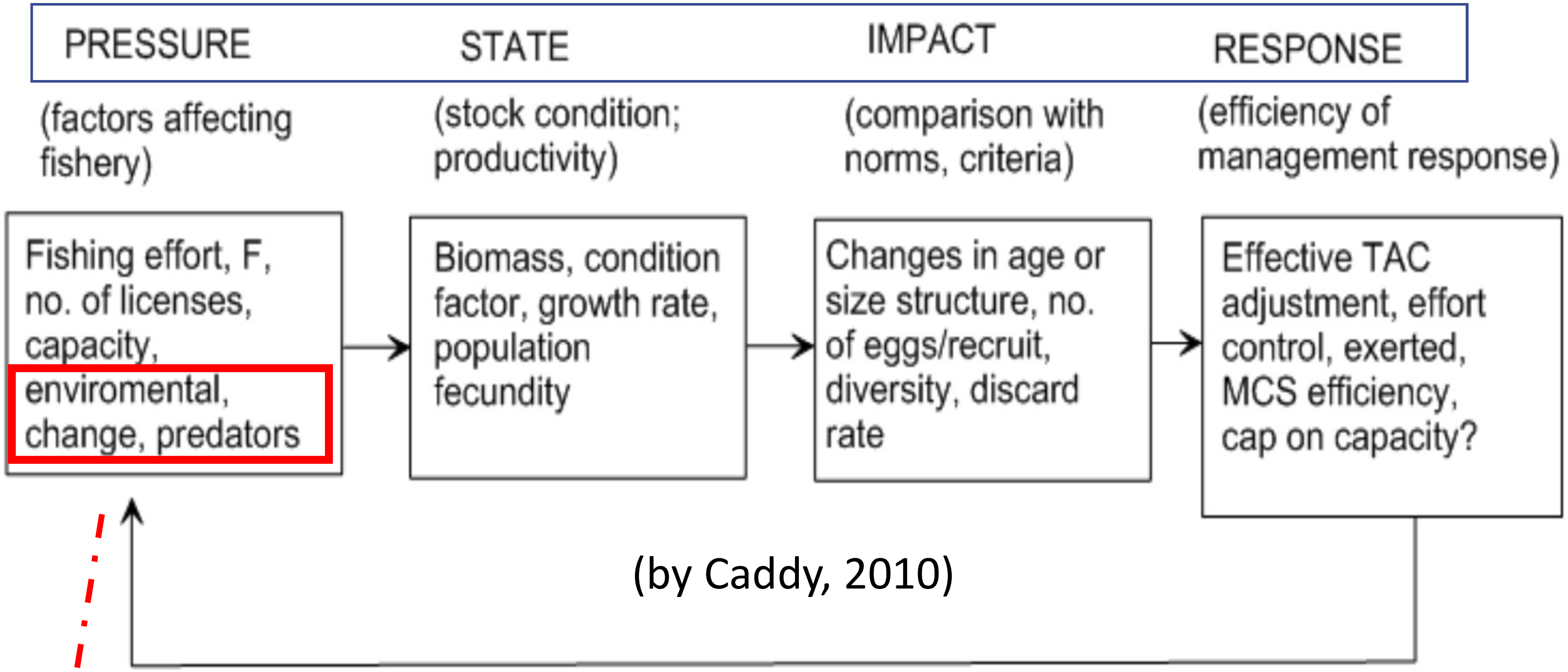
What are the main analytical indicators of fish stock dynamics?

The most common **analytical or model based indicators** are **stock biomass, fishing mortality, spawning stock biomass, recruitment** strength obtained by model of population dynamics



Results of XSA model for deep water rose shrimp in GSAs 12-16

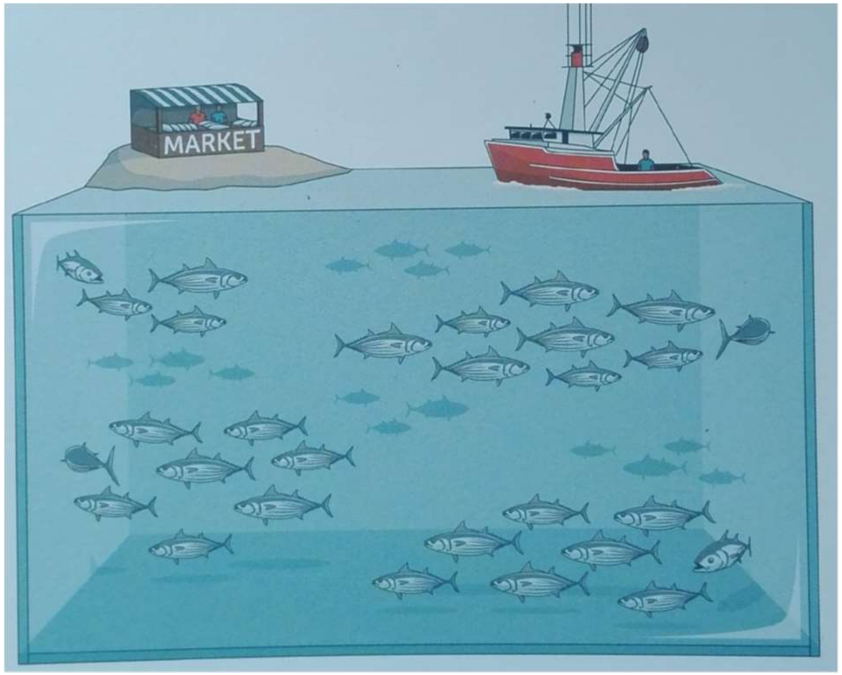
Indicators are used in fisheries management according to a Pressure, State, Impact and Response (PSIR) approach



(by Caddy, 2010)

Drive, Pressure, State, Impact and Response (DPSIR) approach

Why stock assessment?



- **Where is it?**
- **Where is going to?**
- **What if…?**

The assessment of the exploitation status of a stock is necessary for ensuring sustainable yield over time.

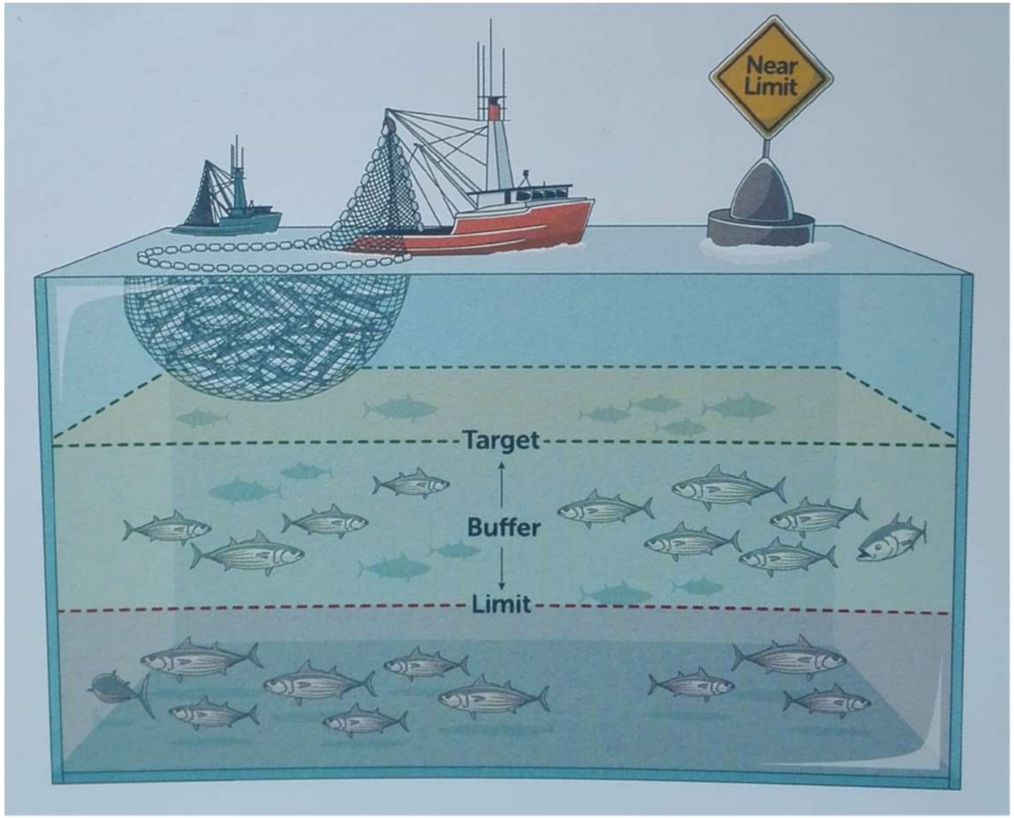
Sustainable yield can be obtained thru regulating the fish removals by set up:

- **catch quota**,
- **effort quota**,
- **technical measure** (minimum landing size, spatial and temporal fishing ban, allowed fishing gears and so on)

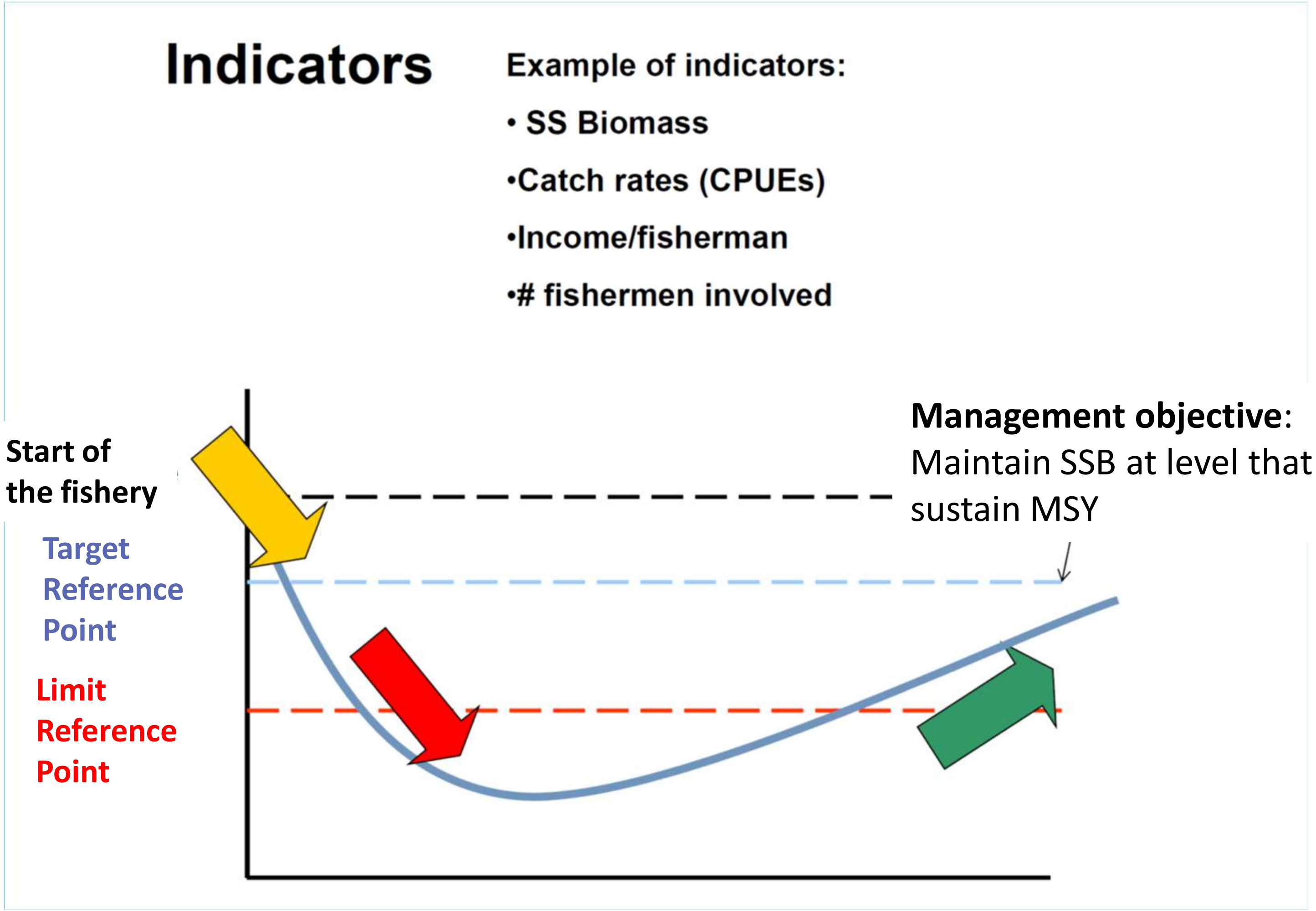
How can we use indicators in stock assessment?

Understanding the status of a fished stock needs:

- **Estimation** of the **trend of the indicator's value** (punctual estimate and uncertainty);
- **Comparison** of the value obtained with the **thresholds** associated with conditions to safeguard the renewability of the population, in terms of **target reference points** and **limit reference points**. These reference points may be **analytical or**, more seldom, **empirical** in nature



Schematized behaviour of an indicator of fishery sustainability



(by Bianchi, 2014)

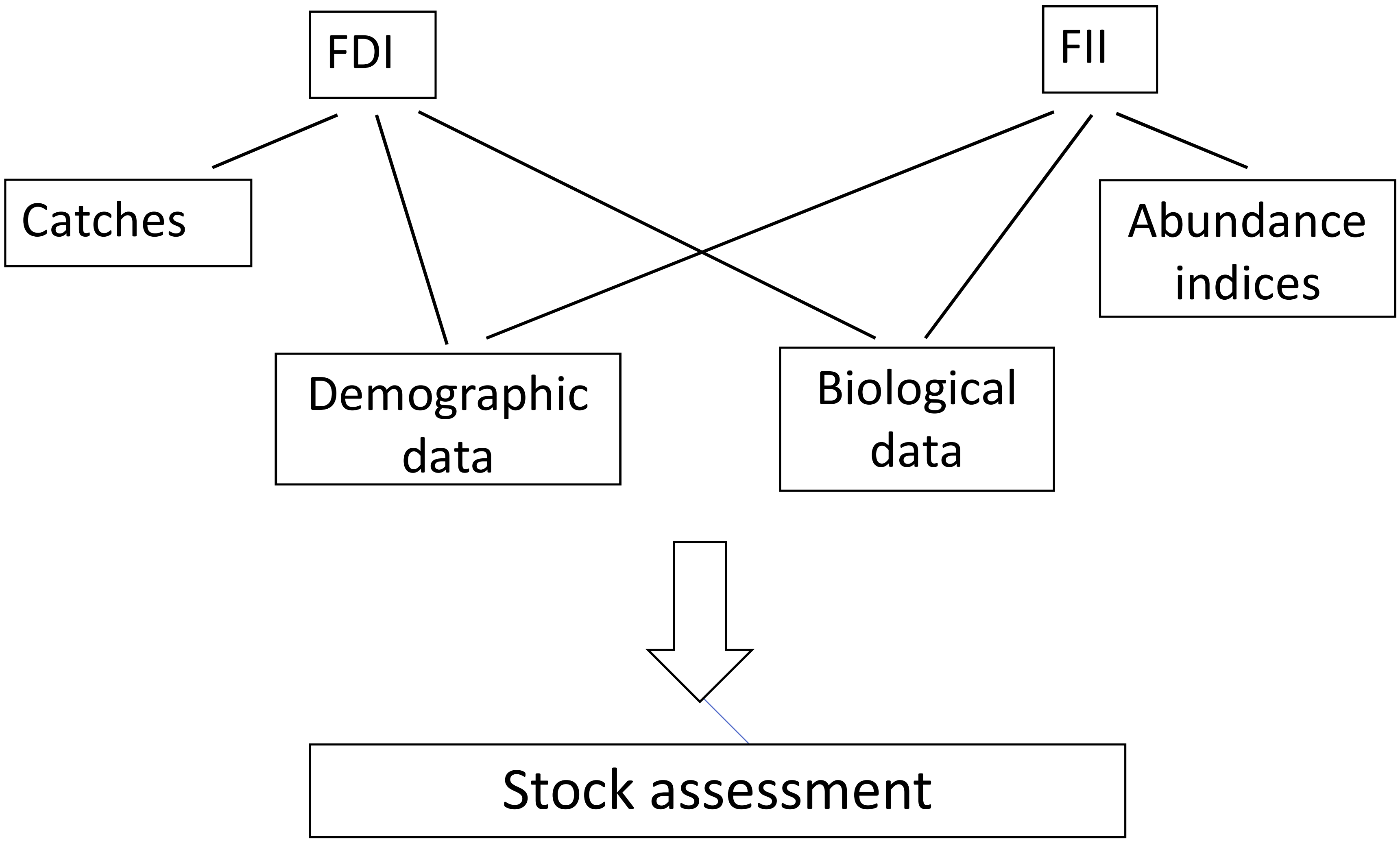
Estimating abundance and demography of stock

We have two main sources of data:

- **Monitoring Commercial Catches** - Fishery Dependent Information (FDI)

- **Carrying out Scientific Surveys** - Fishery Independent Information (FII)- Trawl surveys, echosurveys, visual census, and so on

Using data in stock assessment and fisheries management



Fishery Dependent Information (FDI)

There are a variety of approaches for obtaining fishery-dependent data.

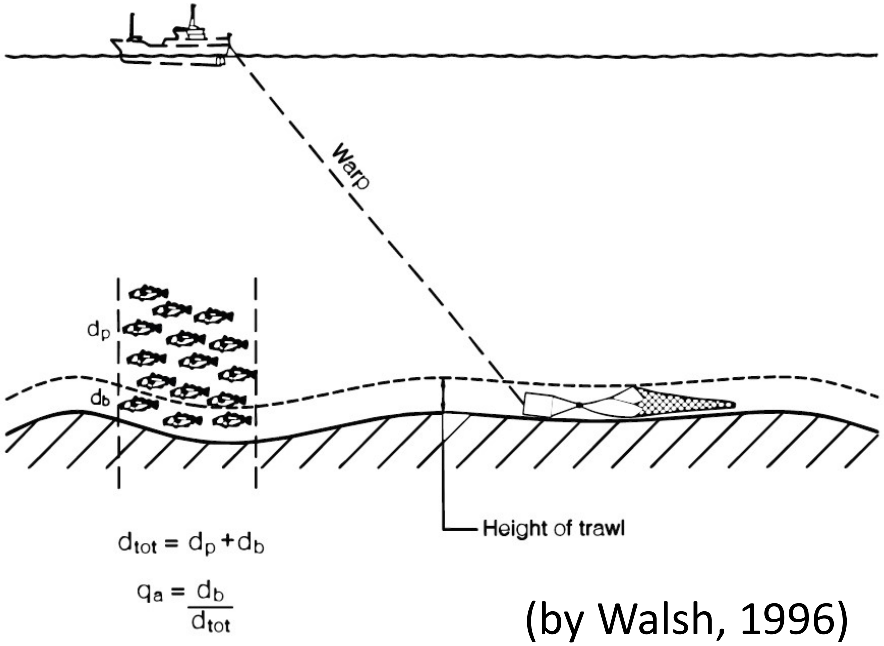
Socio-economic information (i.e. catch, effort, fuel, general costs of fishing trips) and **biological information** (i.e. catch rates, species composition, length, sex, maturity) can be obtained through the use of **on board observers, self-reporting, logbooks, sale notes, telephone surveys and/or other sources**.

Fishery Independent Information (FII)

Scientific surveys are designed to develop unbiased estimate (e.g. **abundance and demographic indices**) which are independent from commercial fisheries.

Since surveys are not influenced by specific management measures (e.g. mesh size, limits on number of hooks, seasonal closures), or socioeconomic factors (discarding), they can provide **a good image of the state of exploited stocks and communities**.

What are the pros and cons of the scientific surveys in producing data for fishery indicators?



(by Walsh, 1996)

Main advantages

➢If generously planned, they allow to sample the **whole spatial distribution** of the population;

➢**Sampling** is directly carried out by **scientists;**

➢Quite **simple random statistical design** allow to collected representative samples of the population

Main disadvantages

➢Surveys are limited to **few months** and the yearly cycle of the biological processes cannot be captured;

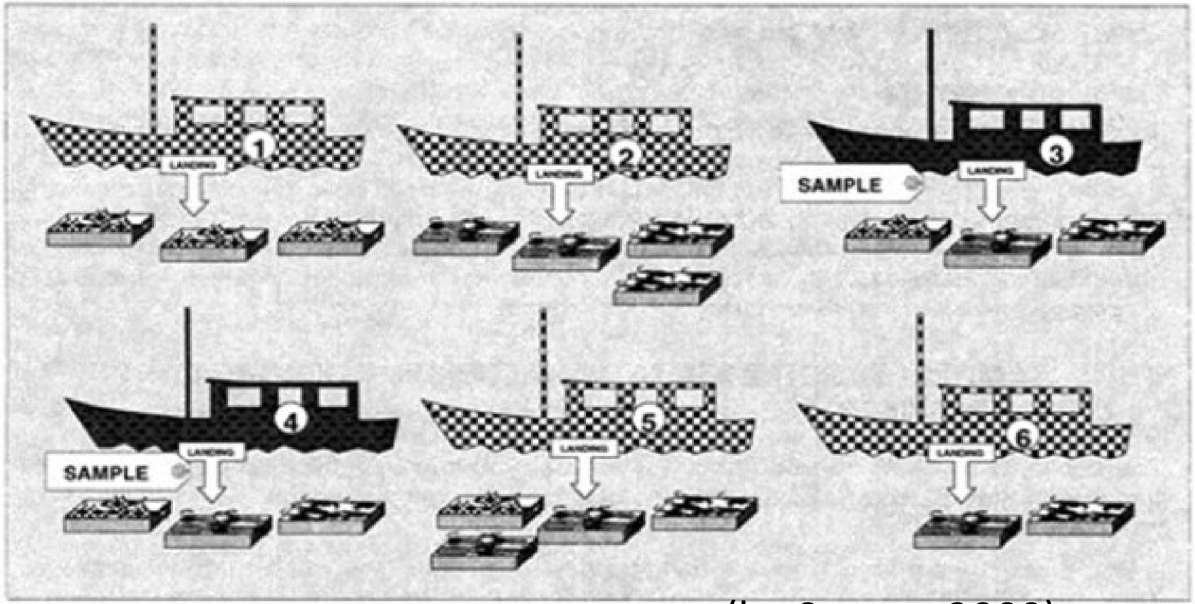
➢Do not furnish information on the fraction of population inhabiting **not investigated grounds**

What are the pros and cons of monitoring catches in producing data for fishery indicators?

Main advantages

➢**Sampling** could be distributed **all around the year**;

➢Coverage of the **different metiers** allows to collect information on the fraction of **population inhabiting grounds not covered by scientific surveys**



(by Sparre, 2000)

Main disadvantages

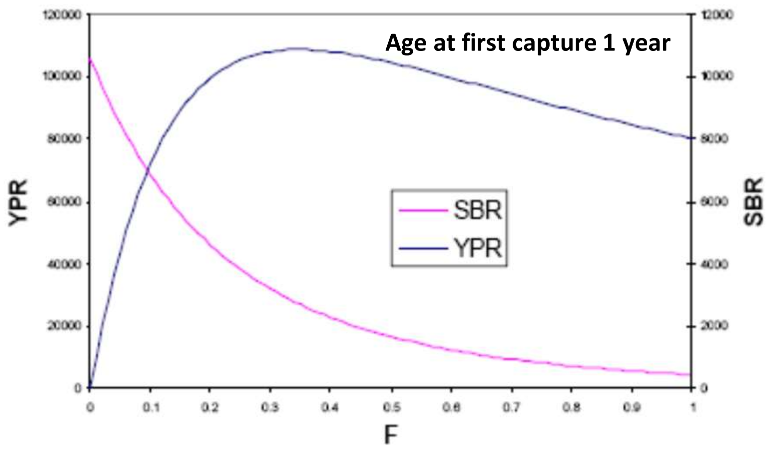
➢**Very complex design** have to be used to obtain samples representative of landings (**stratification by metier, fishing grounds, and commercial categories**);

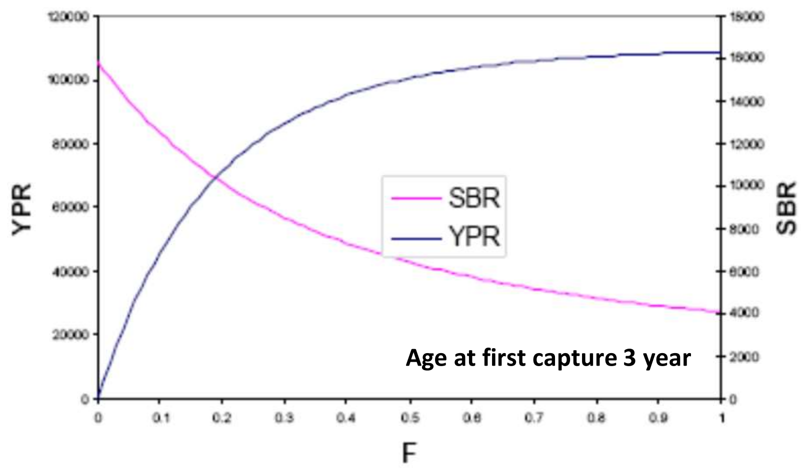
➢**High difficulties** in sampling **discarded fraction** that needs to be considered in recostructing catch rates and length structure of catches

What is overfishing? An excessive exploitation of the fished population

Two kind of overfishing of the exploited stocks are classically recognised

- **Growth overfishing:** fishing rate is higher than that producing the optimal Yield per Recruit (YPR)

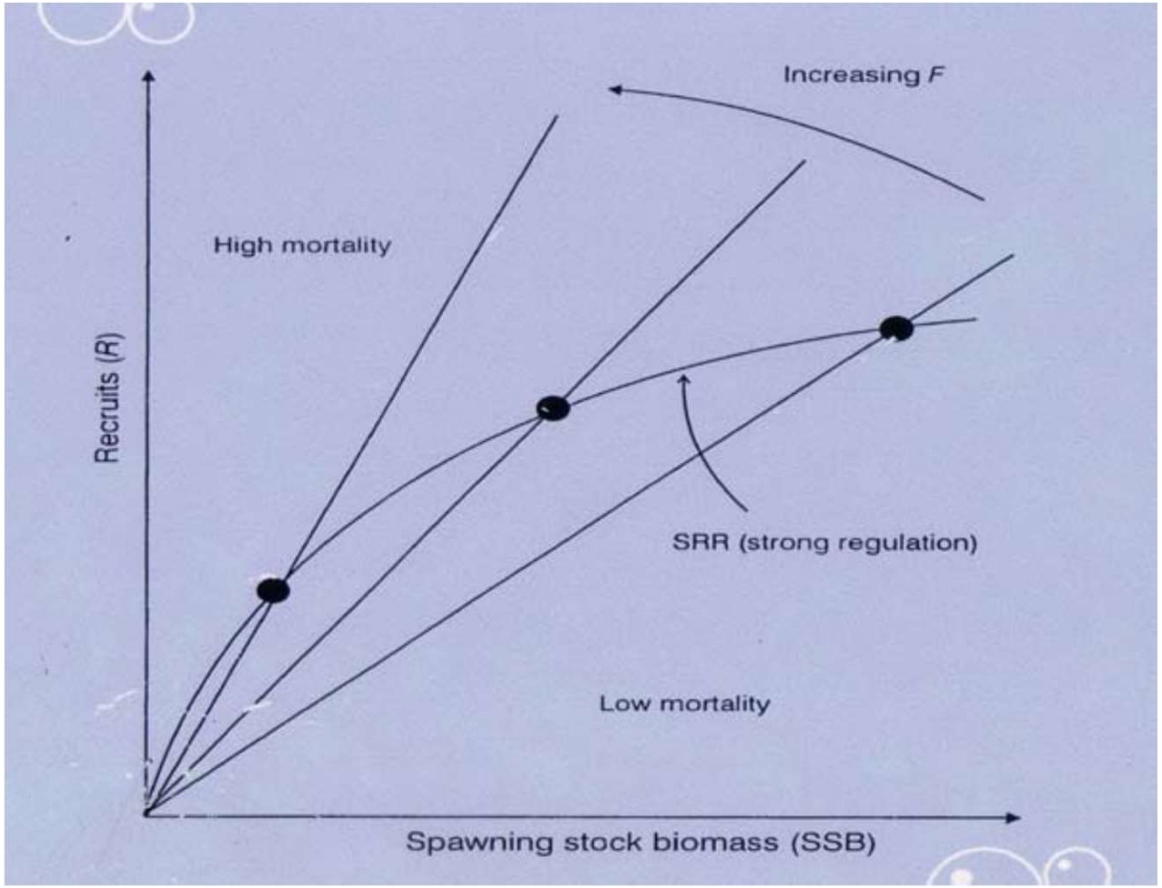




What is overfishing? An excessive exploitation of the fished population

Two kind of overfishing of the exploited stocks are classically recognised

- **Recruitment overfishing:** Fishing rate reduce the probability of future recruitment



(by John Shepherd)

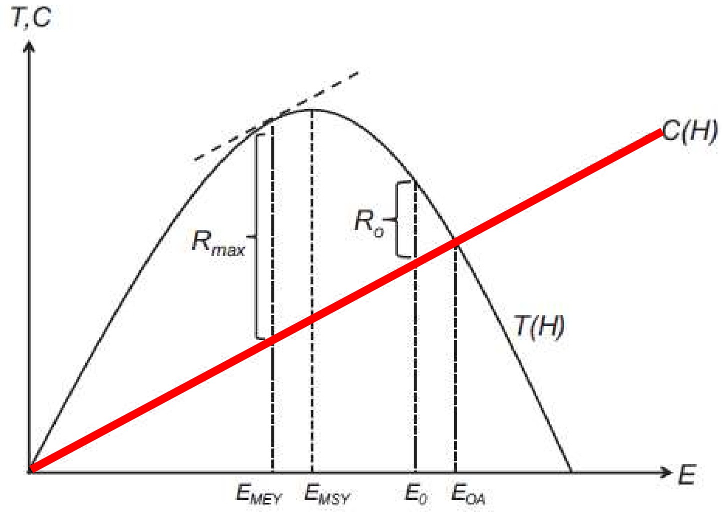
Why must we avoid overfishing?

