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

**CNR IRBIM** ISTITUTO PER LE RISORSE BIOLOGICHE E LE BIOTECNOLOGIE MARINE

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**ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA**

# *Indicators for sustainable fisheries from the perspective of stock status*

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# 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

# The five dimensions of fisheries

Fishing is a **traditional activity** deeply rooted in **coastal communities**. It provides **quality food** and contributes significantly to **local economies** by exploiting **the productivity** of **natural ecosystems**.

Fishing is a very **complex activity** characterised by **several dimensions,** including natural and human aspects**.**
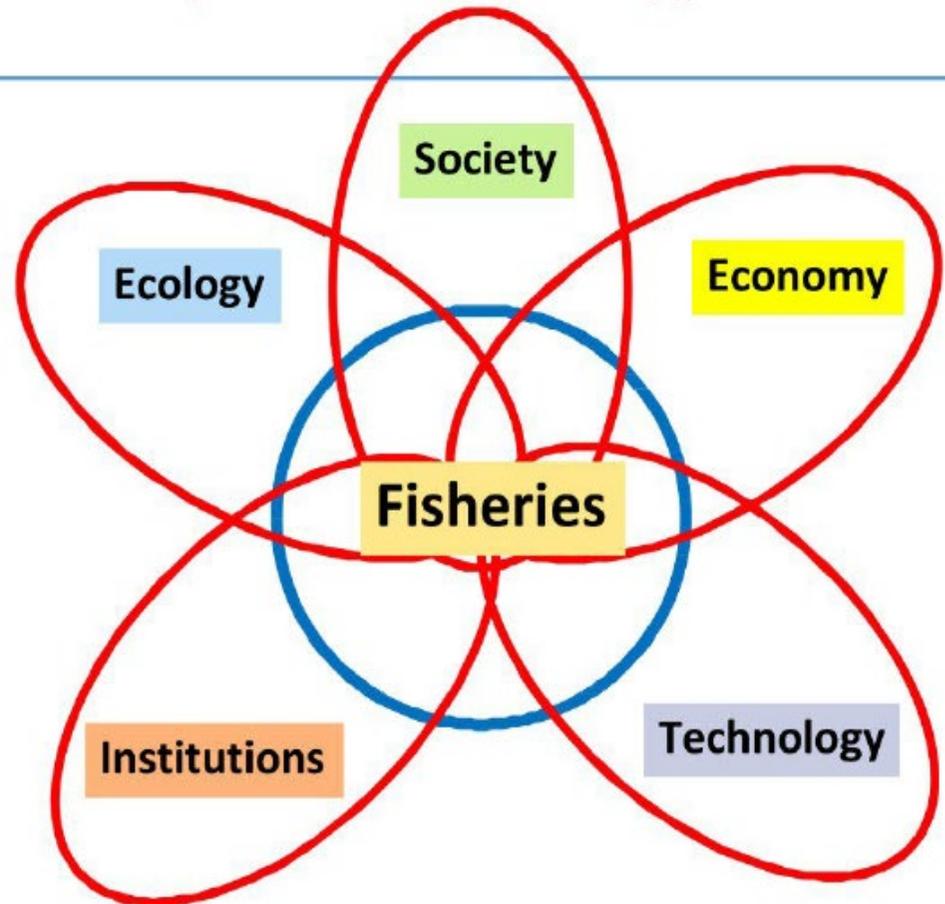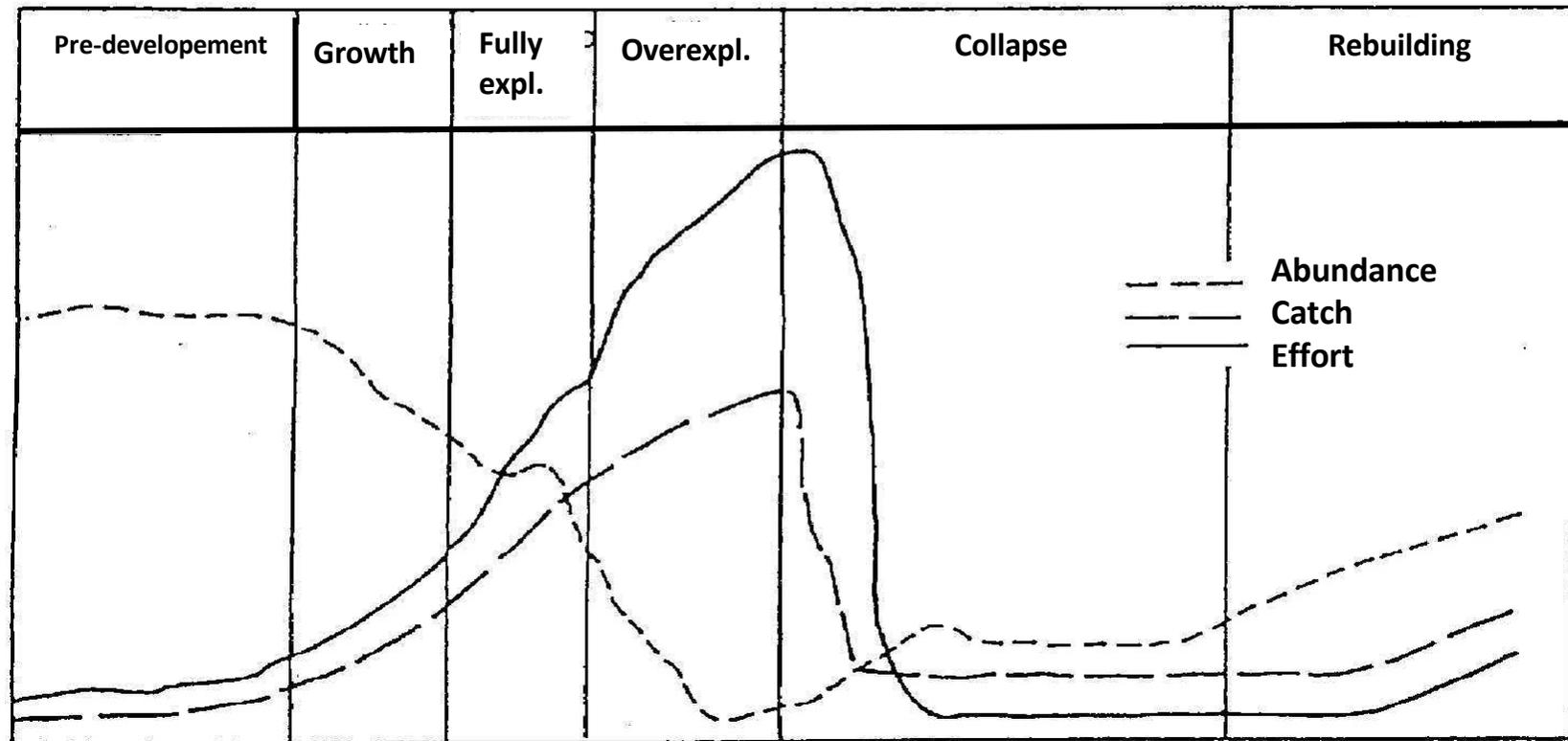
# What is an INDICATOR?

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 **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)



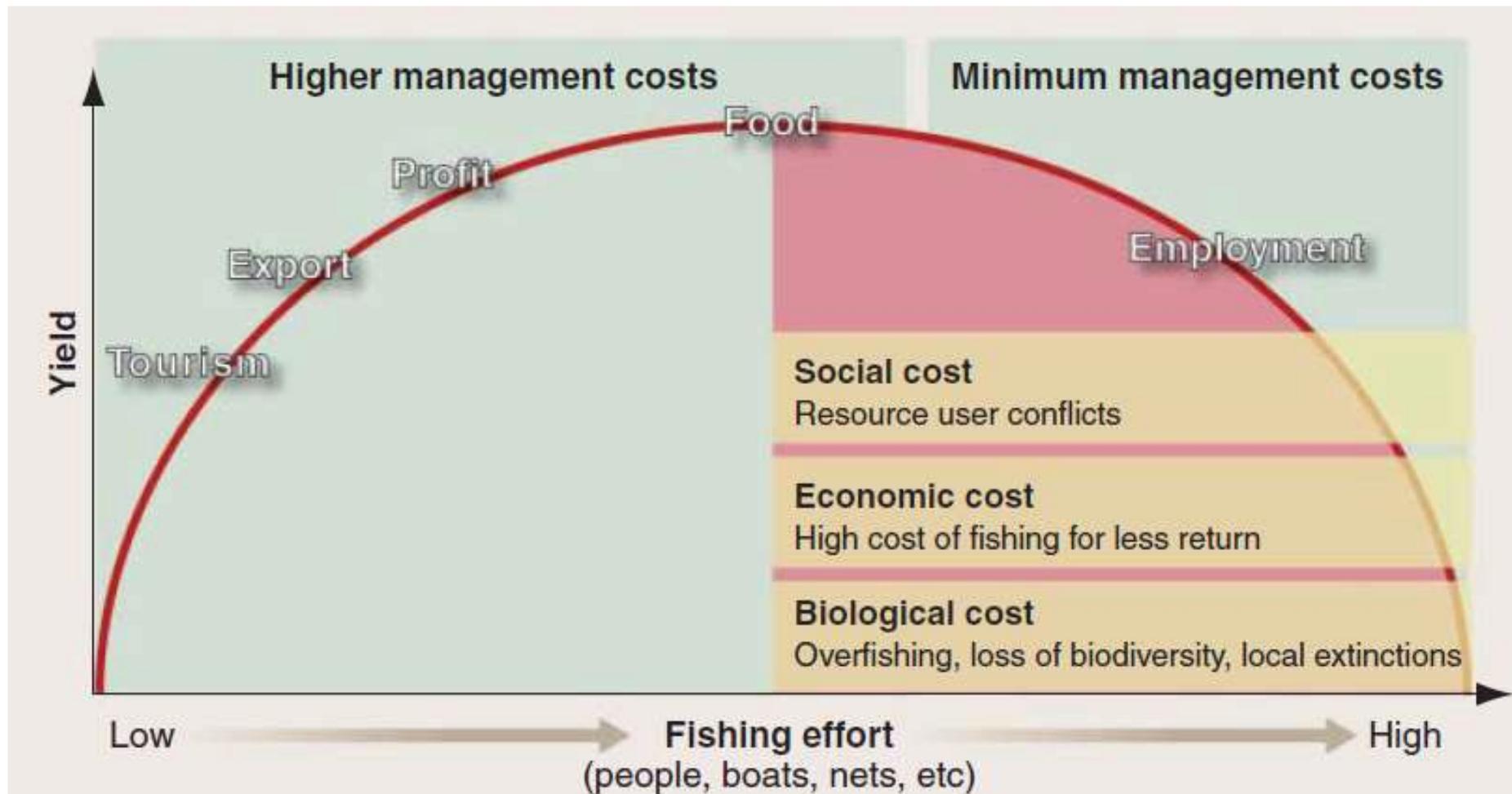| Pre-developement | Growth | Fully expl. | Overexpl. | Collapse | Rebuilding |
|---|---|---|---|---|---|

Abundance
Catch
Effort

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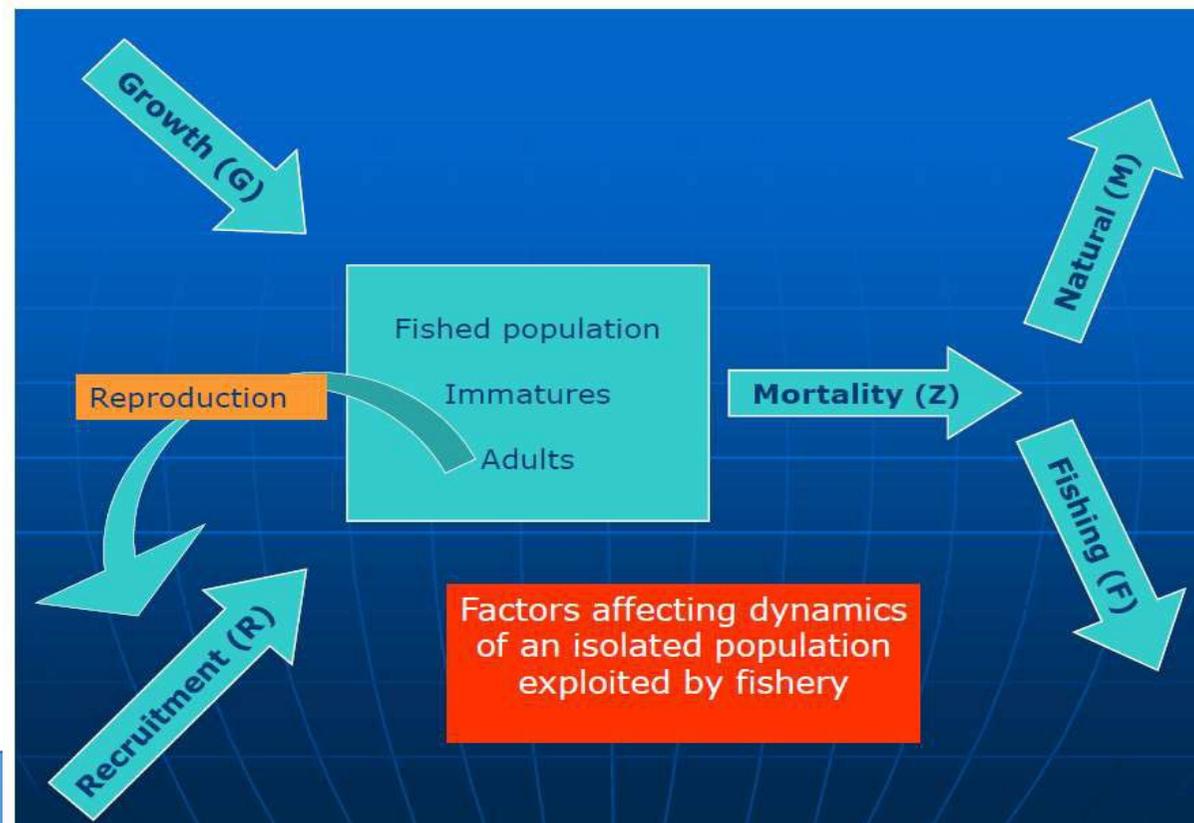
# The "classical" sustainable yield pattern of a single species varying with effort and ...the fishery management dilemma



Higher management costs — Minimum management costs

Yield vs Fishing effort (people, boats, nets, etc) Low → High

Tourism, Export, Profit, Food, Employment

Social cost — Resource user conflicts
Economic cost — High cost of fishing for less return
Biological cost — Overfishing, loss of biodiversity, local extinctions

(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
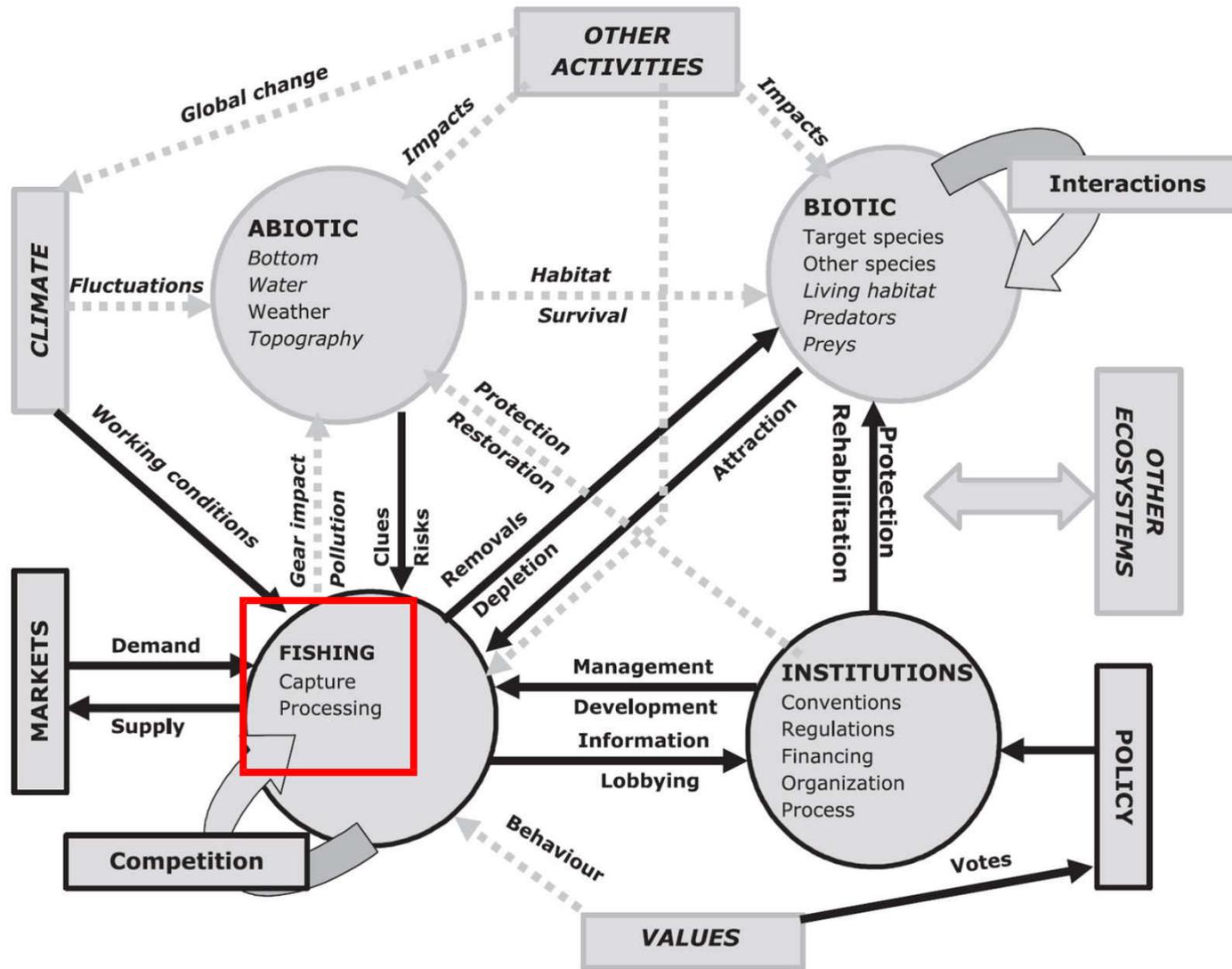


(by Garcia & Cochrane, 2005)

# Why fishery indicators are useful and how they can be classified

**Indicators are useful to:**

- **Describe**
  - the **State** of the stocks /ecosystem
  - the **Pressure** affecting stocks/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 indicators**: abundance, demography, spatial distribution, morphometric and genetic for stock unity identification purpose

- **Socio-economic indicators**: fishing capacity and effort, 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, trophic web

- **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

**Biomass indices of *R. clavata* in the Strait of Sicily**
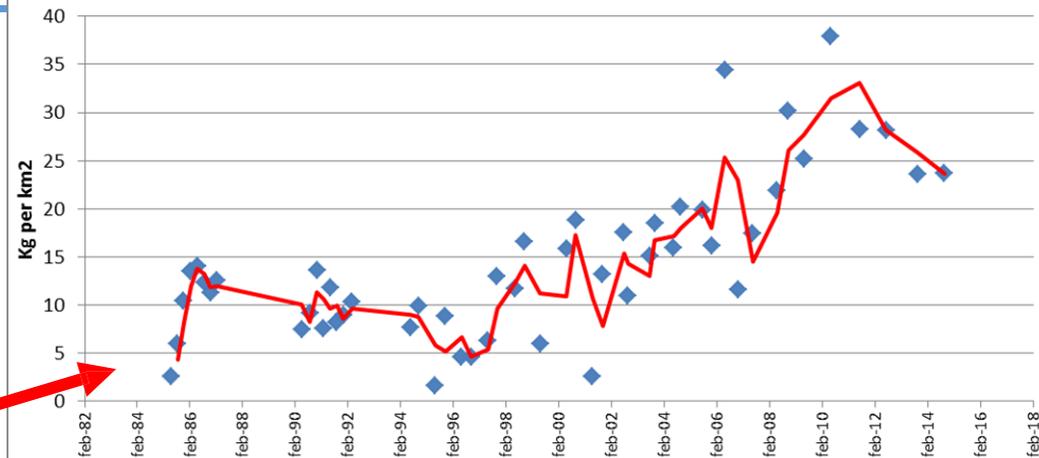


**Catch per Unit Effort (CPUE) of bottom trawling in the Strait of Sicily (b Levi et al., 1989)**
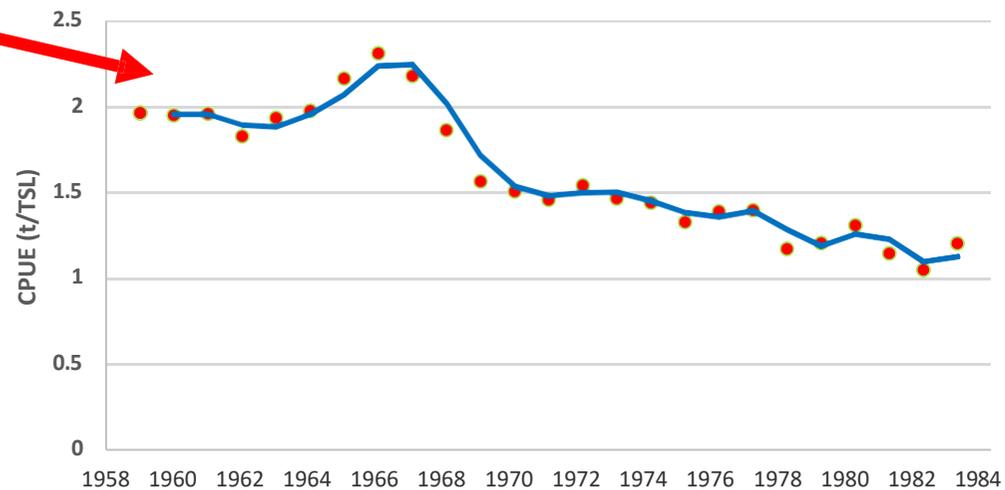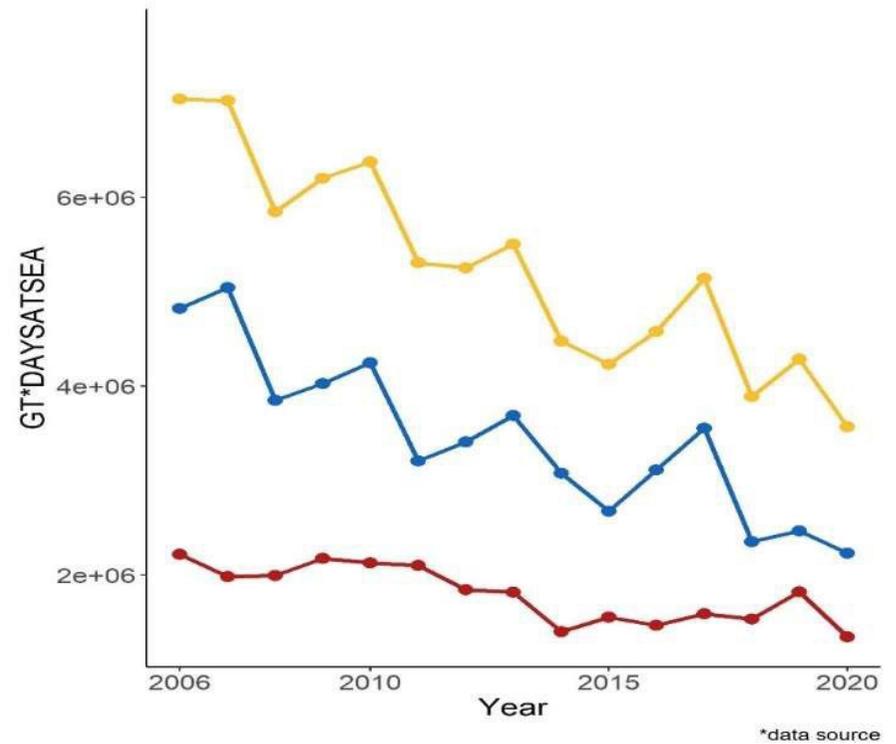
# The most common empirical indicators of fishing pressure on exploited stocks are fishing capacity or fishing effort