- **Removes fish too early** in their life;
- **Reduces recruitment**, in many cases dramatically;
- **Drives** the stock to decline to **a less productive state (**reduced future catches and revenues);
- **Compromise** economic **sustainability**

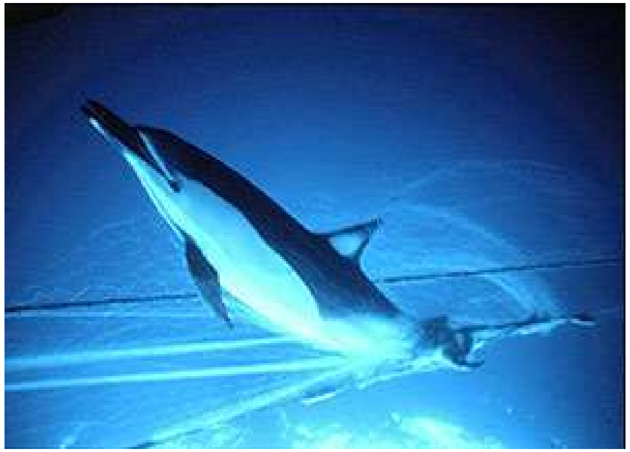
What is overfishing? An excessive exploitation of the fished population

But there are other kind of overfishing:

- **Economic overfishing:** fishing rates and exploitation pattern **reducing the economic gains** at unacceptable levels;
- **Ecological overfishing:** fishing activities **altering the food web and community structure**, producing high level of discards and destroying the marine habitas



(by Nielsen et al., 2014)



Effects of fishing down the ecosystems and some example of ecosystem indicators

Indicators of habitat size/quality

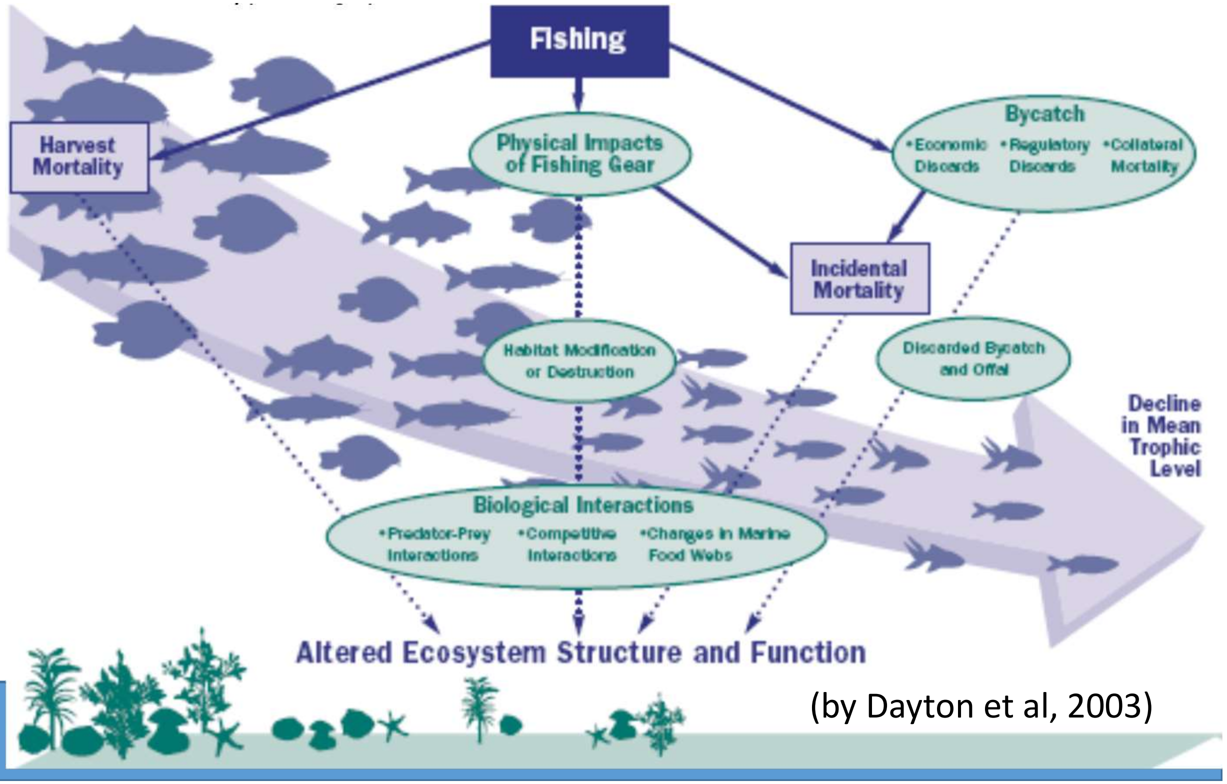
- Size of the habitat (% area covered by habitat), including the Essential Fish Habitat
- Proportion of fished area

Indicators at Ecosystem Level

- Mean trophic level (by size classes)
- Mean trophic level in the catches (Marine Trophic Index, MTI)
- Indicators derived from EwE (Connectance, Primary production required, FiB etc…)

Indicators at community level

- Size-based indicators (slope of the size spectrum;
- Mean weight or mean length (per haul)
- K-dominance, ABC curves
- Diversity indices (richness, diversity, evenness)
- relative biomass of pelagic fish, demersal fish, piscivores, elasmobranch, scavengers, planktivores, plankton, key fishery target



(by Dayton et al, 2003)

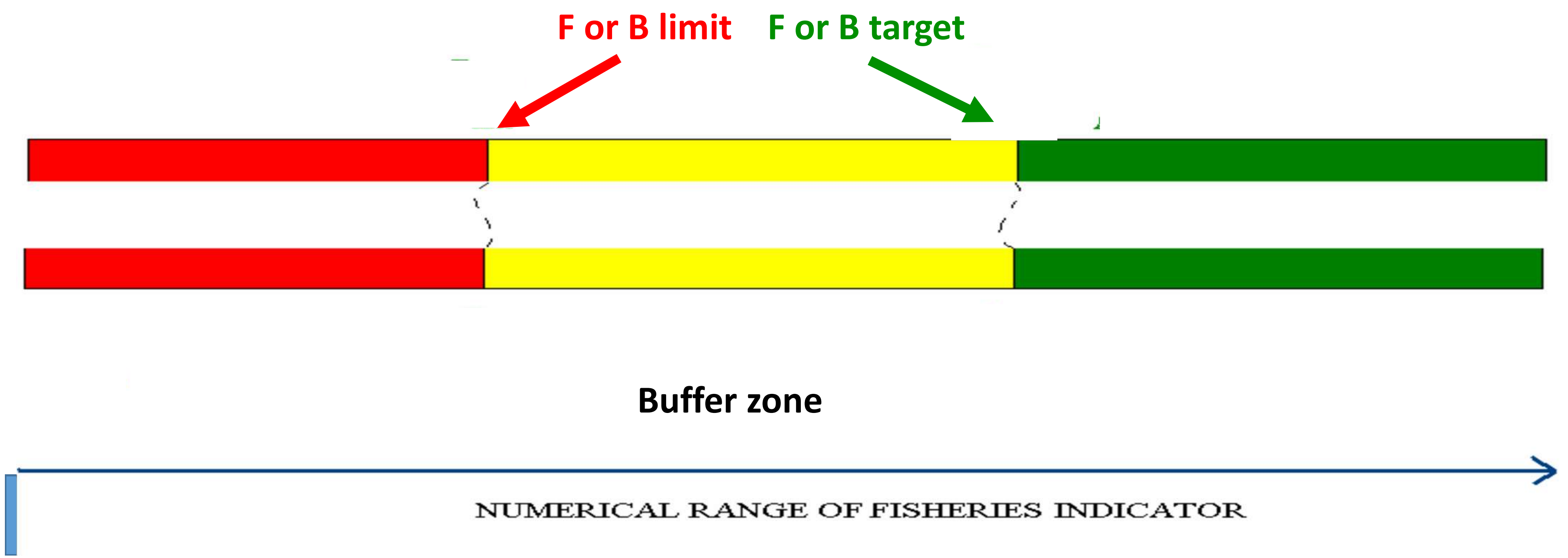
Why do we need Reference Points in the fishery science?

Management requires to known:

- Where to go (***Target Reference Points***);
- When to stop (***Limit Reference Points***)

Reference points

Conventional values of indicators of the state of a fishery or a population (B or/and F) that are considered the desirable objective to be reached (***Target Reference Points***) or an undesirable state of the fishery which needs to be avoided (***Threshold* or *Limit Reference Points***)



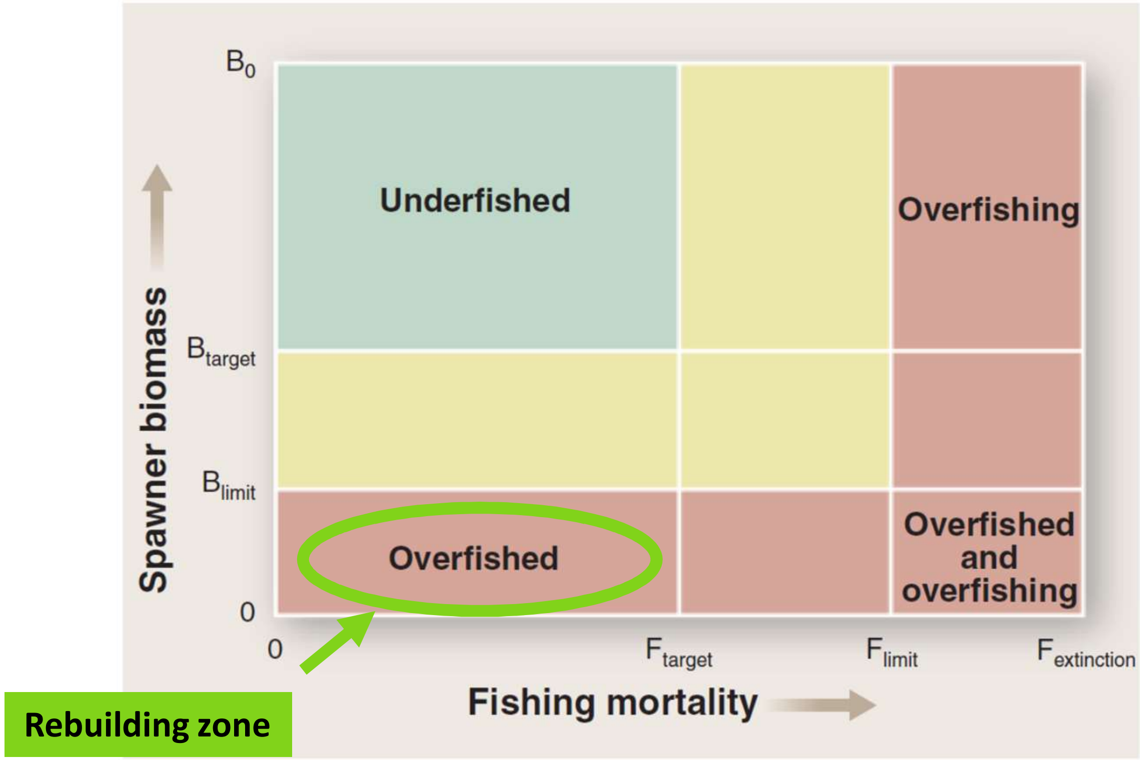
Limit and target Reference Points

- ***Managemnt Limits are:***
- **A F to not be exceed, a biomass to not go below**
- A key reference point value like F_{msy}, $F\%_{SSBv}$ or B_{msy}

Management targets are:

- ***A level of F corresponding to a goal**:* An F target gets you to a desired place (i.e.maximum yields, maximum revenues,etc)

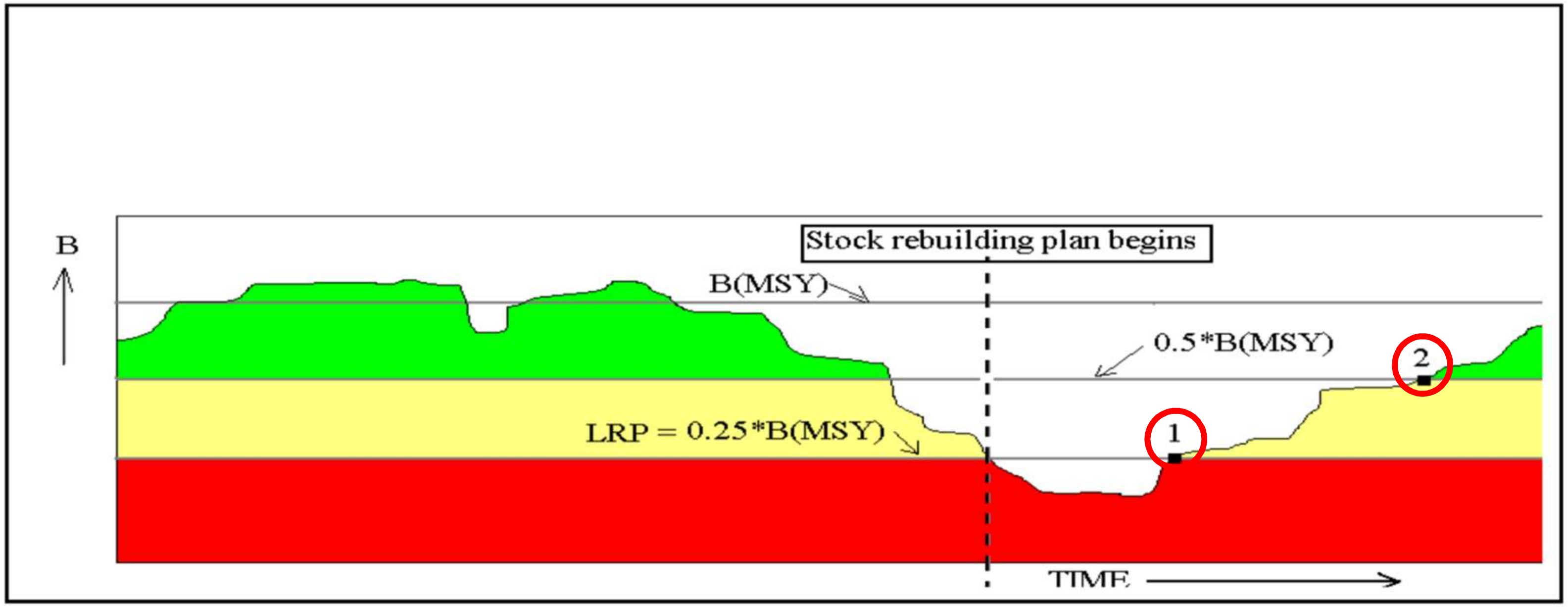
- ***A level of biomass corresponding to a goal:*** A biomass target is a desired place (i.e. a biomass level that represents some fraction of the pristine biomass)



(by Beddington et al., 2007)

Typical reference points and **stock status** definitions for **stock biomass** and **fishing mortality**. The limit of fishing mortality that generates biological extinction is F extinction.

Possible use of a management rule based on RPs for stock rebuilding



When the **biomass is a quarter** of that corresponding to $\mathbf{B_{MSY}}$ **(0.25$\mathbf{B_{MSY}}$)**, a **compulsory recovery plan** starts which continues until the biomass is once again above $\mathbf{B_{MSY}}$. (Points 1 and 2 are 'way stations' serving to check stock status during rebuilding) (by Caddy, 2004).

Main differences between empirical and analytical indicators

Empirical Indicators

- Empirical indicators are based on "**expected" relationships** between **measurable characteristics** and properties of **stock, communities** and **fishery**.
- Since they have **no theoretical grounds**, it is more difficult to insert them into a framework of Limit and Target reference points.
- However, it is possible to use them within **trend analyses** framework highlighting development patterns of the stocks and fisheries to **check progress** towards **management objectives**.

Analytical Indicators

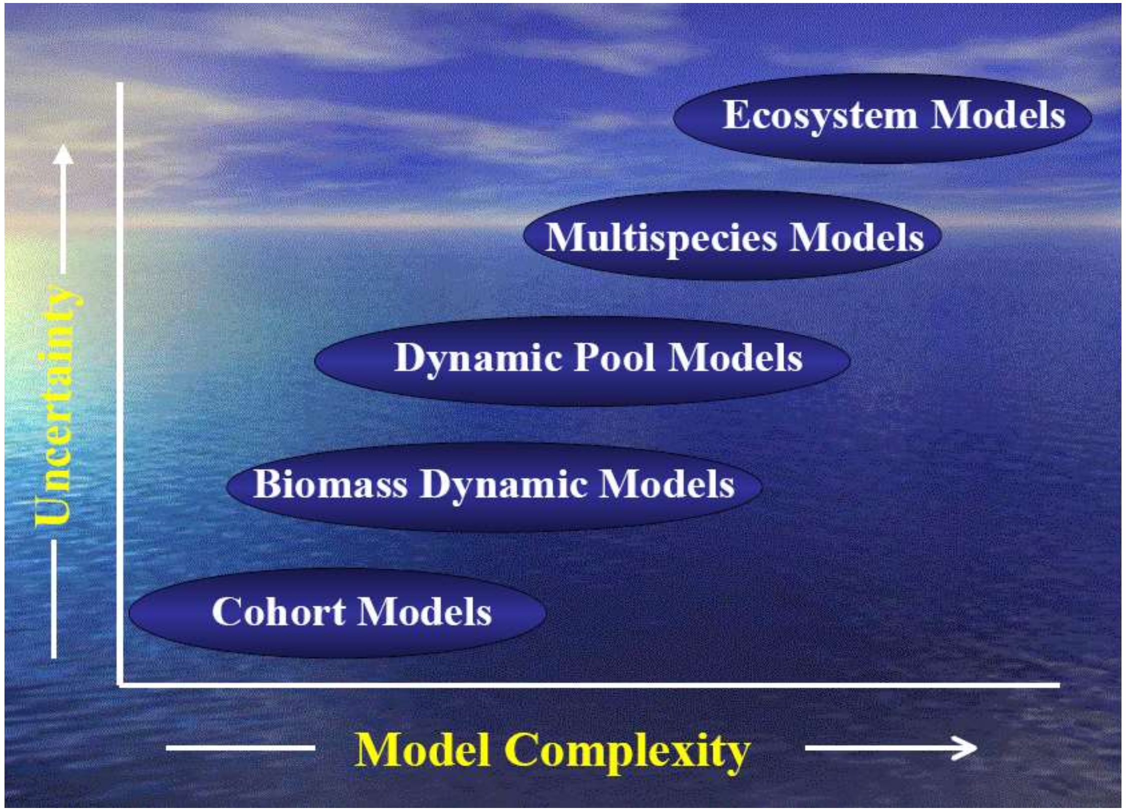
- Analytical indicators are based on **population dynamics models** that reconstruct the evolution of a population, community or fished ecosystem with the ultimate goal of sustainable exploitation of its natural productivity.
- These indicators are based on **mathematical relationships** between the quantities **modelling stock dynamics and fishery performance**.
- They can be embedded in a **framework of RPs** allowing setting of limits and targets reference point to fisheries management

The main approaches for the assessment of a stock status by population models to produce indicators for fishery manangement

The **main available approaches** in the toolbox:

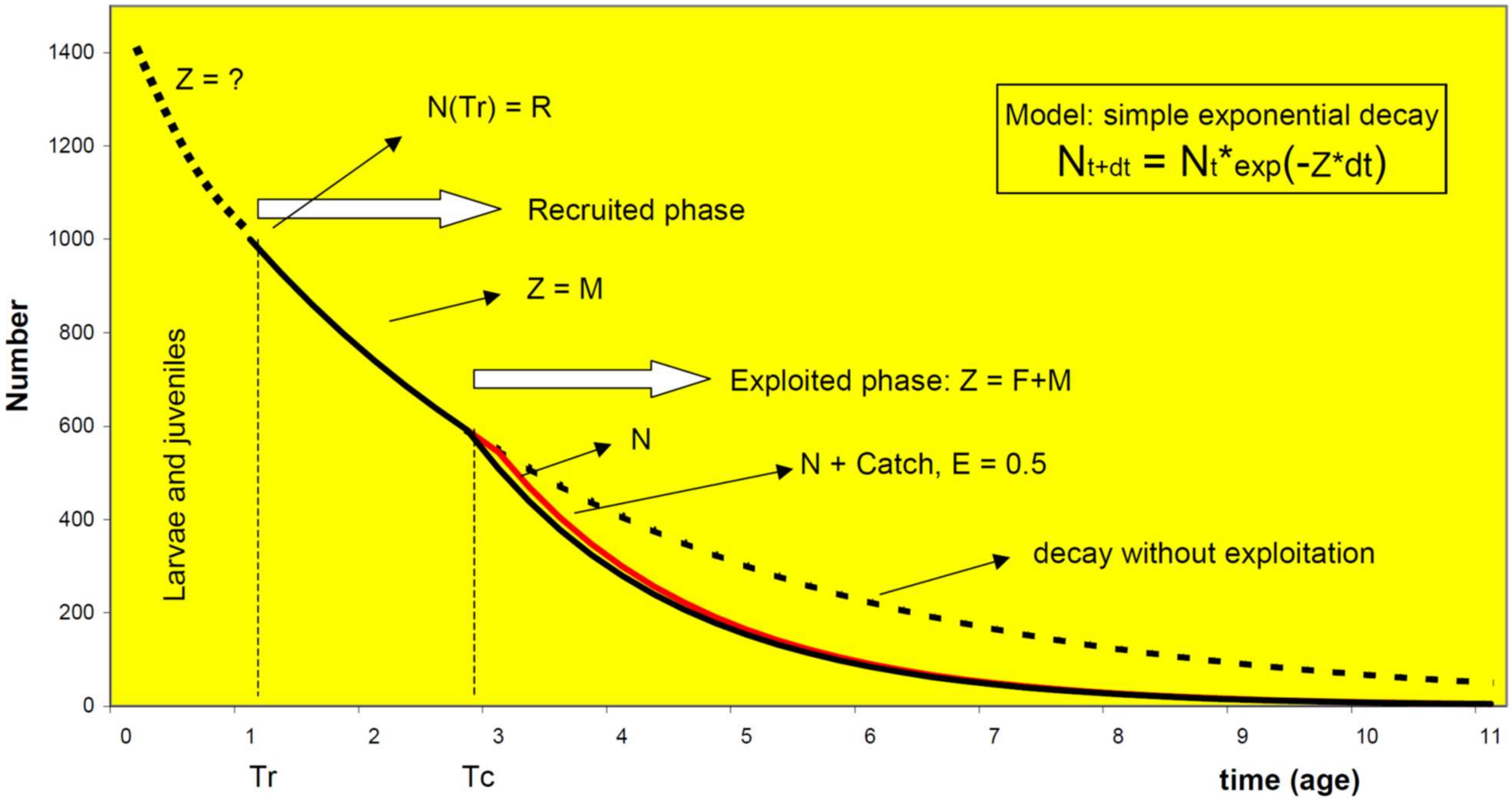
- Cohort Models
- Biomass Dynamic Models
- Dynamic Pool Models
- Multispecies Models
- Ecosystem Models

The **data requirement** and the **output uncertitude increases** with increasing level of model **complexity**.



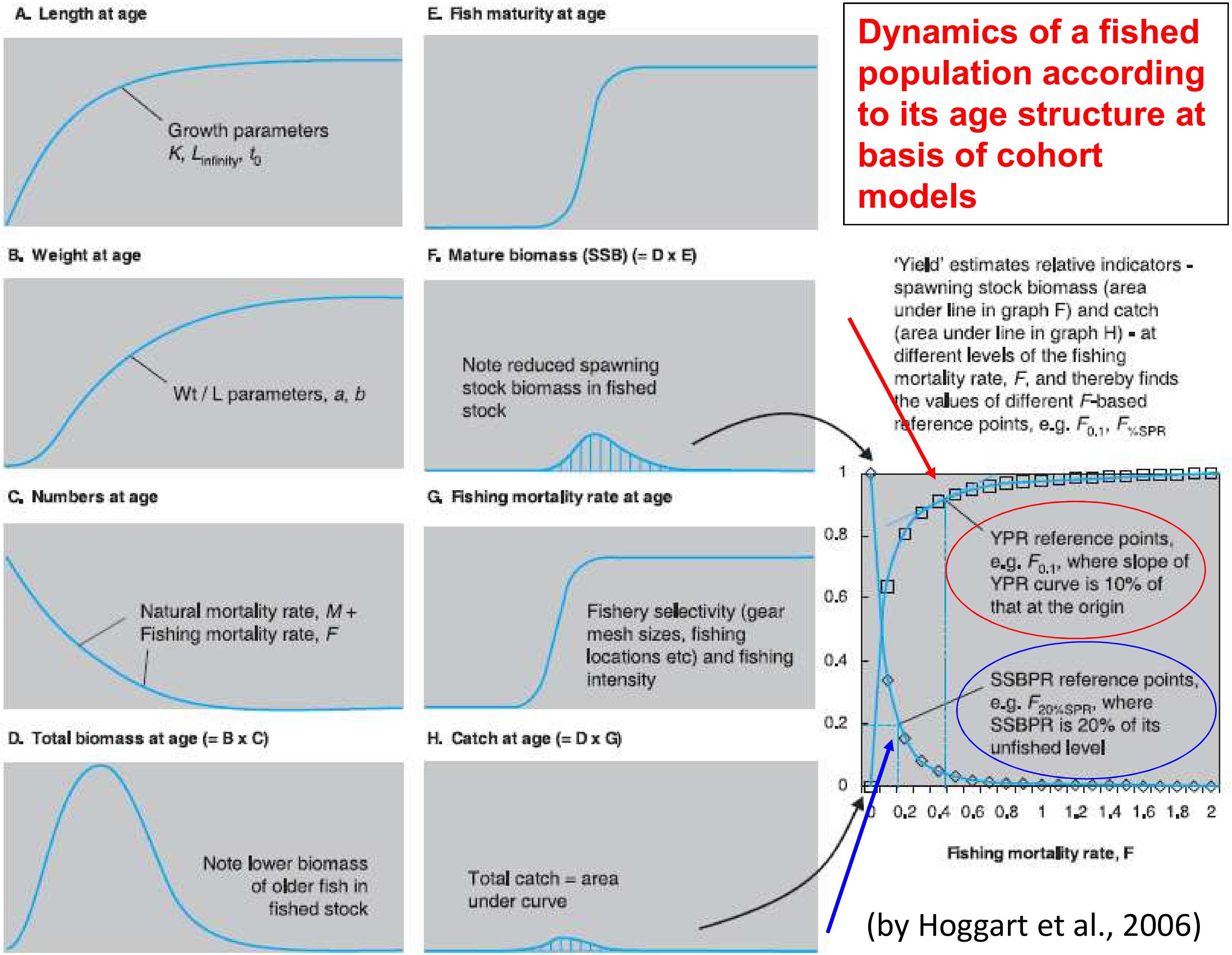
by Lane and Kaufmann (1998)

The Cohort Models, or the dynamics of an exploited cohort (Z=M+F) compared to natural decay without fishing (Z=M).



(by Kolding and Ubal Giordano, 2002)

Dynamics of a fished population according to its age structure at basis of cohort models



(by Hoggart et al., 2006)

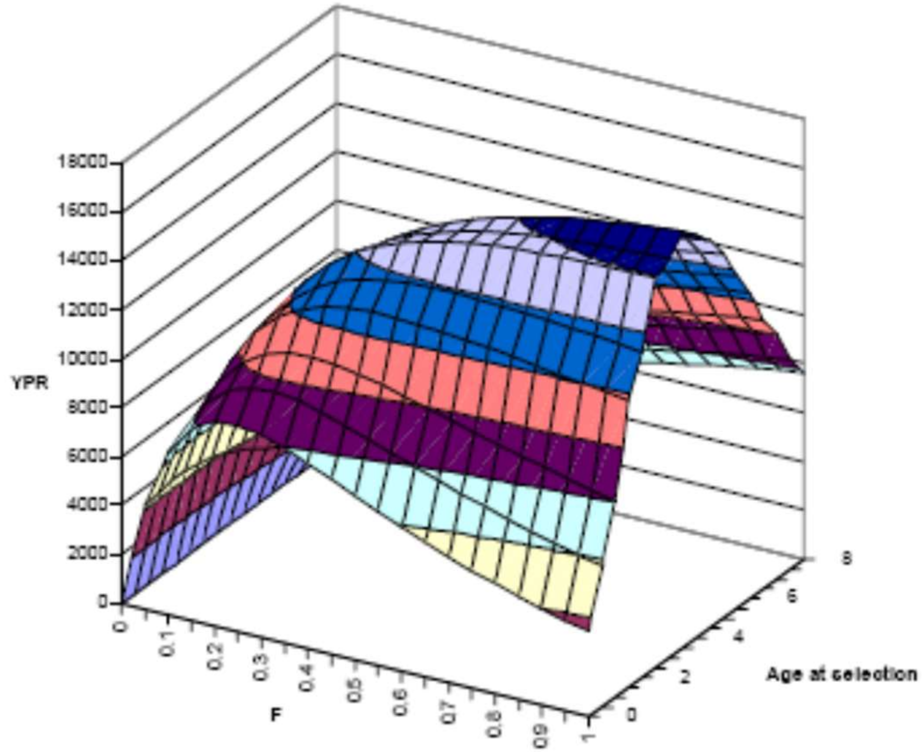
Yield per Recruit models

Y/R analysis is a very simple approach based on knowledge of biological parameters (**Growth, Natural Mortality, Length-Weight relationship, and selectivity by age/length**)

- Allow to estimate **analytical indicators** (Y/R, B/R) and **reference points** (Fmax, F0.1, %SSB)
- Does **not** require **time series**
- Y/R analysis tells us if we are exploiting fish at **the right age/size** and **intensity**
- It is easy to translate into direct management recommendations (**changes in mesh size or regulation of fishing effort**)

But…

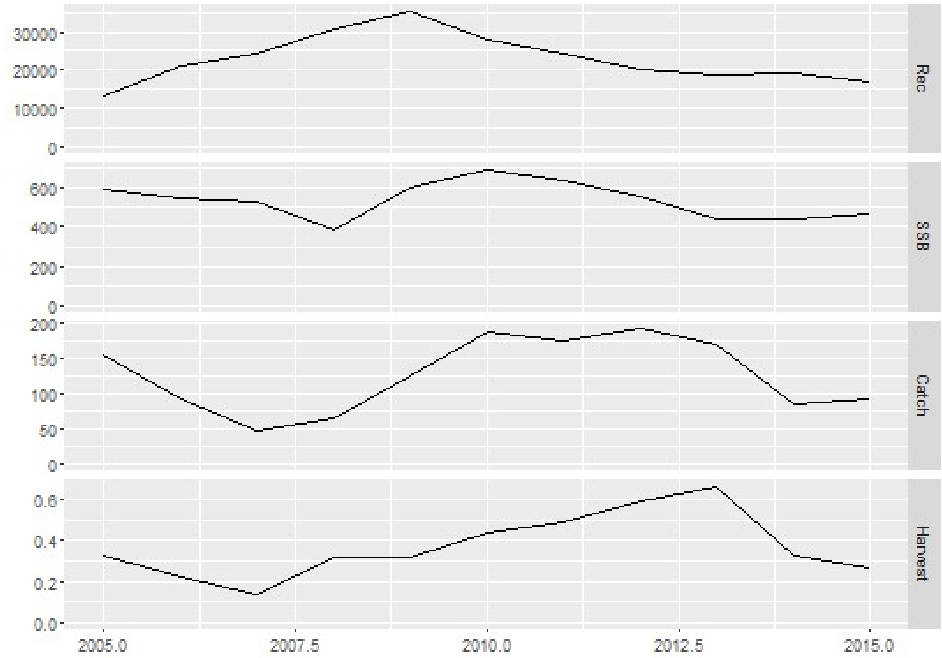
- they assume **equilibrium** in population age structure
- Do **not** incorporate **density-dependent processes** like S/R relationships



Virtual Population Analysys based approaches

VPA works with **catch-at-age data** (assumed as known and without error) to estimate **historical population size and corresponding fishing mortality** (F).

VPA is performed separately for **each cohort** (year class) within the exploited portion of the population, working ***backward in time*** from the latest year and oldest age in each cohort (terminal age) to the youngest age for which it is possible to estimate the numbers of fish if catch-at-age. Method needs natural mortality (M) is known.



The most widely used VPA-based model in the GFCM and STECF working groups is the **Extended Survivor Analysis** (**XSA**; Shepherd, 1999).

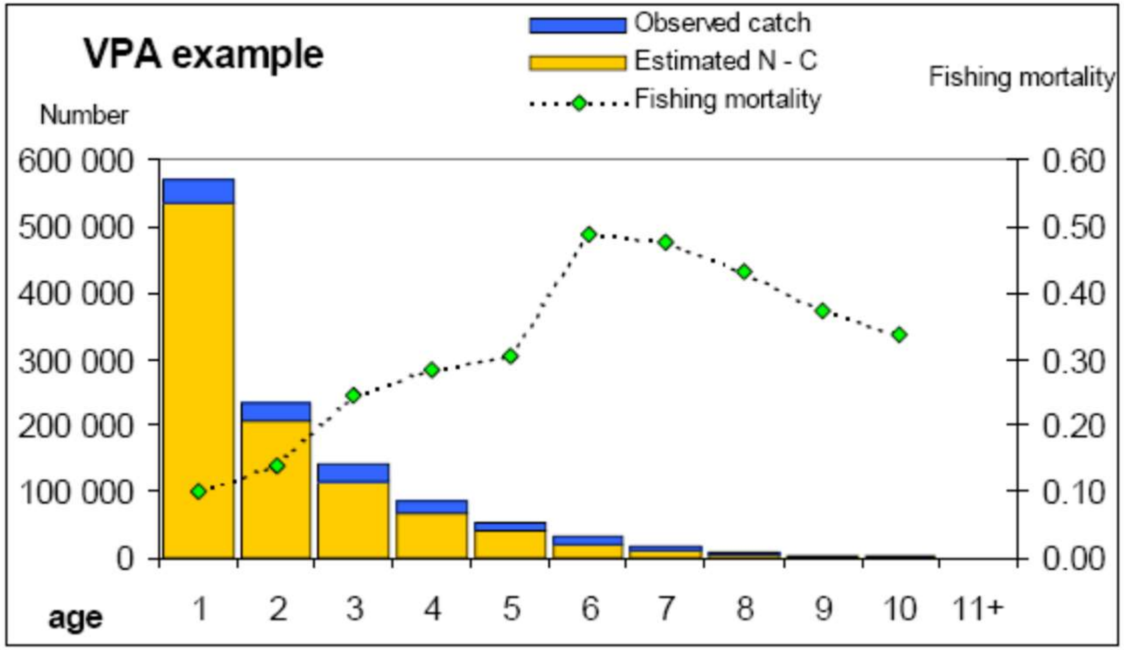
Virtual Population Analysys based approaches

It is…

- Not very simple approach but **high sense of realism**
- Require **time series of demographic structure** of total catch
- VPA tells us values of **fishing mortality** by **age classes**

But…

- **Not easy** to translate into direct *management* recommendations
- **Data demanding**, especially in multigear-multifleet fisheries
- **Very sensible** to input **M** values

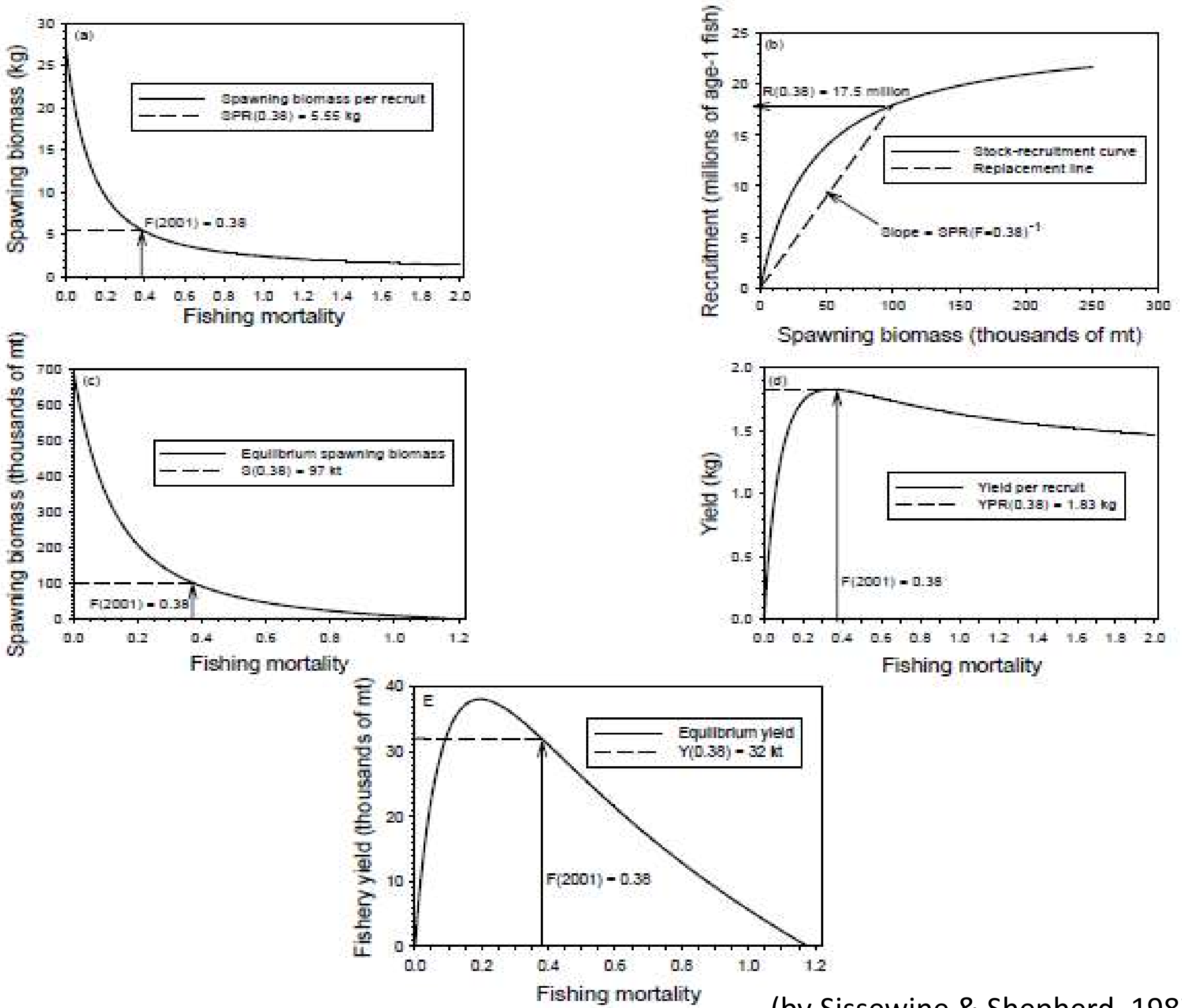


(by Kolding & Ubal Giordano, 2002)

Analytic estimation of sustainable yield

The synthesis of Sissenwine & Shepherd….

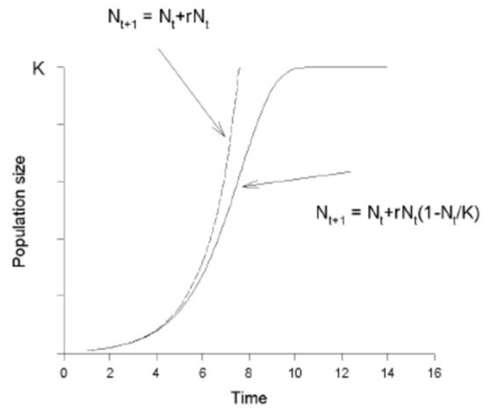
…if you know the **SSRR**, the **Y/R** and **SSB/R** you can estimate the **sustainable yield** and the **corrisponding F**

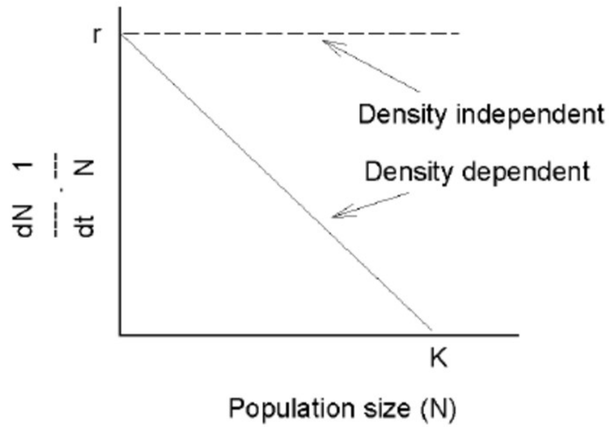


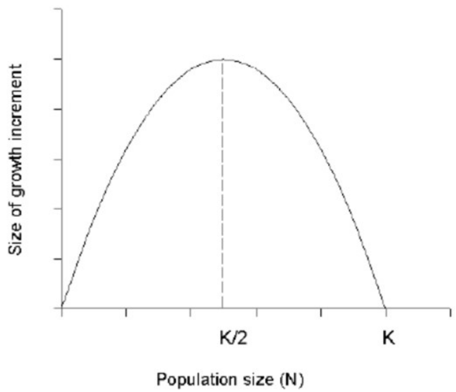
(by Sissewine & Shepherd, 1987)

The surplus production models

The **Gordon–Schaefer model** is a classical bio-economic static fishery model based on **logistic biological growth, constant harvest price, constant unit cost of effort, and harvest linear in stock biomass and fishing effort**



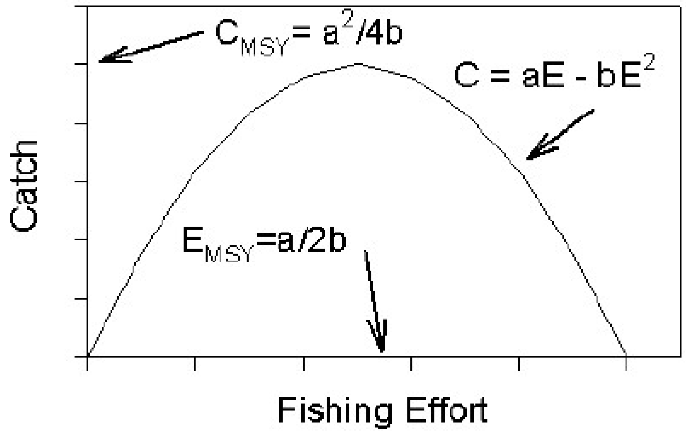




CPUE= a – bE;

CPUE*E= C;

$C = aE - bE^2$



Some warnings on the use of catch data for stock assessment

Ambiguity of catch data

According to the **catch equation**

$$C = F^* B_{mean}$$

Increased catch may be due to:

- **Increasing fishing mortality** (effort) …**a bad think**
- **Increasing of stock size** (biomass)…**a good think**

This is the reason why **catch alone** is **not** enough to understand **stock dynamics**

Some warnings on the use of catch data for stock assessment

CPUE and abundance

Catch Per Unit Effort is the most used index of stock abundance

$\mathbf{C=F^* B_{mean}}$

$F=q^*E$

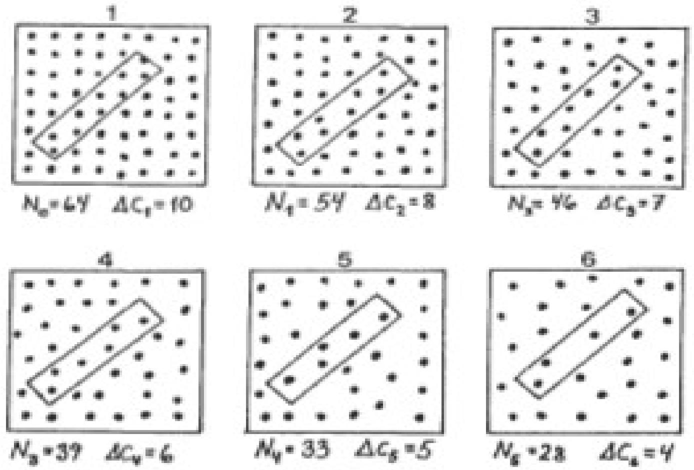
$C= q^*E^* B_{mean}$

$\mathbf{CPUE= C/E= q * B_{mean}}$

a) CPUE is a quite **good** index for **demersal resources** but

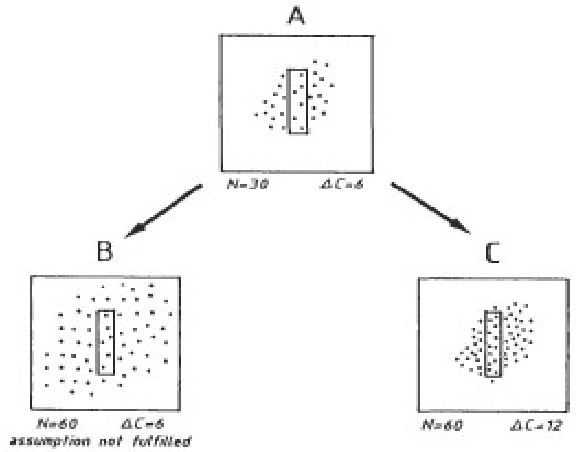
b) CPUE is **not** a **good** index for small **pelagic resources** due to the so called *hyperstability* of CPUE…

a)



CPUEs are proportional to the stock size throughout time **if the area occupied by the stock remain constant**

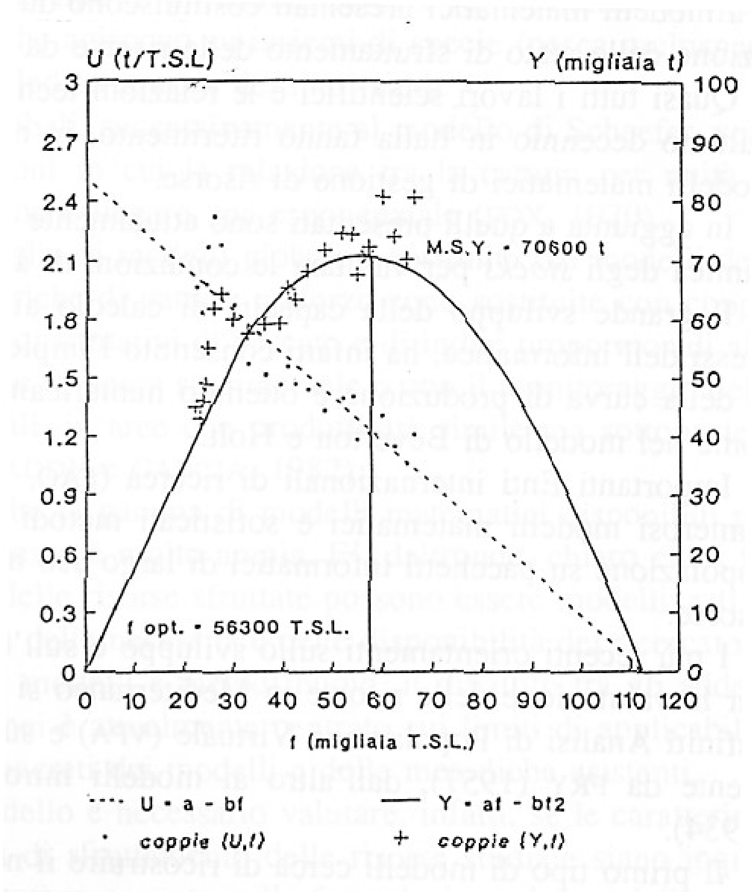
b)



(by Sparre & Venema, 1998)

The Surplus production models

- Very **good cost/benefit** ratio
- **Limited data** requirements
- SPM can yield **critical information** for **assessment and management** (B_o, B_{curr}, level of depletion of the population, MSY, f_{MSY})
- Projections under **different scenarios** (yield, effort), and to evaluate outcomes of each scenario



Surplus production model of the **aggregate catch** of demersal species in the **Strait of Sicily** (1959-1983). The **maximum sustainable yield**, (about 70000 t per year) **was reached in 1983** (about 56000 GRT) (by Levi and Andreoli, 1989, modified).

Surplus Production models (SPM)

FISH and FISHERIES

FISH and FISHERIES, 2017, 18, 506–526

Estimating fisheries reference points from catch and resilience

Rainer Froese[1], Nazli Demirel[2], Gianpaolo Coro[3], Kristin M Kleisner[4] & Henning Winker[5,6]

But **traditional versions….**

- do not incorporate **time delays** (very important for elasmobranchs)
- assume **equilibrium**

- Need of **contrast in levels of fishing** pressure along time series

…new **dynamics version** allows to overcome these limits…

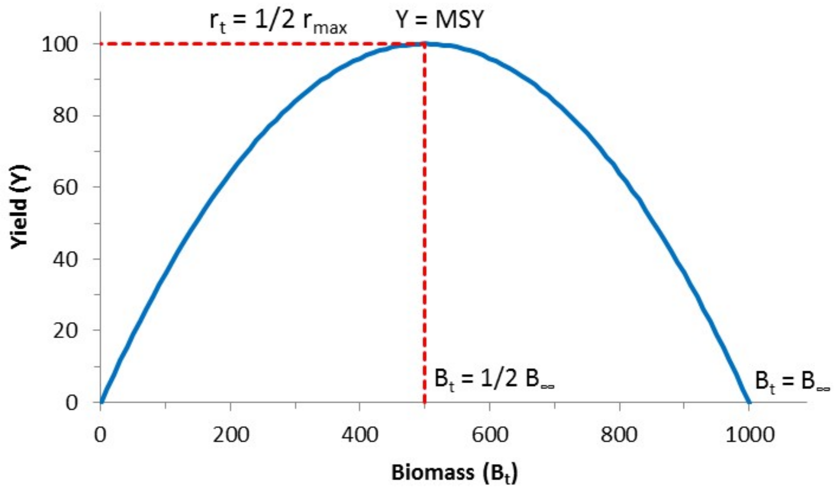
$$B_{t+1} = B_t + r\left(1 - \frac{B_t}{k}\right)B_t - C_t$$

CMSY/BSM (Catch MSY & Bayesian Surplus Production) by Froese et al. (2017)

- Main assumptions: **constant stock productivity**
- Required input data: **long time series of catch** (landing + discard data) **and** expert knowledge of **r and K range priors**. If used in combination with **BSM abundance data** are needed.
- Additional critical issues: expert knowledge in **setting priors** is critically **important**

CMSY/BSM (Bayesian Surplus Production)

- Given a time series of Catch and CPUE, the parameters $r = r_{max}$ and $B_\infty = k$ are estimated from
  - $$B_{t+1} = B_t + r\, B_t\left(1 - \frac{B_t}{k}\right) - C_t$$
    - B∞ = k
    - r = rmax
    - Ct is catch in year t,
    - B = CPUE / q,
    - q is the catchability coefficient,



- Using a **Bayesian approach**, the **r-k combination** that **minimizes the difference** between the **observed biomass and the one predicted** by the above equation is chosen **as best estimate**

CMSY – Catch and resilience

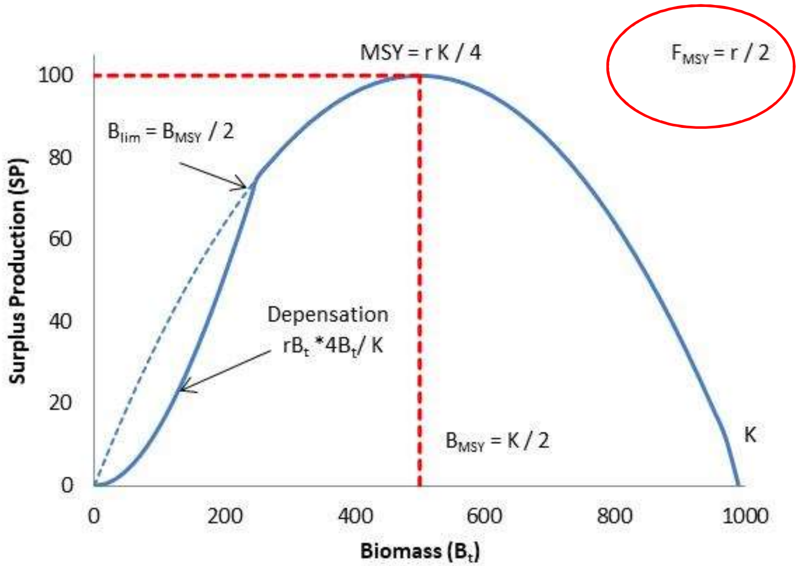
If CPUE is unknown,

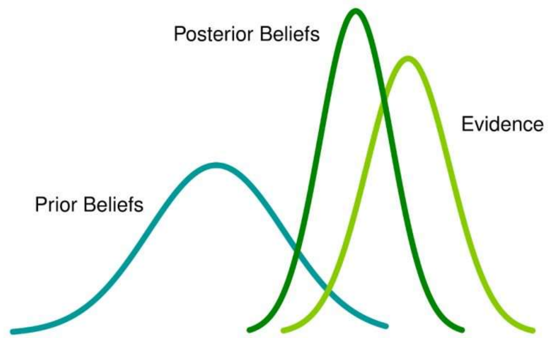
- a **prior range for *r*** is derived from life history traits,
- a **prior range for *k*** is derived from maximum catch,
- prior ranges for B_t/k (at beginning and end of catch time series) are derived from expert knowledge.

$$B_{t+1} = B_t + r\,B_t\left(1 - \frac{B_t}{k}\right) - C_t$$

- **all *r-k* combinations** that are compatible with the life history traits (*r*, *M*, *K*),
- **the catches (C_t) and the expert knowledge (B_t/k)** are identified by a **Monte-Carlo approach**.

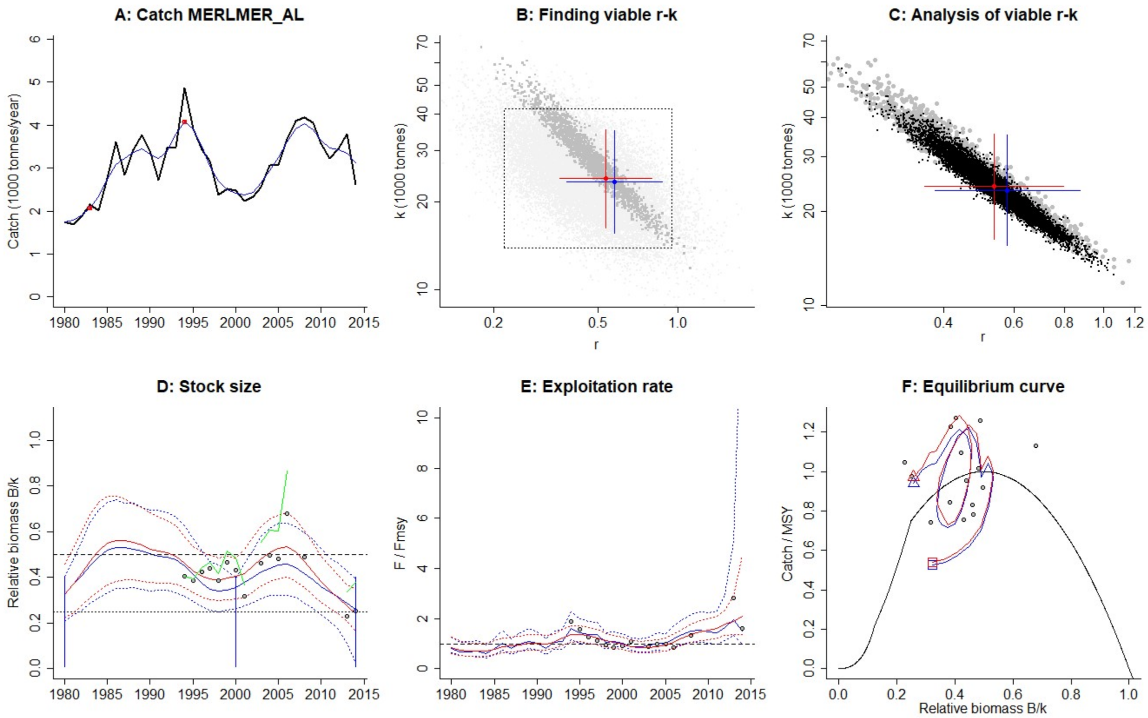
An *r-k* combination representative of high *r* values is chosen as best estimate.