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



power in kw   GT   number >12 m LOA
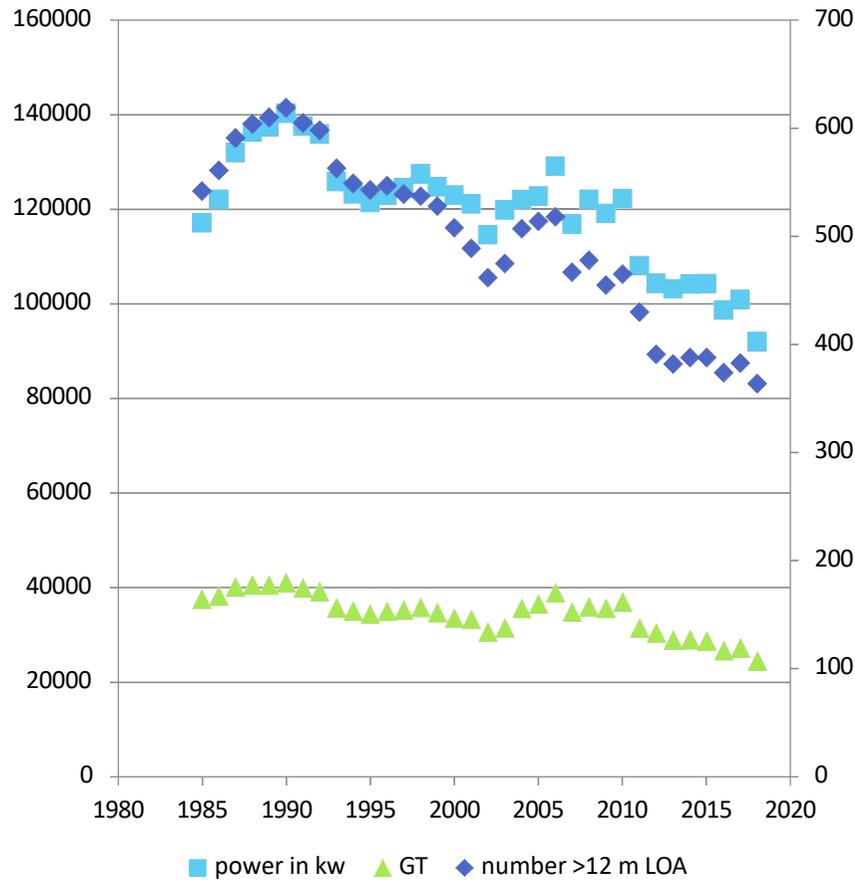
**The fishing effort of trawler fleet in the Strait of Sicily as the product of capacity time activity**
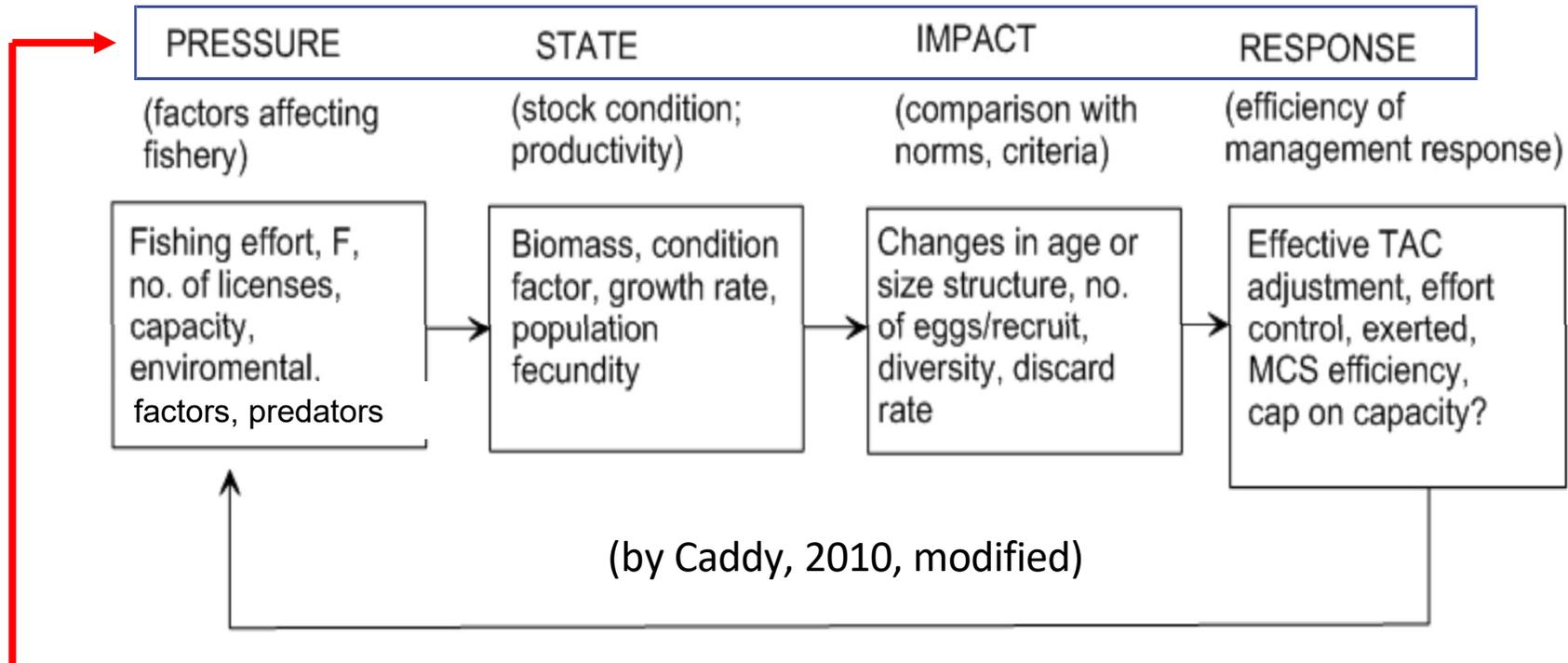


*data source

# 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
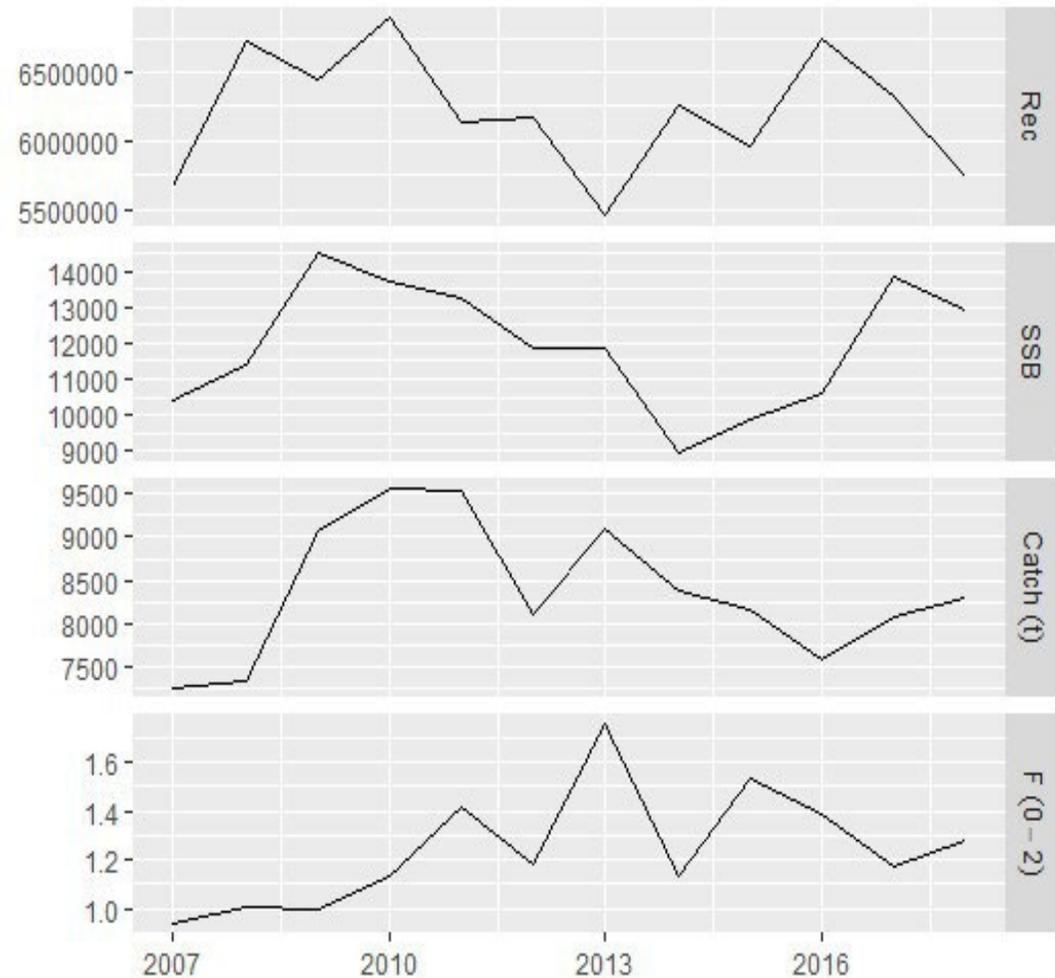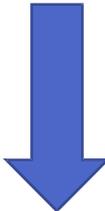


*Results of XSA model for deep water rose shrimp in GSAs 12-16*

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

| PRESSURE | STATE | IMPACT | RESPONSE |
|---|---|---|---|
| (factors affecting fishery) | (stock condition; productivity) | (comparison with norms, criteria) | (efficiency of management response) |
| Fishing effort, F, no. of licenses, capacity, enviromental. factors, predators | Biomass, condition factor, growth rate, population fecundity | Changes in age or size structure, no. of eggs/recruit, diversity, discard rate | Effective TAC adjustment, effort control, exerted, MCS efficiency, cap on capacity? |

(by Caddy, 2010, modified)
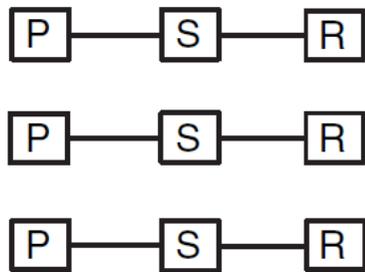
**Demands for food and work & Climate change**

**Drive, Pressure, State, Impact and Response (DPSIR) approach**
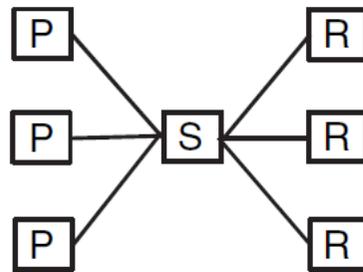
*...Management might require several pressure and response indicators to measure progress towards the target for one state indicator (b), or several response indicators to support a single pressure indicator (d)...*
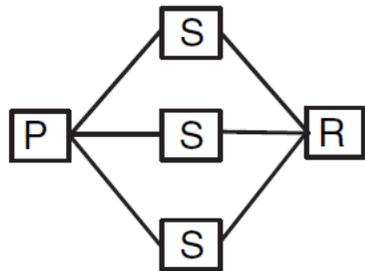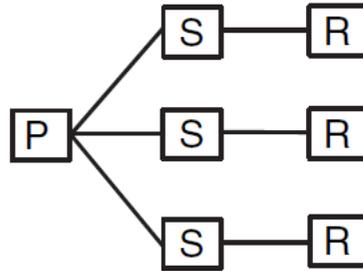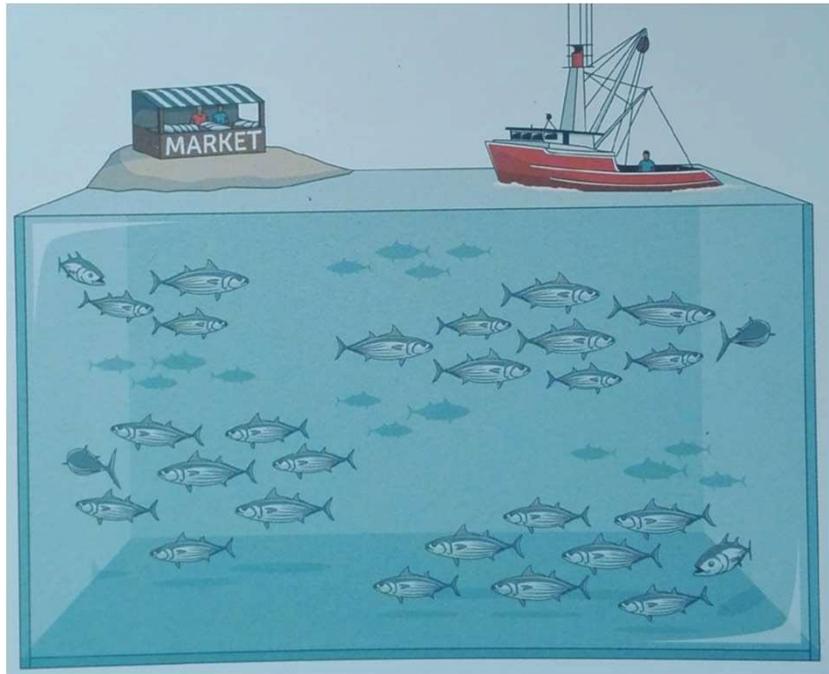


(a) (b) (c) (d)

Possible relationships between pressure (P),state (S) and response (R).

Relationships (b–d) illustrate that indicators for P, S and R are rarely expected to map one on one as in (a).

(by Jennings, 2005)

# Why stock assessment?



The **assessment of the exploitation status** of a stock is necessary for ensuring sustainable yield over time.
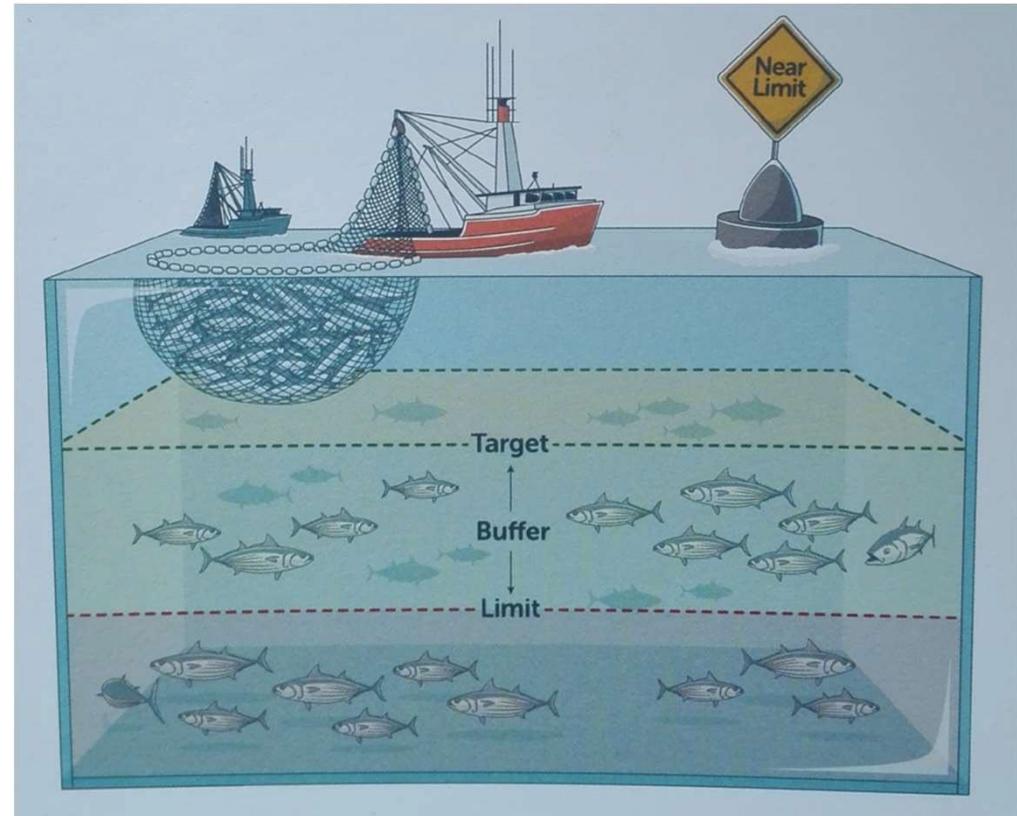
**Sustainable yield** can be obtained thru regulating the fish removals by set up:

- **catch quota**,

- **effort quota**,

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

- **Where is it?**

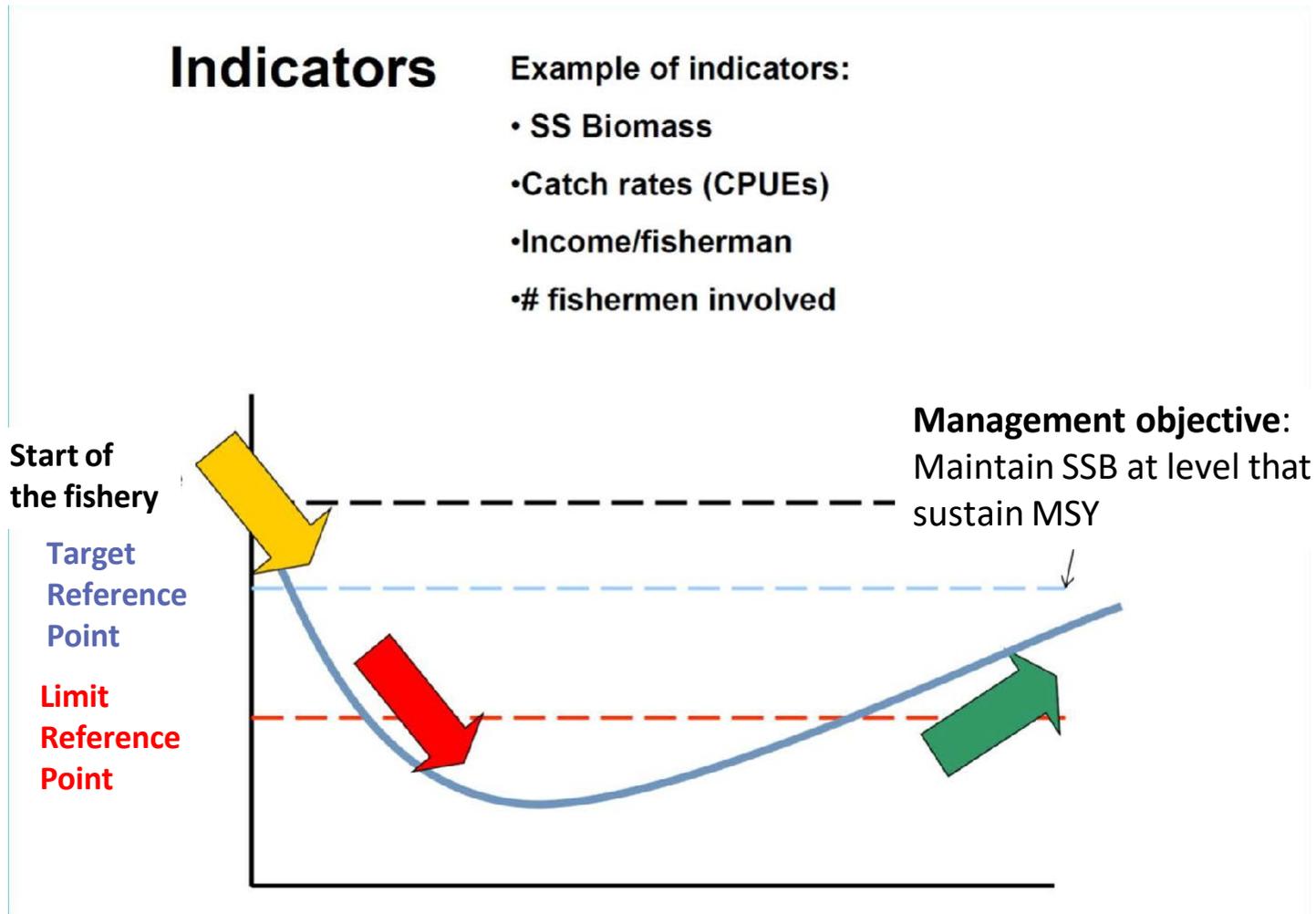- **Where is going to?**

- **What if...?**

# 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.**

# Schematized behaviour
# of an indicator of fishery sustainability

### Indicators

Example of indicators:
- SS Biomass
- Catch rates (CPUEs)
- Income/fisherman
- # fishermen involved

**Start of the fishery**

**Target Reference Point**

**Limit Reference Point**

**Management objective**: Maintain SSB at level that sustain MSY

(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
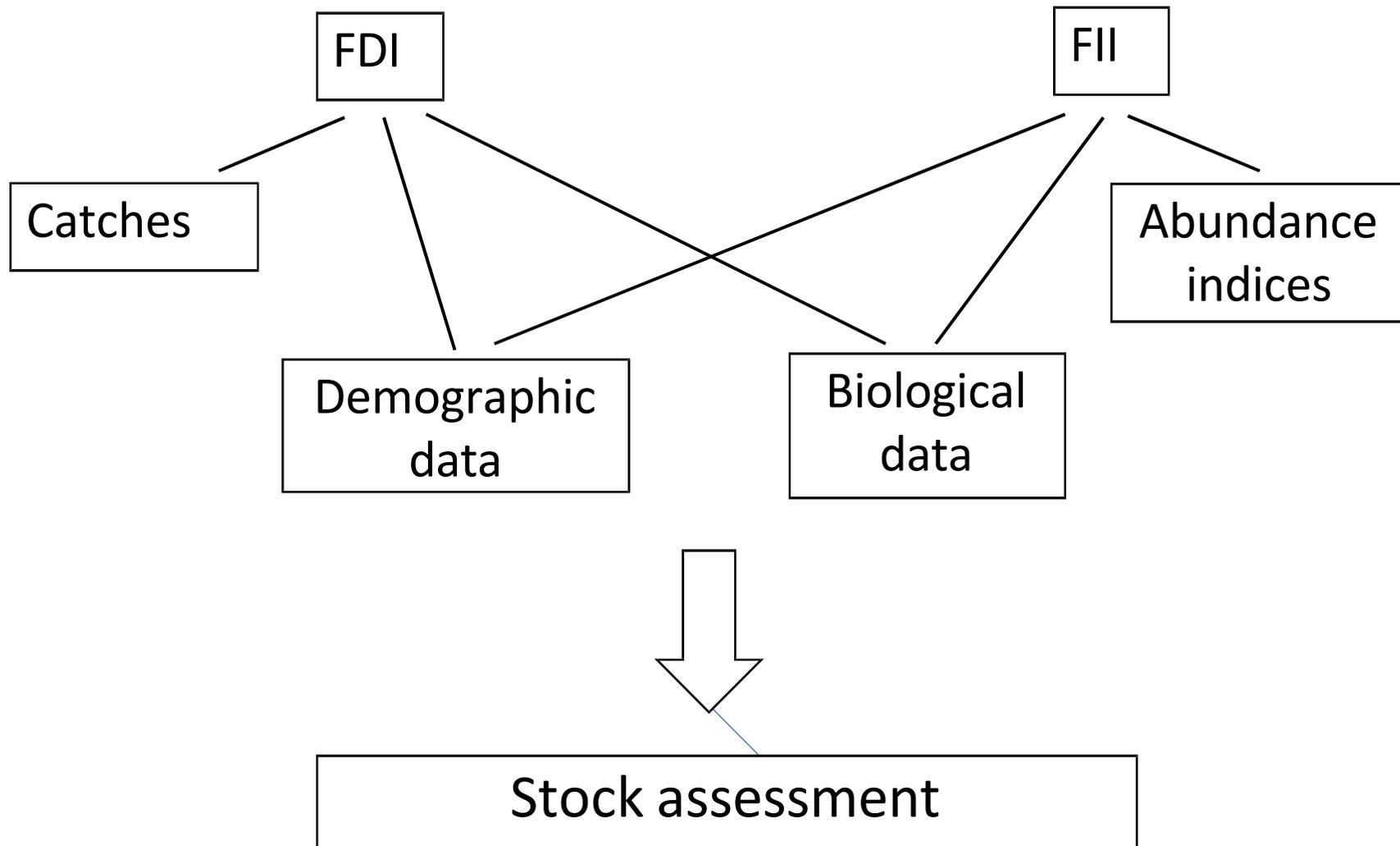
## Fishery Dependent Information (FDI)

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?



$$d_{tot} = d_p + d_b$$

$$q_a = \frac{d_b}{d_{tot}}$$

Height of trawl

(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

➤ It is possible to collect **environmental variables (covariate factors)**
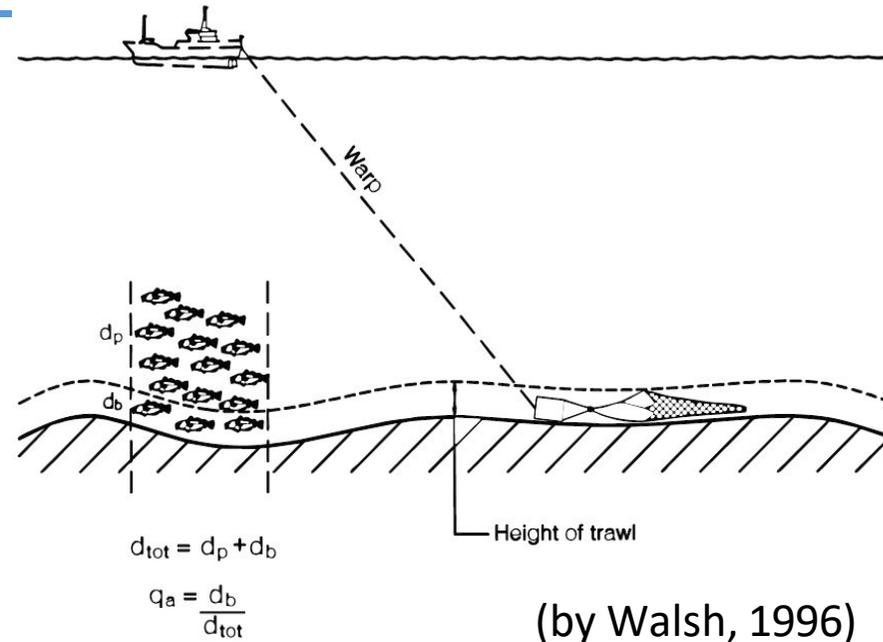
**Main disadvantages**

➤ 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**
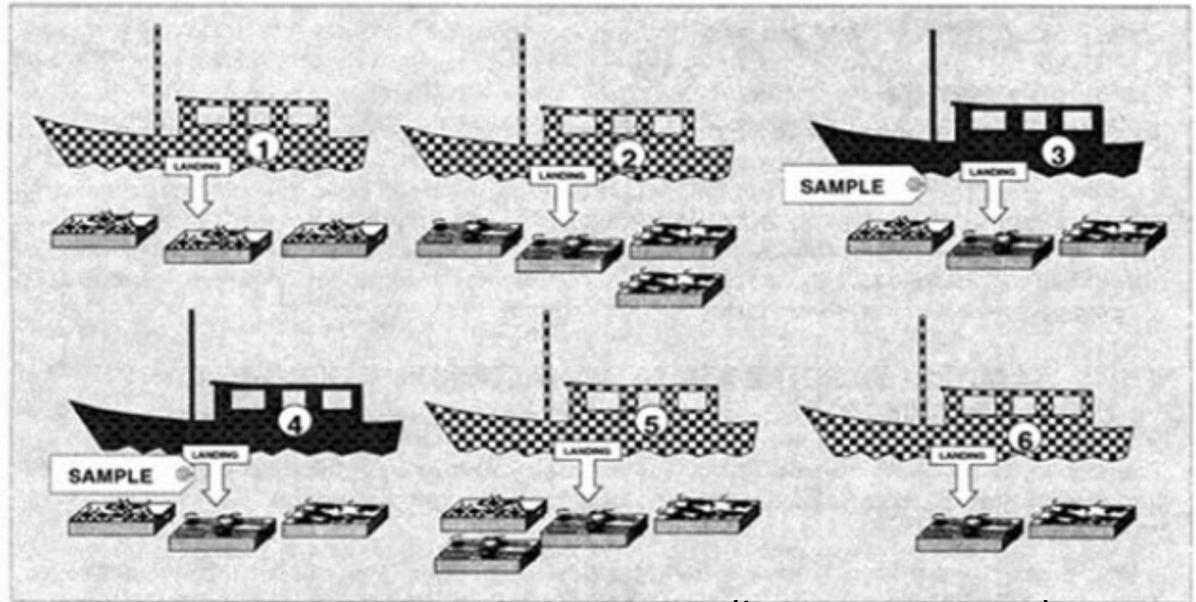


(by Sparre, 2000)

**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)
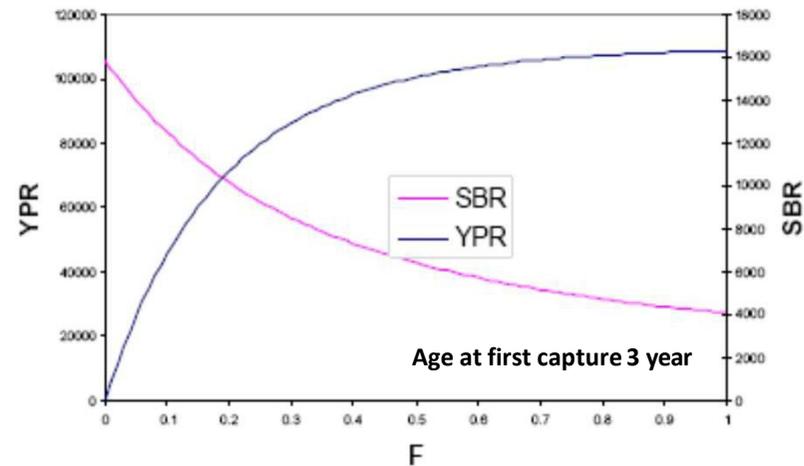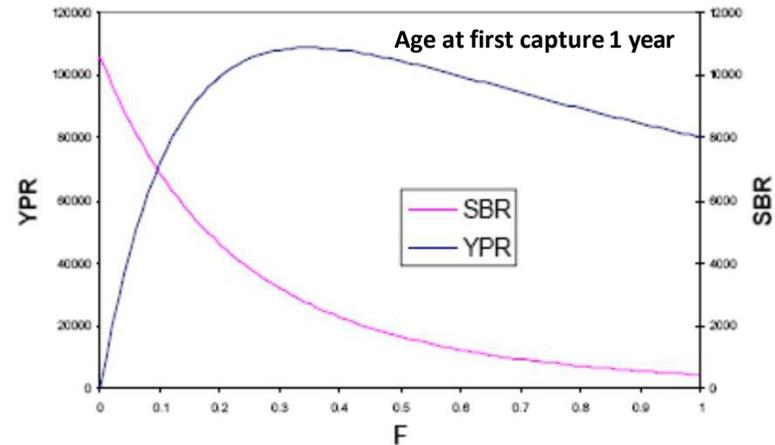


Age at first capture 1 year



Age at first capture 3 year

# *What is overfishing? An excessive exploitation of the fished population*

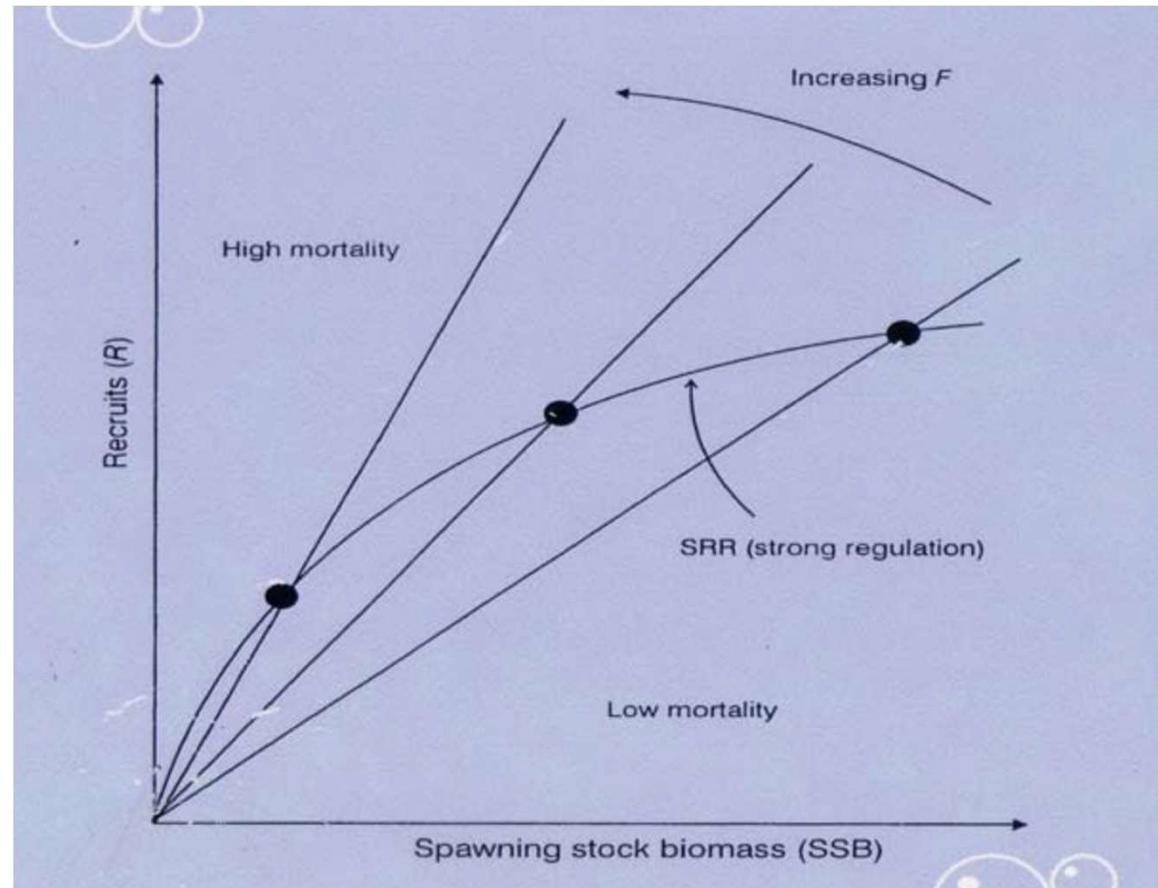Two kind of overfishing of the exploited stocks are classically recognised

- **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
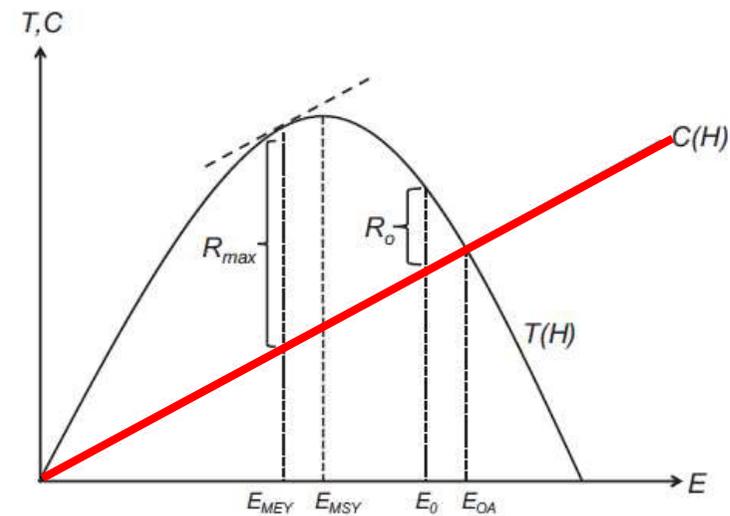


(by Nielsen et al., 2014)

# 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)
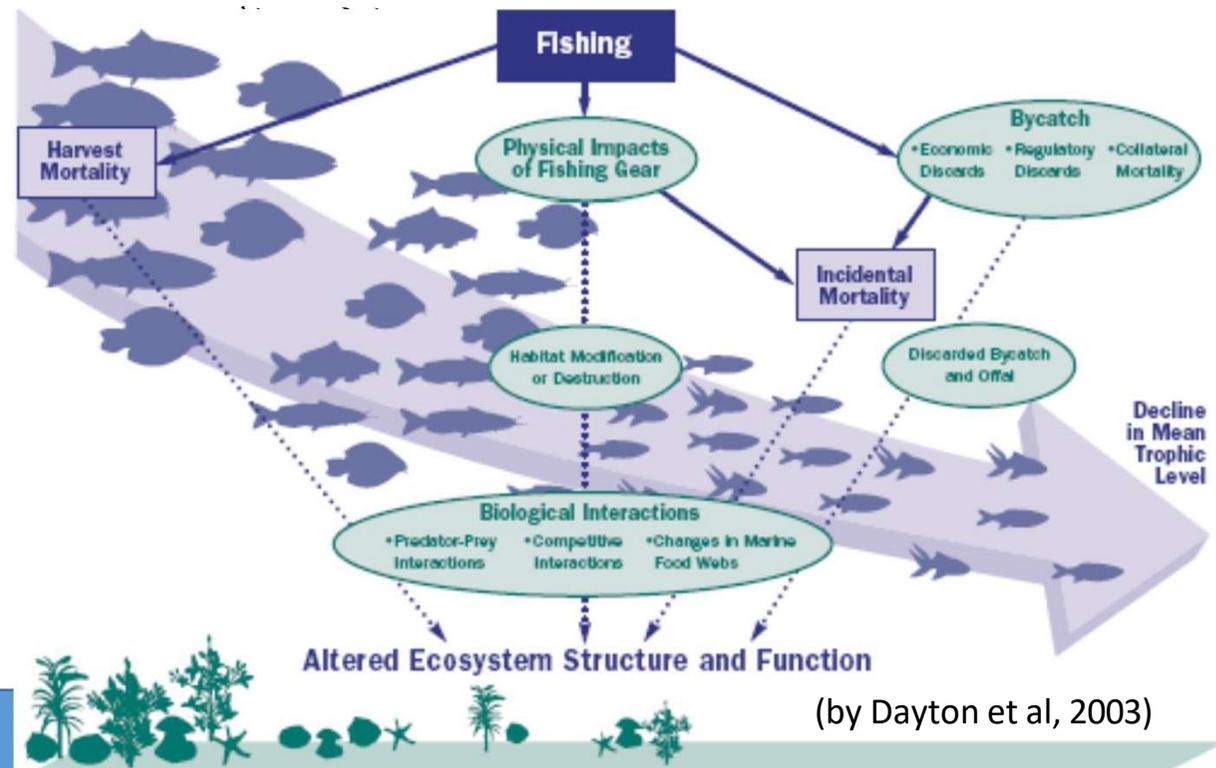
# Why do we need Reference Points in the fishery science?

**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*)

**F or B limit**   **F or B target**

**Buffer zone**

NUMERICAL RANGE OF FISHERIES INDICATOR
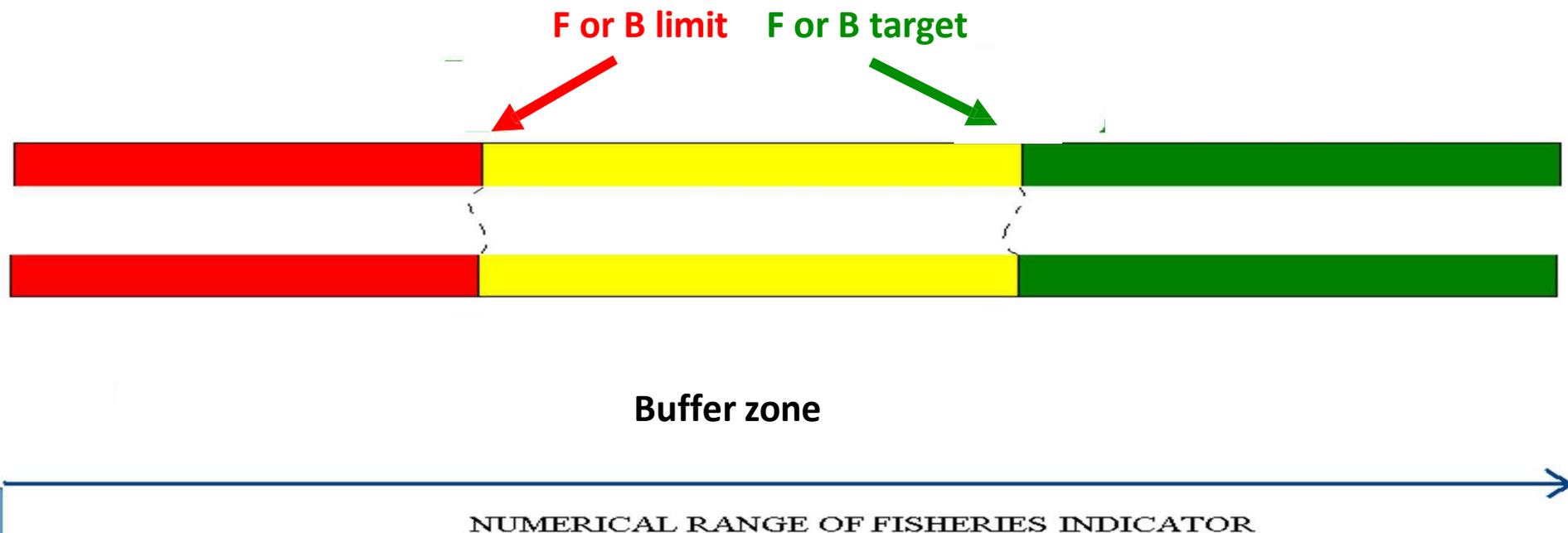
# *Limit and target Reference Points*

- *Managemnt Limits are:*

- **A level of 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)
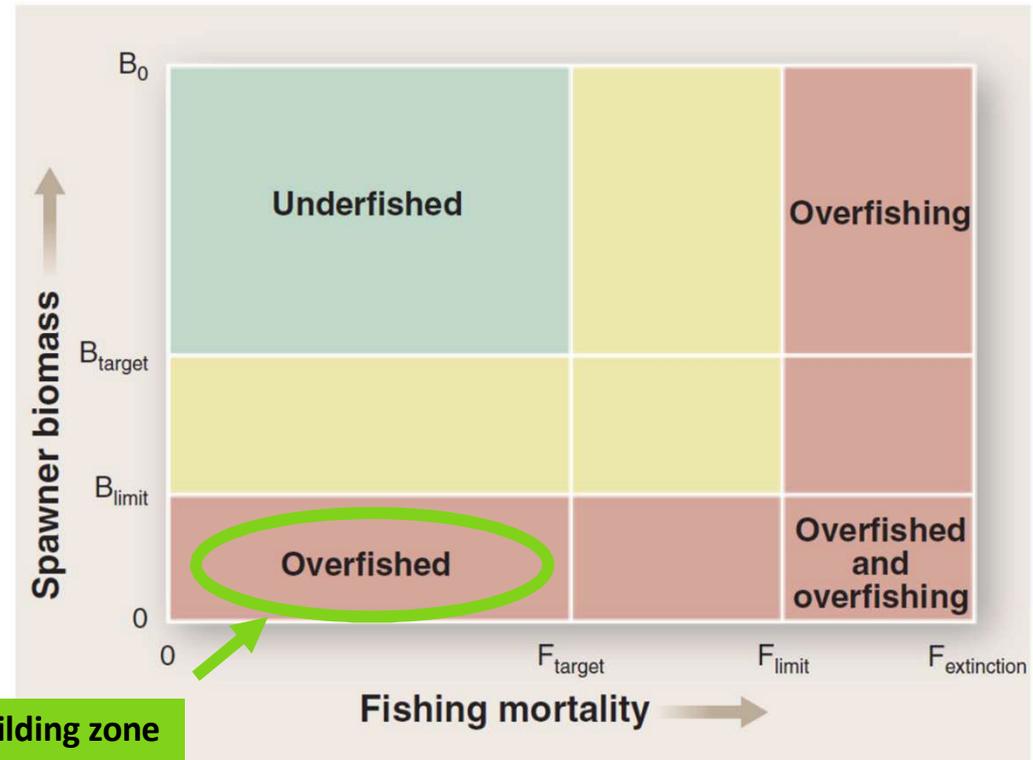


(by Beddington et al., 2007)

**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*
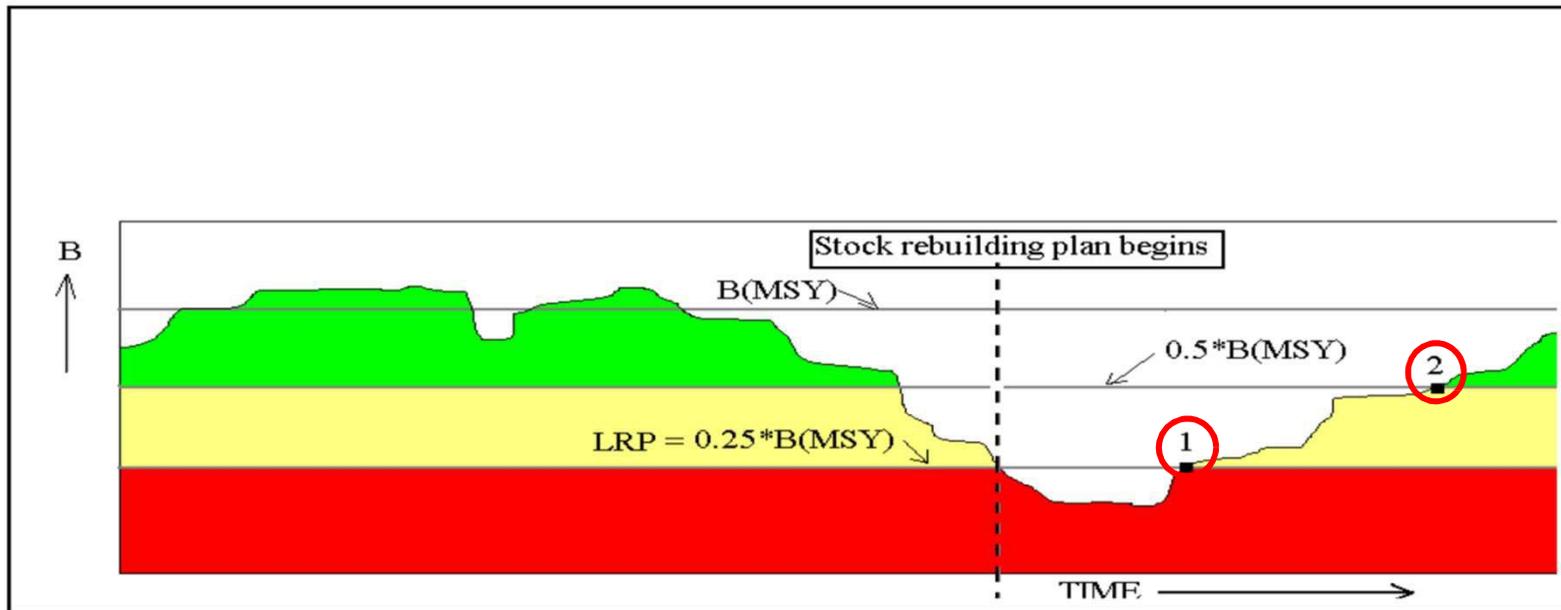


When the **biomass is a quarter** of that corresponding to $B_{MSY}$ **(0.25$B_{MSY}$)**, a **compulsory recovery plan** starts which continues until the biomass is once again above $B_{MSY}$. (Points 1 and 2 are 'way stations' serving to check stock status during rebuilding) (by Caddy, 2004).

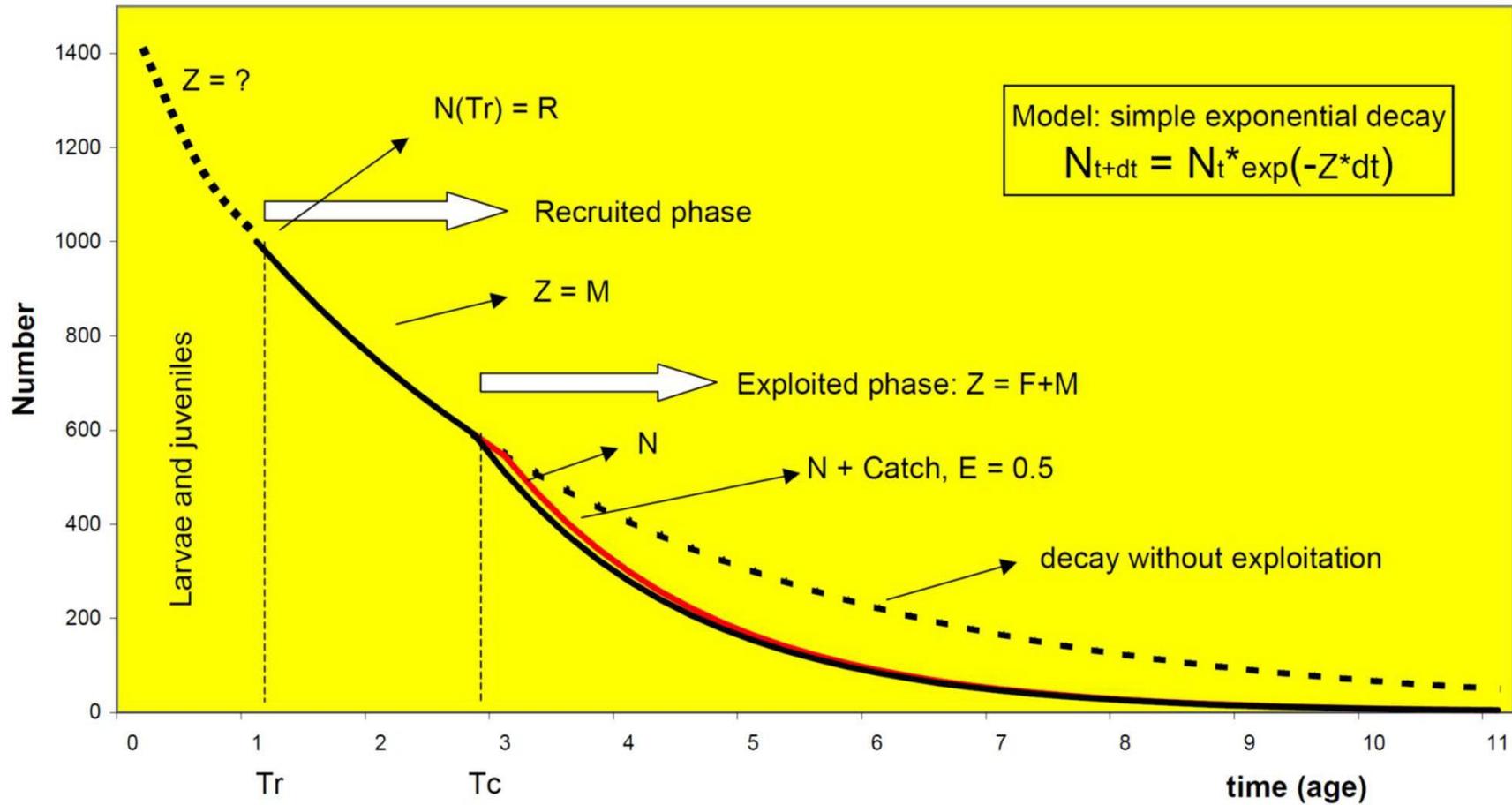# Main differences between empirical and analytical indicators

## 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**.
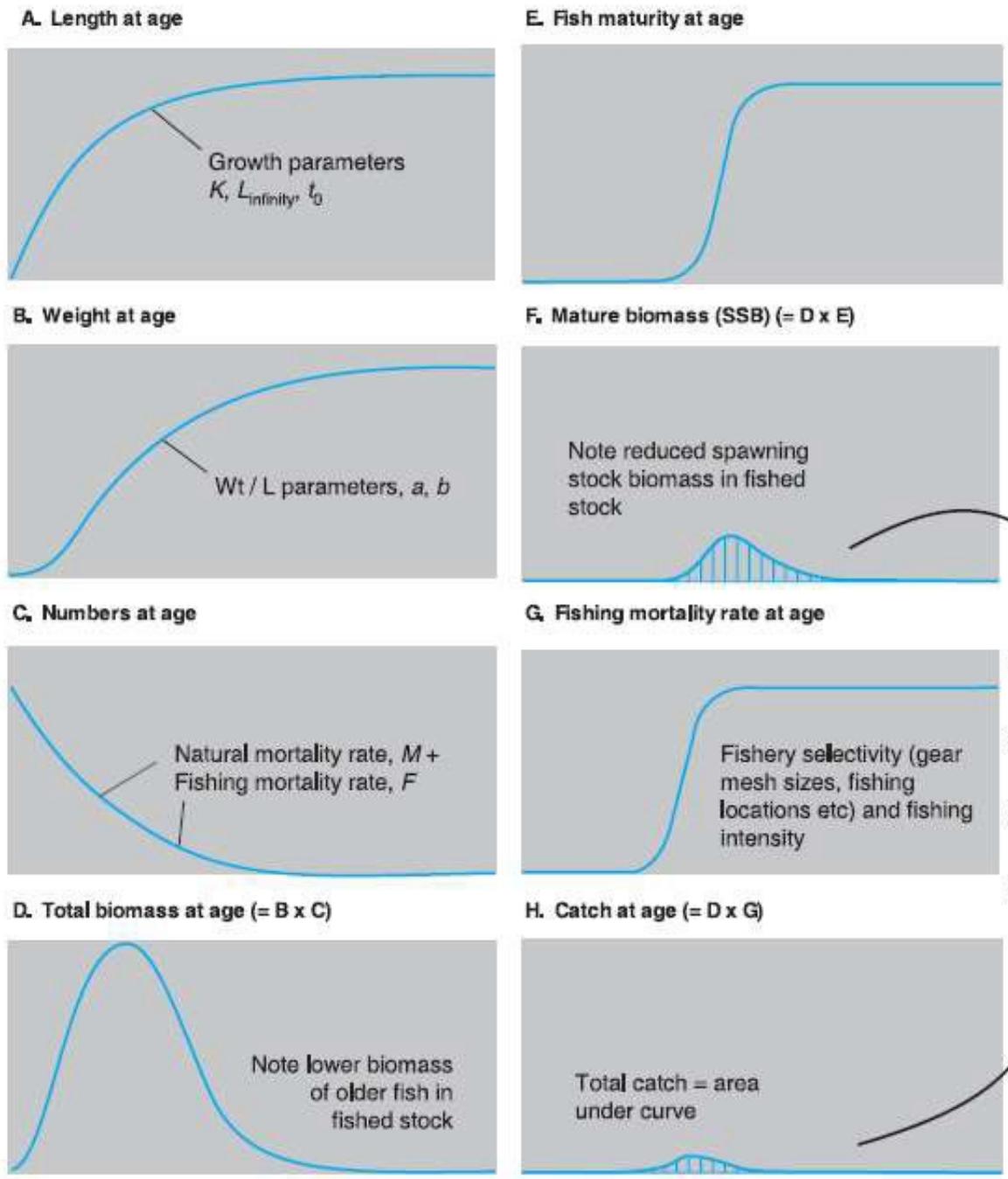
## Analytical Indicators

➢ 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

**Origins of three schools of thought current in fish-stock assessment and some interlinkages. Left: global models of whole populations under fishing pressure. Middle: analytical cohort models using size and age data. Right: models linking recruitment success to parental stock size.**



Hilborn and Walters (1992) [observation error/time-series fitting of production functions*]

Deriso(1980);Schnute(1987) Fournier and Doonan(1987) [delay-difference models]

Bioeconomic models [e.g. Beam]

Csirke and Caddy (1983) [production modelling with mortality rates]

Pope and Knight (1982) [multispecies VPA*]

Anderson and Ursin (1977) [multispecies extension of theory of fishing]

Paulik (1973) [generalization of stock-recruitment relations]

Pella and Tomlinson (1969) [variable geometry and error structure of production models]

Pope (1972) [cohort analysis*]

Gulland (1965) [virtual population analysis*]

Beverton and Holt (1956) [general analytical theory for fish population dynamics]

Gordon (1954) [economic models]

Schaefer (1954) [application of logistic model in fish stock assessment]

Ricker (1954) [stock and recruitment]

Fry (1949) [virtual popl'n*]

Ricker (1949) [catch curves]

Graham (1935) [logistic model for North Sea groundfish]

Von Bertalanffy (1938) [growth models]

Thompson and Bell (1934) [piecewise yield per recruit calculation]

Pearl and Reed (1920) [human demography]

Baranov (1918) [first integrated theory of fishing]

Gilbert (1913) [stock separation by annuli of salmon by natal rivers]

* This type of method has been "reinvented" several times; see e.g. Ricker (1975)

Hjort and Petersen (1905) [modal analysis and "year classes"]

1902 - Founding of ICES [the "overfishing" Committee inaugurated]

Malthus (1798) [exponential growth]

Lankester (1884) ["It's a mistake to suppose that the whole ocean is pratically one vast store-house"]

Huxley (1884) [probably all the great sea-fisheries are inexhausttible...]