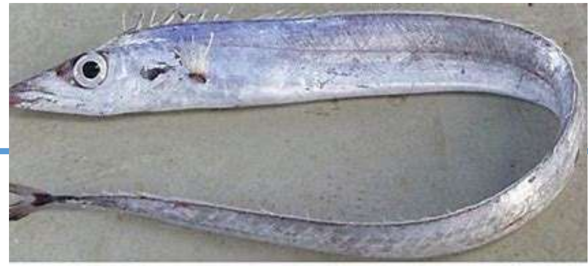
CMSY/BSM (Bayesian Surplus Production)

CMSY – Outputs

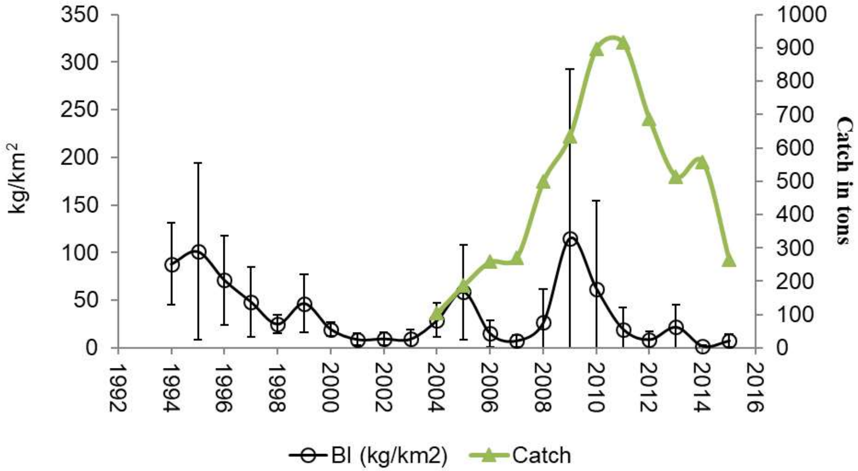


- A: Time series of catches
- B: *r*-*k* pairs by the CMSY/BSM model
- C: Most probable *r*-*k* pair
- D: Estimated biomass trajectory
- E: Harvest rate
- F: Schaefer equilibrium curve

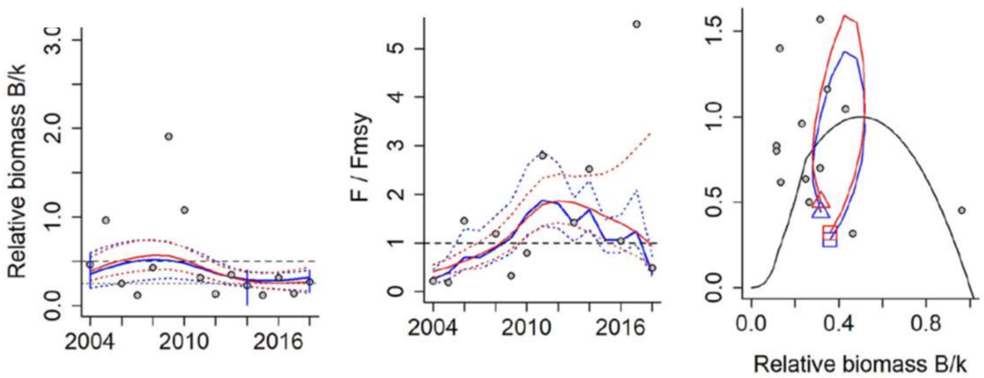
An example of CMSY/BSM to assess exploitation of *Lepidopus caudatus* in the Strait of Sicily combining BI and Catch data

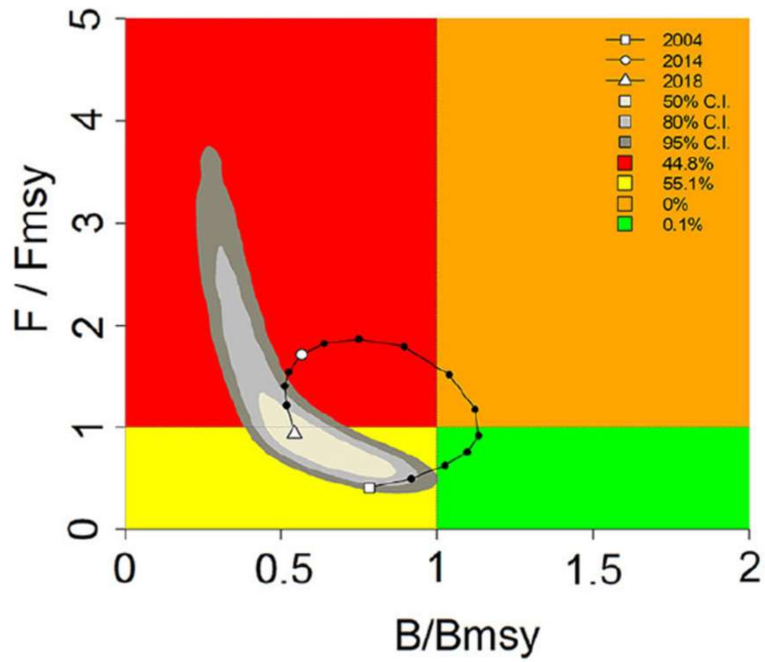


Biomass indices by trawl surveys and commercial catch of *L. caudatus*



BI available before beginning of fishery





Management graph

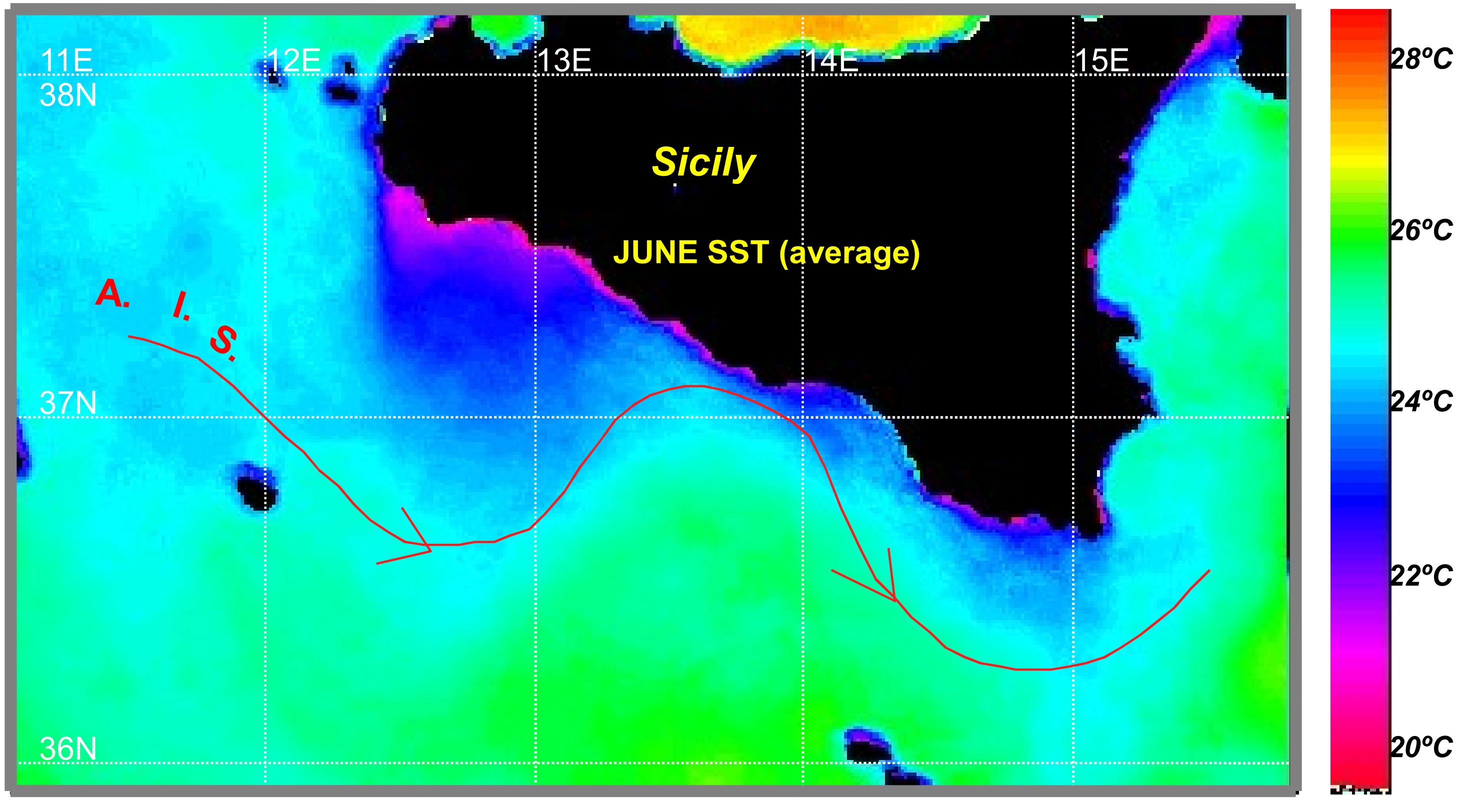
- Catch and MSY & Relative total biomass (B/Bmsy)
- Relative exploitation (F/Fmsy)& B/Bmsy and F/Fmsy

KOBE plot: Evolution of B/Bmsy and F/Fmsy throughout time

(by Falsone et al., 2021)

A general problem of model based indicators… the sensitivity of reference points to climate change

The Atlantic-Ionian Stream (A.I.S) and Surface Sea Water Temperature in June 1998 in the Strait of Sicily



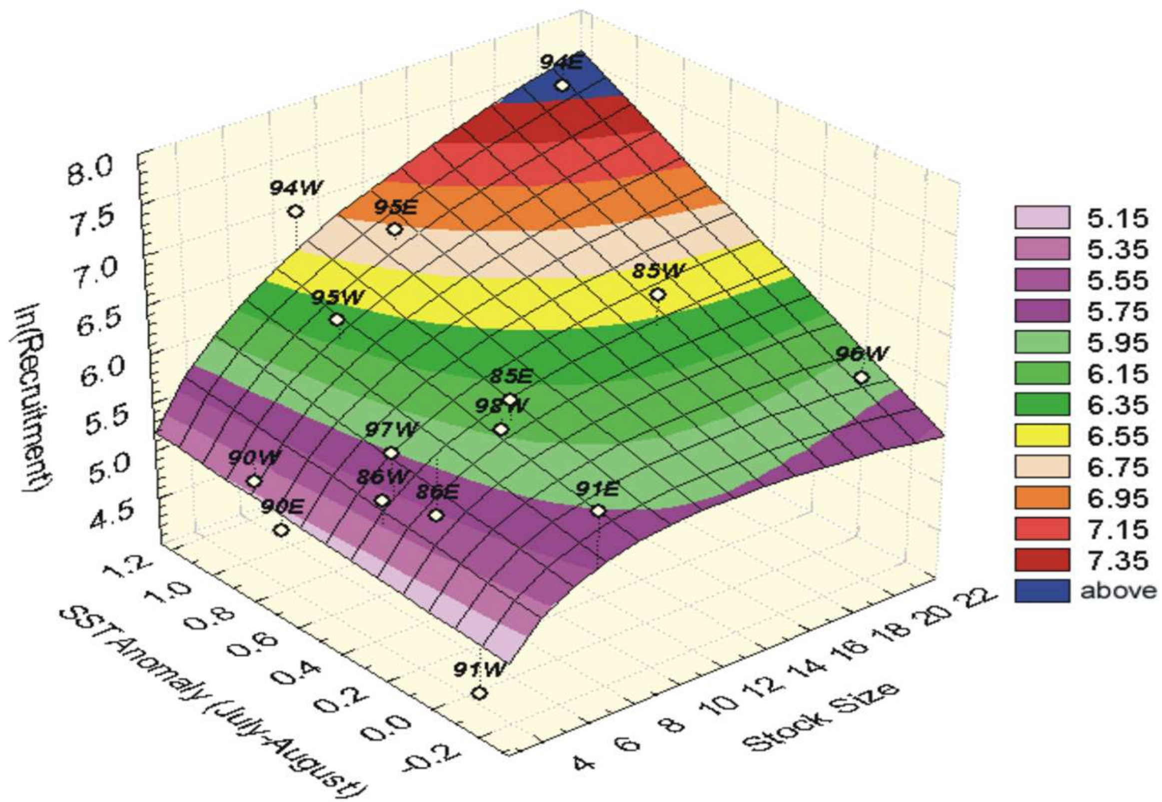
(by Garcia-Lafuente et al., 2002)

A general problem of model based indicators… the sensitivity of reference points to climate change

The Spawing Stock Recruitment Relationship of ***M. barbatus*** in the **Strait of Sicily** including the **anomalies of the Surface Sea Water Temperature (SWT)**. For **a given SSB**, the **strength of recruitment** is **stronger** when **SWT** in pre-recruitment phase is **higher** the the mean.

Model: ln(R)=ln(a)+ln(S)-b*S+c*S*SSTanom

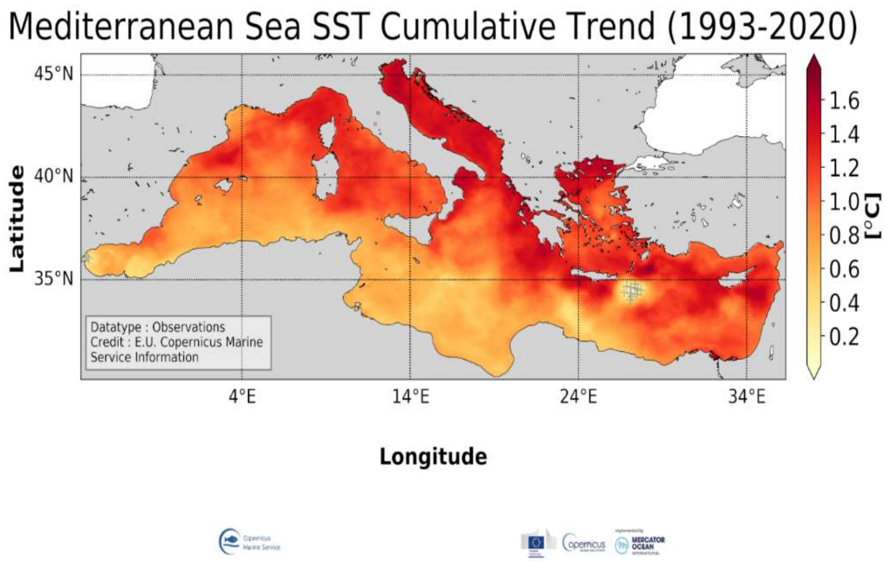
ln(R)=ln(70.17113)+ln(S)-(0.0638123)*S+(0.0605436)*S*SSTanom



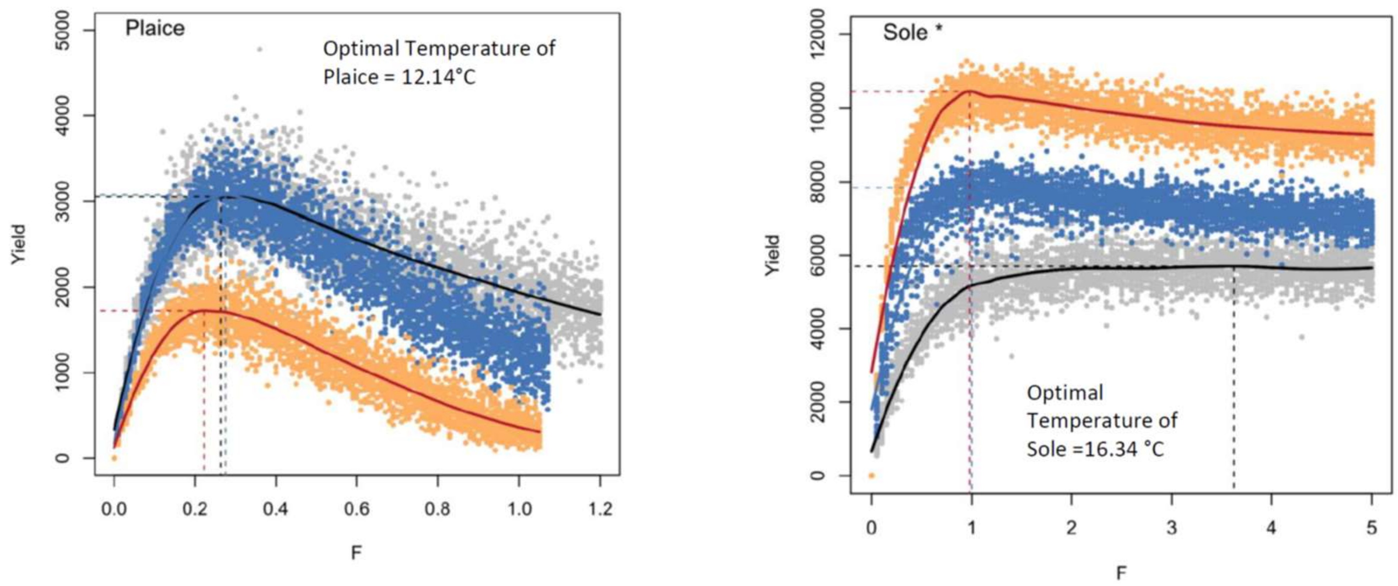
(by Levi et al., 2003)

A general problem of model based indicators…the sensitivity of reference points to climate change

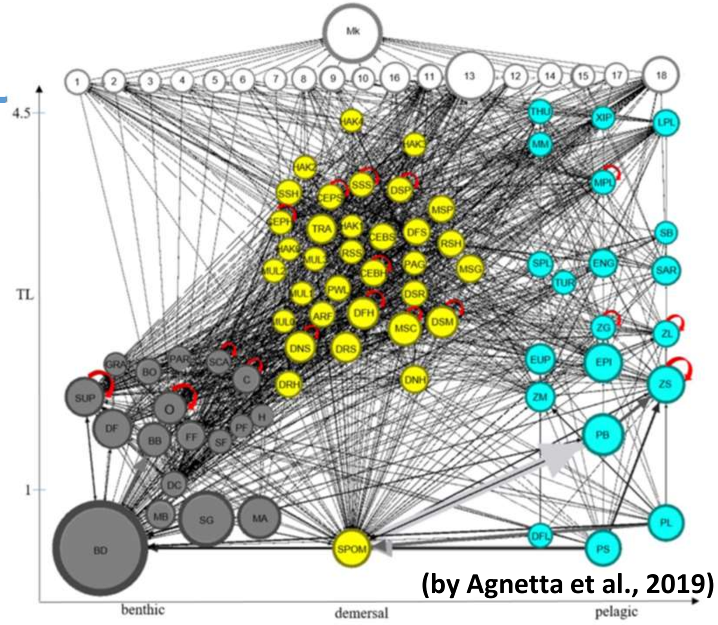
The effects of climate change on reproduction, growth and natural mortality can affect stock productivity and change MSY (by Travers-Trolet et al., 2020)



Some simulations on Sustainable yield vs. fishing mortality of flat fish in the English Channel

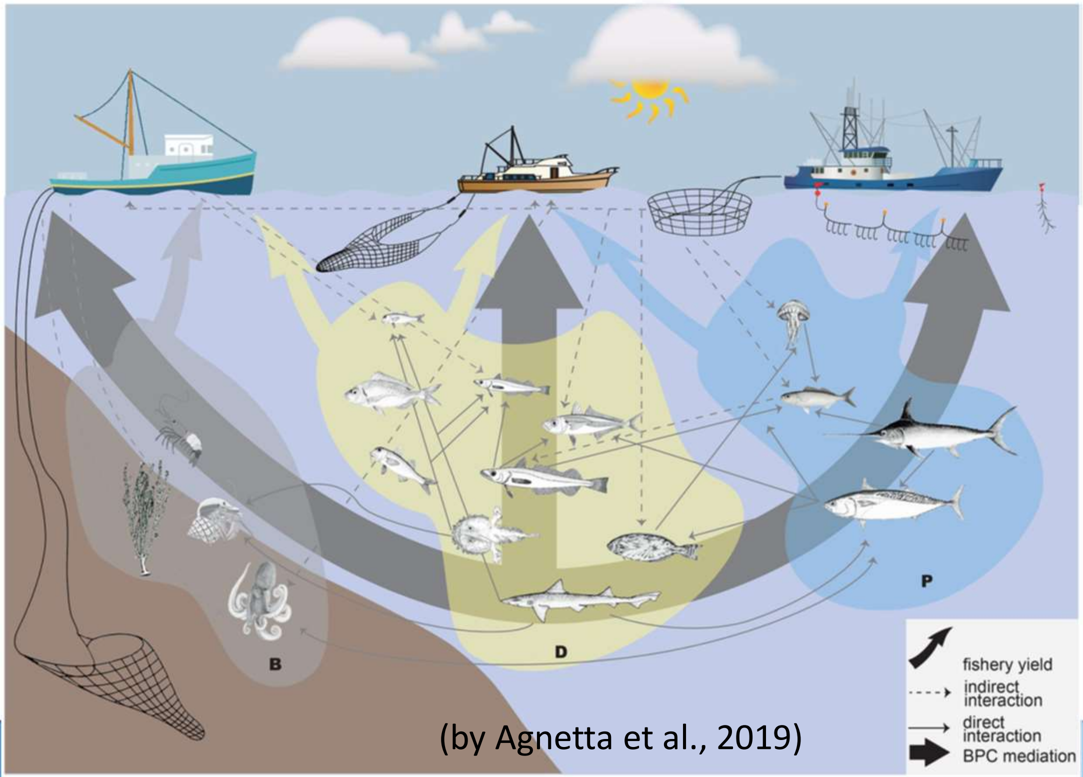


Modelling approaches for Ecosystem Based Fisheries Management



(by Agnetta et al., 2019)

The **progressive transition** in fishery sciences from a **species based approach** to a **"holistic" approach** considering the **trophic interactions** of species within an ecosystem.



(by Agnetta et al., 2019)

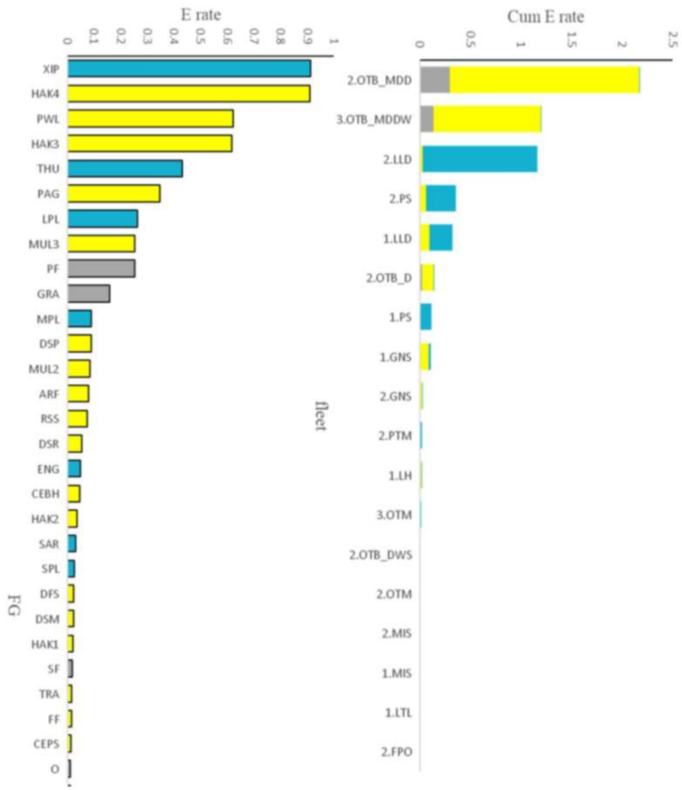
The **single species models** have been extended to more species linked by trophic relationships (**multispecific models**) up to numeric simulation of the ecosystem as a whole (**ecosystem models**) including the **biological, environmental, economic, social and administrative components of the system**.

Modelling approaches for Ecosystem Approch to Fisheries Management (EAFM)

The **EAFM perspective overcomes** the classic management targeting to maximize their production surplus (**Maximum Sustainable Yield**) or their economic performance (**Maximun Economic Yield**).

Despite several different ecosystem models are available (**EwE, Atlantis, Osmose, and so on**) they are still used mostly as **“strategic” tools** to provide insights on the **effects of fishing on the ecosystem in long term**.

Therefore the **short term advice** on the status of the stocks (**regulation of catch and/or fishing effort**) is still largely based on **single species models**.



()

Direct effects of fishing on the pelagic (cyan), demersal (yellow) and benthic (gray) domain in the Strait of Sicily assessed by Ecopath with Ecosim software. Exploitation rate (E) by fish functional groups (FGs) (left) and cumulative exploitation rate (Cum E) by fleet (right) (by Agnetta et al., 2019).

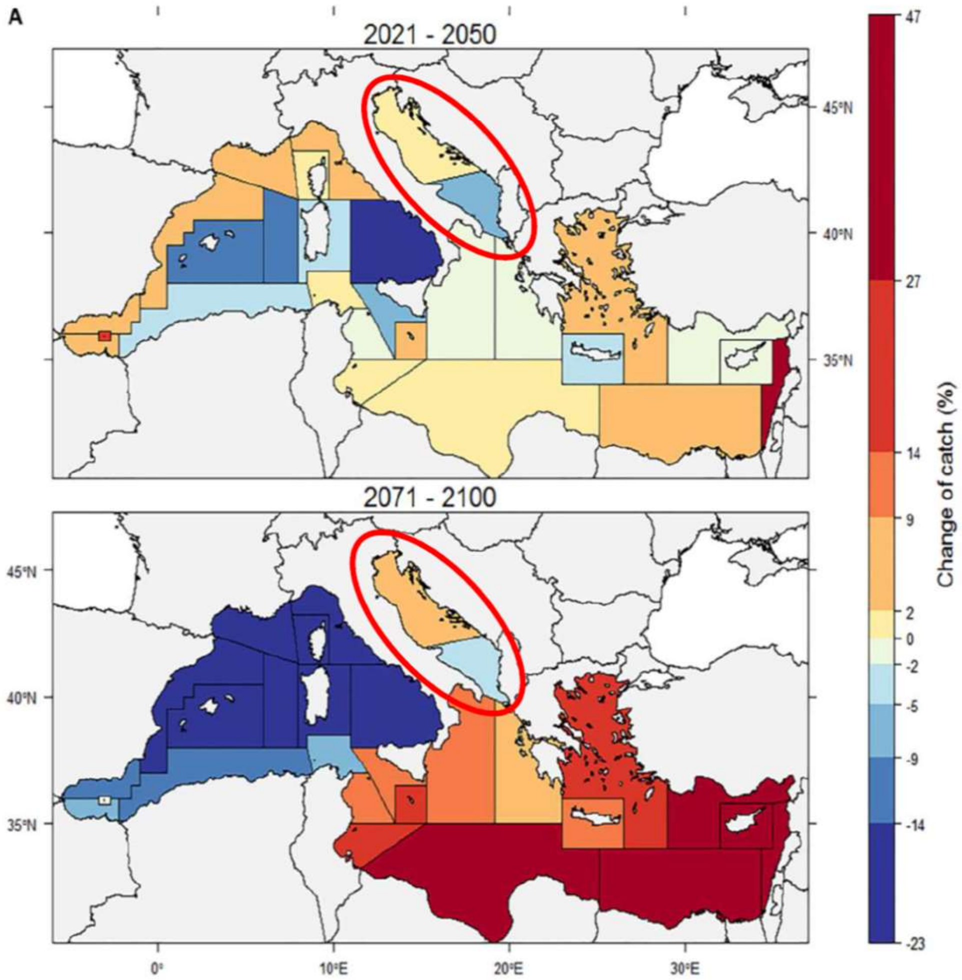
Some simulation of multispecies spatial dynamics under the current emission of CO_2 and fishing mortality scenarios using Eco3M-S coupled with OSMOSE models

The total catch of the Mediterranean is expected to increase by 0.3 and 7% in the first and second half of the XXI century, respectively.

Catch would increase in the south-eastern part of the basin while it could decrease by up to 23% in the Western part.

Winner species would mainly belong to the thermophilic and/or exotic pelagics, with smaller size and low trophic level.

Loser species are expected to be large-sized, some of them of great commercial interest, with a contraction or shift of their geographic range.



by Moullec et al., 2019

The importance of evaluating modeling approaches in stock assessment

- **Model exploration** allows to evaluate the consequences of model choice and provides guidance on **uncertainty and limitations of both models and available data**

- The **use and comparison of multiple models** may provide insights on uncertainty

- **Graphical methods, diagnostic approaches, and model comparisons** provide a good way of understanding the behaviour of models taking into account the quality and quantities of information

- A **single number of statistic** may give **false sense of security** (certainty) about the question being addressed

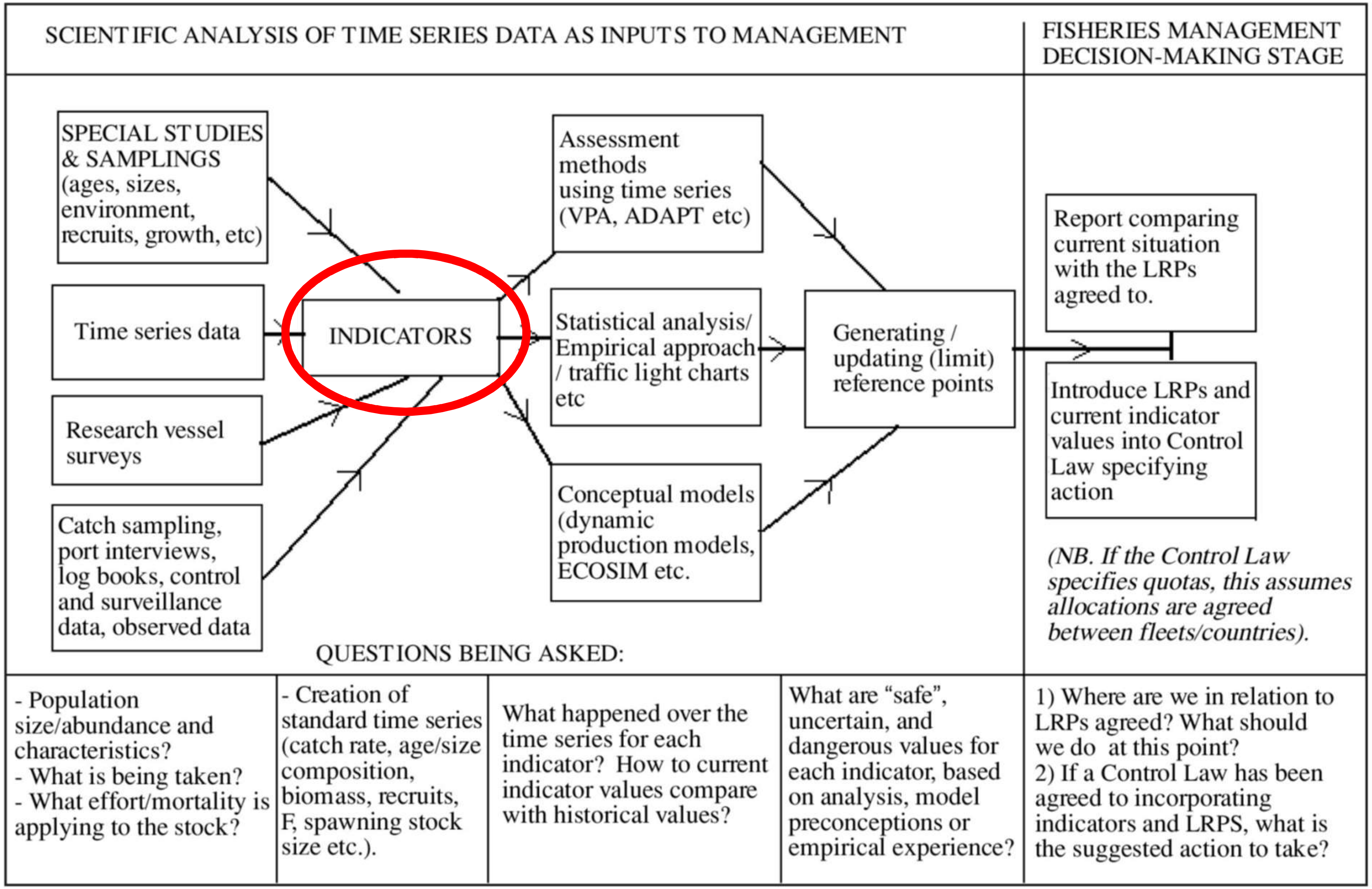
- Both **real and simulated data** are useful in understanding and characterizing **model performance**.