# The dynamics of an exploited cohort (Z=M+F) compared to natural decay without fishing (Z=M).
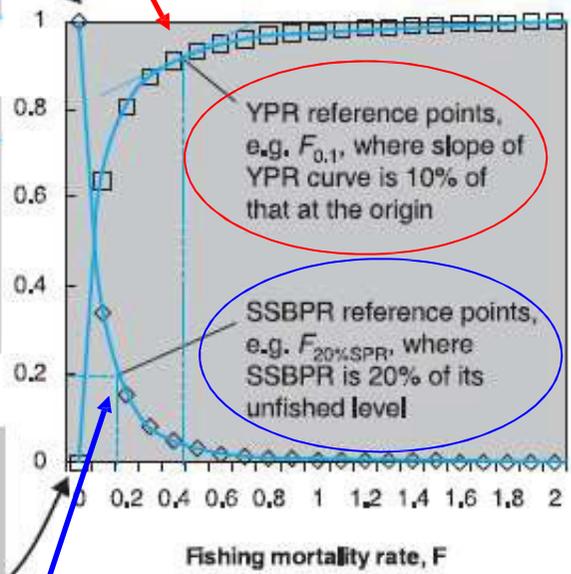


(by Kolding and Ubal Giordano, 2002)

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

A. Length at age

Growth parameters $K$, $L_{infinity}$, $t_0$

B. Weight at age

Wt / L parameters, $a$, $b$

C. Numbers at age

Natural mortality rate, $M$ + Fishing mortality rate, $F$

D. Total biomass at age (= B x C)

Note lower biomass of older fish in fished stock

E. Fish maturity at age

F. Mature biomass (SSB) (= D x E)

Note reduced spawning stock biomass in fished stock

G. Fishing mortality rate at age

Fishery selectivity (gear mesh sizes, fishing locations etc) and fishing intensity

H. Catch at age (= D x G)

Total catch = area under curve

'Yield' estimates relative indicators - spawning stock biomass (area under line in graph F) and catch (area under line in graph H) - at different levels of the fishing mortality rate, $F$, and thereby finds the values of different $F$-based reference points, e.g. $F_{0.1}$, $F_{\%SPR}$

YPR reference points, e.g. $F_{0.1}$, where slope of YPR curve is 10% of that at the origin

SSBPR reference points, e.g. $F_{20\%SPR}$, where SSBPR is 20% of its unfished level

Fishing mortality rate, F

(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
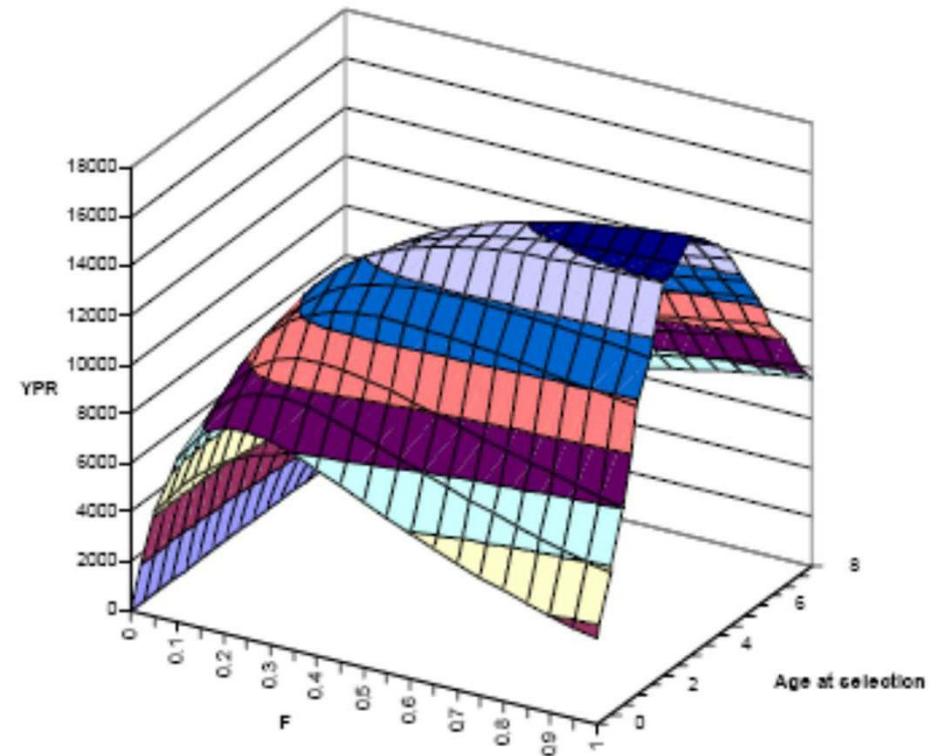
# Analytic estimation of sustainable yield
# The synthesis of Sissenwine & Shepherd....

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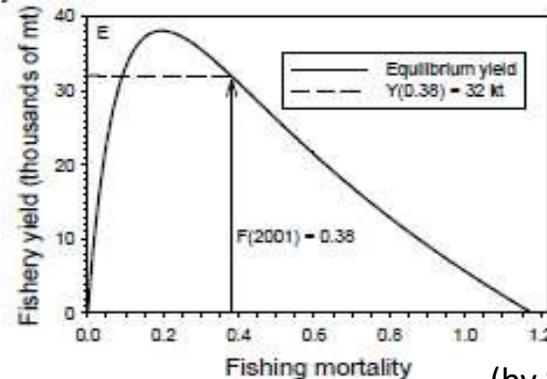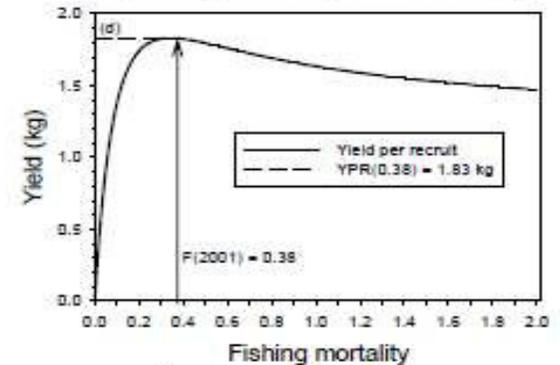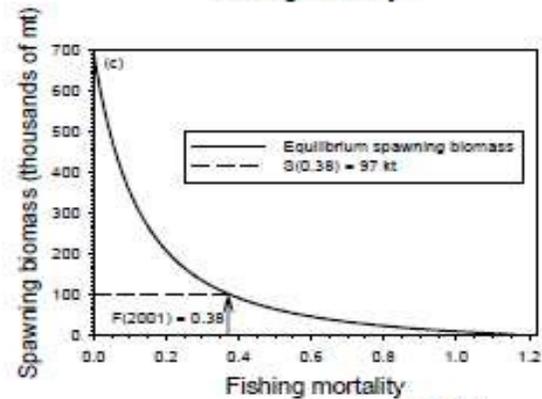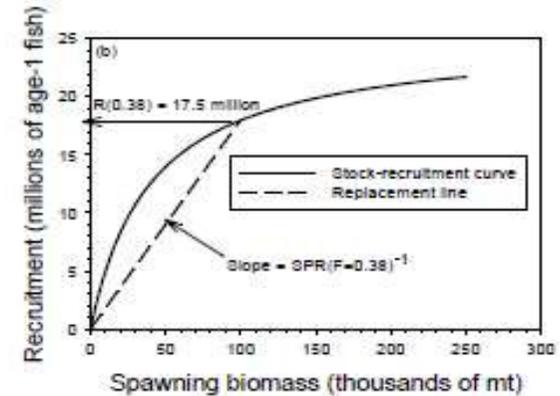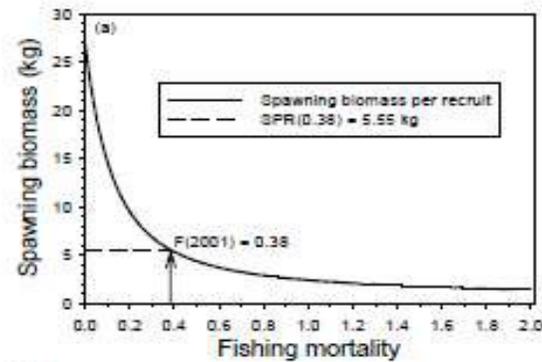


(by Sissewine & Shepherd, 1987)

# *The Surplus production models ... the classical approach*

- 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
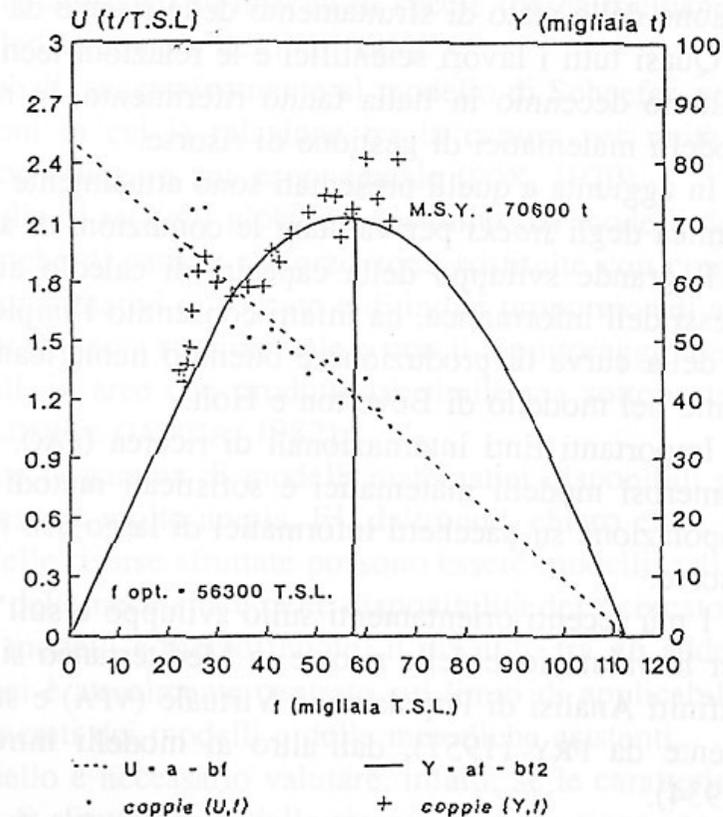


Surplus production model of the **aggregate catch** of demersal species in the **Strait of Sicily** (1959-1983). The **maximum sustainable yield**, (about 70000 t per year) **was reached in 1983** (about 56000 GRT) (by Levi and Andreoli, 1989, modified).

# *Surplus Production models (SPM)*

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**

# *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


a)

**CPUE and abundance**

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

$C = F \cdot B_{mean}$

$F = q \cdot E$

$C = q \cdot E \cdot B_{mean}$

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

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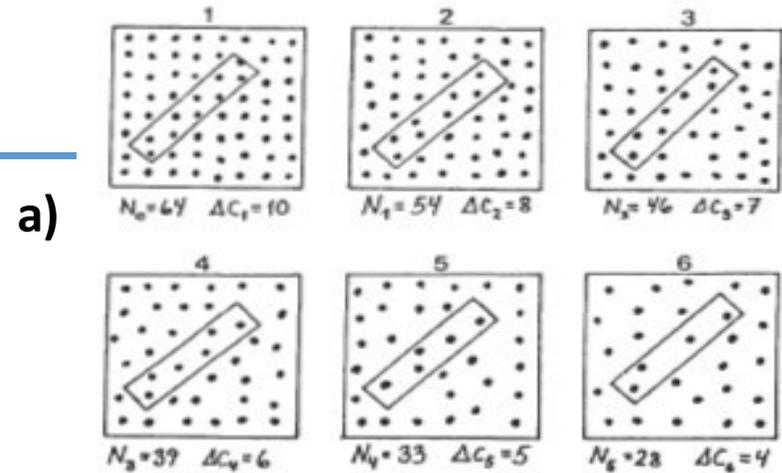
CPUEs are proportional to the stock size throughout time **if the area occupied by the stock remain constant**

b)


(by Sparre & Venema, 1998)
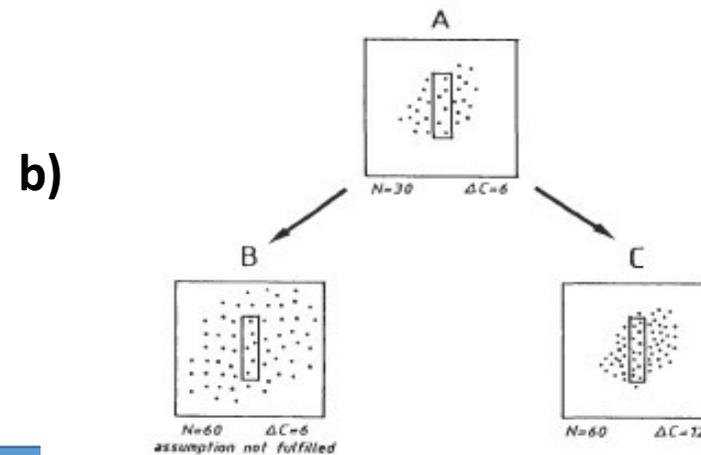
# An example of CMSY/BSM to assess exploitation of *Lepidopus caudatus* in the Strait of Sicily combining BI and Catch data



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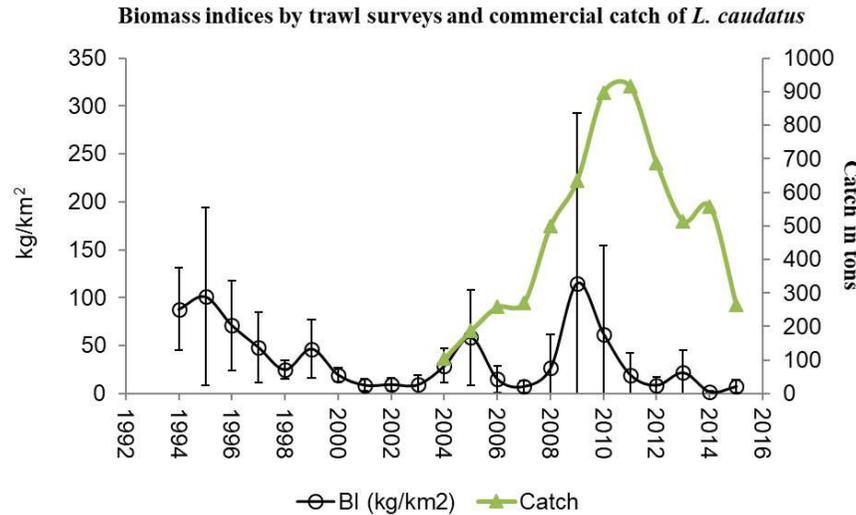

BI available before beginning of fishery
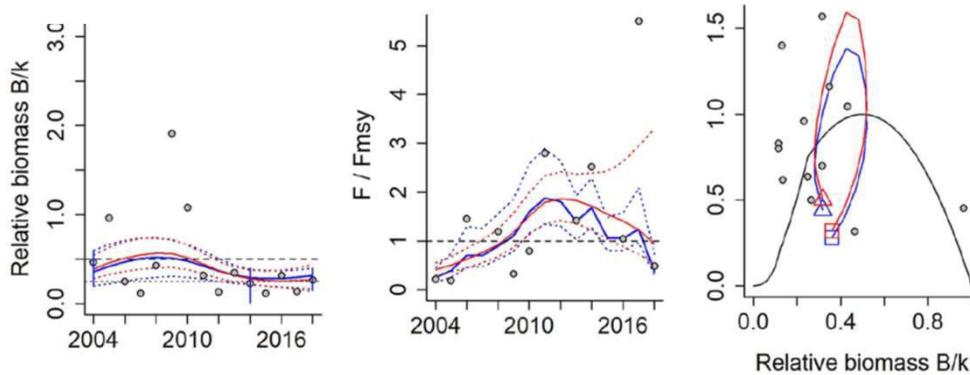
Management graph
➢ Catch and MSY & Relative total biomass (B/Bmsy)
➢ Relative exploitation (F/Fmsy) & B/Bmsy and F/Fmsy
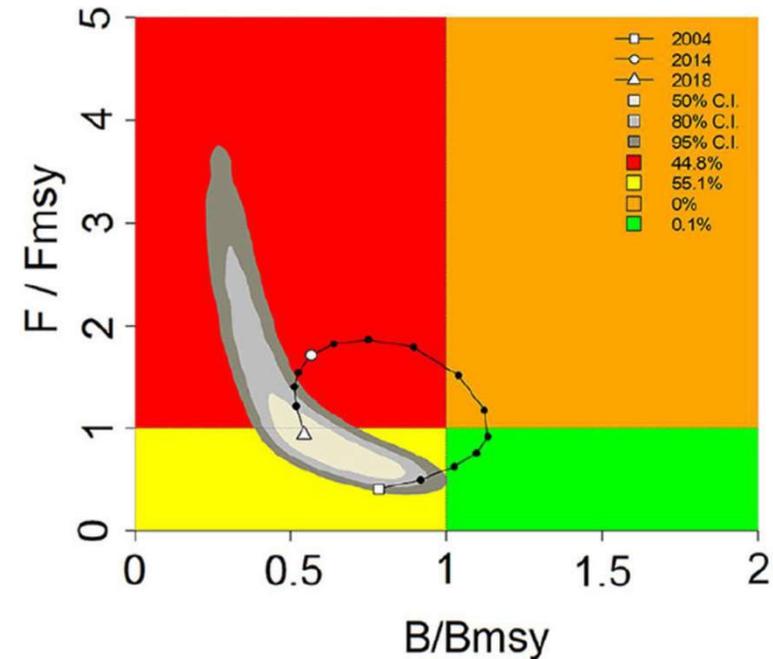
KOBE plot: Evolution of B/Bmsy and F/Fmsy throughout time

(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**
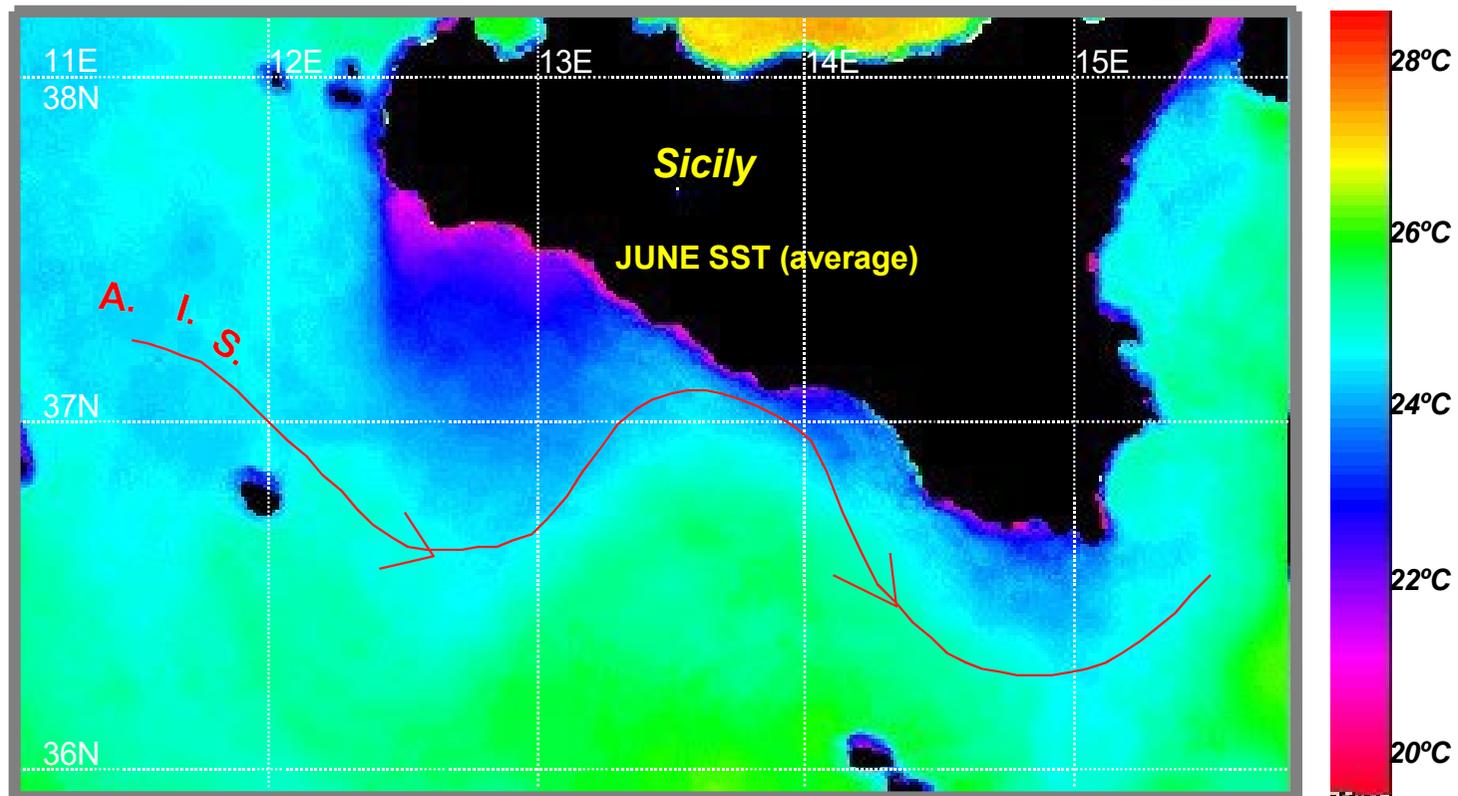


**(by Garcia-Lafuente et al., 2002)**

# 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: $\ln(R) = \ln(a) + \ln(S) - b*S + c*S*SSTanom$

$\ln(R) = \ln(70.17113) + \ln(S) - (0.0638123)*S + (0.0605436)*S*SSTanom$
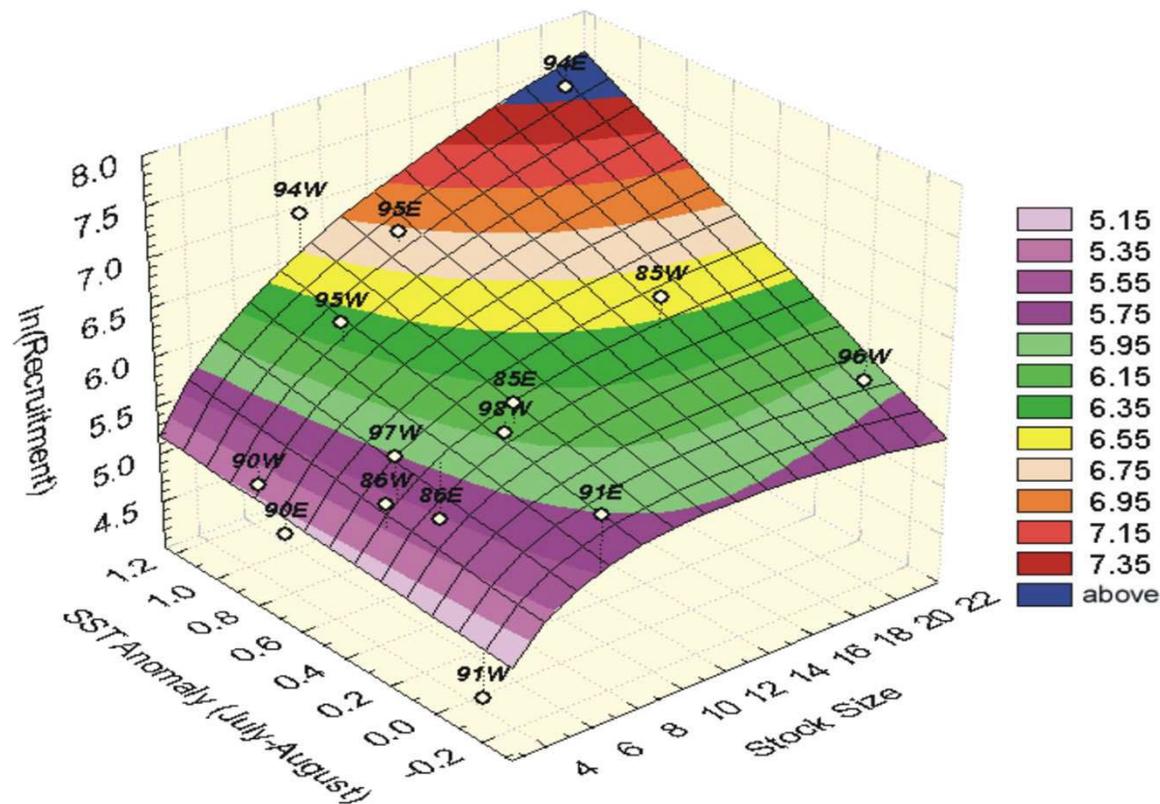
(by Levi et al., 2003)