Some indicators of different proprieties of fishery systems

Indicator	*Characteristic*
1. Mean survey catch per trap	Abundance
2. Area with density $>5 \cdot m^{-2}$	
3. Early-season catch per trap haul	
4. Bycatch species A on trawl fishery for species B	
1. Number of recruits (carapace length <5 cm)	Production
2. Area of recruit density $>10 \cdot m^{-2}$	
3. Mean size of mature females	
4. condition factor (carapace length = 10-15 cm)	
1. Mean Z_t from survey data	Fishing pressure
2. Fleet days fished per season	
3. Immature individuals (%)	
4. Annual number of trap hauls per area grounds	
1. Abundance (predator 1/species A)	Ecosystem/environment
2. Abundance (predator 2/species A)	
3. Absolute value (bottom, temperature - optimum temperature)	
4. Prey abundance$\cdot m^{-2}$	

by Caddy, 2010

Some alternative trajectories for scientific data-gathering, analysis, and advice to fisheries management. The central role of indicators is shown



(by Caddy, 2009)

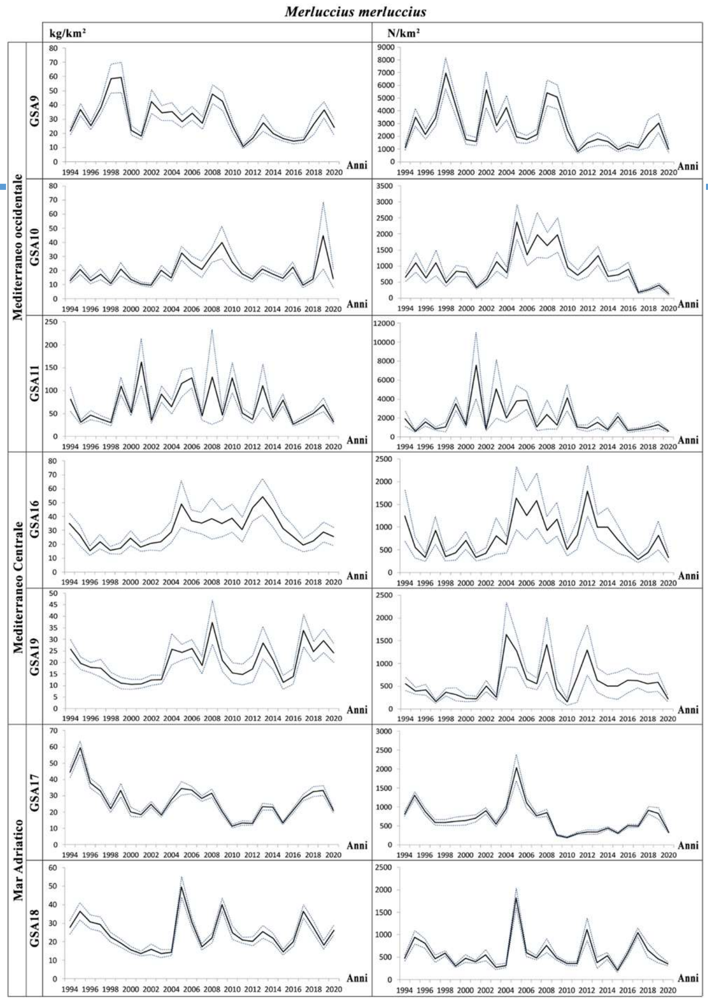
The main features of the Mediterranean fisheries and the choice of good indicators and modelling approaches

The choice of **indicators and models** to describe stock status and fishery performances **in the Mediterranean** must consider the following characteristics:

- Frequent use of **non selective gears**
- **Premature size/age** of first capture
- **Multispecies** targets
- **Multigear** fisheries
- **Scattered** distribution of **landing** sites
- Good market interest on **small-sized individuals**
- Short-life species **fishing success** depending from **recruitment**

Some examples of empirical indicators – abundance throughout time

Biomass (kg/km2) and density (N/km2) indices of **Hake** (Merluccius merluccius) in the GSAs around Italy (Medits series 1994-2020).



Spearman's Rho of the biomass (kg/km2) and density (N/km2) indices of **Hake** (Medits series 1994-2020). In bold the significant values (alpha ≤ 0.05).

	Western Mediterranean			Central Mediterranean		Adriatic Sea	
Indicator	**GSA9**	**GSA10**	**GSA11**	**GSA16**	**GSA19**	**GSA17**	**GSA18**
Occupied area	0,240	**0,407**	-0,170	0,235	0,273	-0,437	0,190
Biomass (kg/km^2)	**-0,417**	0,237	-0,081	0,350	0,338	-0,374	-0,024
Number (n/km^2)	**-0,4119**	-0,207	-0,273	0,003	0,336	-0,433	-0,054

(by Maiorano et al., 2022)

Using a suite of indicators to describe the status of exploited species and communities of demersal resources in the Ligurian Sea and North Tyrrhenian Sea (GSA 9) – trend analyses

SPECIES									
INDICATOR	***M. merluccius***	***M. barbatus***	***N. norvegicus***	***P. longirostris***	***A. foliacea***	***A. antennatus***	***E. cirrhosa***	***E. encrasicolus***	***S. pilchardus***
Occupied area	[yellow]	[green]	[yellow]	[green]	[green]	[yellow]	[yellow]	[green]	[yellow]
Biomass (kg/km^2)	[red]	[green]	[yellow]	[green]	[yellow]	[yellow]	[red]	[green]	[yellow]
Number (n/km^2)	[red]	[green]	[yellow]	[green]	[yellow]	[yellow]	[red]	[green]	[yellow]
$L_{0,95}$	[yellow]	[yellow]	[yellow]	[red]	[yellow]	[yellow]	[yellow]	[green]	[green]
L minimum									
L median									
L maximum									
Recruitment	[red]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[red]	[yellow]	[yellow]
Stock status	[red]	[green]	[green]	[red]	[red]	[red]		[green]	[green]

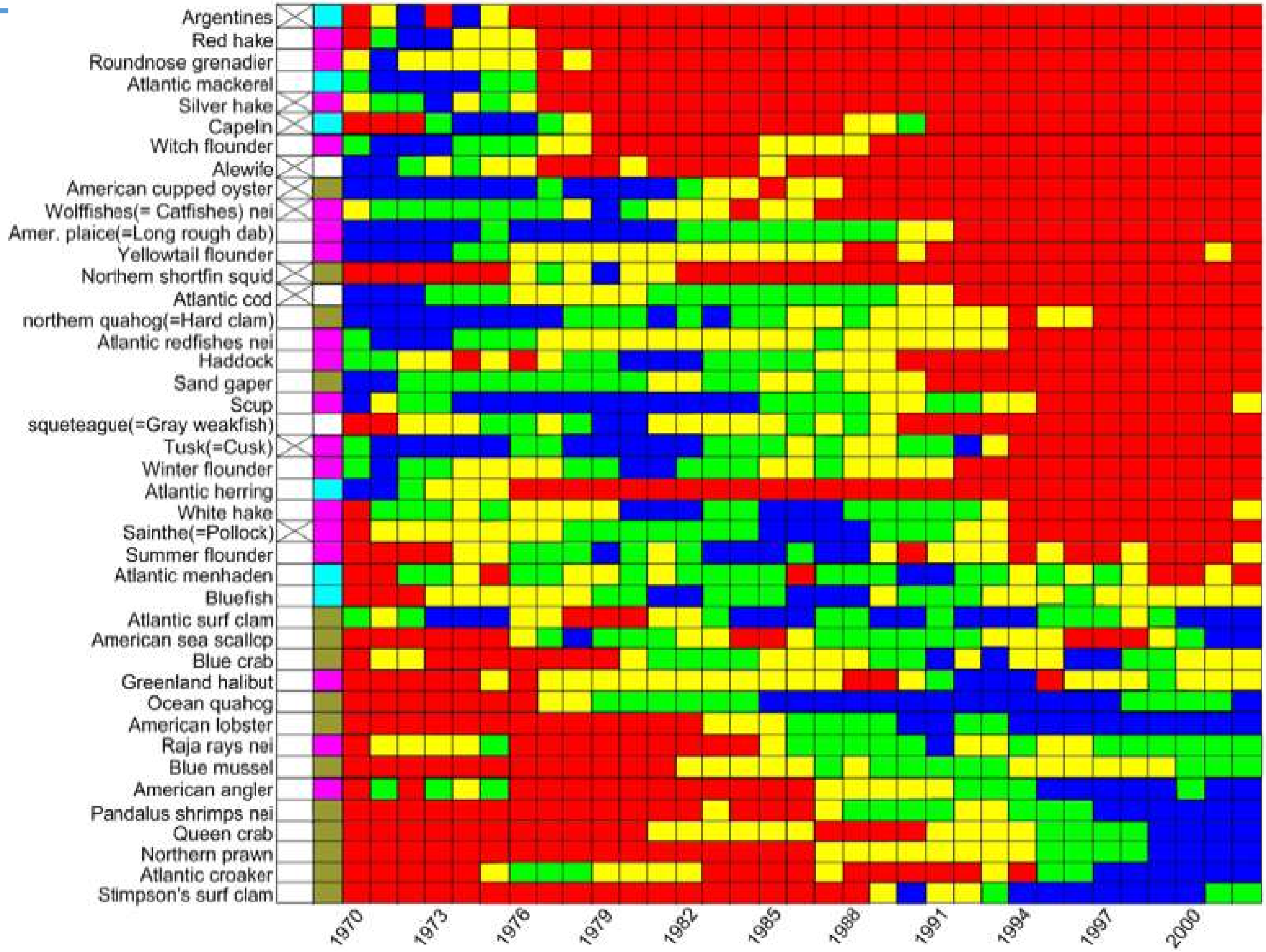
COMMUNITIES							
INDICATOR	**Biomass**					**Diversity**	**$L_{0,95}$**
	Teleosts	**Selachians**	**Cephalopods**	**Crustaceans**	**Total**		
	[yellow]	[green]	[yellow]	[green]	[yellow]	[yellow]	[red]

Color refers to positive (green), stable (yellow) and negative (red) trend from 1994 to 2020

Out of 58 indicators considered, 18 are positive and 13 are negative

(by Maiorano et al., 2022)

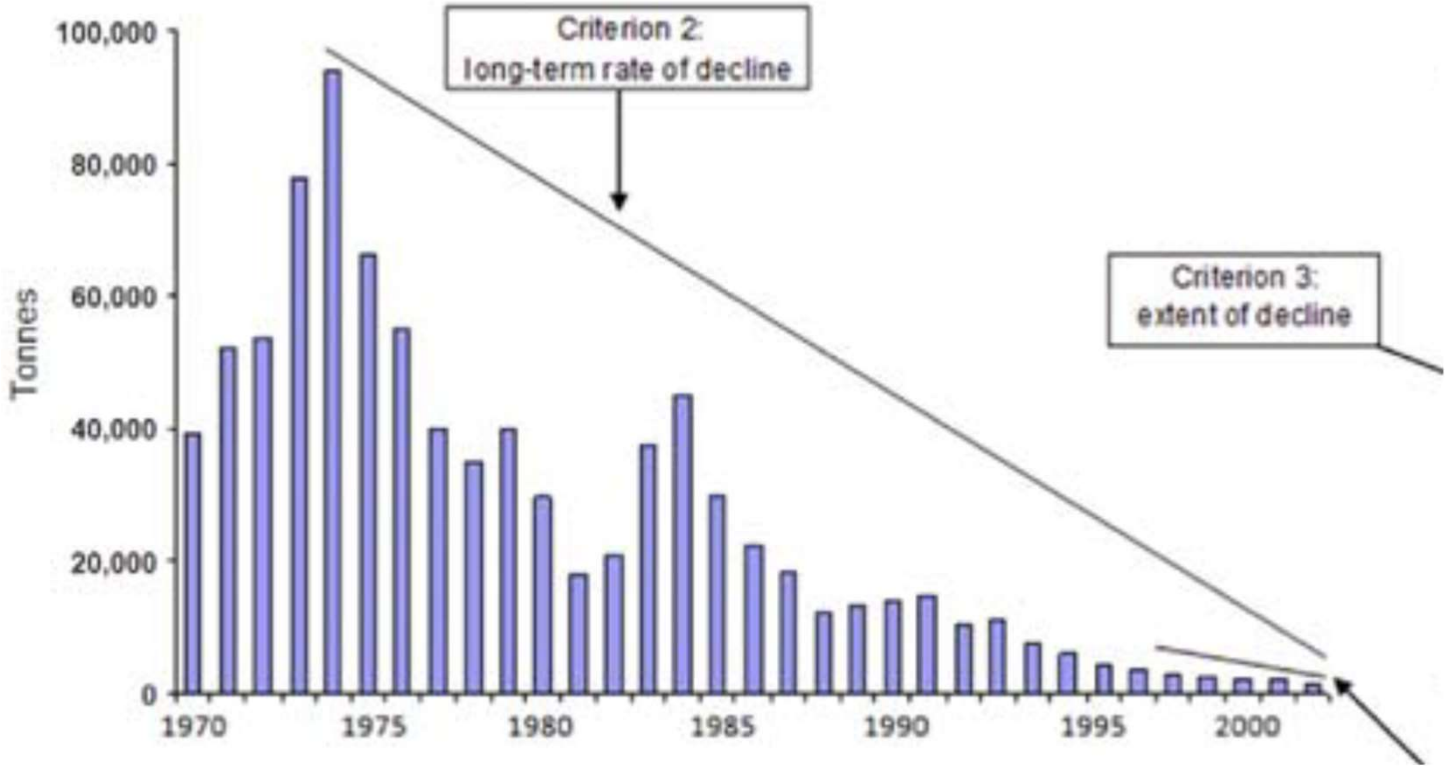
Some example of use of empirical indicators for assessing the stock status of the fisheries resources – the ranking and the temporal pattern of catch quantile



If indicators have to be aggregated, weighting is necessary according to the relative importance of each one considering the management objectives

(by Caddy, 2010)

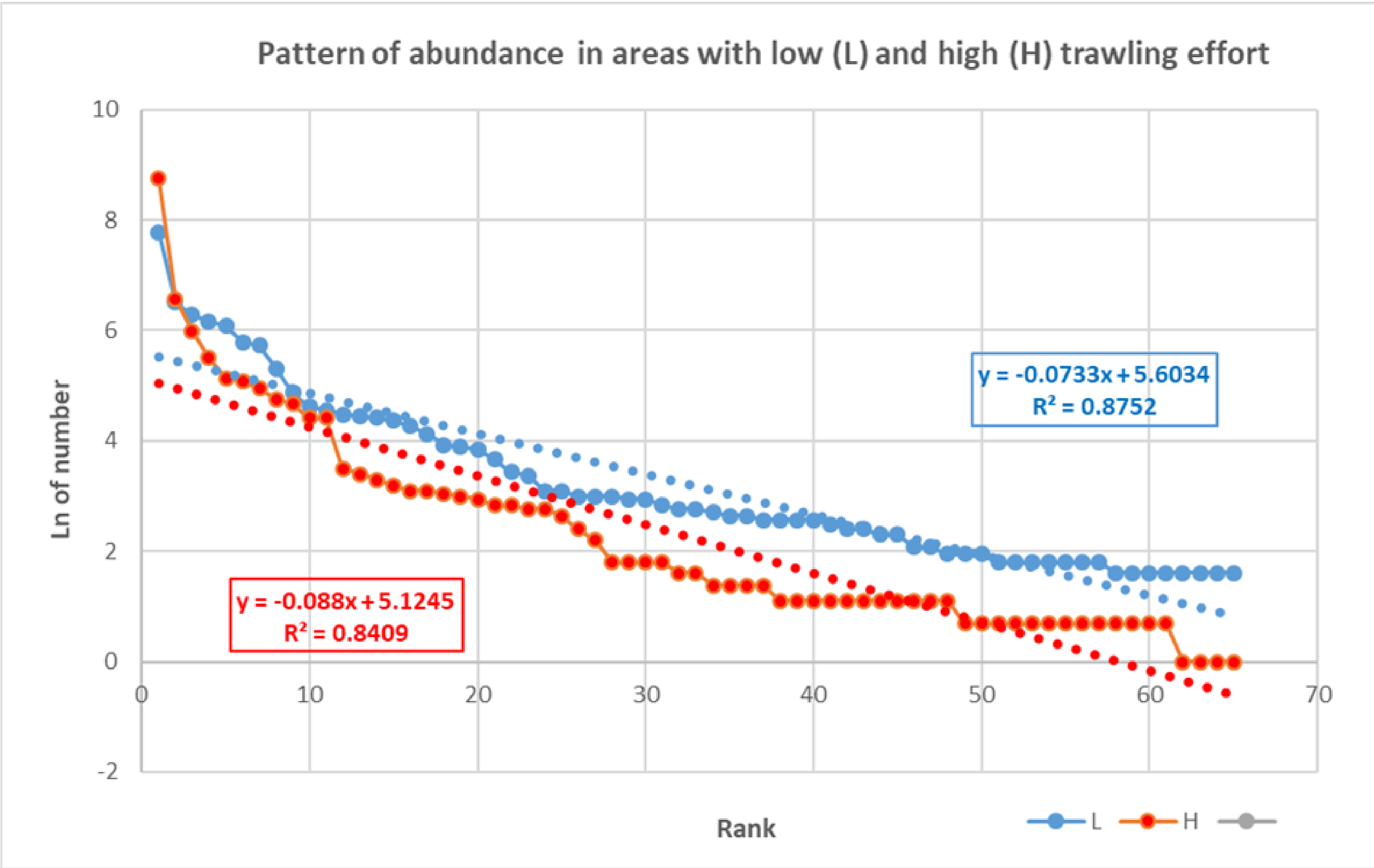
An empirical indicator for assessing the stock status of the fisheries resources – the rates in catch decline



(by Caddy, 2010)

An empirical indicators for assessing the stock status of the fisheries resources

The slope of the rank abundance in two areas of the Strait of Sicily affected by low (L) and high (H) trawling effort

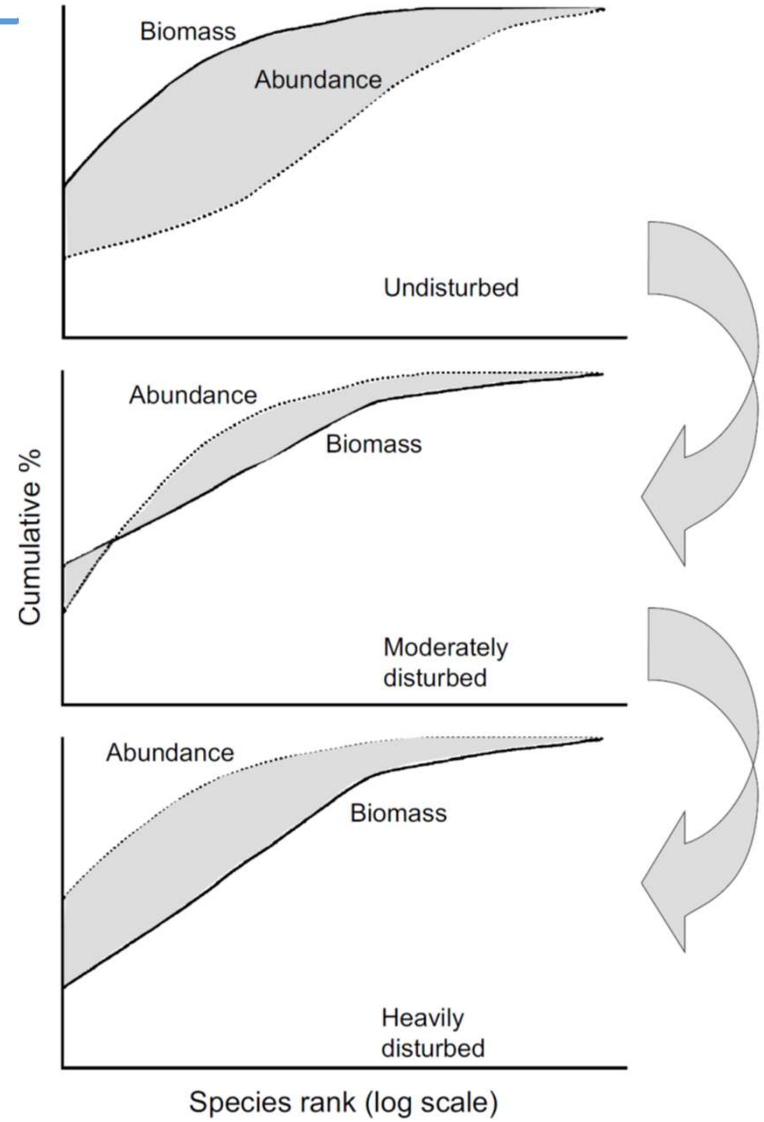


An indicator of the status of fished communities
- the Abundance Biomass Comparison

The **Abundance Biomass Comparison** (**ABC**) assumes that, in a **"stressed" community**, **densities increase at the expense of** biomass.

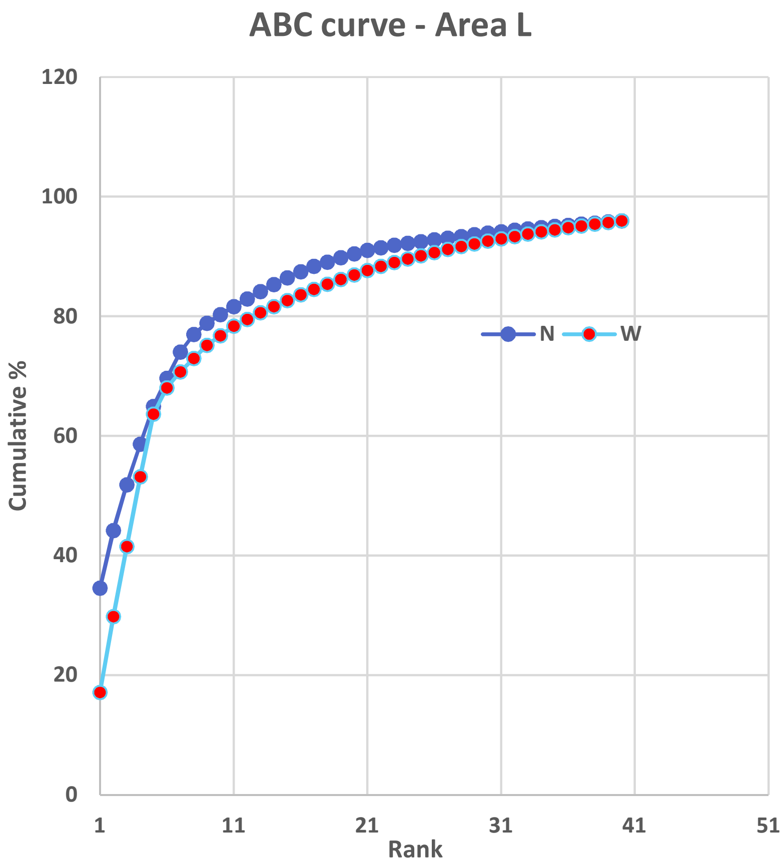
The **ABC curves** allow to obtain profiles representative of **three different situations**:

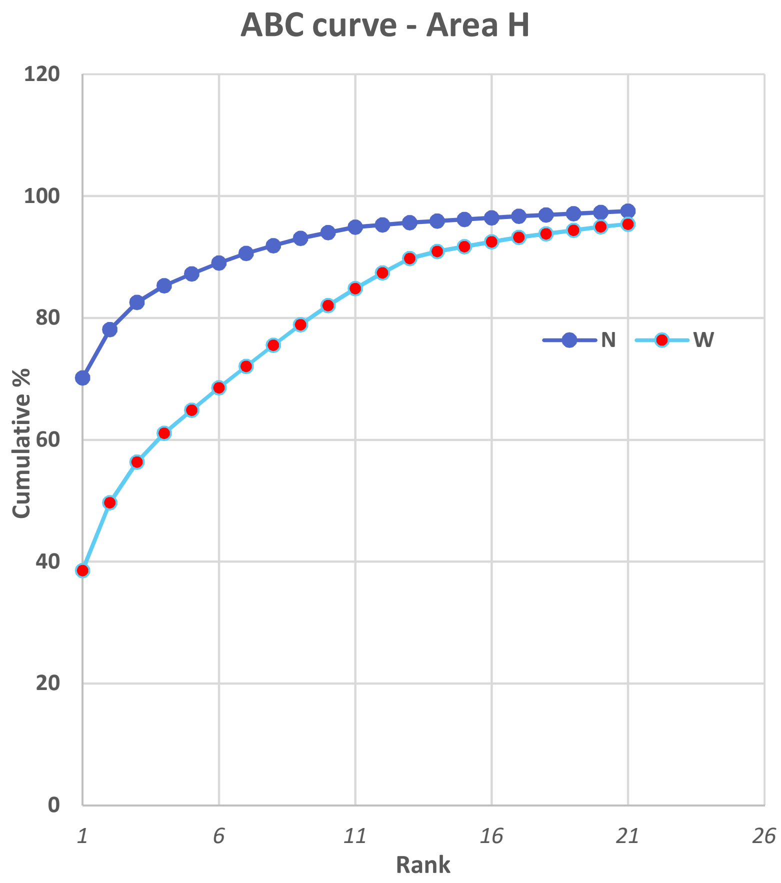
- non-stressed (biomass curve (BC) is significantly higher than the density curve (DC)),
- moderately stressed (the two curves tend to overlap and are not clearly distinguishable),
- highly stressed (the cumulated DC lies above the cumulated BC) communities.



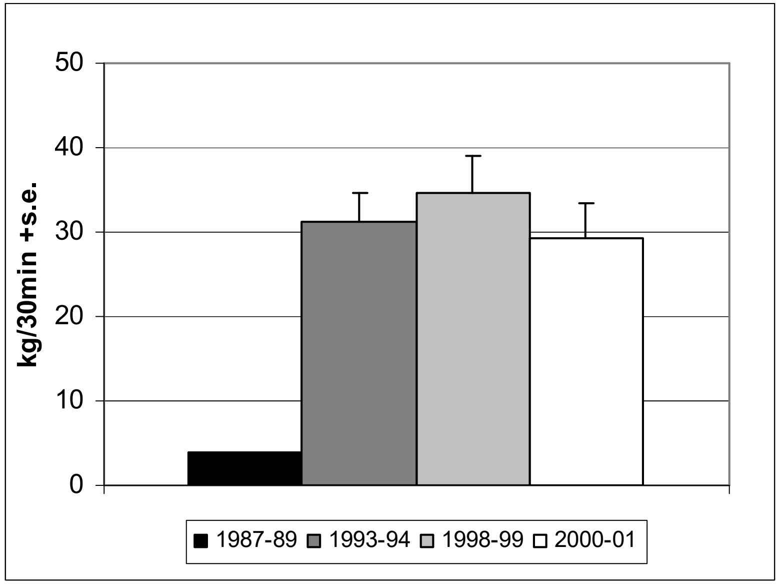
(by Yemine et al., 2005)

An example of Abundance Biomass Comparison (ABC) curves from two areas of the Strait of Sicily affected by low (L) and high (H) trawling effort





What do the empirical indicators tell us on the restoring of Biomass and Size Structure in a Mediterranean Fisheries Restricted Area?



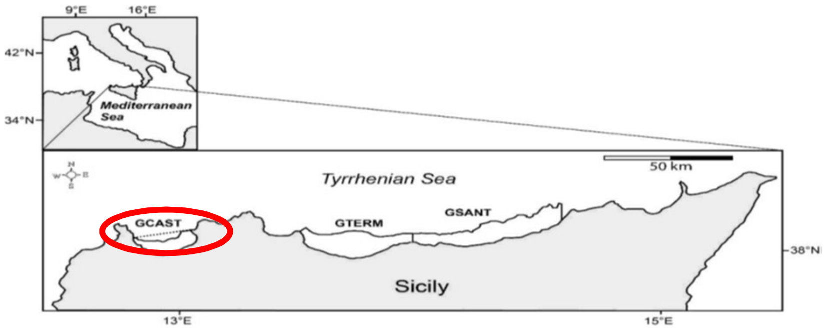
Catch rate in trawl surveys in the Gulf of Castellammare (GCAST) **before** (1987-89) **and after** the implementation of the **FRA** (from Pipitone et al., 2001).

Table 3. Mean biomass (kg/km²) of the total trawlable assemblage in the before-1990 and after-1990 periods in the three gulfs. s.d.: standard deviation.

	Before-1990	s.d.	After-1990	s.d.
GCAST	203.1	±54.12	1265.6	±866.81
GTERM	108.7	±43.15	130.7	±49.39
GSANT	139.9	±53.59	132.0	±90.06

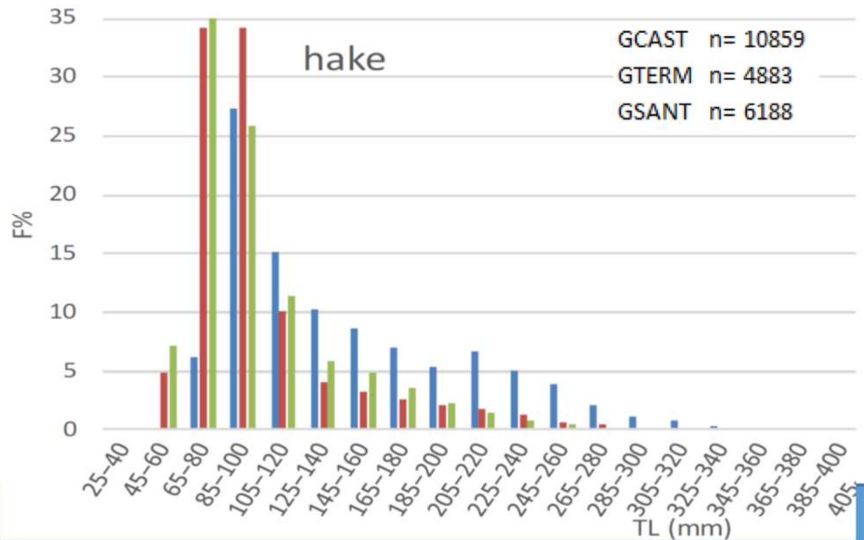
The size structure of each selected species was described by its length frequency distribution (LFD) and by the following **length based indicators** :

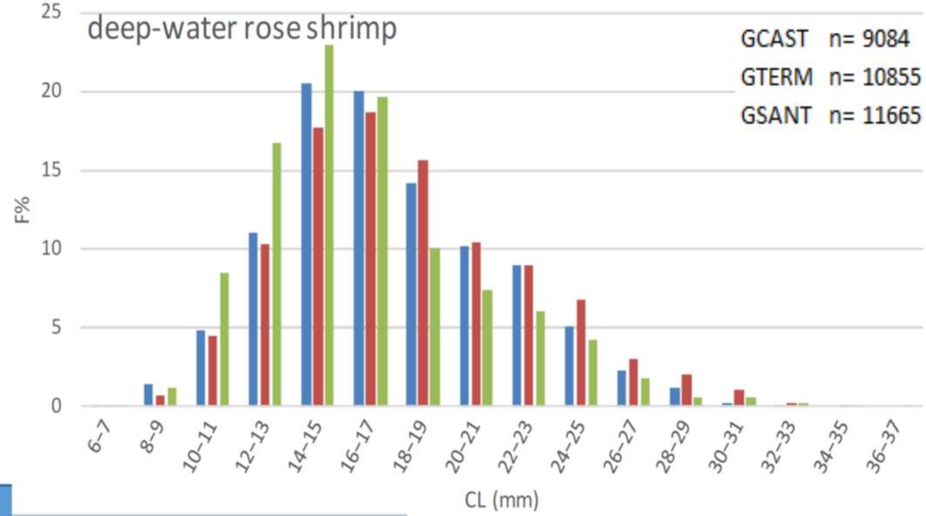
- **Lm, median length**;
- **L95, the 95% percentile of each LFD**;
- **L2/3, the percentage of individuals larger than 2/3 of the maximum length** recorded in the samples.



The Gulfs of **Castellammare (GCAST), Termini Imerese (GTERM)** and **Sant'Agata (GSANT)**

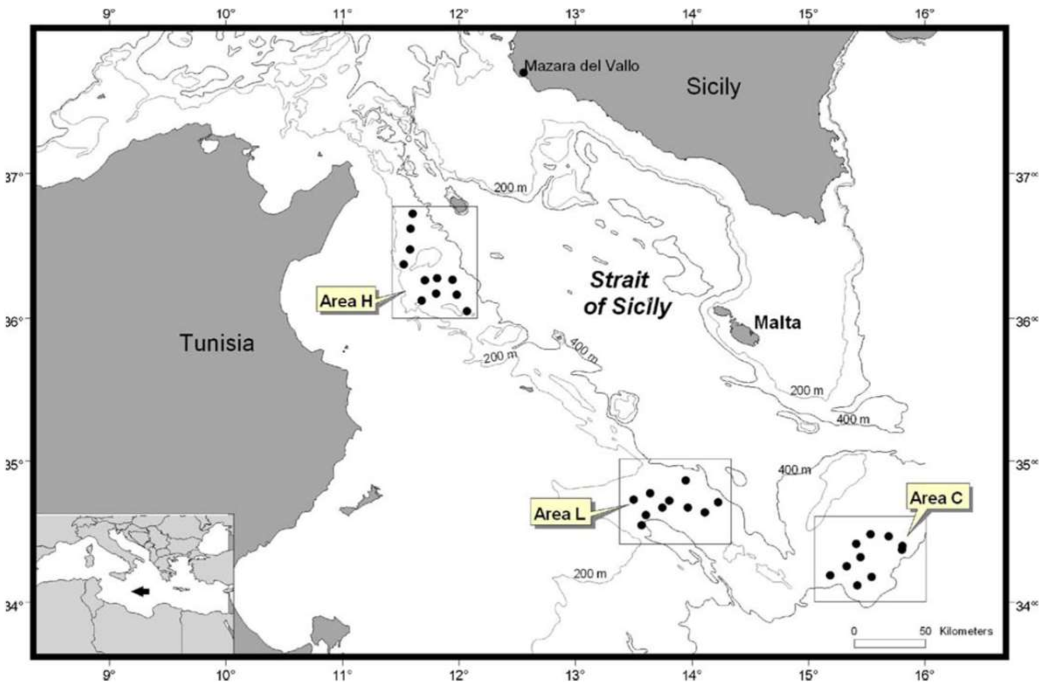
	L_m (mm)			L_{95} (mm)			$L_{2/3}$ (%)		
	GCAST	GTERM	GSANT	GCAST	GTERM	GSANT	GCAST	GTERM	GSANT
midsize squid	**52**	47	42	77	**78**	67	**15**	6	2
horned octopus	**92**	72	77	111	117	**121**	**38**	27	19
broadtail squid	62	**68**	58	**183**	153	91	**11**	5	2
elegant cuttlefish	**38**	32	32	51	**53**	51	**47**	15	13
deep-water rose shrimp	16	16	**18**	111	117	**121**	**38**	27	19
scaldfish	**97**	88	82	**142**	127	127	**24**	6	**24**
boarfish	**48**	42	42	72	51	**74**	3	2	**11**
red gurnard	**132**	72	77	**223**	81	90	**16**	1	2
large-scaled gurnard	**102**	68	72	**121**	92	108	**61**	3	11
hake	**127**	87	87	**262**	192	203	**7**	0	0
red mullet	**123**	122	117	**172**	166	**172**	4	11	**15**
pandora	**168**	117	142	**268**	211	212	6	**21**	16
greater forkbeard	**127**	108	103	**232**	172	171	9	10	**15**
picarel	**128**	122	122	172	177	**178**	**39**	22	21



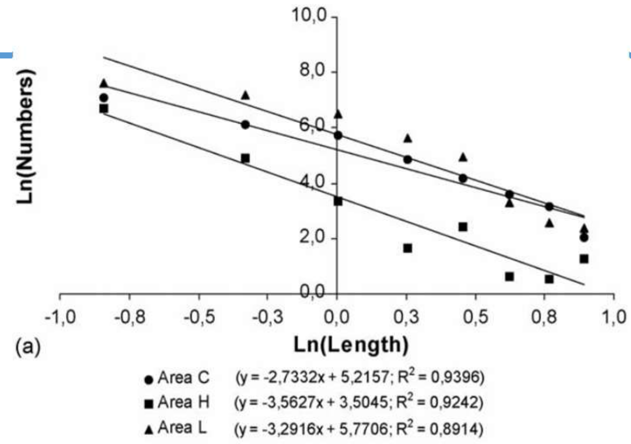


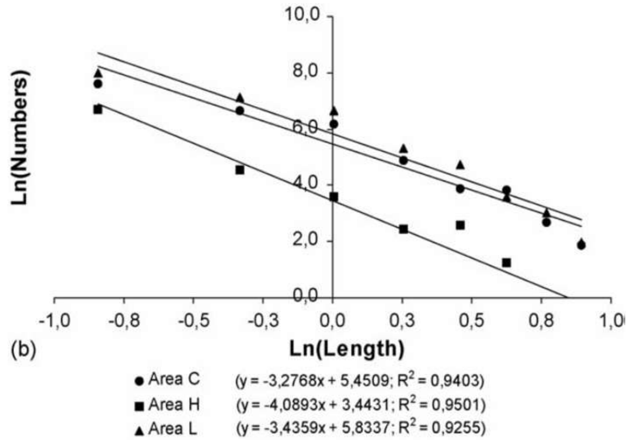
Blue CAST; RED term, and green SANT

The empirical indicators and how fishing can shape the fish communities



Three areas of Strait of Sicily affected by null (C), low (L) and high (H) trawling effort

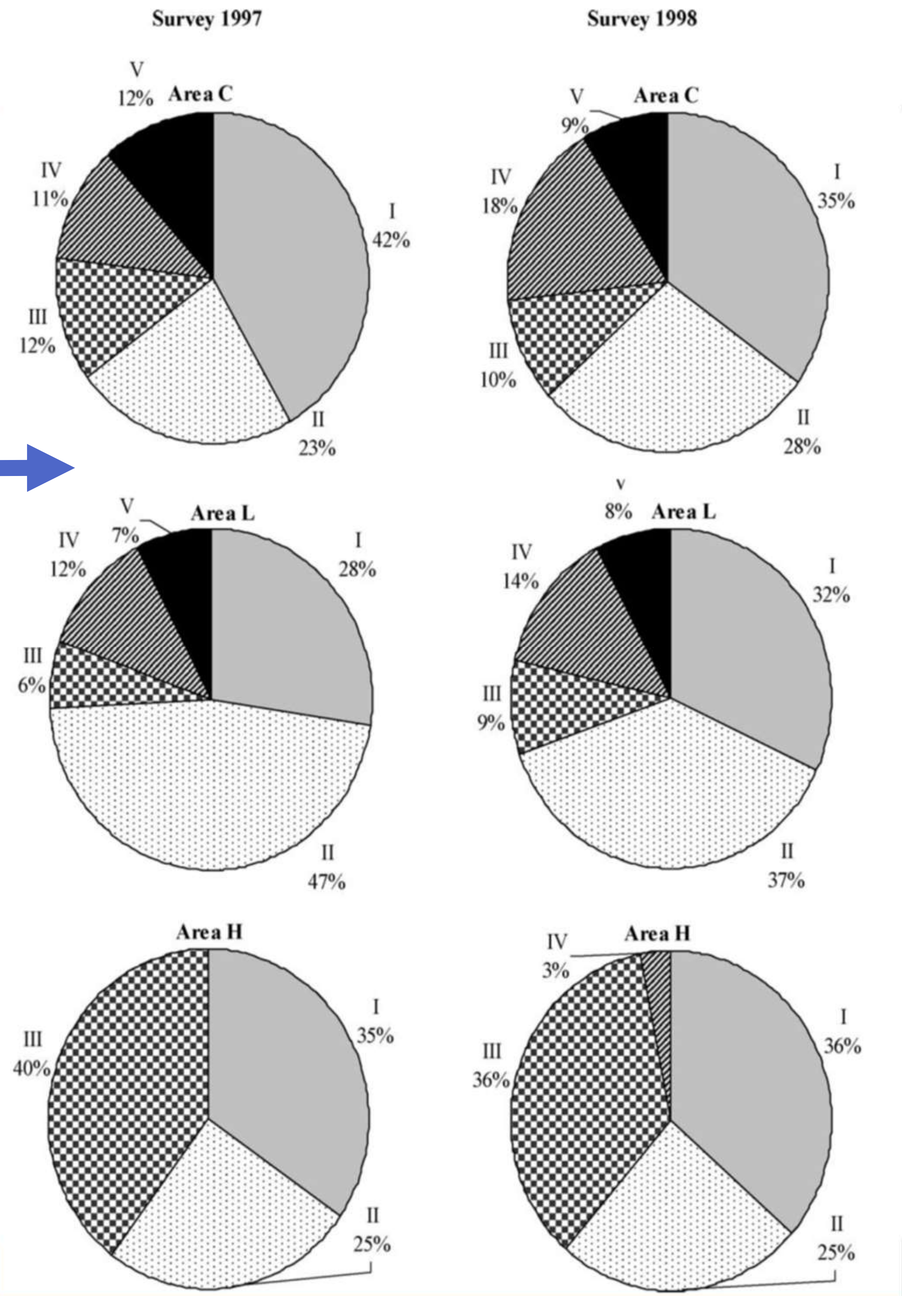




The **size spectra** analyses (Ln of numbers vs ln of length) show that the size structure in the area H is characterized by smaller size than those in the other two ones (C and L)

Proportion of fish biomass by categories of vulnerability to trawling, resulted different in the three areas, being the elasmobranchs virtually absent in the catch in the H area

Vulnerability categories: (I) small teleosts; (II) medium teleosts; (III) large teleosts; (IV) small elasmobranchs; (V) large elasmobranchs



Diversity indices

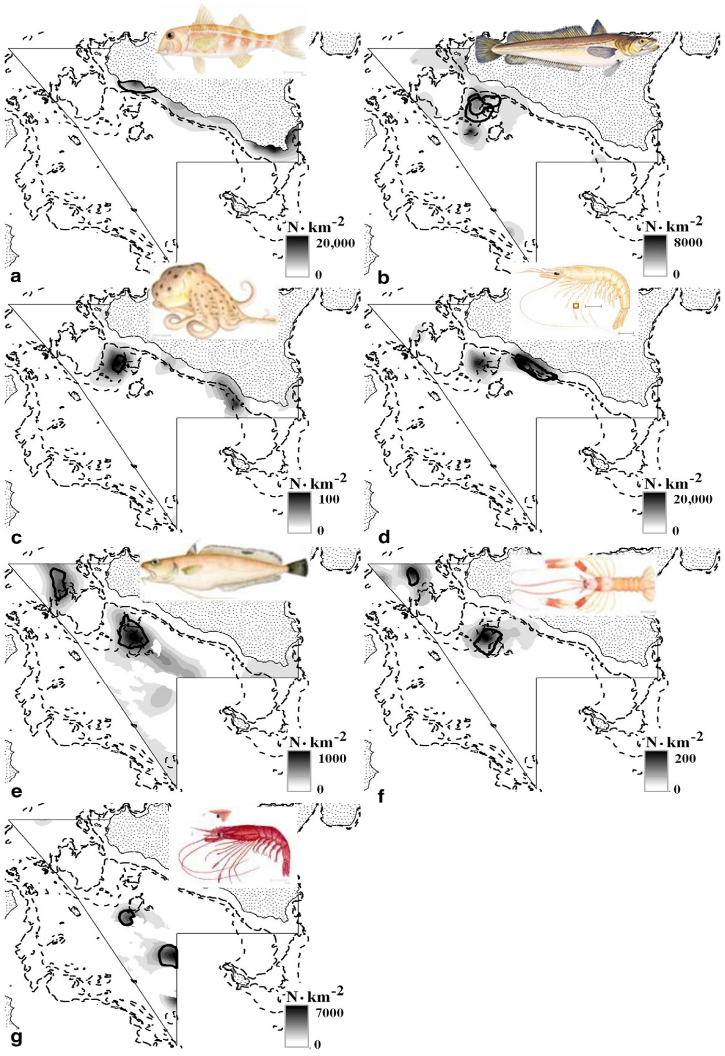
	C97	H97	L97	C98	H98	L98
J'	0,52	0,54	0,49	0,55	0,49	0,51
H'(loge)	1,59	1,60	1,60	1,74	1,51	1,66
Δ*	67,80	59,38	67,70	67,54	60,51	67,49
	└ * ┘	└ * ┘		└ * ┘	└ * ┘	
Δ⁺	71,31	67,83	71,65	71,00	67,77	71,74
	└ * ┘	└ * ┘		└ * ┘	└ * ┘	

J': Pielou's evenness index, H': Shannon–Wiener diversity index, Δ^*: distinctness index, Δ^+: distinctness index presence/absence. Indices showing significant differences among areas according to the Kruskal–Wallis test in

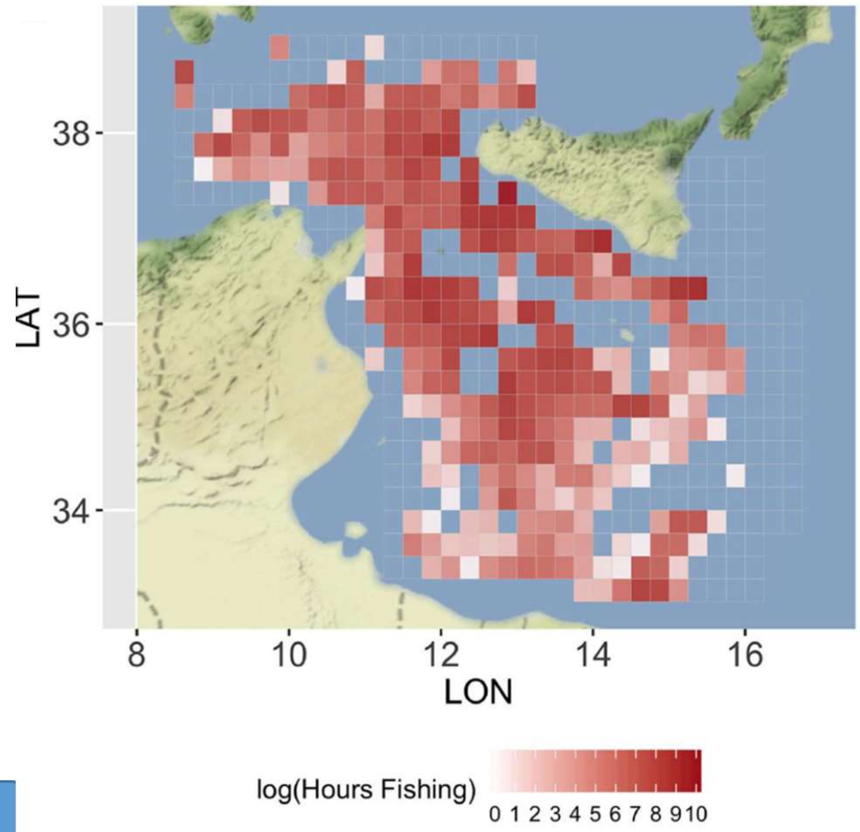
Diversity indices show differences only in taxonomic distinctness

The use of spatial based indicators of stock status and fishing pressure

Density maps of recruits and persistent nurseries (by Garofalo et al., 2011)

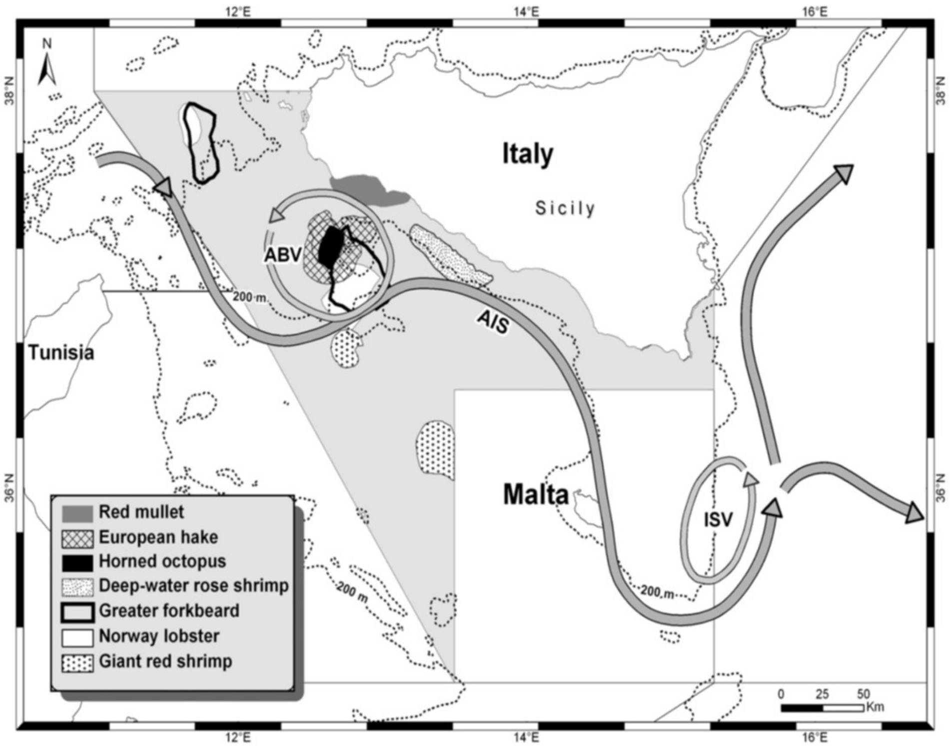


The mean annual fishing effort (2012–2016) as red-scale color (log of total fishing hours) (by Russo et al., 2019)



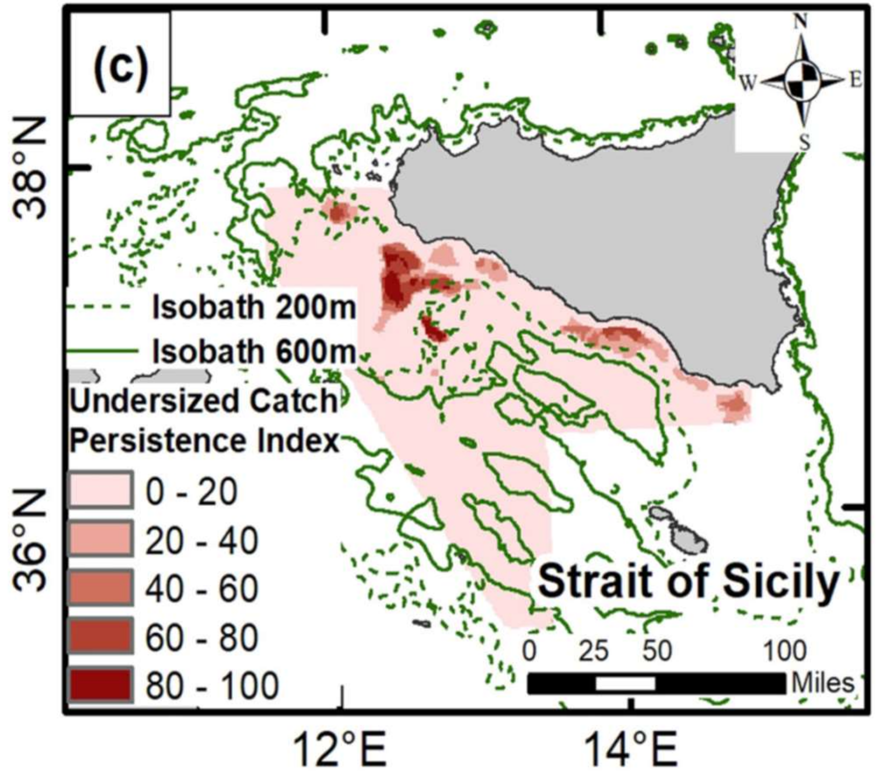
The use of spatial based indicators of stock status and fishing pressure

The persistent nurseries and main hydrological features in the northern sector of the Strait of Sicily



(by Garofalo et al., 2011)

Persistence index maps of undersized catch of species subjected to Minimum Conservation Reference Size in the Strait of Sicily



(by Despoti et al., 2020)

Framework of stock assessment categories according to available knowledge for producing advice in the ICES area

Increasing of available information ↑

	Stock categories		Advice basis
1	Stocks with quantitative assessments	Stocks with full analytical assessments and forecasts as well as stocks with quantitative assessments based on production models	MSY approach
2	Stocks with analytical assessments and forecasts that are only treated qualitatively	Stocks with quantitative assessments and forecasts which for a variety of reasons are considered indicative of trends in fishing mortality, recruitment and biomass	MSY approach
3	Stocks for which survey-based assessments indicate trends	Stocks for which survey or other indices are available that provide reliable indications of trends in stock metrics, such as total mortality, recruitment and biomass	Precautionary approach, MSY approach being developed
4	Stocks for which only reliable catch data are available	Stocks for which a time series of catch can be used to approximate MSY	Precautionary approach, MSY approach being developed
5	Landings only stocks	Stocks for which only landings data are available	Precautionary approach
6	Negligible landings stocks and stocks caught in minor amounts as by-catch	Stocks for which landings are negligible in comparison with discards and stocks that are primarily caught as by-catch species in other targeted fisheries	Precautionary approach

The choice of indicators and assessment approaches for stock evaluation depends on data availability, and biological and fishery features

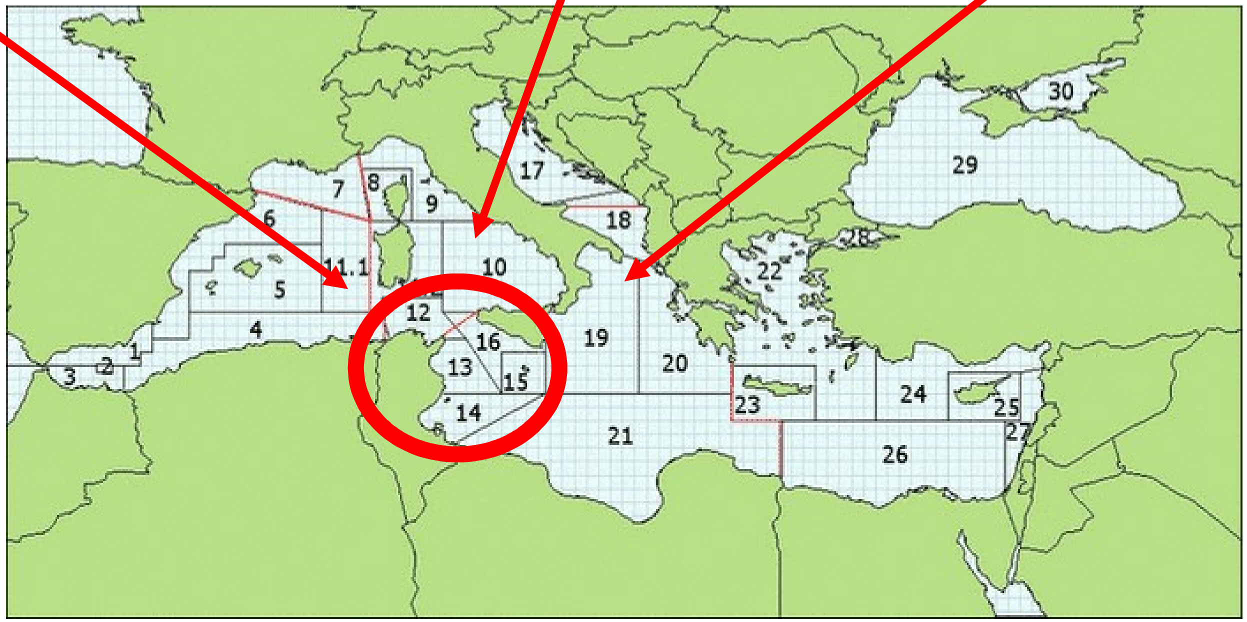
(by Spedicato et a., 2019)

How can we use indicators and related reference points obtained by a formal stock assessment?
The case of the target species of the Multi Annual management Plans in the Strait of Sicily adopted by the GFCM and EU...