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

Mediterranean Sea SST Cumulative Trend (1993-2020)



The effects of climate change on reproduction, growth and natural mortality can affect stock productivity and change MSY (by Travers-Trolet et al., 2020)
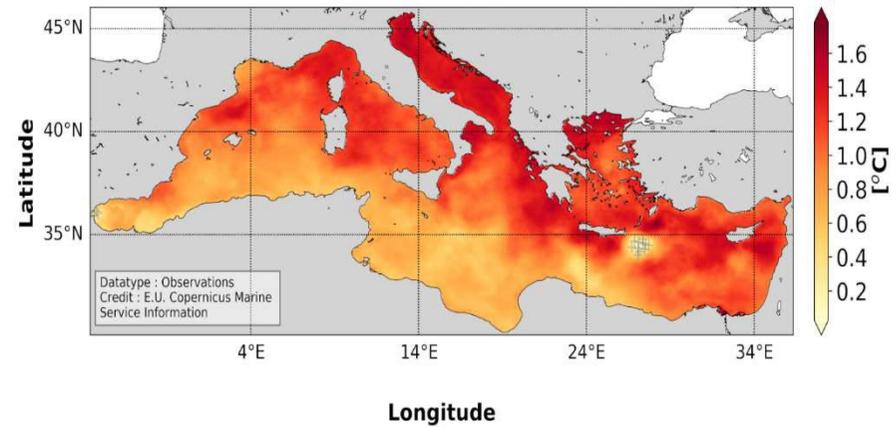
Some simulations on Sustainable yield vs. fishing mortality of flat fish in the English Channel
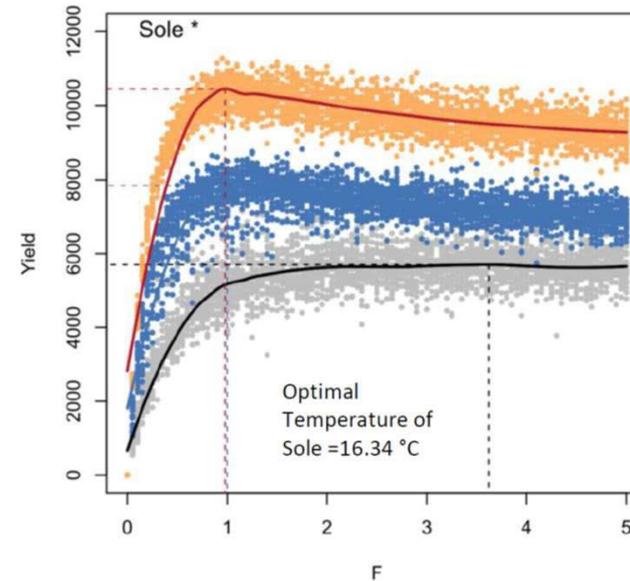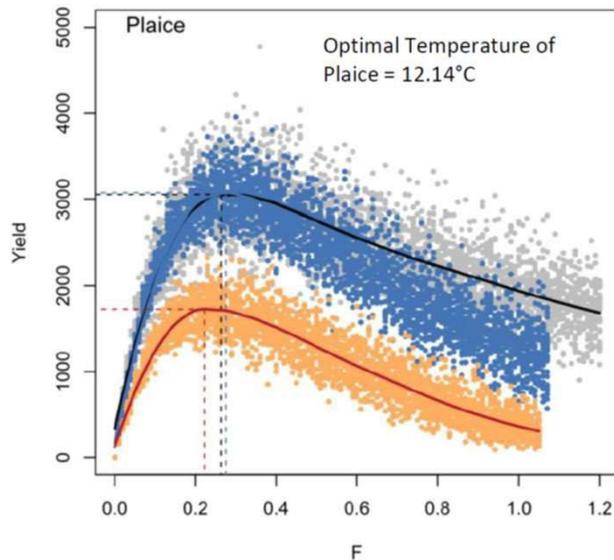
# Some simulation of multispecies spatial dynamics under the current emission of $CO_2$ and fishing mortality scenarios using Eco3M-S coupled with OSMOSE models

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.
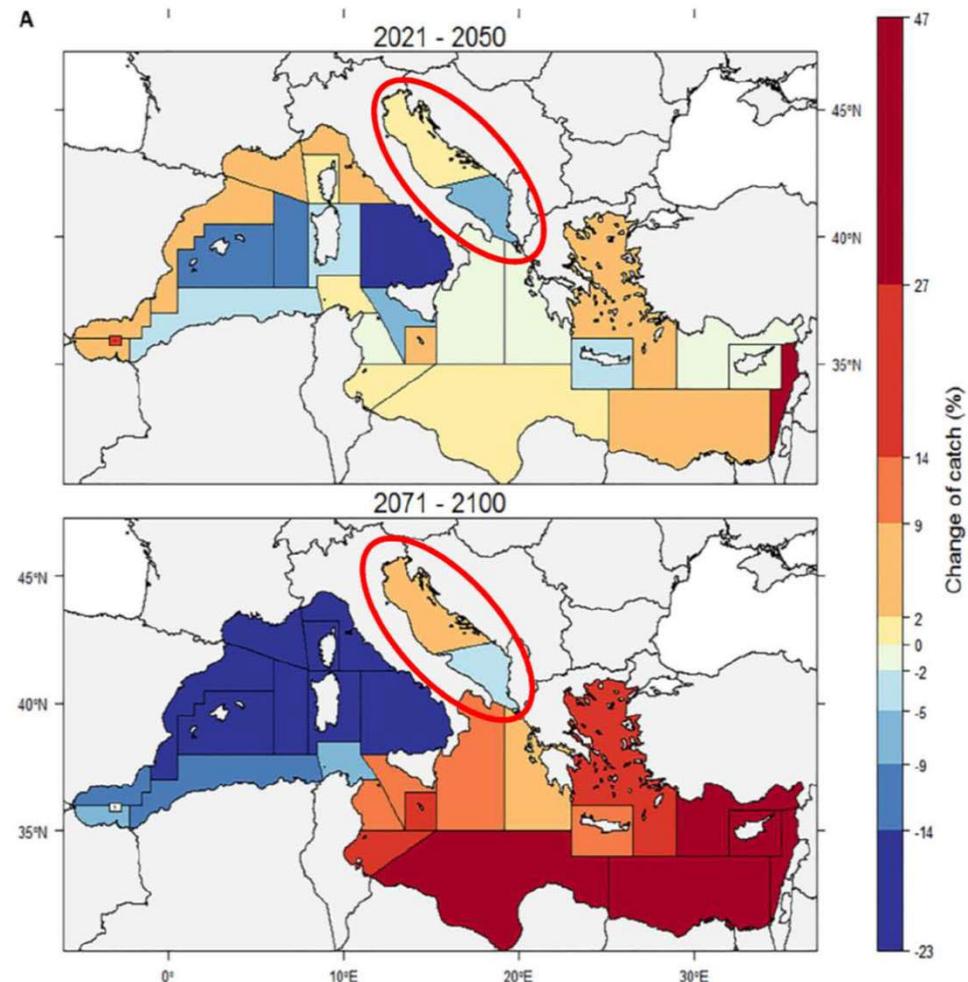


by Moullec et al., 2019

# Some empirical 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)
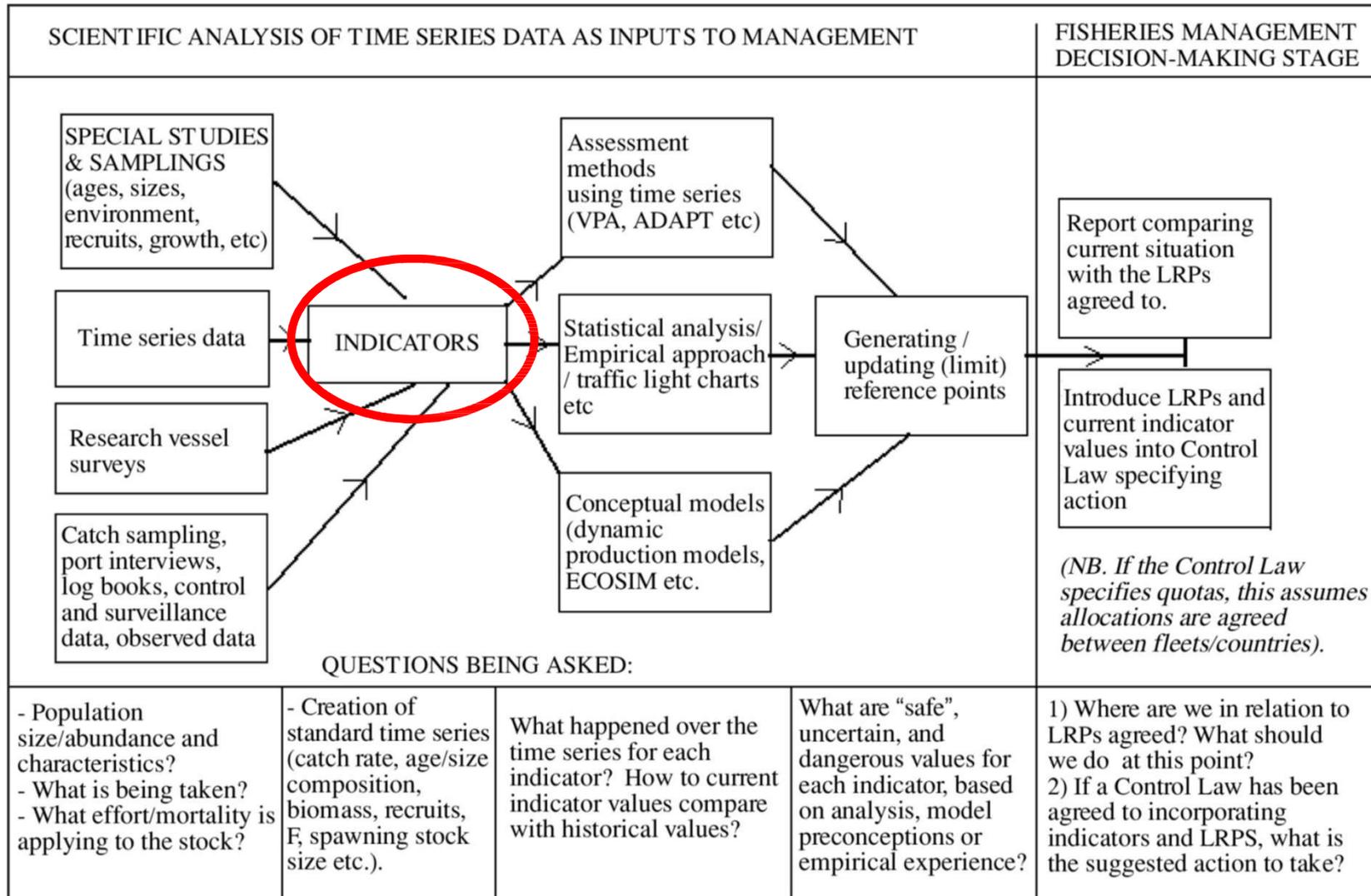
## *The main features of the Mediterranean fisheries and the choice of good indicators and modelling approaches*

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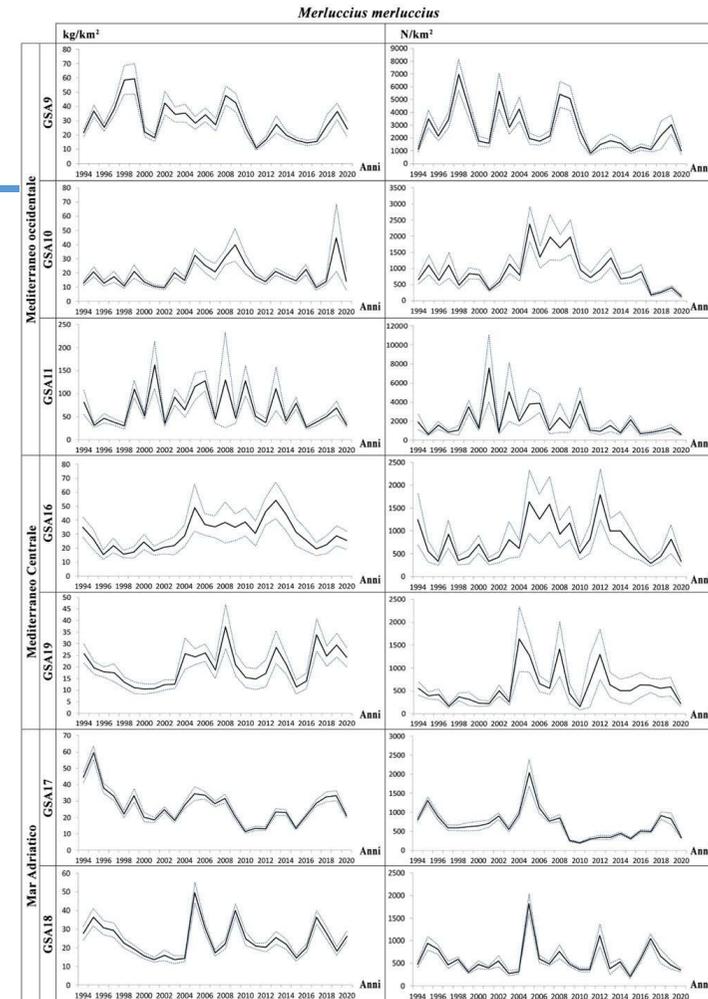
Spearman's Rho of the biomass (kg/km2) and density (N/km2) indices of **Hake** (Medits series 1994-2020). In bold the significant values (alpha ≤ 0.05).



*Merluccius merluccius*

| Indicator | Western Mediterranean | | | Central Mediterranean | | Adriatic Sea | |
|---|---|---|---|---|---|---|---|
| | **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*



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
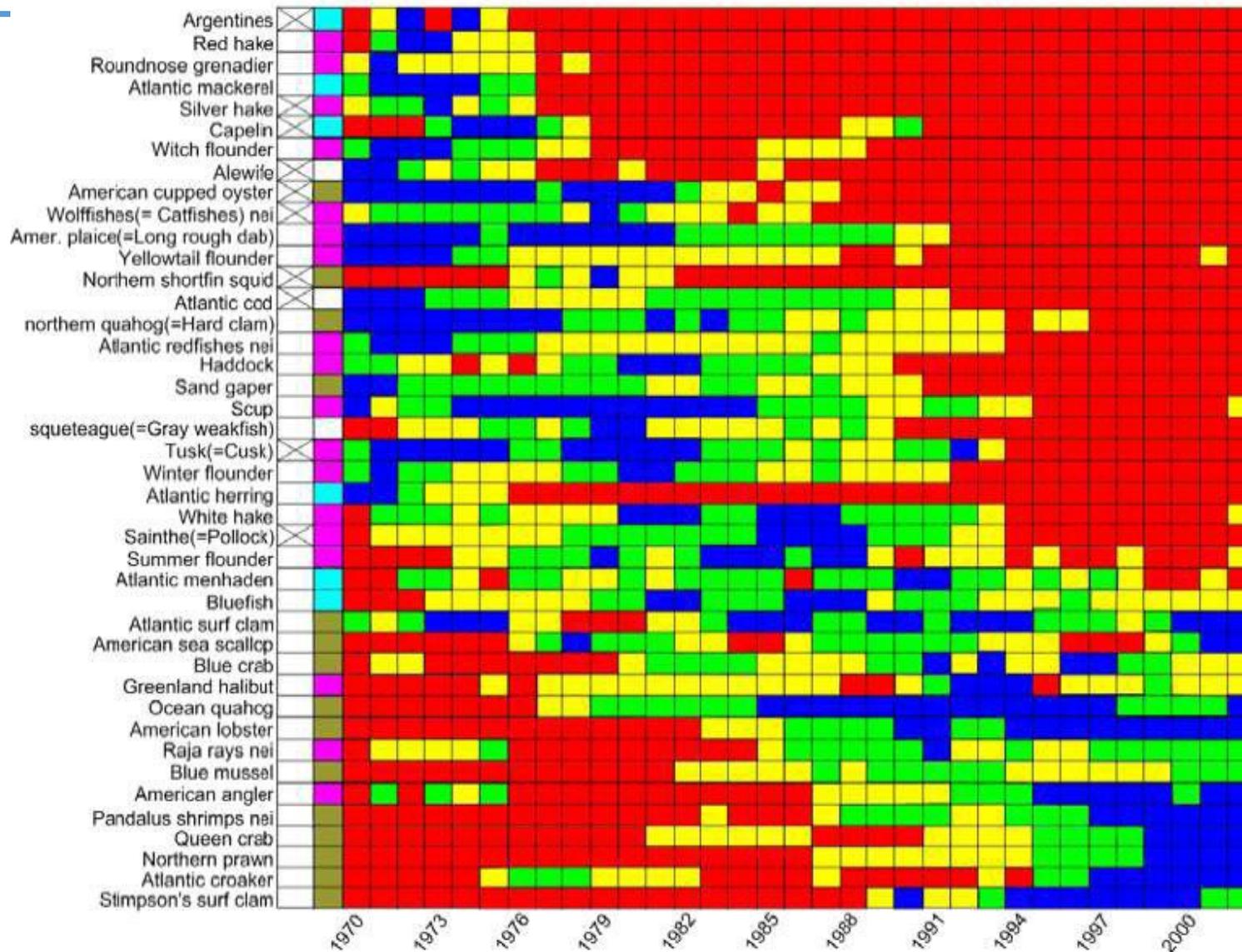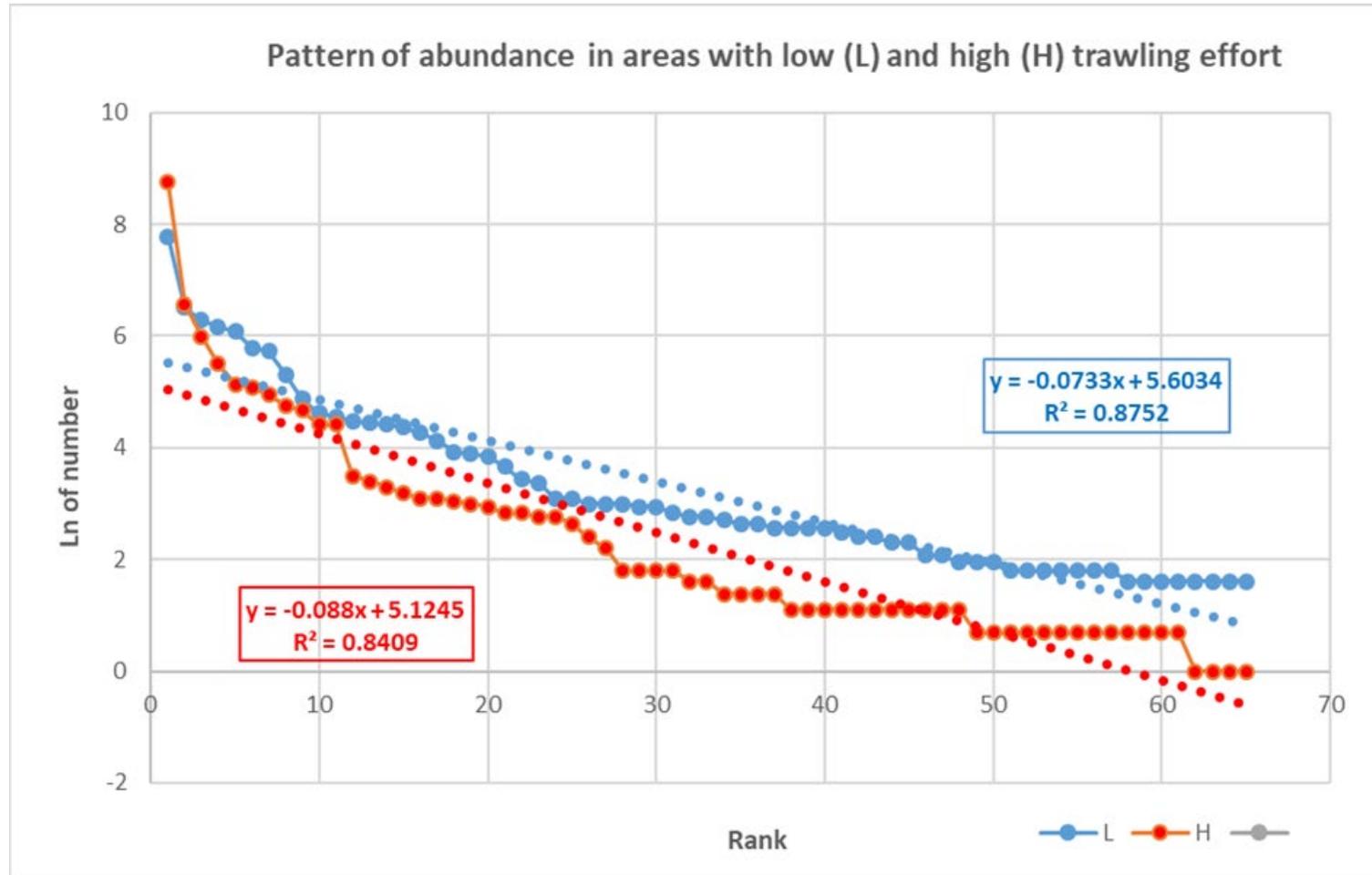


If indicators have to be aggregated, weighting is necessary according to the relative importance of each one considering the management objectives

(by Caddy, 2010)

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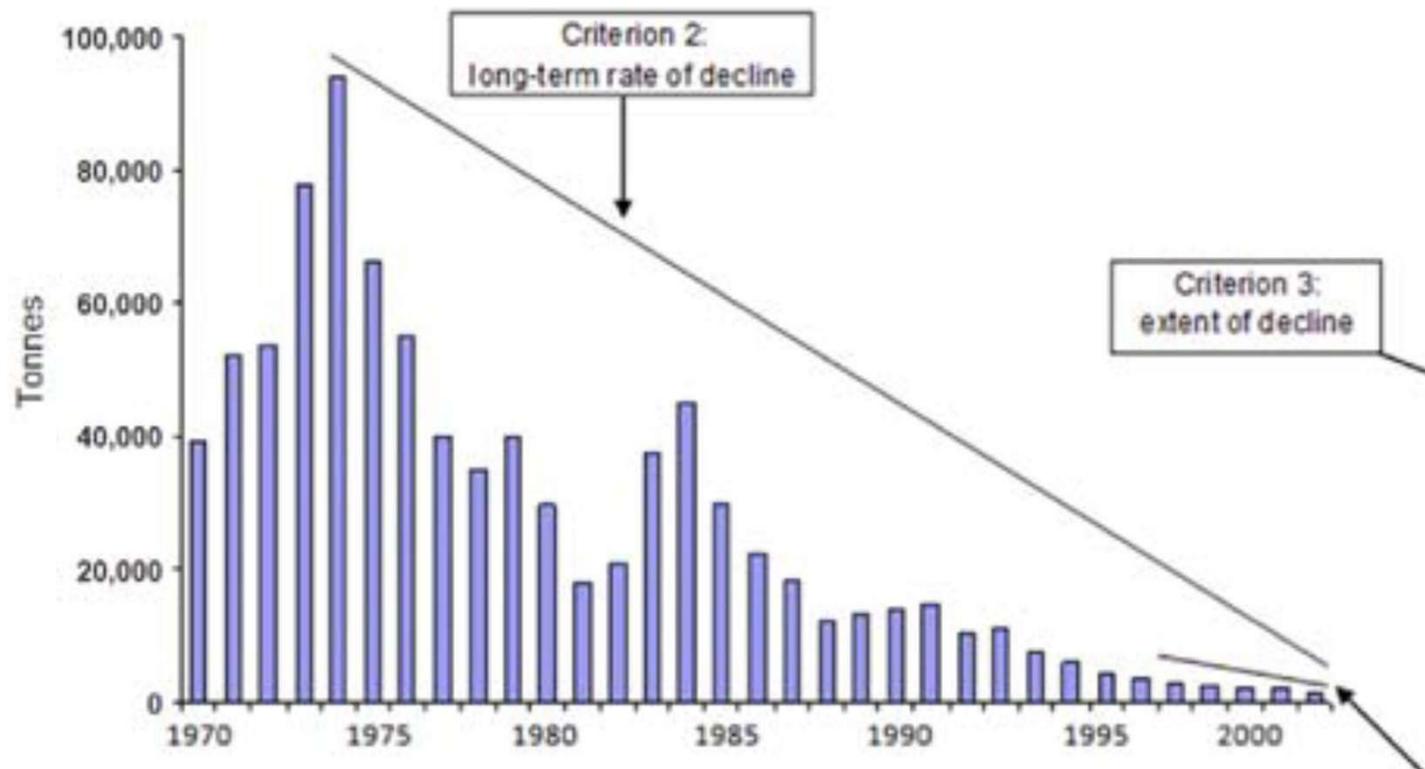


(by Caddy, 2010)