Rec. GFCM/45/2022/4 : Hake, and Deep water rose shrimp

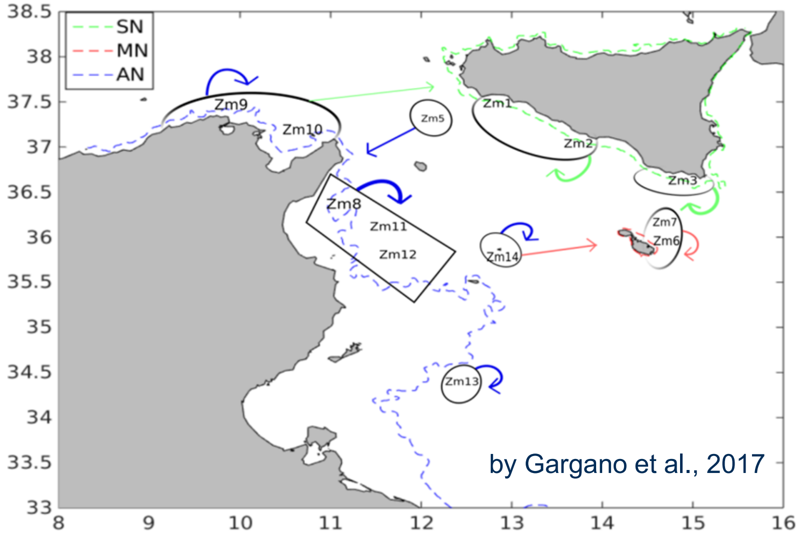
Rec. GFCM/45/2022/5 Giant red shrimp, and Red and violet shrimp

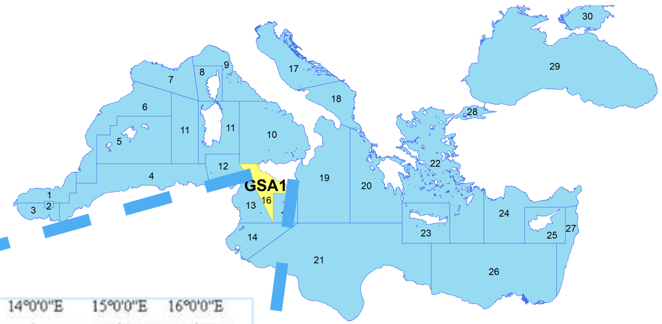
Reg. 195/2023

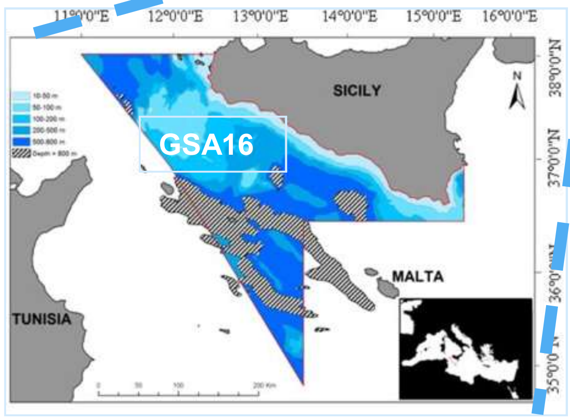


The case of red mullet in GSA 16…an example of sustainable European fisheries in the Mediterranean… a yield of about 200 t in 2021…

STOCK IDENTIFICATION



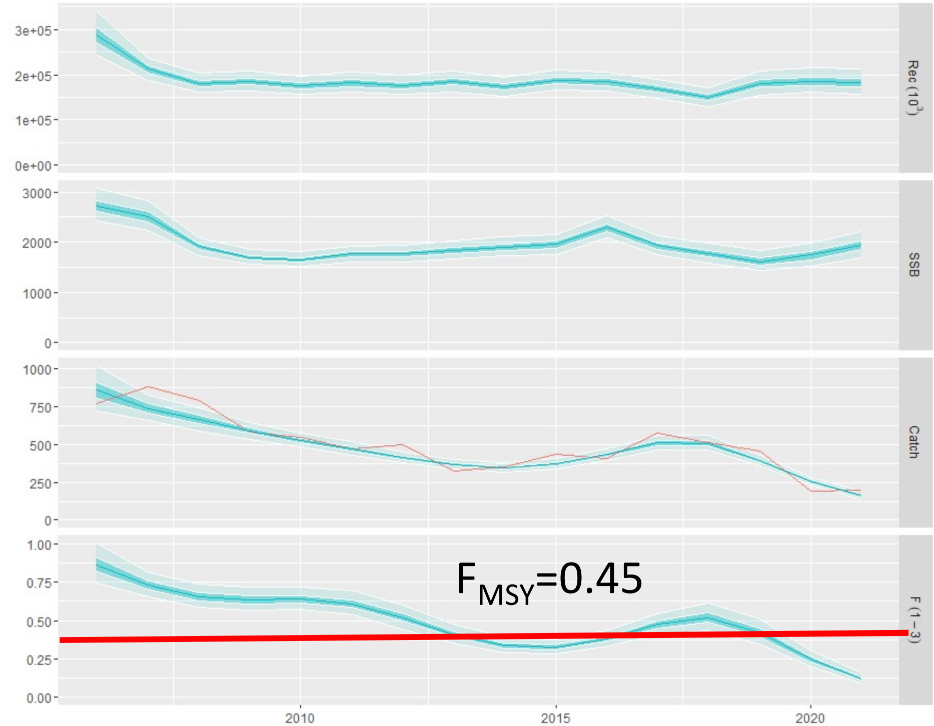


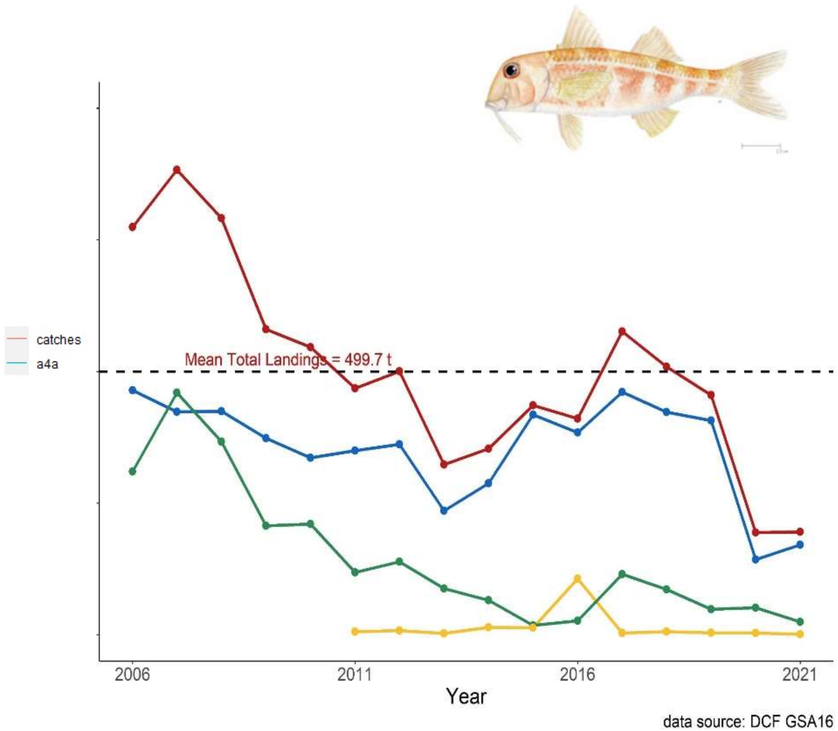


Based on available knowledge Red mullets inhabiting the continental shelf off the southern coast of Sicily (GSA 16) are considered as a stock unit for stock assessment purposes

Mullus barbatus

The stock assessment of red mullet in the Strait of Sicily by a4a analisys presented at GFCM Working Groups on Stock Assessment (WGSAs) 12-17 December 2022 in Rome





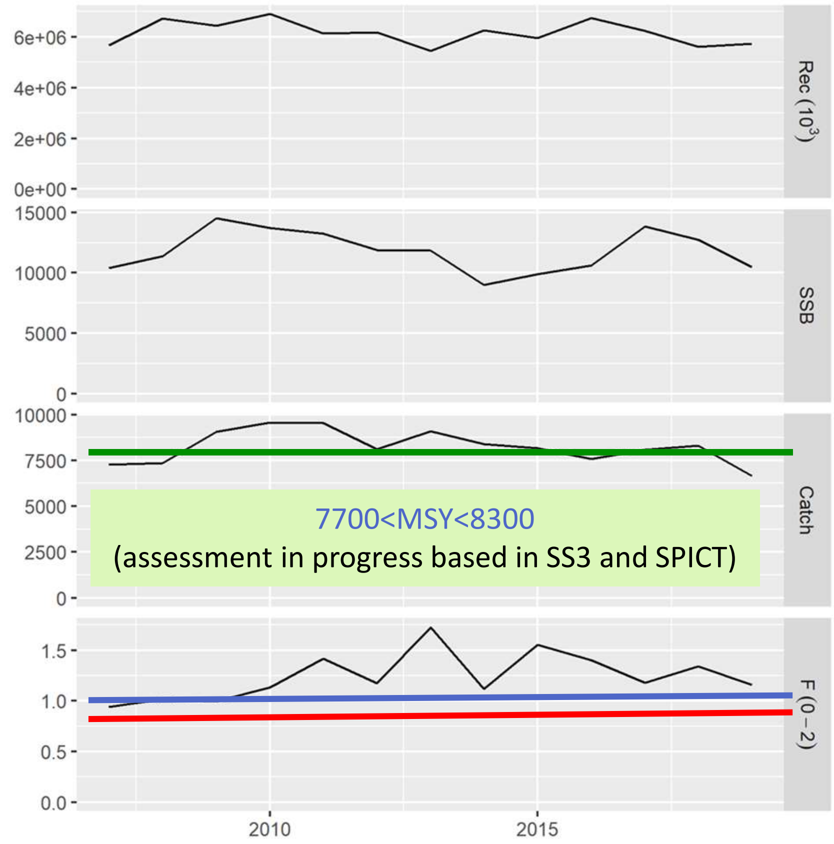
Red mullet off the southern coast of Sicily (GSA 16) is in sustainable exploitation:

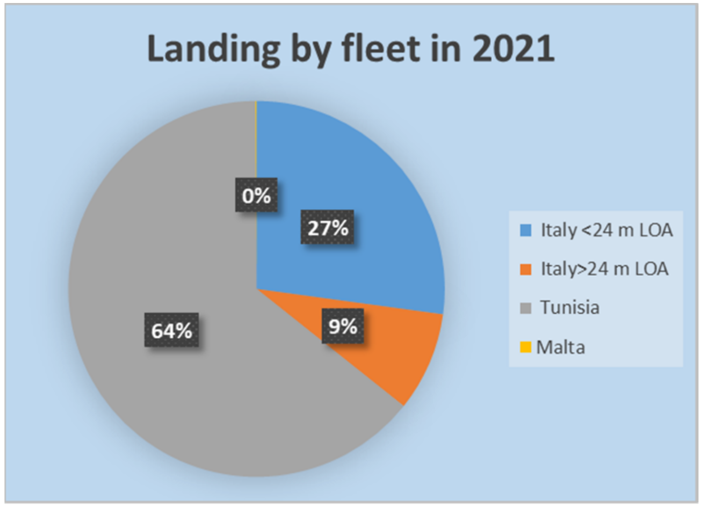
- Nurseries within 3 miles protected from trawling;
- Reduction of bottom trawling targeting "fish and cephalopods"
- Trawling stop in autumn suitable to avoid capture of red mullet juveniles.

(by Scannella et al., 2022)

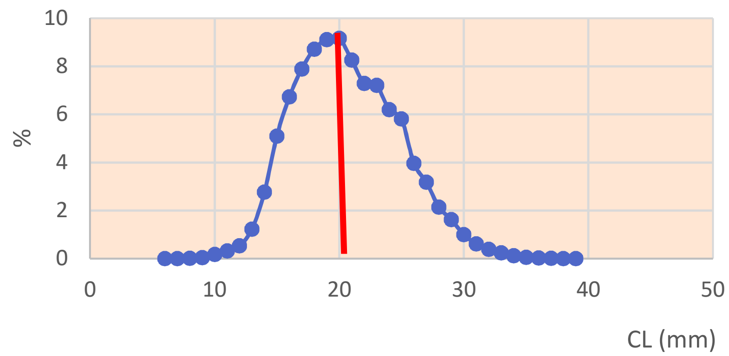
The case of deep water rose shrimp...a stock shared with EU and third countries...a yield in 2020 of 4300 t...of 6400 t in 2021......the updated assessment of the status of the resource is in progress....

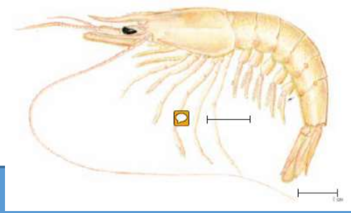
The old assessment based on XSA and data up to 2020





LFD of catches 2018-2021

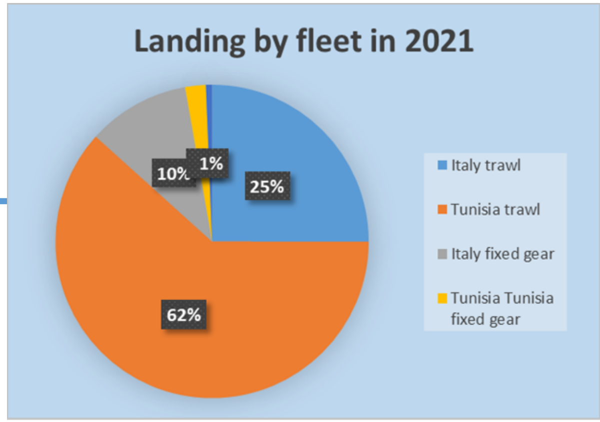


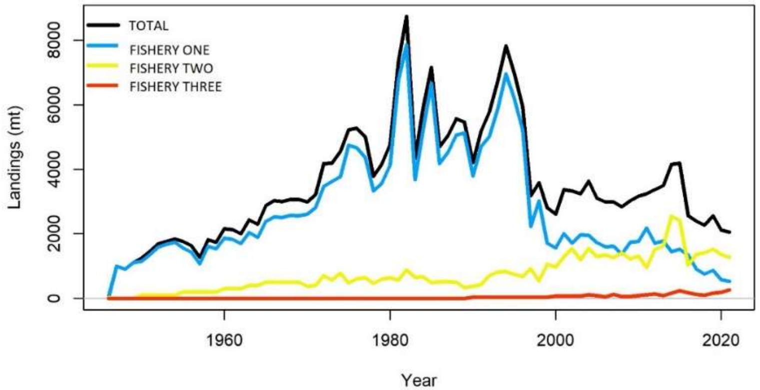


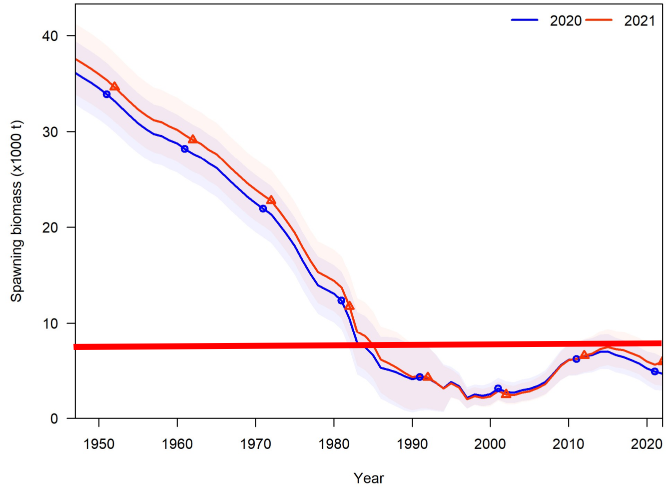
F_{MSY}=0.84-0.93;
F_{MSY}= 1.0-1.1
(blue in progress)

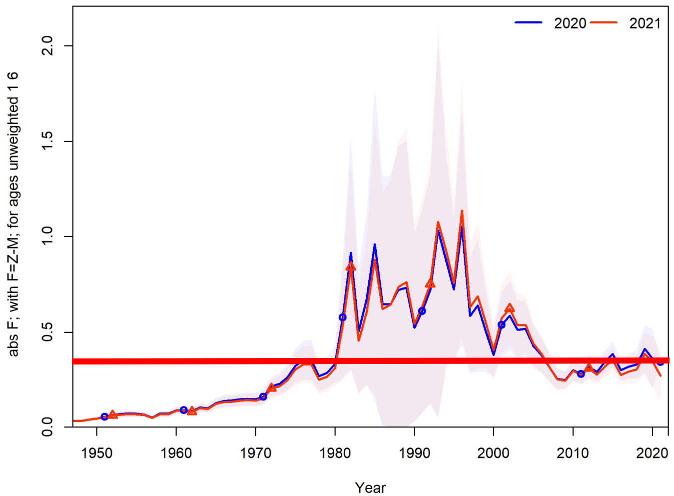
(by Gancitano et al., 2021)

The case of hake…the main bycatch of the deep water rose shrimp fisheries…a yield of 2100 t in 2021…an improving but still overfished resource…









	2018	2019	2020	2021
F_{MSY}	0.29	//	//	//
SSB_{MSY}	7021	//	//	//
$Catch_{current}$	2274	2569	2118	2058
$F_{current}$	0.48	0.50	0.36	0.27
$F_{current}/F_{MSY}$	1.66	1.72	1.24	0.90
SSB (tonnes)	4397	4744	4885	5894
SSB/ SSB_{MSY}	0.63	0.68	0.70	0.83

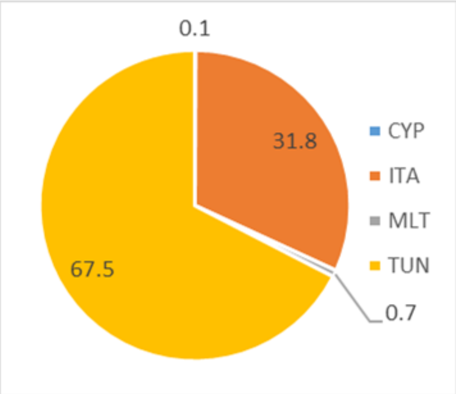
(by Falsone et al., 2022)

Recommendation GFCM/45/2022/4 on the management plan for the sustainable exploitation of demersal stocks the Strait of Sicily and Reg. EU 195/2023

Fishing opportunities in the Strait of Sicily (GSAs 12, 13, 14, 15 and 16) for the transitional period 2023-2025.

Maximum level of activity in fishing days in 2023-2025

Country	Segment	Typology	Vessels	Fishing days
CYP	T 12	Bottom Trawlers >24	1	51
ITA	T 07	Pelagic Trawlers < 24	594	90
ITA	T 10	Bottom Trawlers < 12		188
ITA	T 11	Bottom Trawlers < 24		19366
ITA	T 12	Bottom Trawlers >24		3657
MLT	T 11	Bottom Trawlers < 24	15	338
MLT	T 12	Bottom Trawlers >24		165



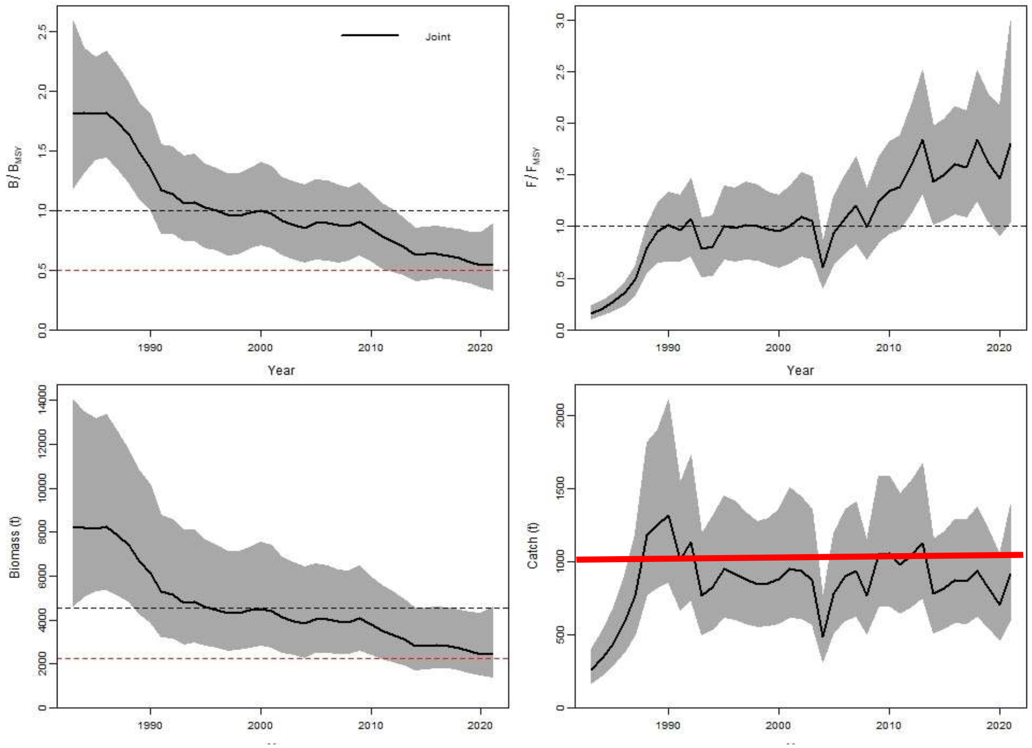
Quota by countries for 2023-2025

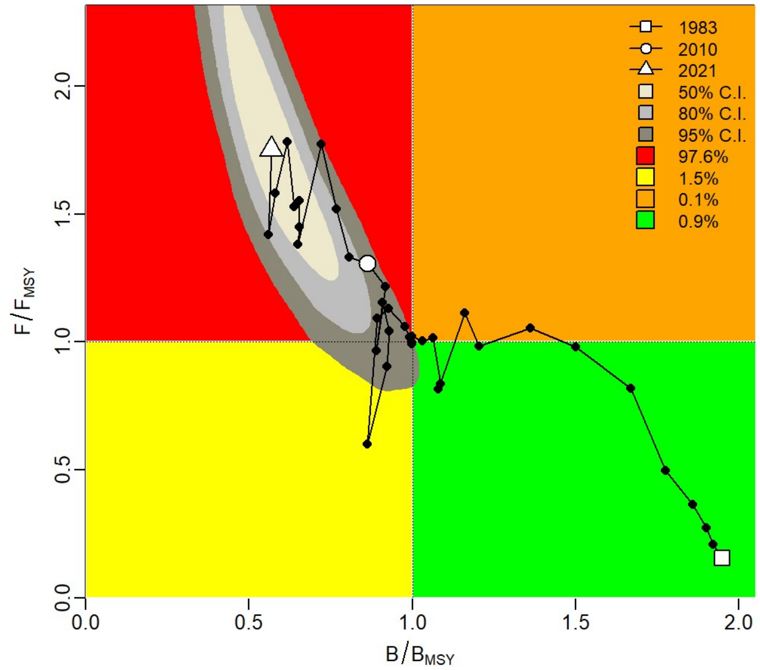
Maximum level of catches in tonnes live weight for 2023 = 6147 tonnes (65% Tunisia and 35 % EU)

EU 2023	EU 2024	EU 2025	TUN 2023	TUN 2024	TUN 2025
2154	2090	2026	3993	3874	3757

Maximum level of EU catches in tonnes live weight for 2023 by countries (2147, Italy; 1 Cypru; 6 Malta)

...the case of deep water red shrimp ...a fishery that is still Italian with a yiled of 870 t in 2021...





B/B_{MSY}=0,59, F/F_{MSY}=1,53, MSY=1.002 t ±94 t

This is a single-species fishery so a combination of individual catch quotas along with technical measures that reduce the catch of juveniles may prove to be the best management strategy

(by Scannella et al., 2022)

Recommendation GFCM/45/2022/5 on the Deep Water Red Shrimp Management Plan in the Strait of Sicily (GSA 12 to 16) and Reg. EU195/2023

Maximum level of catches of Deep Water Red Shrimps (ARS+ARA) in tonnes live weight in 2023-2025

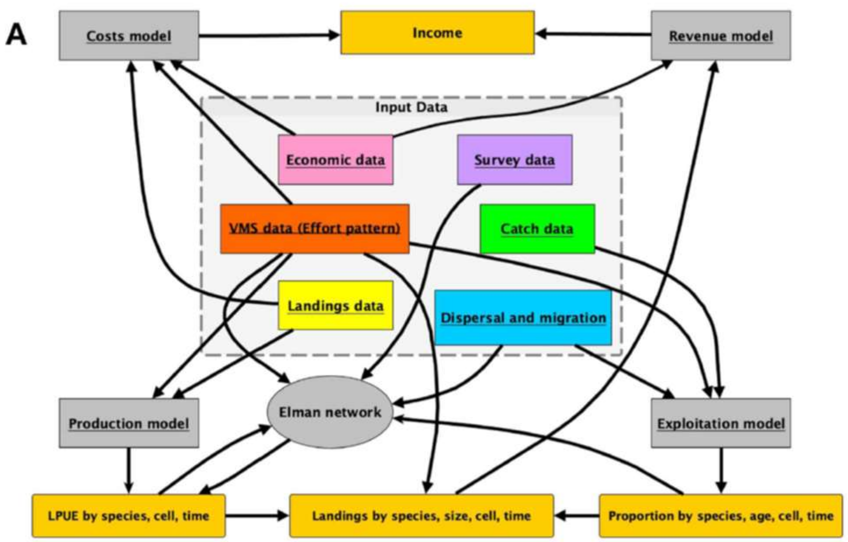
Species	EU 2023	EU 2024	EU 2025	TUN 2023	TUN 2024	TUN 2025
Catch limit (Tons) for giant red shrimp (ARS)	908	881	854	39	38	37
Catch limit (Tons) for blue and red shrimp (ARA)	104	101	98	126	122	119

Vessels and catch distribution among the EU countries

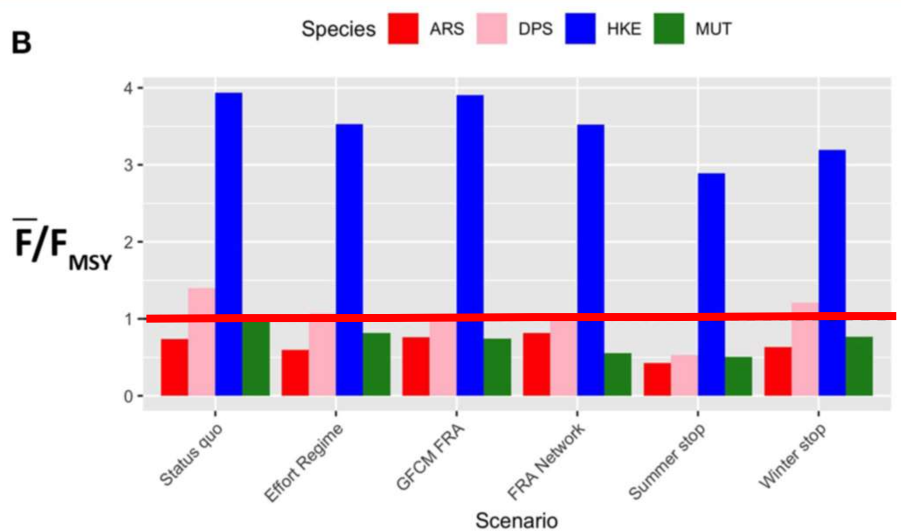
Country	Vessels	ARS	ARA
Spain	2	1	1
Italy	320	870	101
Malta	15	35	2
Total	337	906	104

Including spatial based indicators in stock assessment model
The SMART: A Spatially Explicit Bio-Economic Model for Assessing and Managing Demersal Fisheries

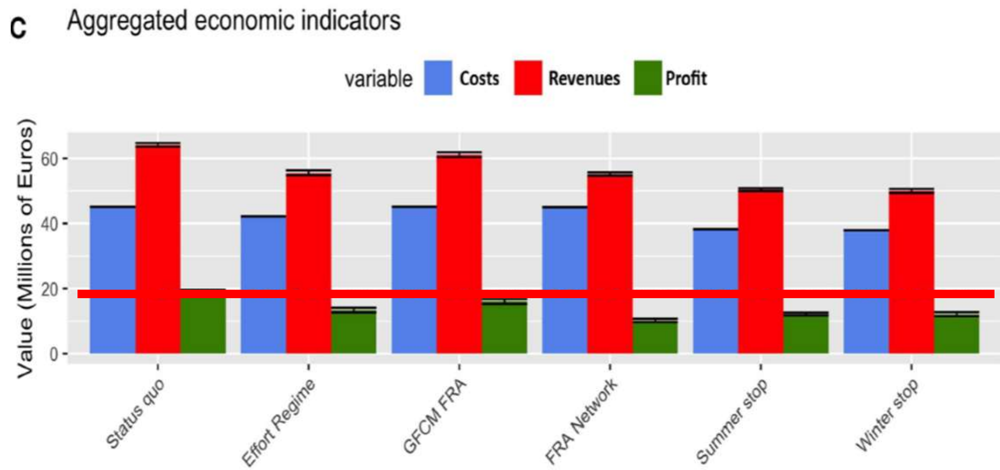
The architecture of the **smartR model**, showing as the different input data are processed by different modules



SMART works with georeferenced data on demography of catch and standing stock, and fishing effort



Relative fishing mortality (F/FMSY) by species and scenarios.



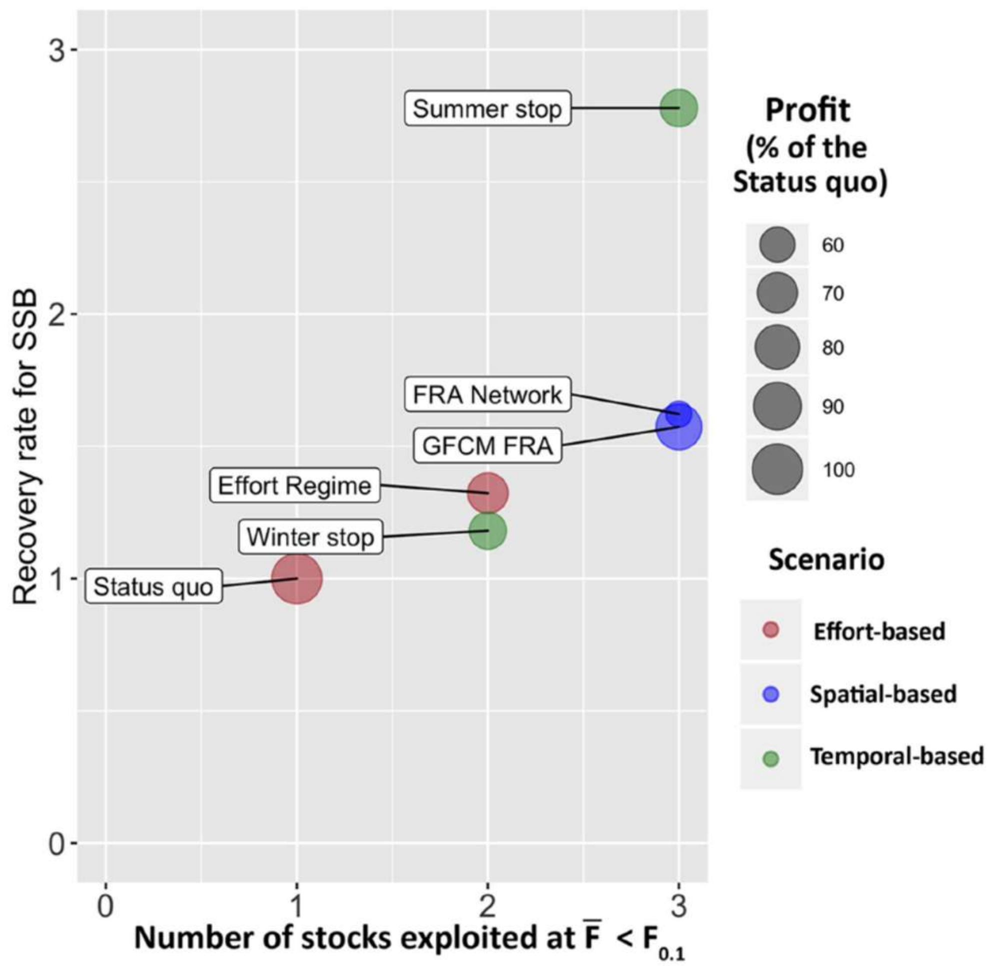
The aggregated costs, revenues, and corresponding profit by scenario, for the whole fleet of Italian trawler.

(by Russo et al., 2019)

Management Strategy Evaluation of the different scenarios of trawling in the Strait of Sicily

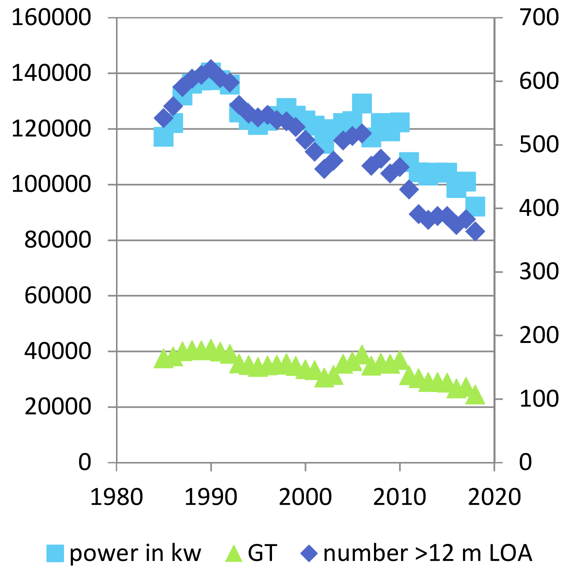
The x axis corresponds to the number of stocks that are expected to be exploited at **F0.1** after the implementation of the corresponding scenario, the y axis corresponds to the mean recovery rate for SSB of the four stocks, computed as SSB Scenario 2017−2022 / SSB Status quo 2017−2022 .

The size of the bubble represents the percentage of profit with respect to the status quo, for each scenario, in the first year (2017) of application. The color of the bubble groups the scenarios by type.

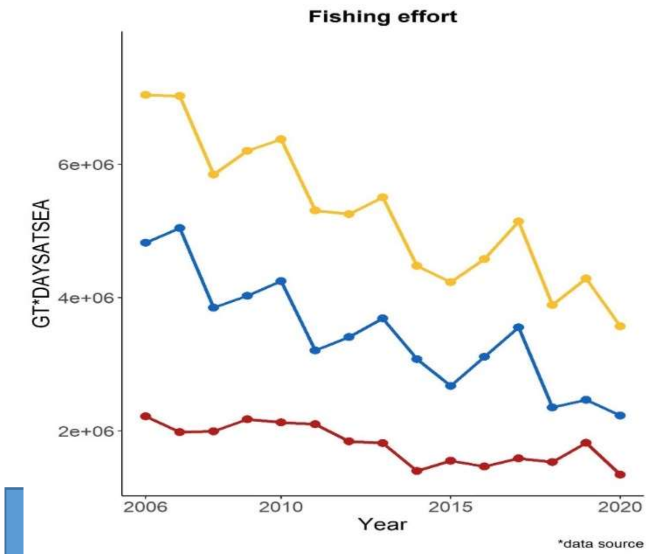


(by Russo et al., 2019)

...the reduction of fishing effort in the Strait of Sicily...a policy so far limited to the European countries...



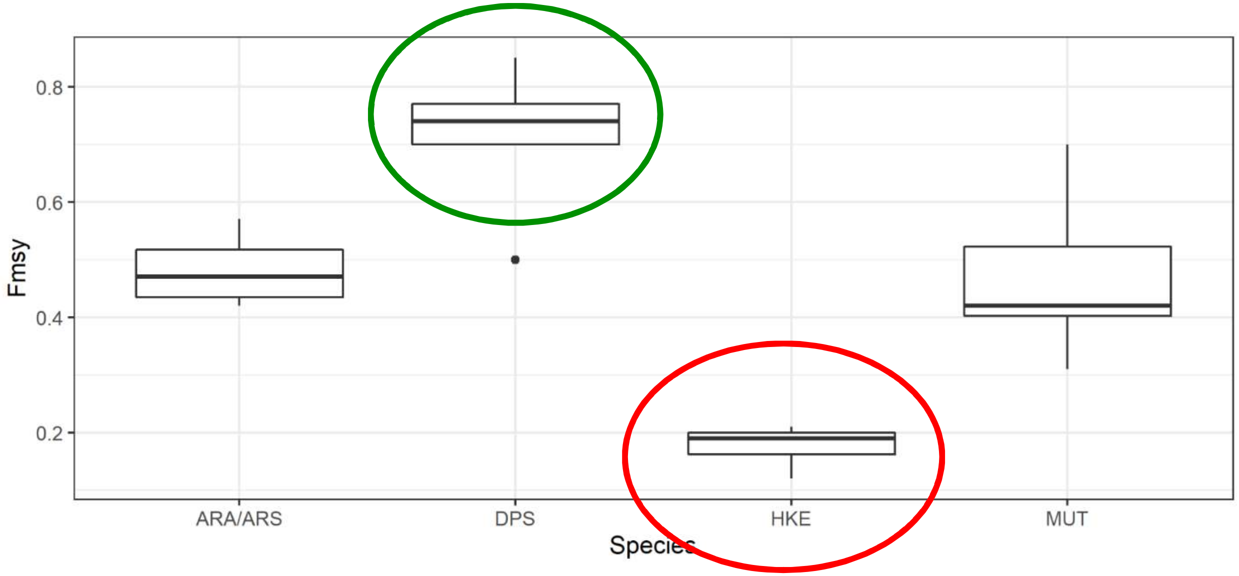
GSA	Species	Stock Status	Scientific Advice
12,13,14,15,16, 21w	ARS	Overexploited and in overexploitation	Immediate action to ensure a reduction in fishing mortality
12,13,14,15,16	HKE	Overexploited and in overexploitation	Reduce fishing mortality
12,13,14	MUT	In overexploitation, with relatively low biomass	Reduce fishing mortality
15	MUT	In overexploitation, with relatively low biomass	Reduce fishing mortality
16	MUT	Sustainable exploitation, with relatively low biomass	Do not increase fishing mortality
14	OCC	Overfishing	Reduce fishing mortality



...the reduction in fishing effort is limited to European countries...this different management policy seems to be reflected in a higher level of overfishing of resources fished exclusively by third country fleets and it could affect the state of exploitation of shared resources ...

How can we improve the management of demersal fisheries in the Strait of Sicily? The problem of multispecies fisheries…

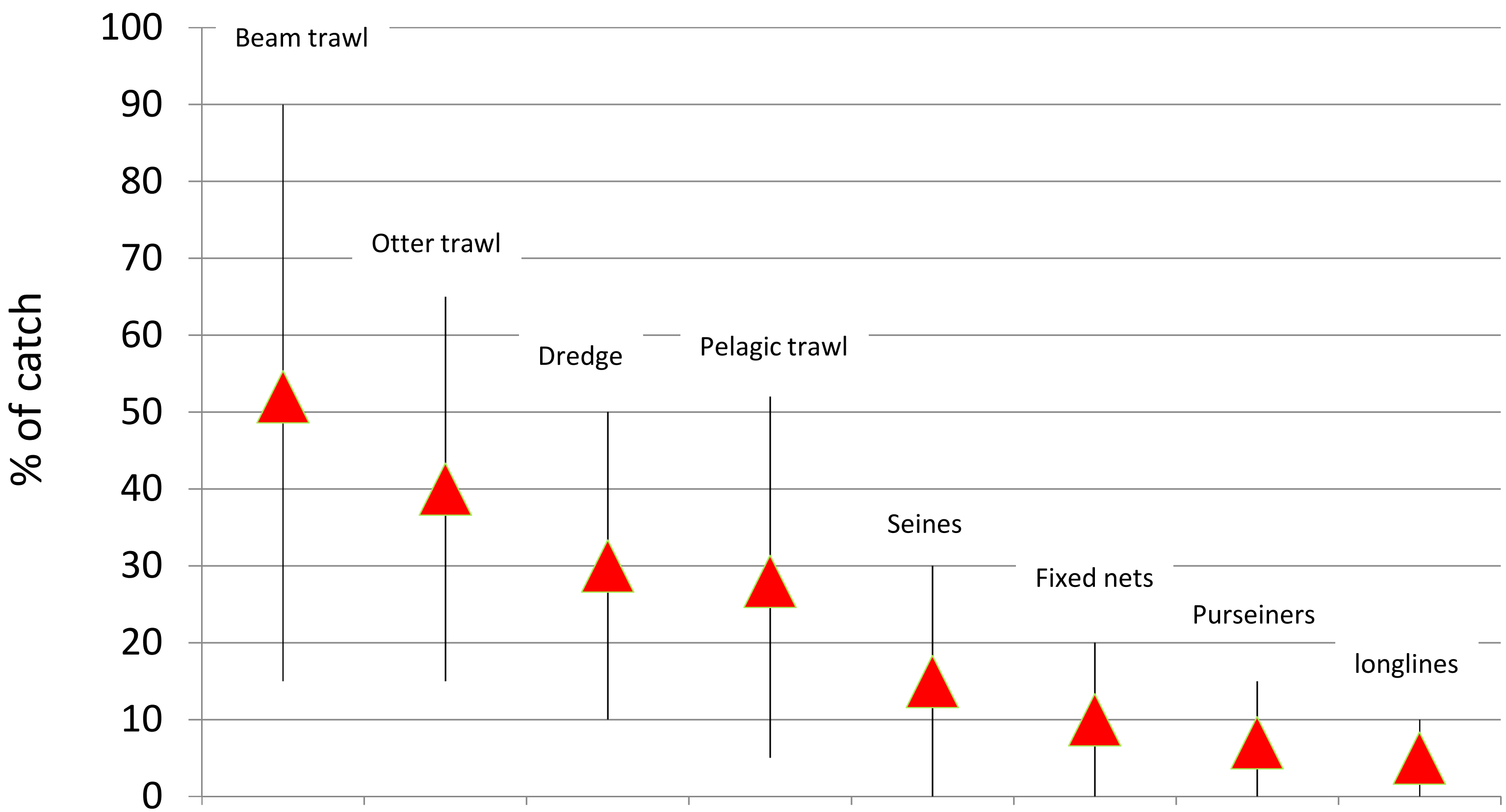
In multi-species fisheries, such as **deep water rose shrimp** trawl fisheries whose main commercial bycatch is **hake**, fishing effort should be managed so as **to maximize the catch of commercial-size shrimp while minimizing that of hake**



Different levels of optimal F for the main target species of the demersal fisheries in the Strait of Sicily

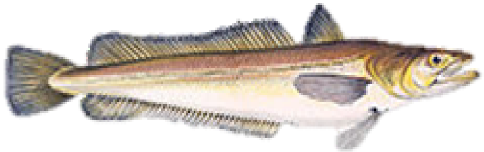
(by Fiorentino e Vitale, 2021)

Percentage of the discarded catch in the different fishing gears in use in the Mediterranean Sea

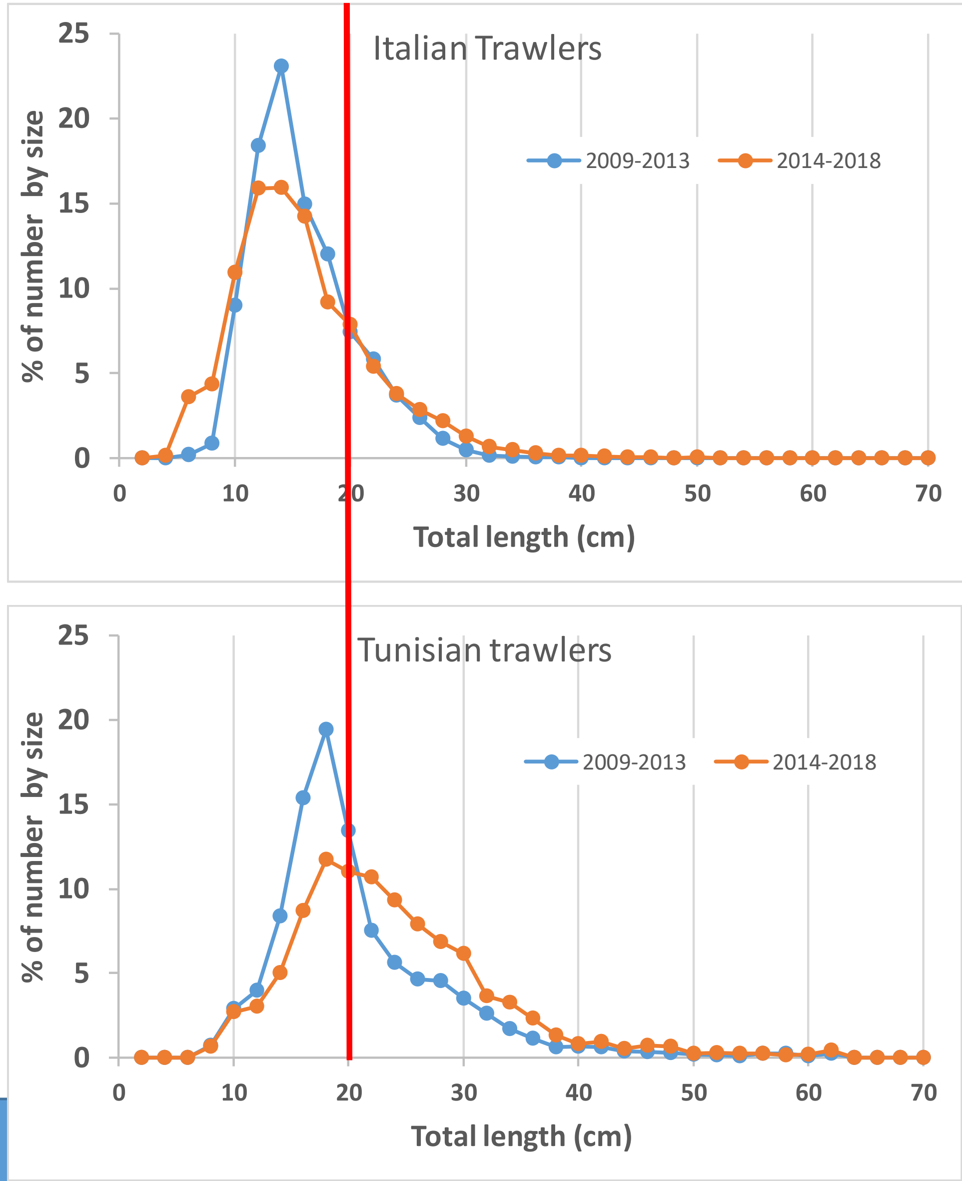


(by FAO- GFCM, 2016)

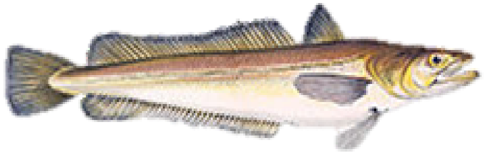
The state of the stocks in the Strait of Sicily
The case of Hake - Merluccius merluccius



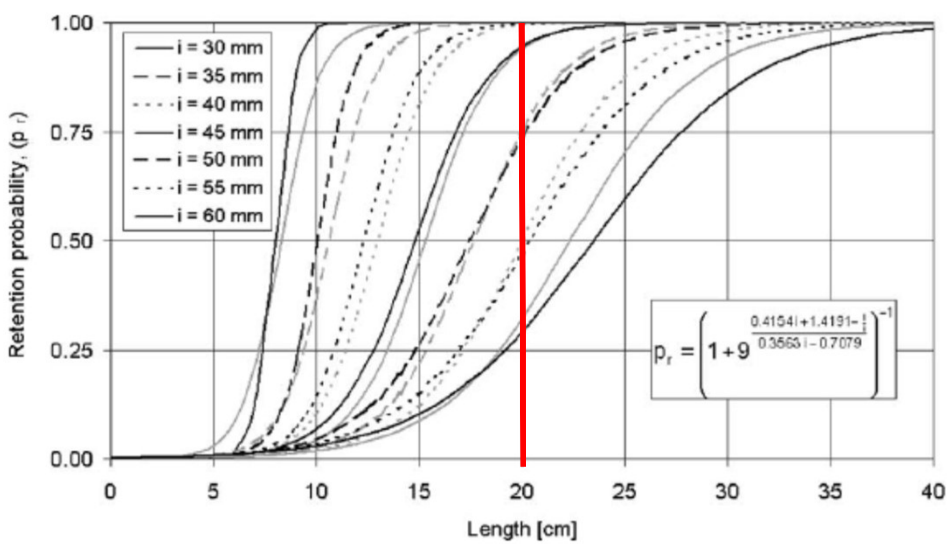
Due to the high level of undersized hake (Total Length<20 cm) in the catch, a reduction of fishing mortality and catches of juveniles is recommended by the GFCM Working Groups to improve the Hake stock status in the Strait of Sicily



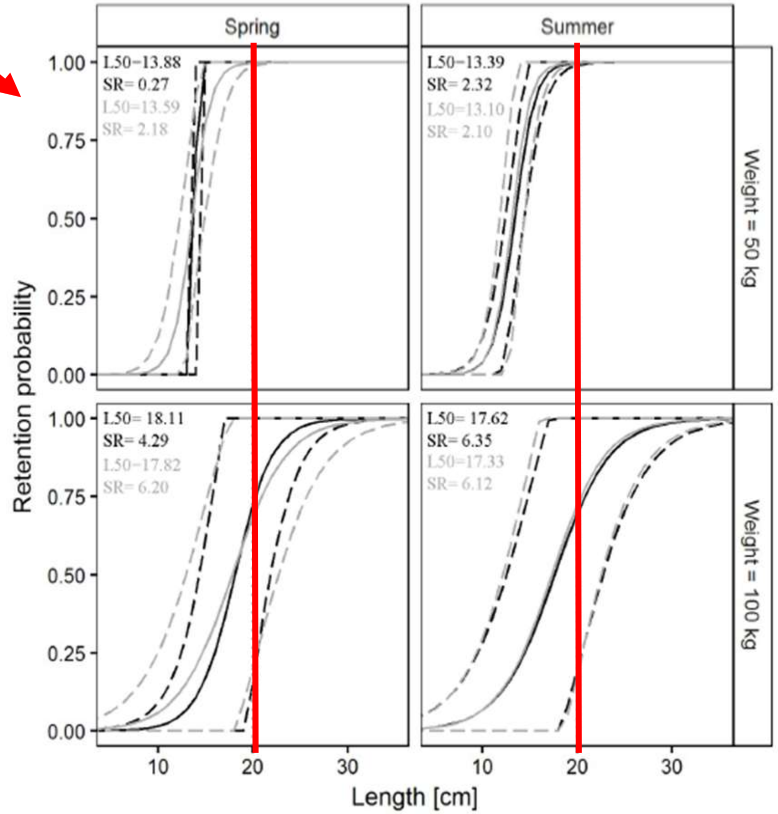
The state of the stocks in the Strait of Sicily
The case of Hake - Merluccius merluccius



Undersized hake are vulnerable to the legal mesh size... both to 50 mm diamond and 40 mm square

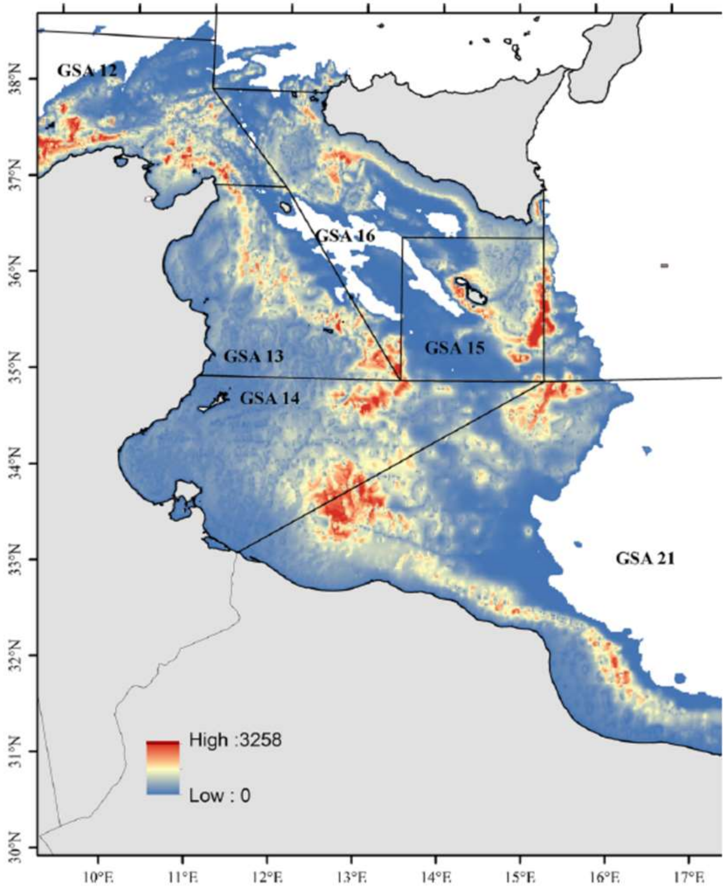


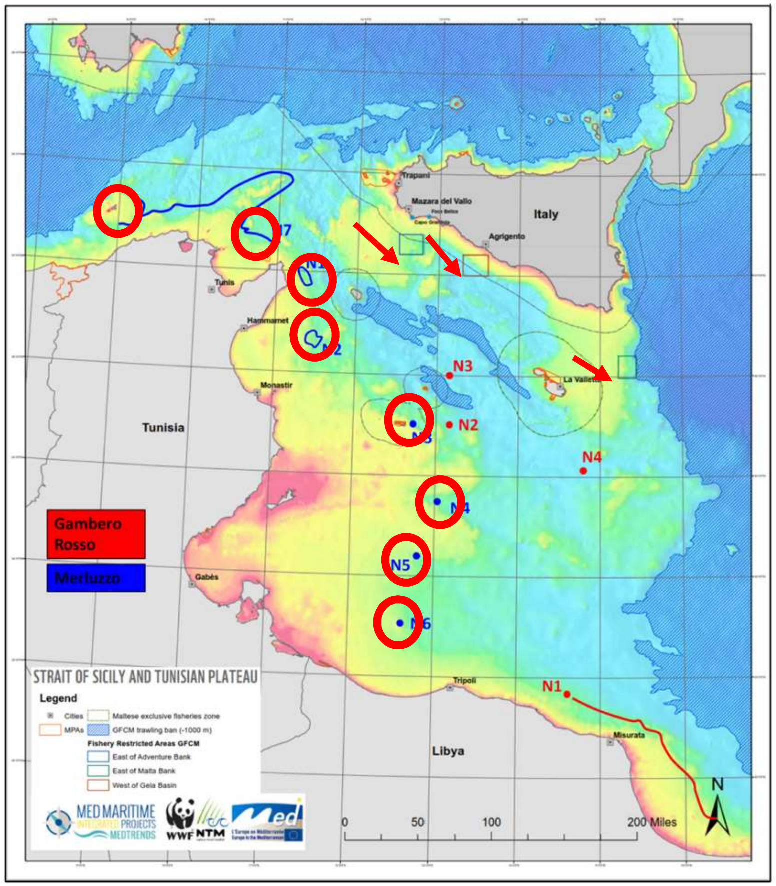
(from Bethke, 2004)



(from Brčić et al., 2018)

The __protection__ from trawling of __areas where juveniles of commercial and protected species are concentrated__ to improve the hake exploitation pattern... the integration of __scientific research__ (left) with fishers' knowledge (__Traditional Ecological Knowledge__) (right)...



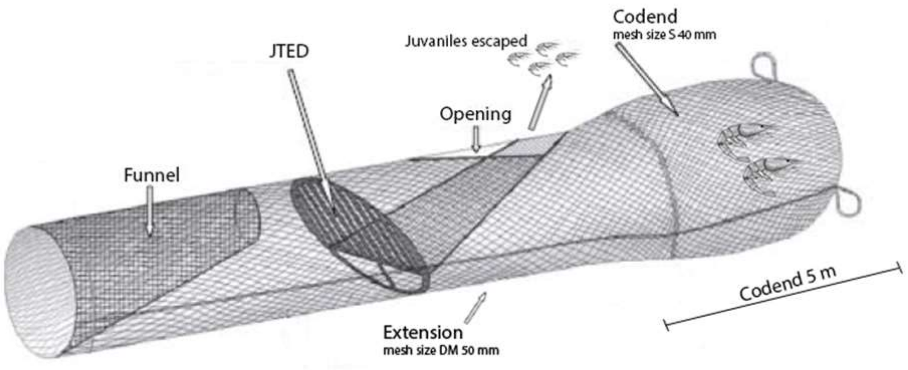


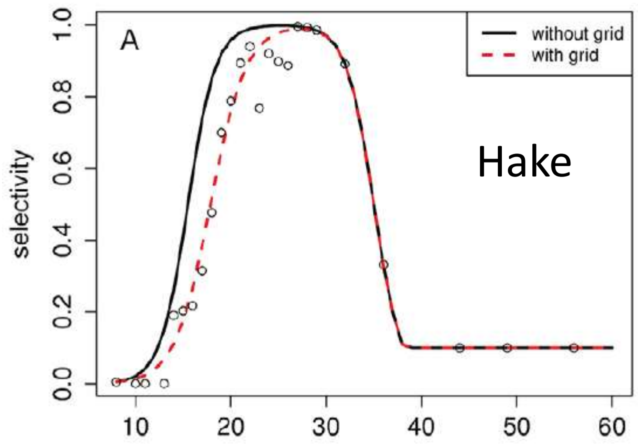
(by Garofalo et al., 2018)

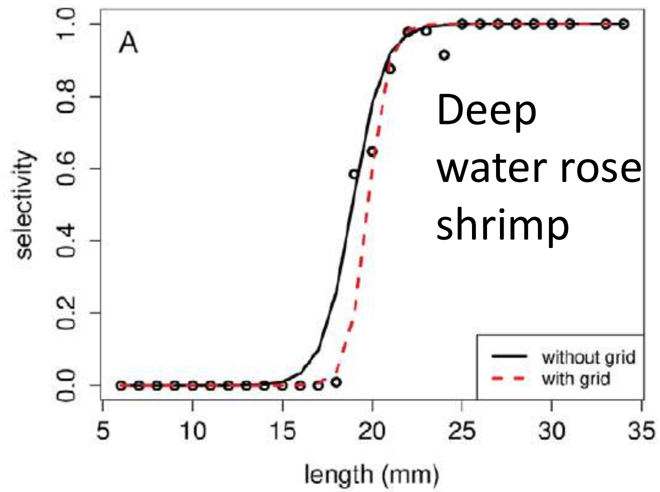
(by Fiorentino et al., 2019)

How can we improve the management of demersal fisheries in the Strait? <u>Experimentation with new, more selective fishing gear...</u>

In addition to "spatial" measures to reduce undersized catches and preserve sensitive habitats, new fishing gears that are more selective and reduce the impact of fishing on the environment and resources need to be tested on a large scale.





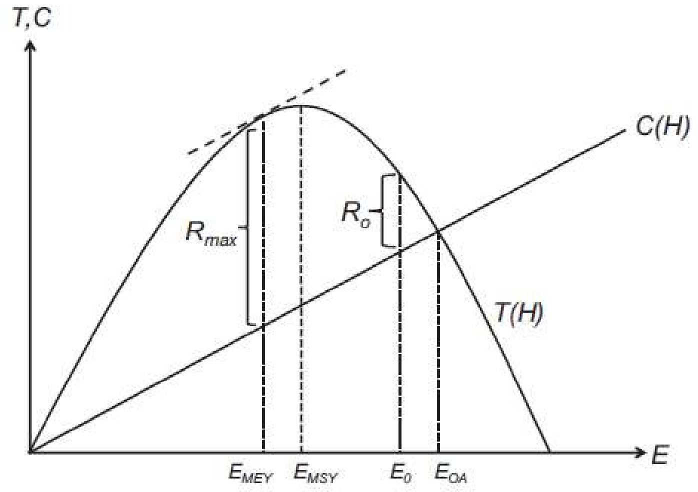


(by Vitale et al., 2018)

How can we improve the management of demersal fisheries in the Strait? <u>Global change and conflicts in use of fishery resource between EU and non-EU countries</u>...

The exploitation of the same resource for an international market by countries with different socio-economic characteristics creates distortions in the market and is likely to rapidly lead stocks into heavy overfishing conditions.

...the relationship between fishing effort (E), total social costs (C) and total revenues (T)...



(by Nielsen et al., 2014)

Products fished by European fleets need to be protected (quality/ecolabelling marks) from competition with the same products fished by third-country fleets without compliance with the EU's sustainability criteria

A summary of advices to improve fisheries management in the Strait of Sicily

- **Balance fishing effort to the productive capacities** of the resources taking into account **climate change**;
- **Improve gear selectivity** by reducing the discarded fraction of catches (precision fishing);
- **Protect areas** where critical phases of the life cycles of fishery resources (**recruitment and reproduction**) and protected and/or species indicator of **sensitive habitats** are concentrated (precision fishing);
- **Develop** a **permit regime** that regulates **access to fishing areas**, compatible with the philosophy behind the CFP and GFCM Management Plans, and allows for overcoming the outdated "free fishing in free seas" philosophy.
- **Hold fishers responsible** for the productivity of **their allocated fishing areas** in accordance with the **FAO Code of Conduct for Responsible Fisheries** and in the logic of the **Ecosystem Approach to Fishery Management**.
- **Protect UE fish production** from third country competition through traceability, ecolabelling, MSC and more strict import controls.

Some final recommendations to take home…

In case you have to choose **indicators, methods, and reference points** to assess and manage Mediterranean fisheries resources make sure to select those that are:

- **Compatible with available data**
- **Realistic**
- **Simple**
- **Robust**
- **Including uncertainty considerations**
- **Easy to be transated into management advice**
- **Understandable to stakeholders**

Some final recommendations to take home…

Developing sets of **model based reference points**, such as $\mathbf{F_{0.1}}$ or $\mathbf{B_{MSY}}$, is useful to assess sustainable harvesting. However at least two main problems should be considered in setting these thresholds :

- The **uncertainties in current stock biomass and virgin stock biomass** in estimating biomass based reference points;
- The **shift in stock productivity** due the **climate change** that can strongly **affect** reference points based on **MSY**

On the other hand, when **available information** is **not enough** to obtain **reliable** model based **reference points, trend based approaches** grounded on a suite of **empirical indicators,** could be **more functional to regulate** in effective way **catch and effort in time and space**

Compare the results of **divers methods,** examining critically and wisely **different results**, is the **best approach** to provide the final assessment on the **status of a stock** and **advice for sustainable fisheries**

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