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



Pattern of abundance in areas with low (L) and high (H) trawling effort

$y = -0.0733x + 5.6034$
$R^2 = 0.8752$

$y = -0.088x + 5.1245$
$R^2 = 0.8409$

Ln of number

Rank

L — H

# 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.
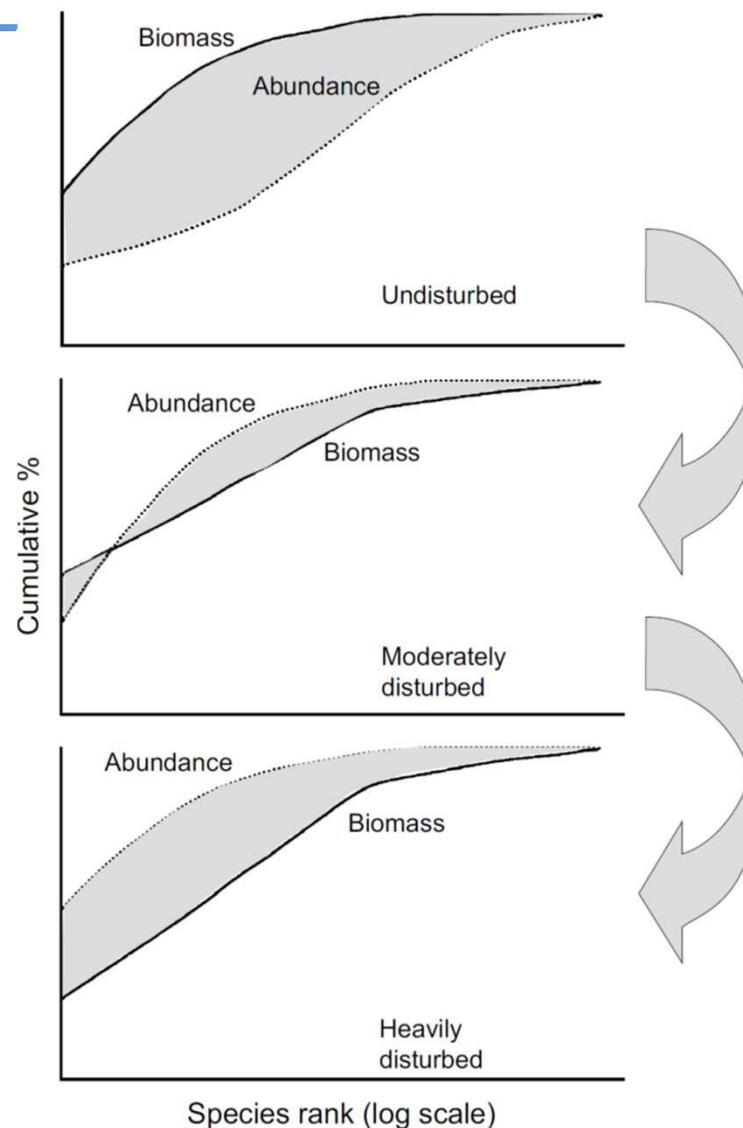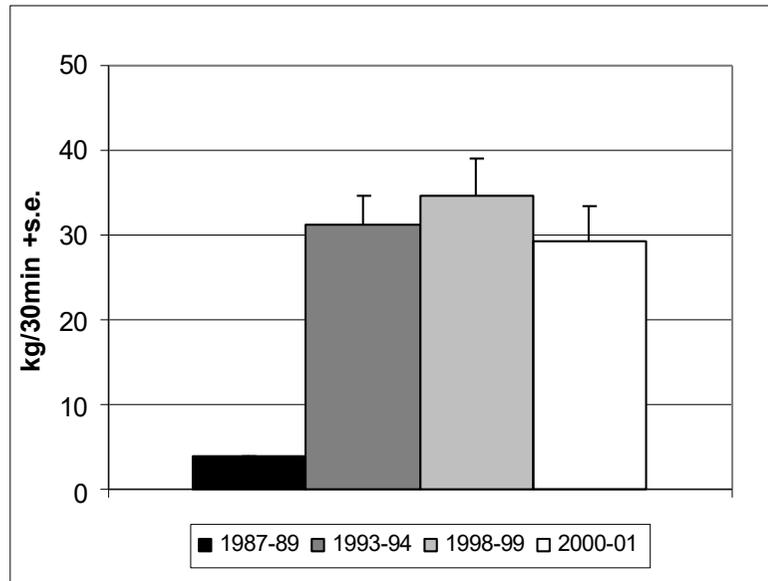


(by Yemine et al., 2005)

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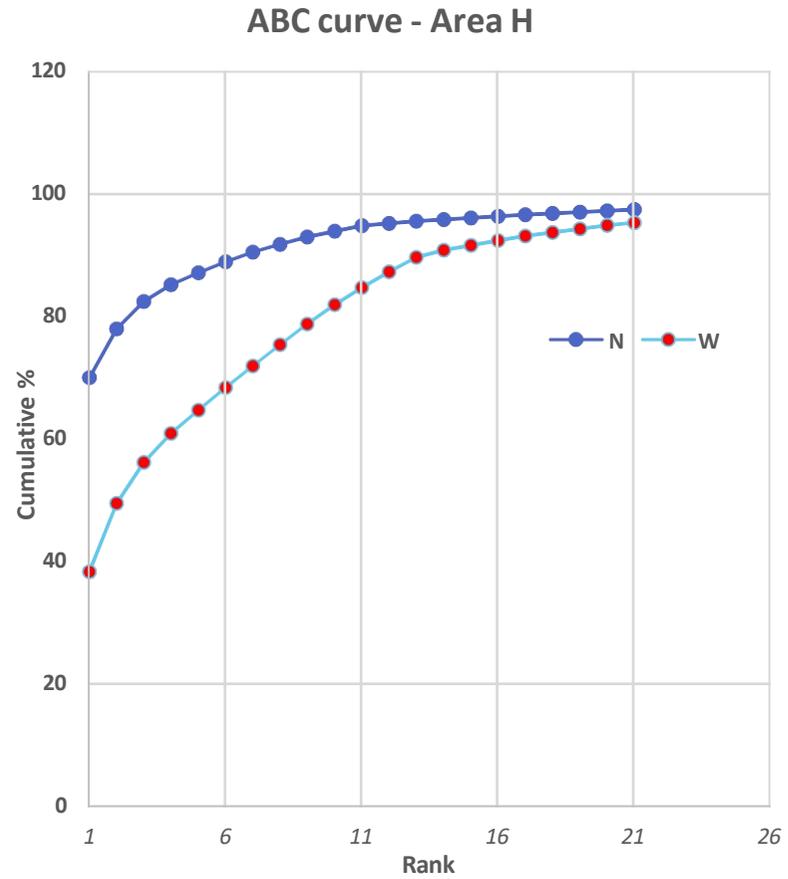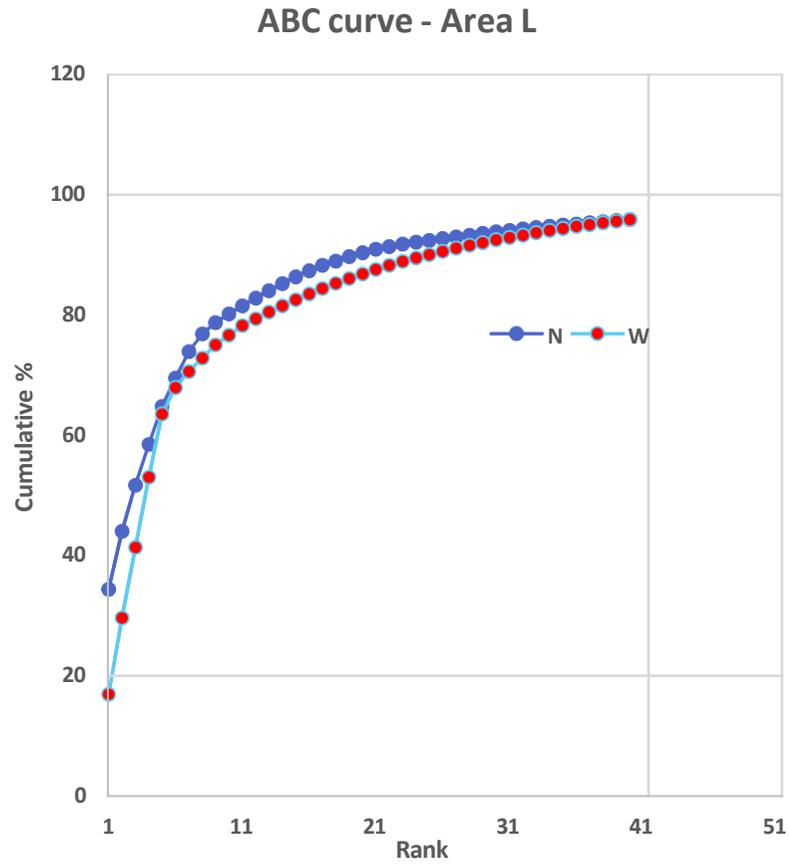
## What do the empirical indicators tell us on the restoring of Biomass and Size Structure in a Mediterranean Fisheries Restricted Area?
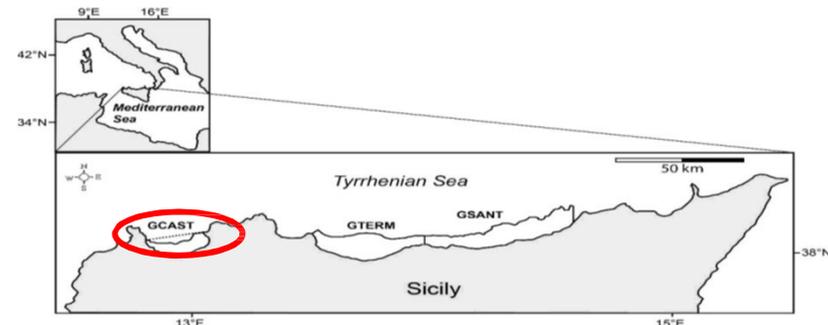


**Catch rate in trawl surveys** in the Gulf of Castellammare (GCAST) **before** (1987-89) **and after** the implementation of the **FRA** (from Pipitone et al., 2001).
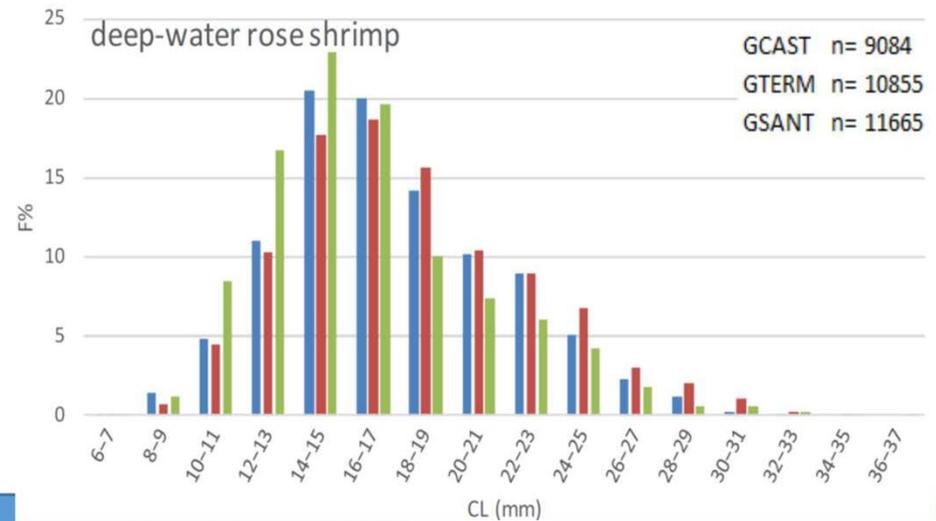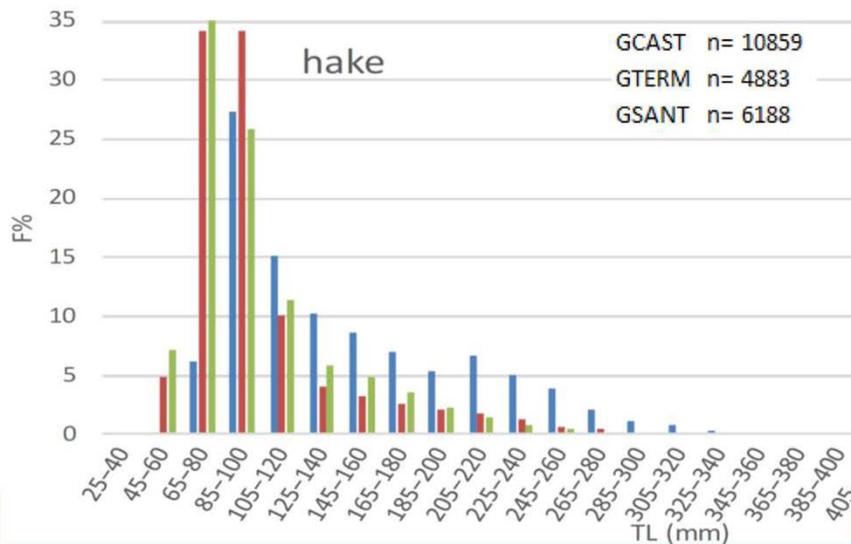
**The size structure** of each selected species was described by its length frequency distribution (LFD) and by the following **length based indicators** :

➢ **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)**

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 |

| | $L_m$ (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 |



hake    GCAST  n= 10859
        GTERM  n= 4883
        GSANT  n= 6188



deep-water rose shrimp    GCAST  n= 9084
                          GTERM  n= 10855
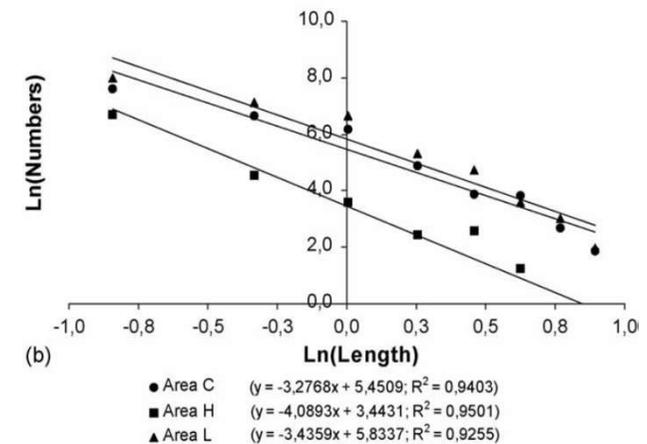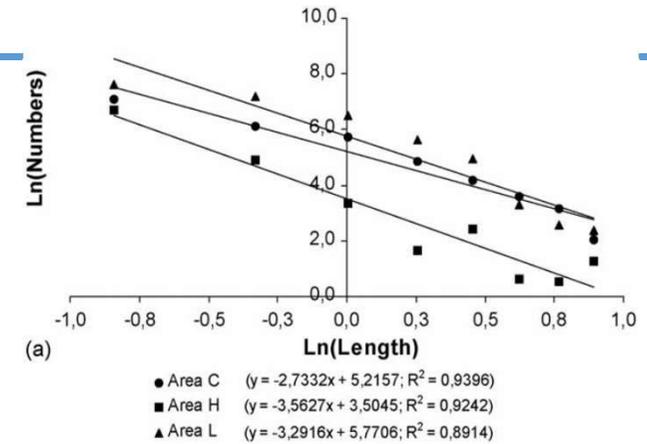                          GSANT  n= 11665

Blue CAST; RED term, and green SANT

# The empirical indicators and how fishing can shape the fish communities
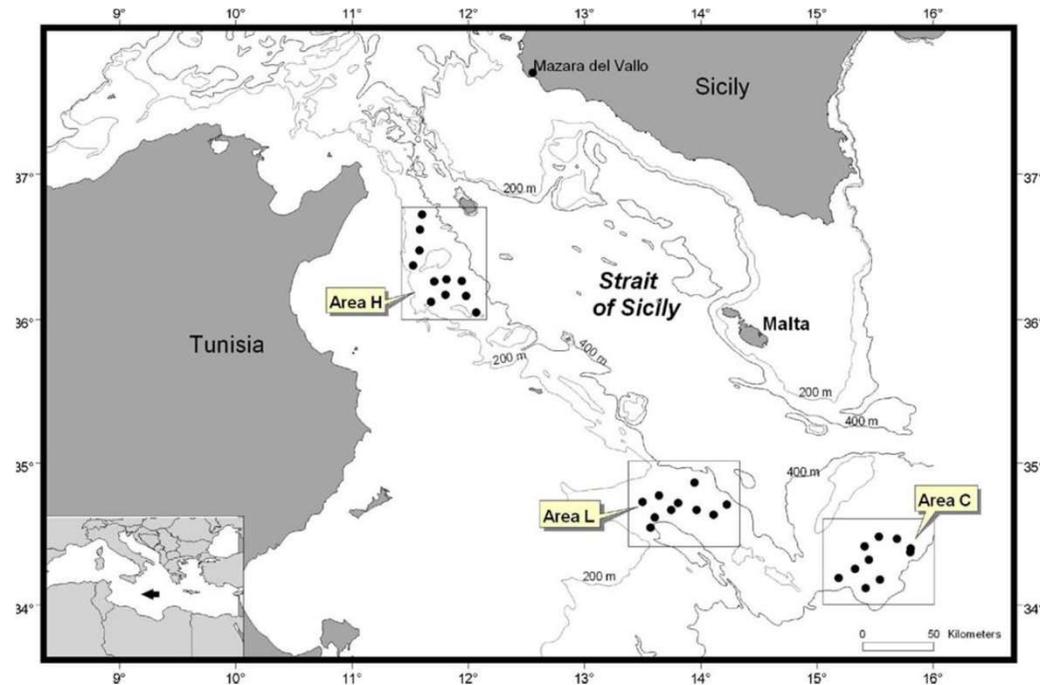


Three areas of Strait of Sicily affected by null (C), low (L) and high (H) trawling effort

(by Gristina et al., 2006)

The **size spectra** analyses (Ln of numbers vs ln of length) show that the size structure in the area H is

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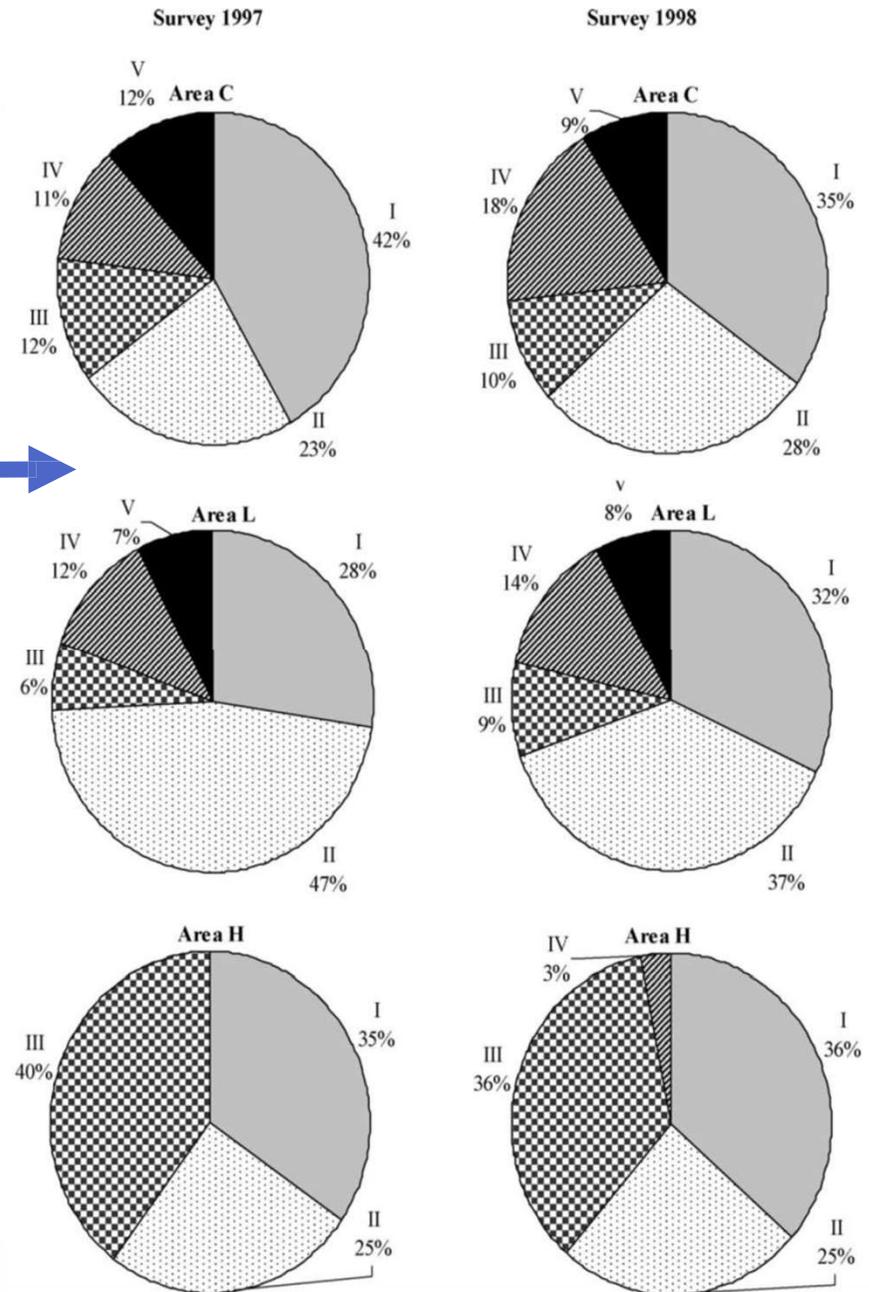
Vulnerability categories: (I) small teleosts; (II) medium teleosts; (III) large teleosts; (IV) small elasmobranchs; (V) large elasmobranchs

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 |
| $\Delta^*$ | 67,80 | 59,38 | 67,70 | 67,54 | 60,51 | 67,49 |
| | └ * ┘ | └ * ┘ | | └ * ┘ | └ * ┘ | |
| $\Delta^+$ | 71,31 | 67,83 | 71,65 | 71,00 | 67,77 | 71,74 |
| | └ * ┘ | └ * ┘ | | └ * ┘ | └ * ┘ | |

$J'$: Pielou's evenness index, $H'$: Shannon–Wiener diversity index, $\Delta^*$: distinctness index, $\Delta^+$: 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



Survey 1997

Area C
V 12%
IV 11%
III 12%
II 23%
I 42%

Area L
V 7%
IV 12%
III 6%
II 47%
I 28%

Area H
III 40%
II 25%
I 35%

Survey 1998

Area C
V 9%
IV 18%
III 10%
II 28%
I 35%

Area L
V 8%
IV 14%
III 9%
II 37%
I 32%

Area H
IV 3%
III 36%
II 25%
I 36%

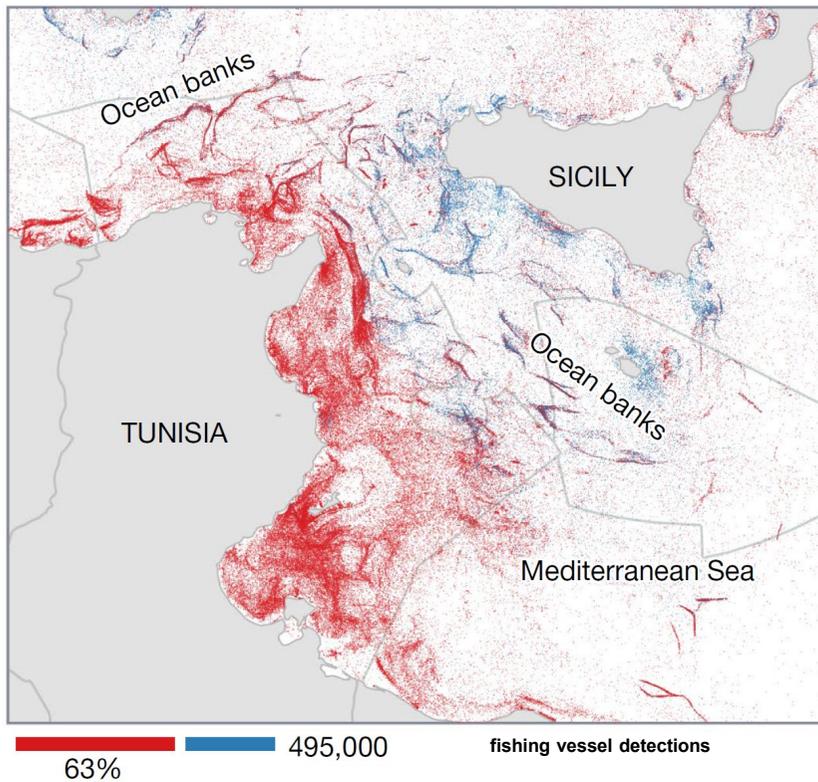# The use of spatial based indicators of stock status and fishing pressure

Density maps of recruits and persistent nurseries ( by Garofalo et al., 2011)
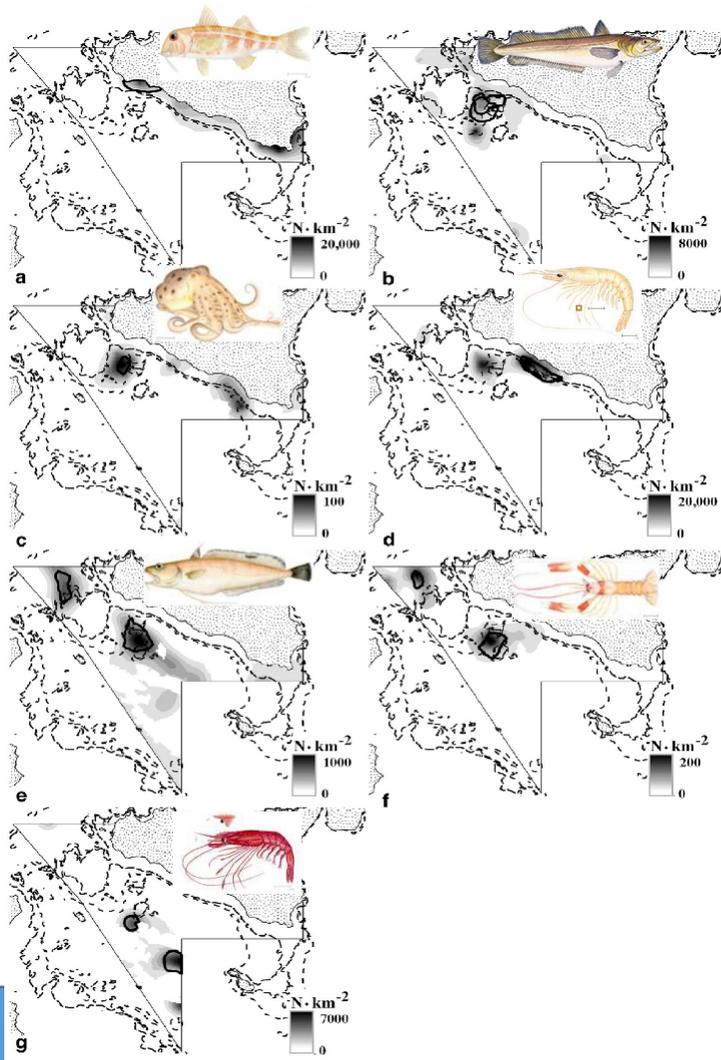
The mean annual fishing effort (2012–2016) as red-scale color (log of total fishing hours) (by Russo et al., 2019)
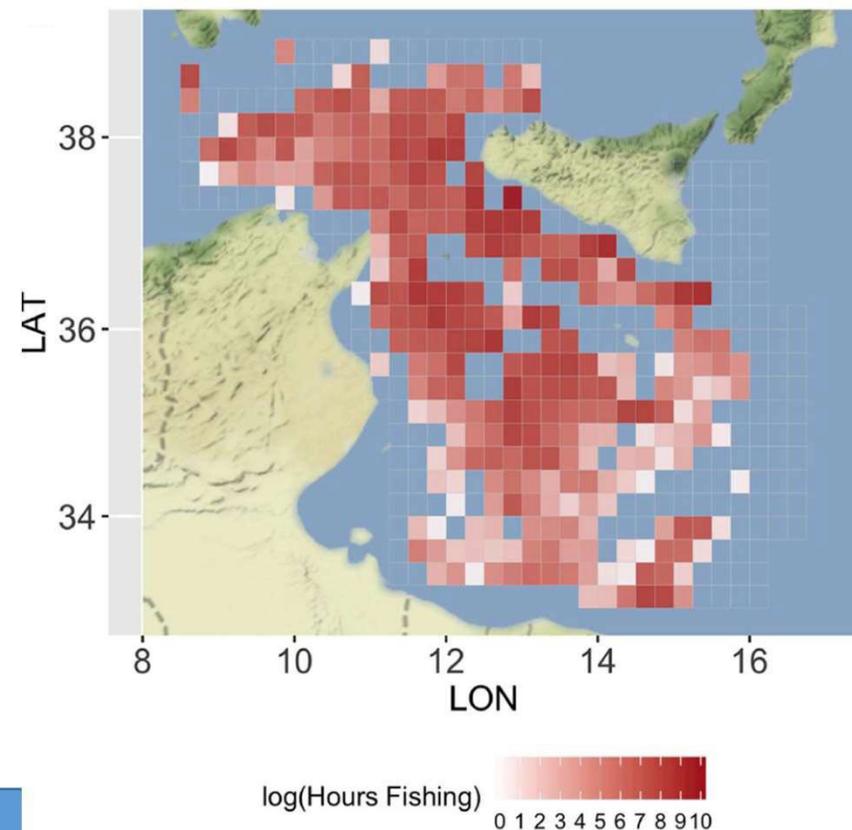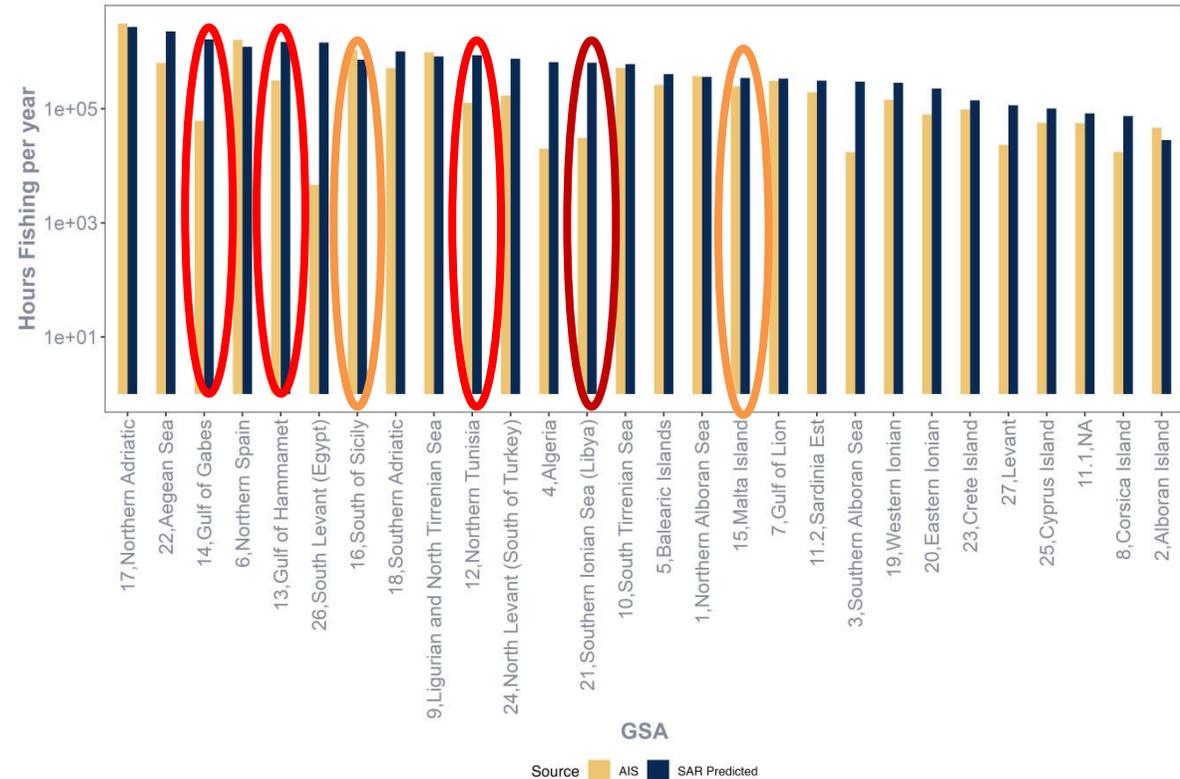
# The spatial distribution of fishing effort by trawlers in the Strait of Sicily using AIS and SAR (2017-2021)...the varying coverage of remote sensing of fleets

Detection of fishing vessels using Synthetic Aperture Radar (SAR; in red) and Automatic Identification System (AIS; in blue).

(by Paolo et al., 2024)

Bar chart showing expected fishing activity (based on SAR) and observed fishing activity (based on AIS), expressed in fishing hours (y-axis). The number of fishing hours is represented on a Log 10 scale.
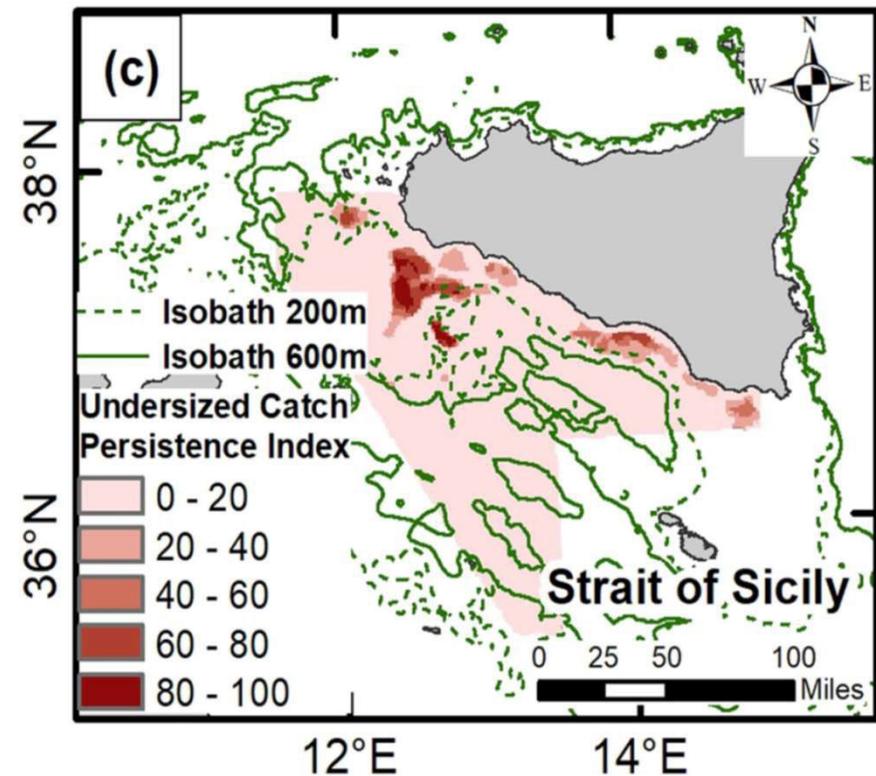
(by Marsaglia et al., 2024)

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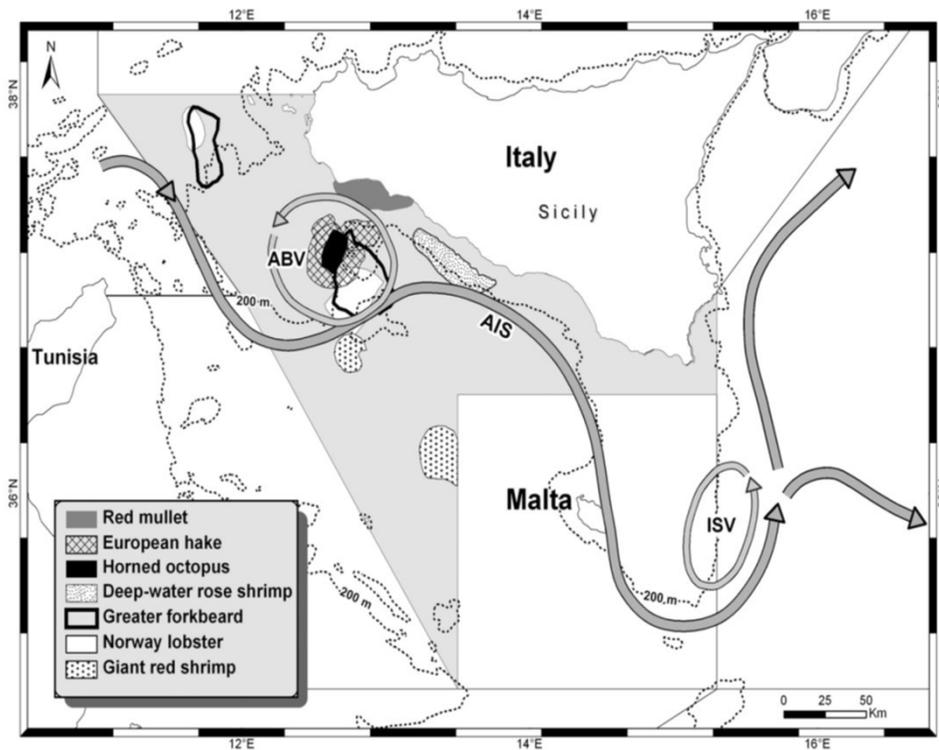
Persistence index maps of undersized catch of species subjected to Minimum Conservation Reference Size in the Strait of Sicily



(by Garofalo et al., 2011)

(by Despoti et al., 2020)

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

| | | Stock categories | Advice basis |
|---|---|---|---|
| Increasing of available information → | 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 and modifications**

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

**Reg. UE 266/2026**
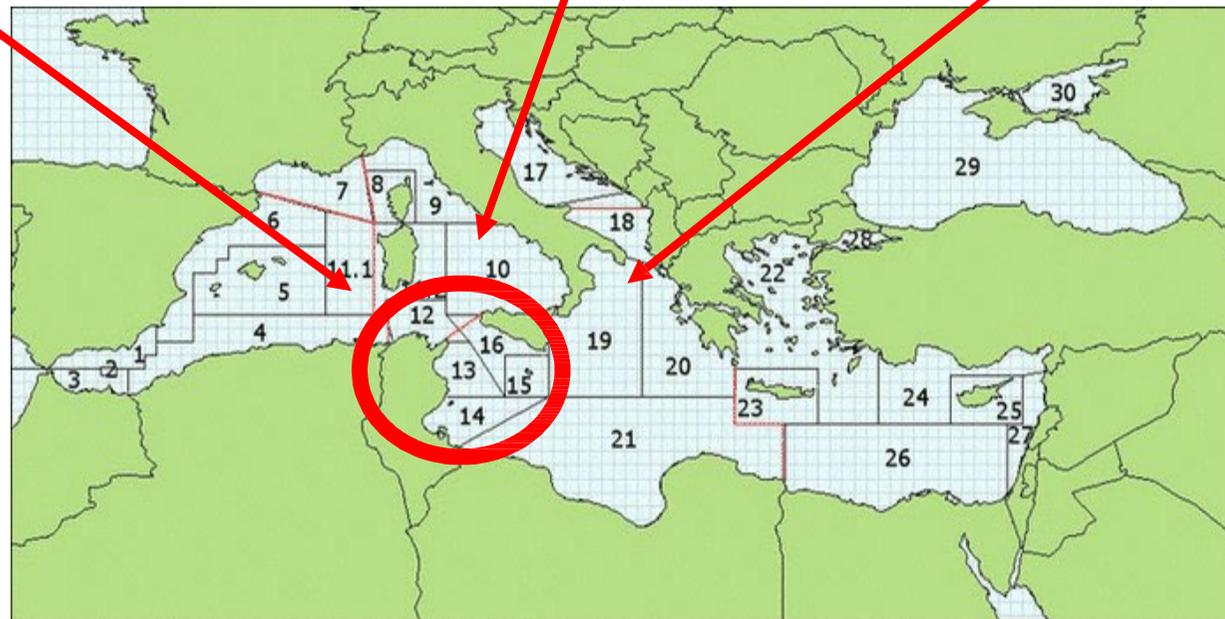
# The management of the demersal stocks in the Strait of Sicily

The **demersal fisheries** in the Strait of Sicily is regulated by the **Rec. GFCM/45/2022/4** and all subsequent amendments, having as main target Hake and Deep water rose shrimp, and the **EU reg. 266/2026** adopting a **multiannual management plan (MAP)** for bottom trawl fisheries exploiting demersal stocks in the GSA from 12 to 16.

This MAP applies to **bottom trawlers above 10 m LOA** and aims to:
- apply the **precautionary approach** to fisheries management;
- ensure that exploitation levels of key stocks are at the **maximum sustainable yield** (MSY) within **31st December 2030**;
- prevent increase in **fishing capacity effort** in relation to year 2021;
- protect **essential fish habitats (EFHs)** important for the key stocks in the area;
- Adopt **MCRS for the target species** (20 cm TL for HKE and 20 mm CL for DPS)
- contribute to elimination of **discards**, by avoiding and reducing unwanted catches, and by ensuring that all catches are landed;

The MAP consists of two phases:
- during the first three years, extended to four years(**transitional phase, 2023-2026**), **effort and catch limits** and **spatial-temporal based measures** will be applied;
- from 2027 onwards, the SAC will **assess the state of stocks** and **update annual measures** and catch limits in line with achieving **Fmsy** and abundances at sea within **safe biological limits.**

# The Deep water rose shrimp is the main target species of bottom trawling in the Strait of Sicily with a catch of 4112 t in 2024
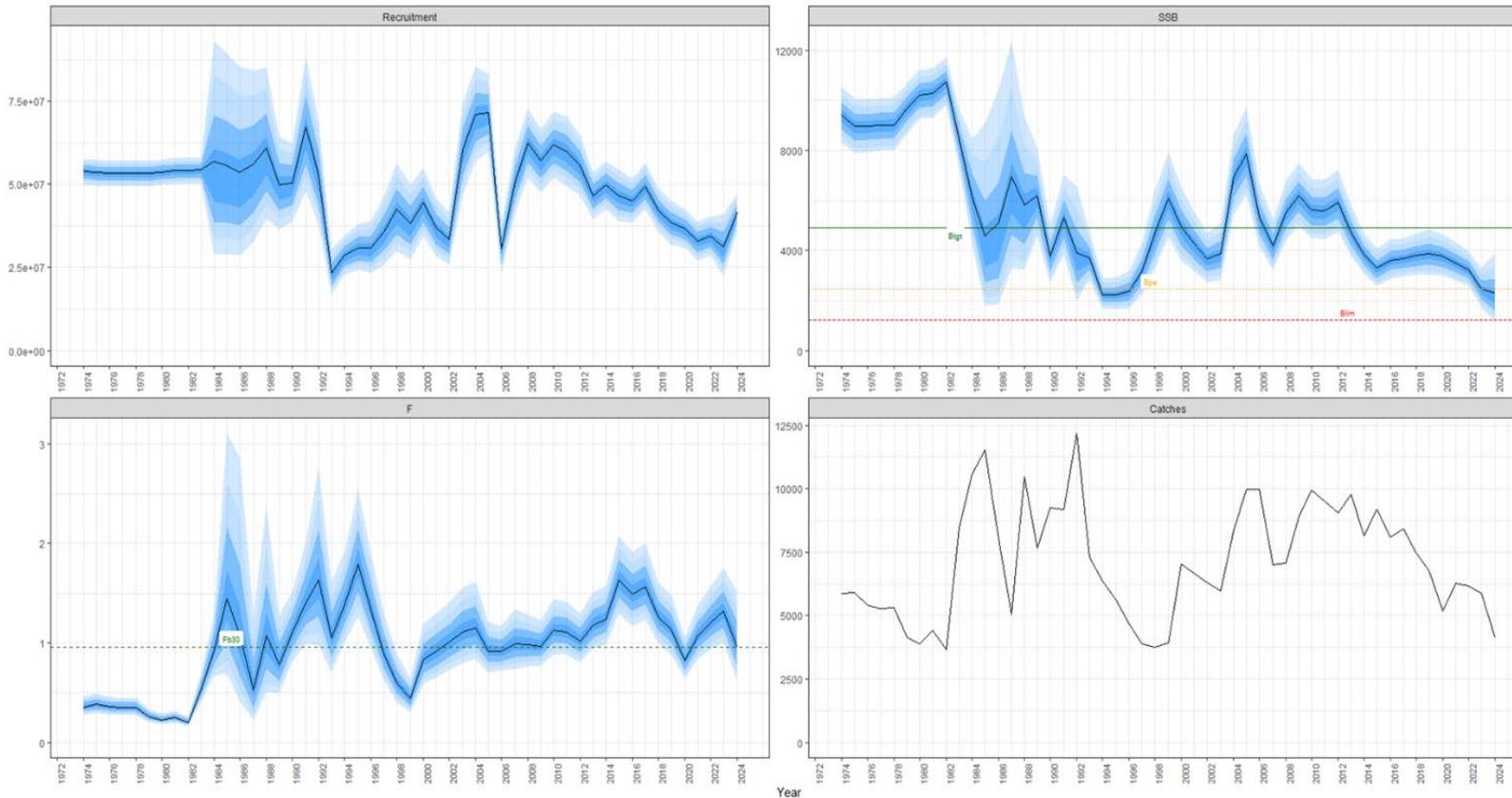


$F_{b30}$ = 1.2,
$B_{30}$ = 5804,
$B_{pa}$ = 2902,
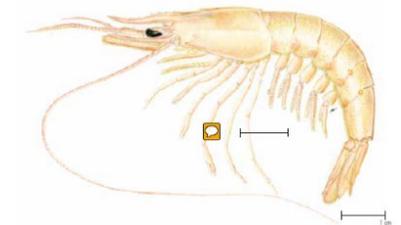$B_{lim}$ = 1451

F/Ftarget = 0.87
B/Btarget = 0.84
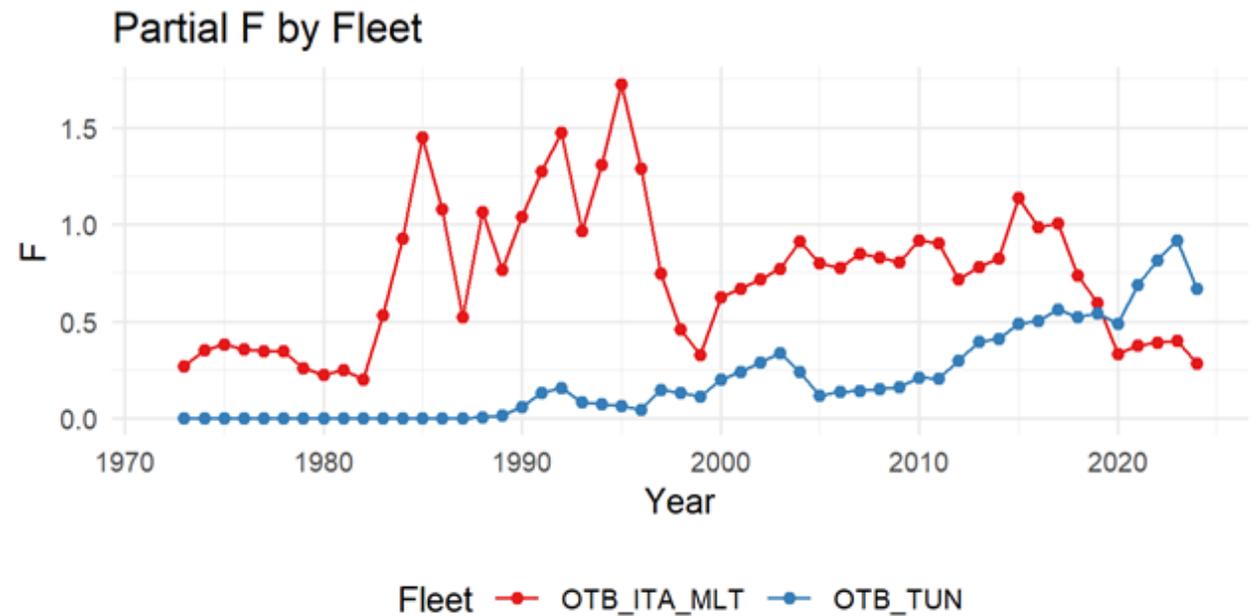B/Bthreshold = 1.67
B/Blimit = 3.34

(by Falsone et al., 2025)

**The main management measures…the controlled access to fisheries, and the limit of fishing effort and catch**

**It is evident that in recent years, Tunisian trawlers account for the bulk of fishing mortality**

| Country | Segments | Fishing days | % |
|---|---|---|---|
| CYP | T12 | 51 | 0.07 |
| ITA | T07 | 90 | 0.12 |
| ITA | T10 | 188 | 0.26 |
| ITA | T11 | 19366 | 26.42 |
| ITA | T12 | 3657 | 4.99 |
| MLT | T11 | 338 | 0.46 |
| MLT | T12 | 165 | 0.23 |
| TUN | T11 | 25994 | 35.47 |
| TUN | T12 | 23443 | 31.99 |
| Total | all segments | 73292 | 100.0 |

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



Partial F by Fleet

Fleet — OTB_ITA_MLT — OTB_TUN

(by Falsone et al., 2025)

Limits of effort and catch in 2025 was extended to 2026 by Rec. GFCM 48/2025/2
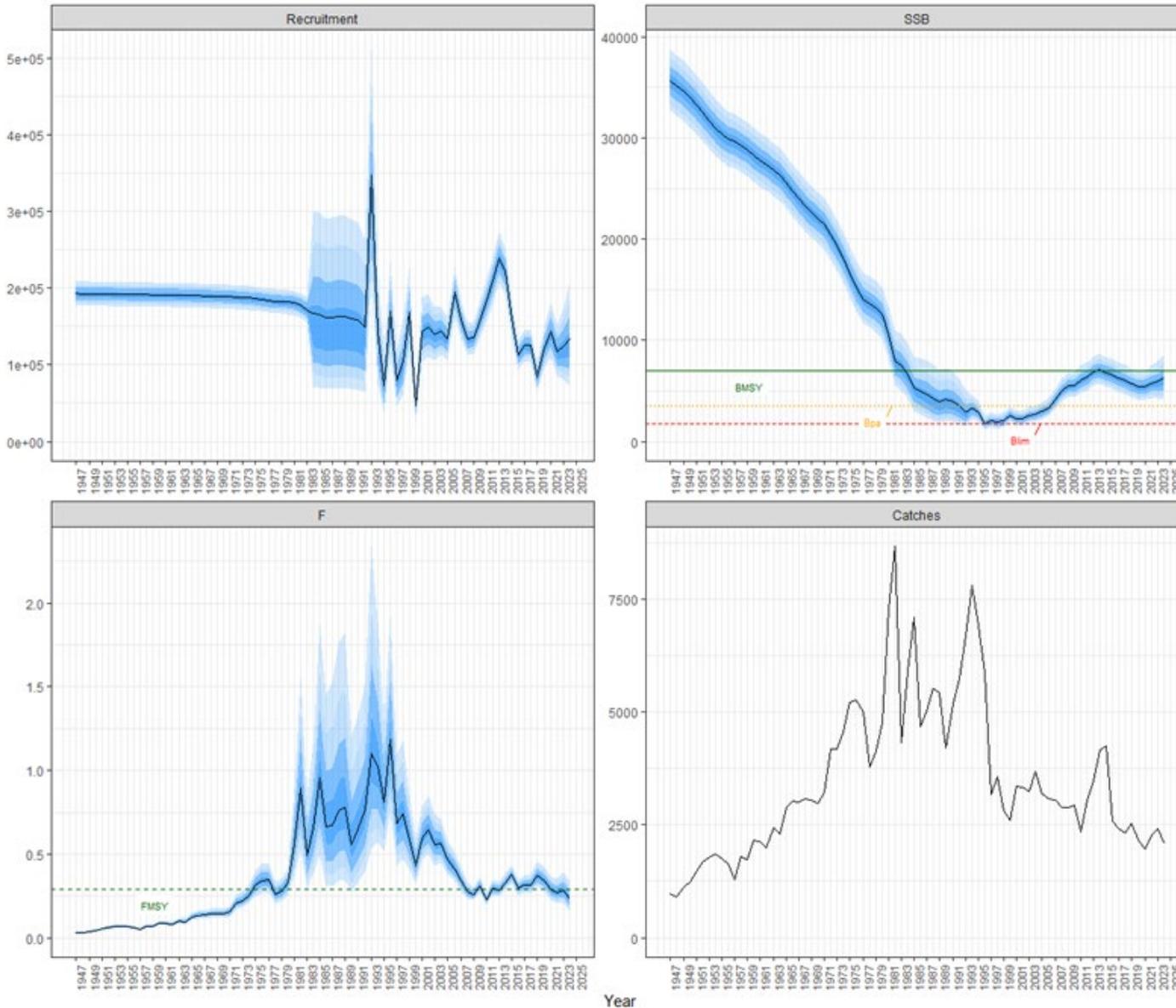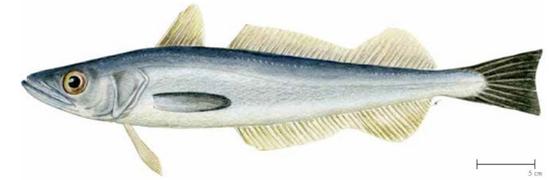
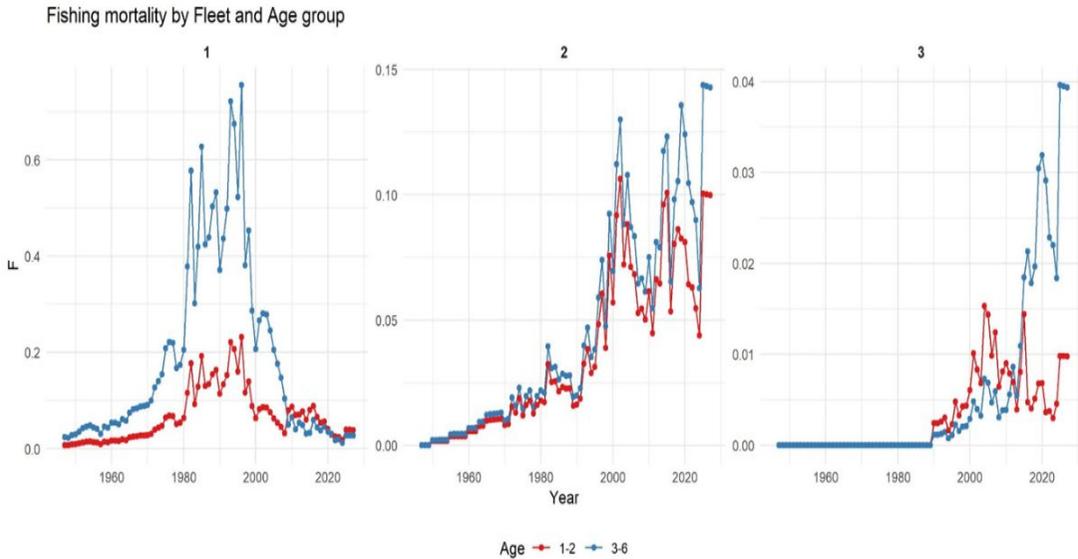**The case of hake...the main bycatch of the deep water rose shrimp fisheries with a yield of 2076 t in 2024...**

MSY= 3616 t±201;
$SSB_{MSY}$ = 7021 t;
$F_{MSY}$ = 0.29

$SSB/B_{MSY}$=0.89,
$F/F_{MSY}$=0.79

(by Falsone et al., 2025)

# The improving of the stock status of hake in the Strait of Sicily



The trends of fishing mortality by age groups are shown (in red for ages 1-2 and in blue for ages 3-6) for European (1) and Tunisian (2) trawlers , and overall SSF (3).
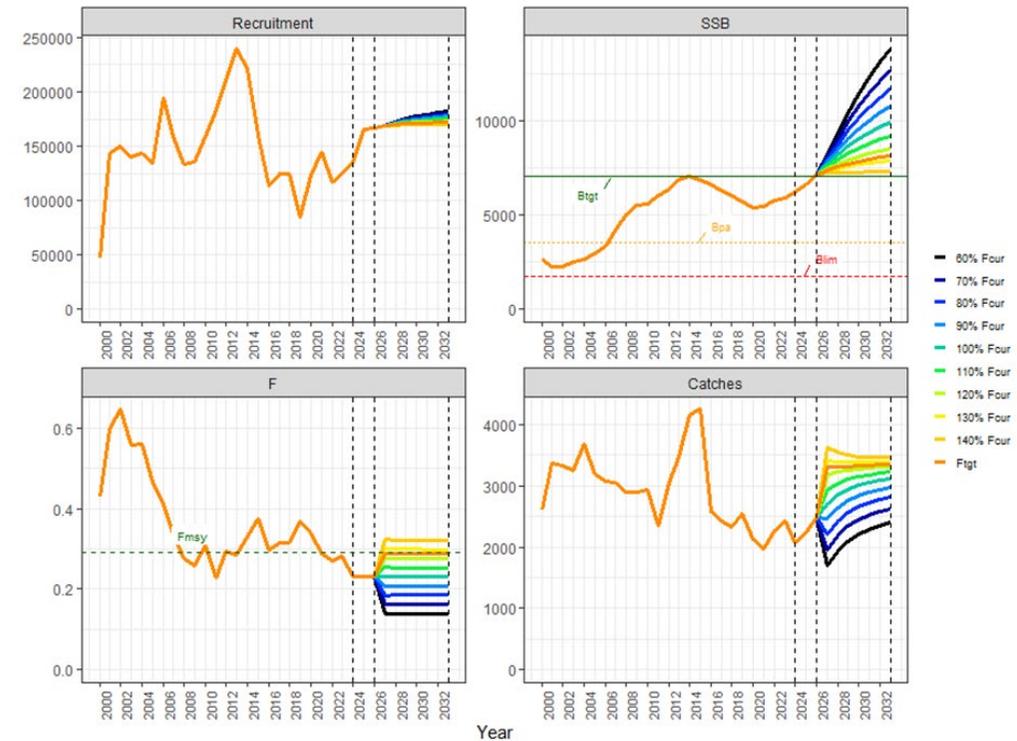
Stochastic forecast conducted applying different fishing mortalities options

(by Falsone et al., 2025)

The MAP is aimed at:

- Applying the **precautionary approach** to fisheries management.

- Implement a **regime of vessels authorized to fish DWRS** in the area.

- Ensuring that exploitation levels at **MSY at the latest by December 31, 2030**.

- **Preventing an increase in fishing capacity and effort** in relation to the year 2019

- Adopting the **MCRS of 25 mm CL** for both DWRS species.

- **Protecting EFHs**.

- Contributing to the **elimination of discards and unwanted catches**

- Adjusting the **fishing capacity and catches** to levels of fishing mortalities **consistent with the MSY**, with a view to having **economically viable fleets** and without overexploiting marine biological resources.

The MAP is based on a two-step approach:

(a) in the first three years, extended to four years (**2023-2026**), catch limits and technical measures will be applied, and

(b) **from 2027 onward**, on the basis of new scientific data, the SAC will evaluate the state of the stocks and, on the basis of the Harvest Control Rule (HCR), propose further measures and **advisable yearly catch limits per species**.

Maximum level of catches of Deep Water Red Shrimps (*A. foliacea and A. antennatus*) in tons live weight in 2023-2026

| Species | EU | EU | EU | EU | TUN | TUN | TUN | TUN |
|---|---|---|---|---|---|---|---|---|
| | 2023 | 2024 | 2025 | 2026 | 2023 | 2024 | 2025 | 2026 |
| **Catch limit (Tons) for giant red shrimp (ARS)** | 908 | 881 | 854 | 829 | 126 | 122 | 119 | 115 |
| **Catch limit (Tons) for blue and red shrimp (ARA)** | 104 | 101 | 98 | 95 | 39 | 38 | 37 | 36 |

Nominal catches (Tons) in 2024:
EU 882 (846 IT+36 ML) & TUN 294 – **Total 1176**

*The case of deep water red shrimps in the Strait of Sicily... a mainly Italian fishery with an overall production (EU+TUN) of about 1176 t in 2024 managed by Recommendation GFCM/45/2022/5*
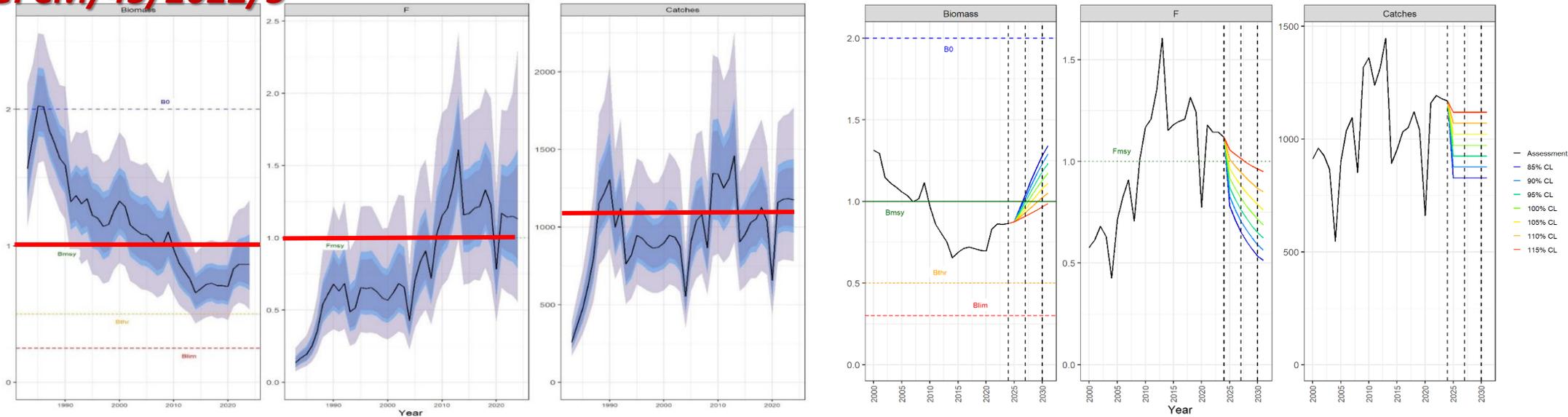


B/B$_{MSY}$=**0.87**, F/F$_{MSY}$=**1.14**,
**MSY=1200 t ±120 t**

This is an almost **single-species fishery**, so a combination of **individual catch quotas** together with **technical measures** that reduce the **catch of juveniles** to increase Y/R should be a particularly appropriate management strategy

(by Scannella et al., 2025)
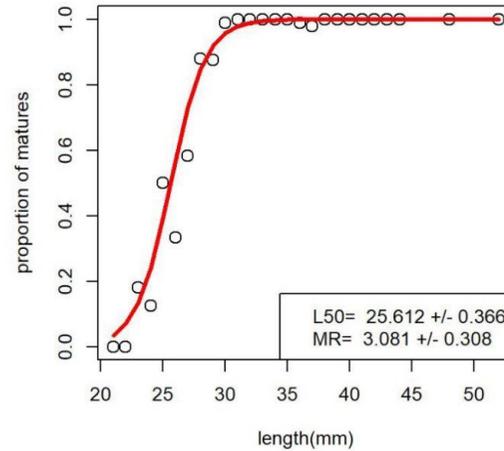
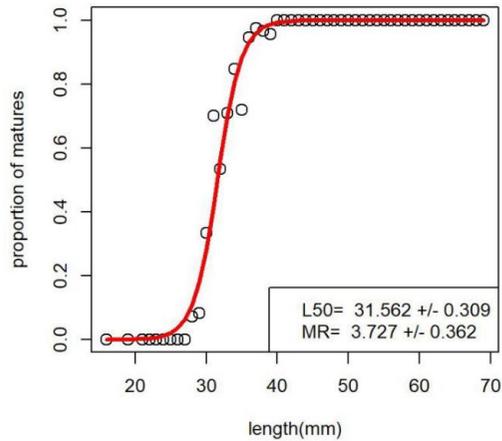# The size at maturity of the DWRS females are higher than the current MCRS of 25 mm CL…
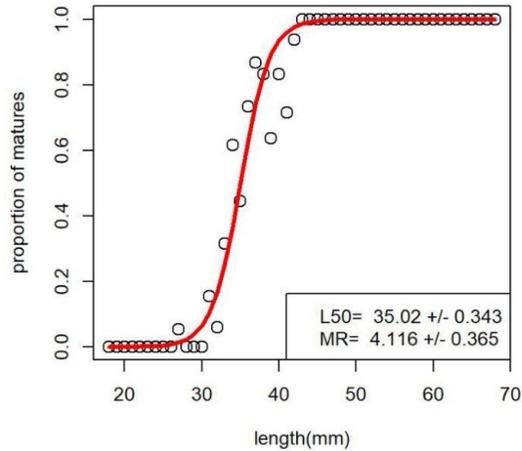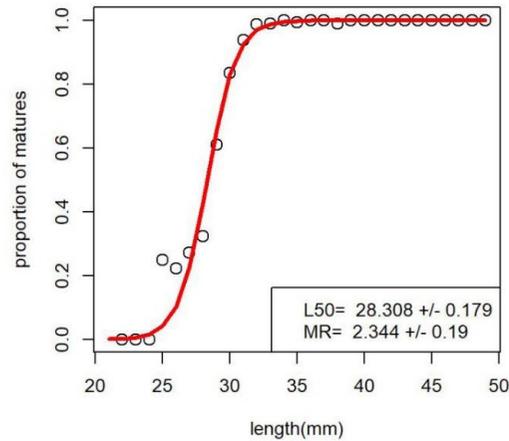


The length at 50% of maturity ranges between **31.6** and **35.0** mm CL in females and **25.6** and **28.3** in males
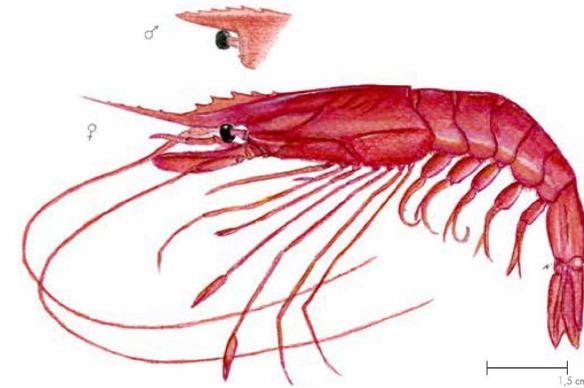
(IRBIM CNR; unpublished data )

# It is necessary to enhance the current exploitaiton pattern of the DWRS by improving gear selectivity and/or adopting seasonal closures

Relationships between length at 50% capture (L50) and Selection Range (SR) in ARA and ARS with square and diamond mesh size
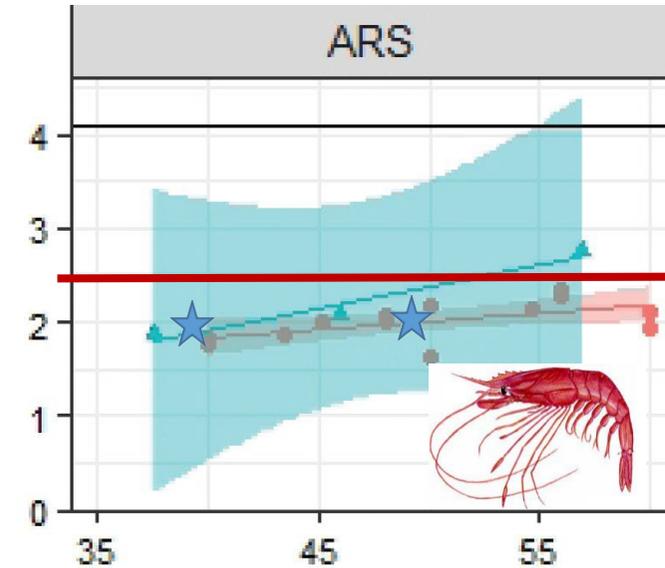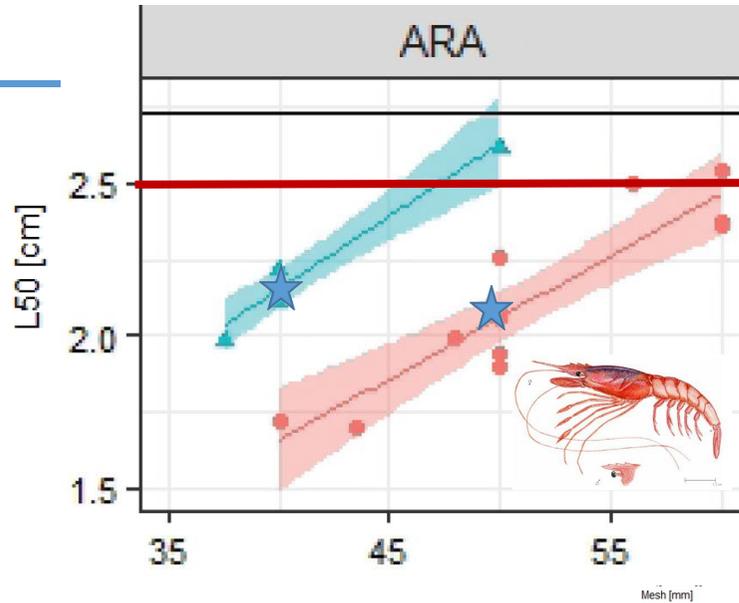


Green = Square
Red = Diamond
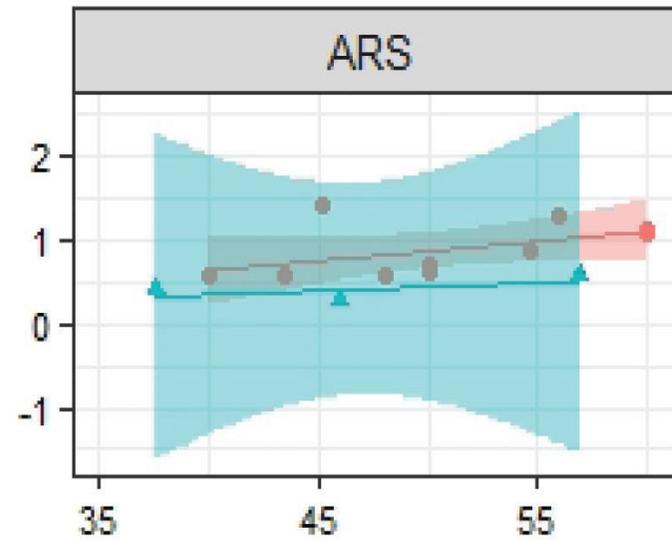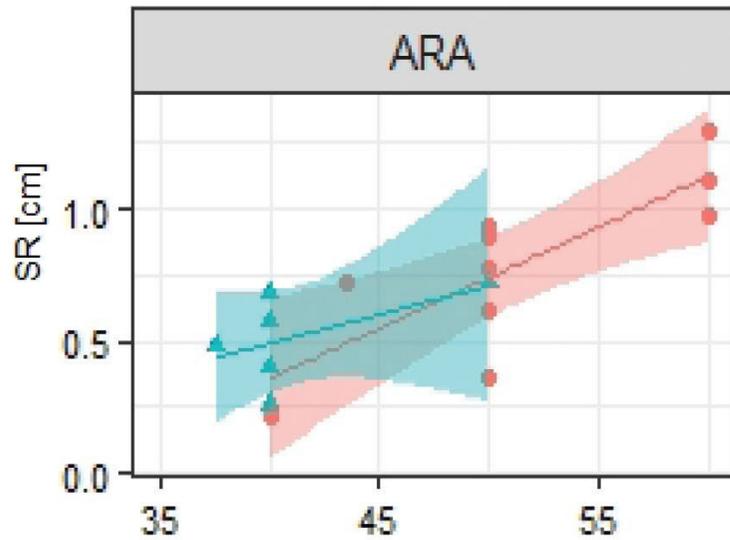
(by Lucchetti et al., 2021)

# *The case of red mullet, Mullus bartbatus, in GSA 16...*

**STOCK IDENTIFICATION**



by Gargano et al., 2017
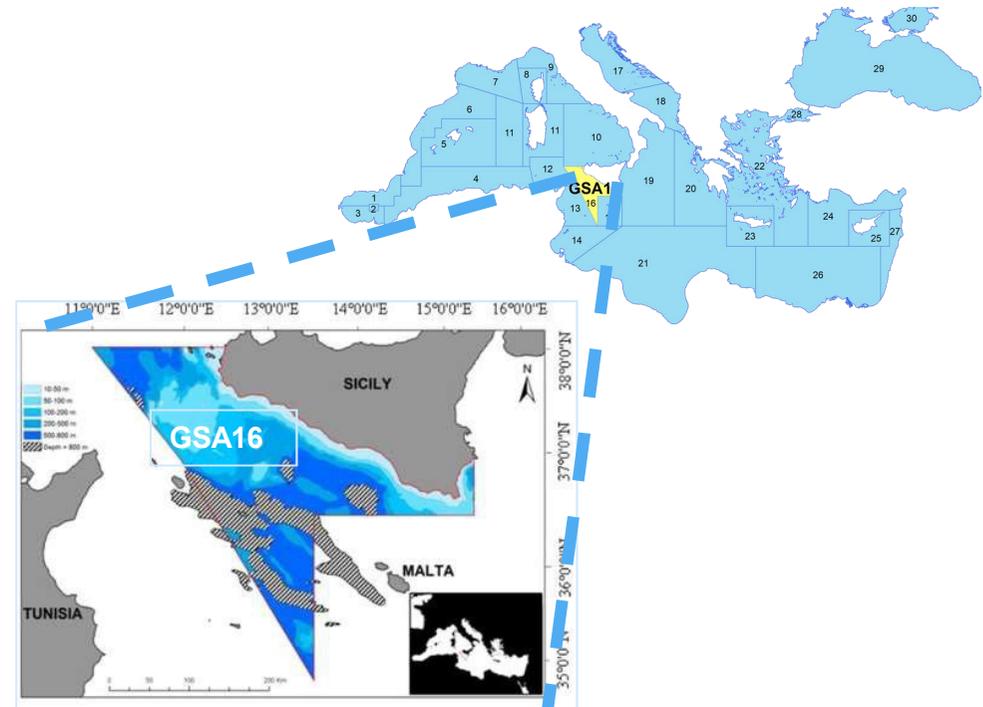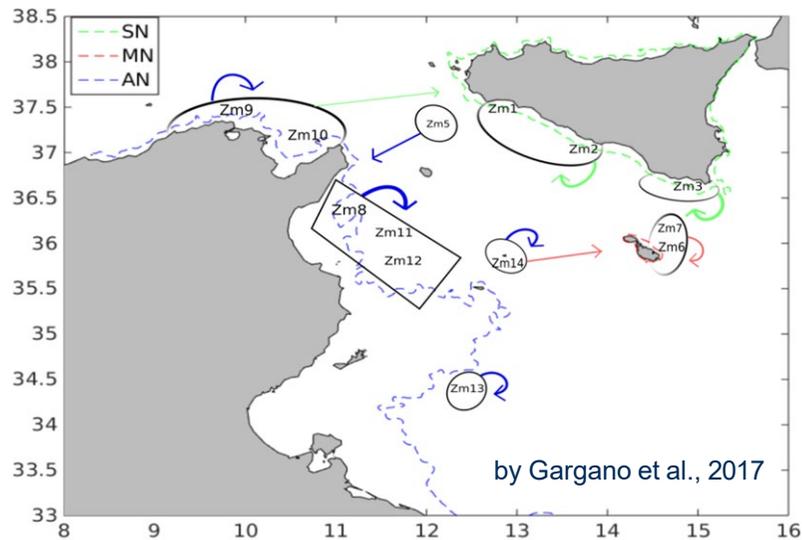
Based on available knowledge Red mullets inhabiting the continental shelf off the southern coast of Sicily (GSA 16) are considered as a stock unit for stock assessment purposes

**An example of sustainable Italian fishing...the case of red mullet in GSA 16...a production of about 140 t in 2024...**
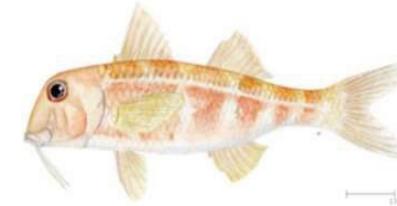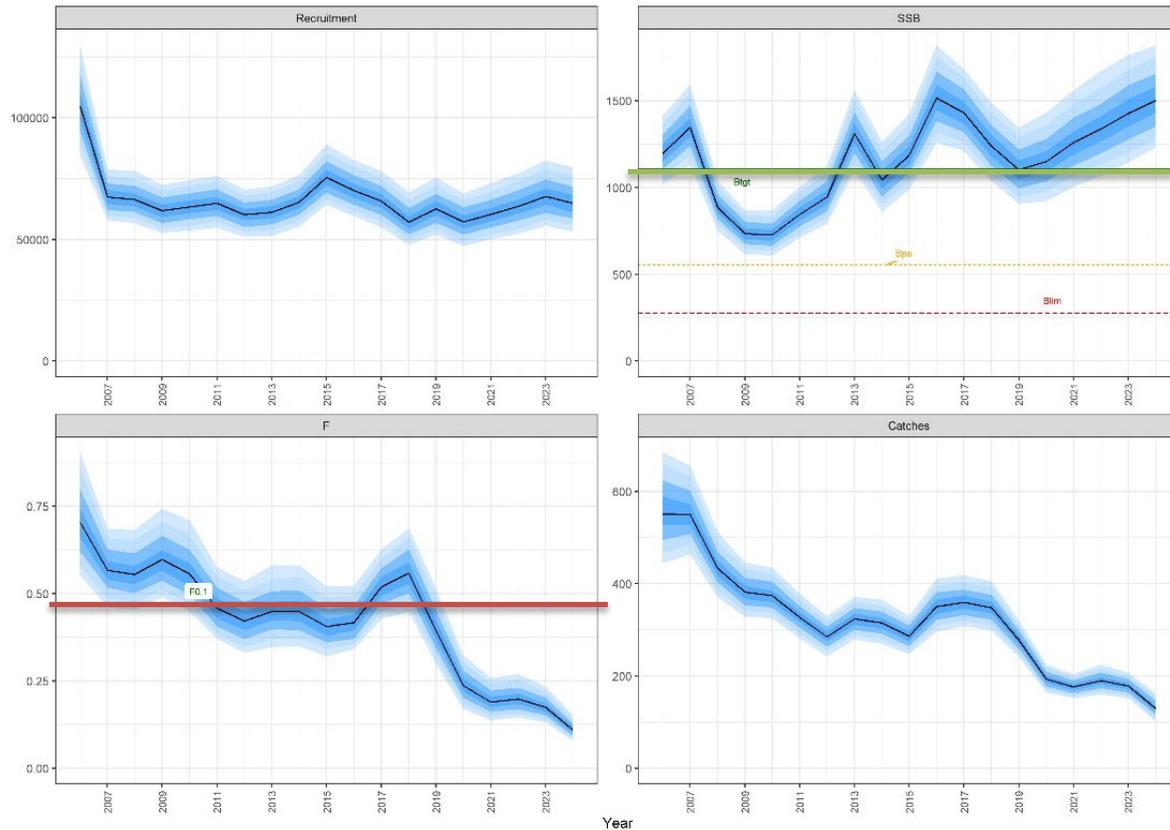
| RefPoint | Value |
|---|---|
| F0.1 | 0.47 |
| Btgt | 1106 |
| Bpa | 553 |
| Blim | 276 |
| Fcur | 0.11 |
| Bcur | 1502 |
| B0.33 | 1100 |
| B0.66 | 1304 |
| $Fcur/F_{0.1}$ | 0.23 |

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., 2025)

# *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 $F_{0.1}$ or $B_{MSY}$, 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 **different indicators and approachs,** 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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