Laurea Magistrale in Scienze per l'Ambiente MArino e Costiero (SAMAC)

Anno accademico 2023-2024

Gestione delle risorse alieutiche

Parte - Simone Libralato
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Lezione 4

UNIVERSITY OF TRIESTE

OGS

i) Introduzione alla gestione dello sfruttamento delle risorse alieutiche, problematiche generali, stato delle risorse, targets internazionali.

ii) Massimo rendimento sostenibile, sforzo di pesca, mortalità da pesca, costi, rendimento economico. *esercizi*

iii) (continua) Massimo rendimento sostenibile, sforzo di pesca, mortalità da pesca, costi, rendimento economico. *esercizi*

iv) Le specie ittiche: crescita, riproduzione, mortalità: esercizio modelli e dati.

v) Stock assessment basi: dalla cohort analysis e virtual population analysis ad oggi (*esercizi*).
Le attività di pesca: selettività, catturabilità, impatto sugli habitat. Dati fishery dependent e fishery independent per la gestione: uso, limitazioni, problematiche.

vi) Pesca e interazioni con altri fattori: approccio multispecifico integrato. Modelli di ecosistema per la gestione della pesca: Ecopath with Ecosim (*esercizio EwE*). Sintesi problematiche, approcci, limitazioni, gaps e aree di sviluppo

vii) Prodotti ittici da acquacoltura: sistemi di produzione, problematiche generali, sostanibilitá, soluzioni. Gestione integrata pesca e acquacoltura. Target di pesca sostenibile, approcci alla gestione, problematiche: il caso del mediterraneo. Gestione spaziale della pesca, essential fish habitats, regolamenti comunitari ed internazionali. Sforzo di pesca, gestione dello sforzo di pesca, misure tecniche, misure economiche.

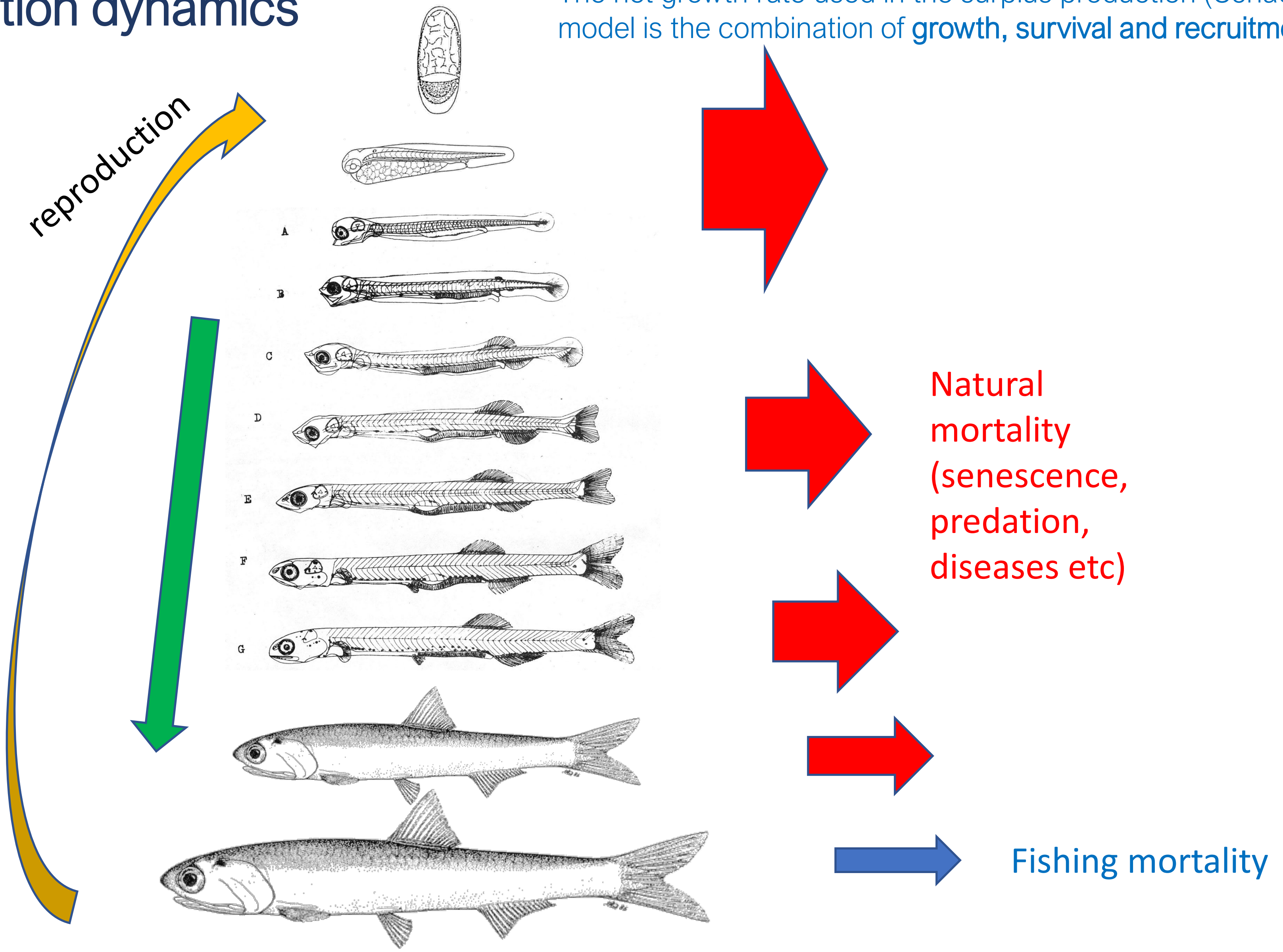
Processes involved in population dynamics

The net growth rate used in the surplus production (Schaefer) model is the combination of **growth, survival and recruitment**

Growth at all life stages
>> depending on prey availability; **environmental conditions;**

Survival at all life stages
>> depending on **fisheries pressure, on predators abundance, on env conditions**

Recruitment >>
depending on mature **adults (SSB), environmental conditions**



Estimating Growth

The individual growth model, published by von Bertalanffy in 1934, can be used to model the rate at which fish grow. It exists in a number of versions, but in its simplest form it is expressed as a differential equation of length (L) over time (t):

$$\frac{dL(t)}{dt} = \mathrm{k} \cdot [L_\infty - L(t)]$$

$$L(t) = L_\infty\left[1 - e^{-k(t-t0)}\right]$$

To transform then into weight: use an «allometric relathionship» of weight and lenght:

$$W = a \cdot L^b$$

$$W(t) = \left\{W_\infty\left[1 - e^{-k(t-t0)}\right]\right\}^b$$

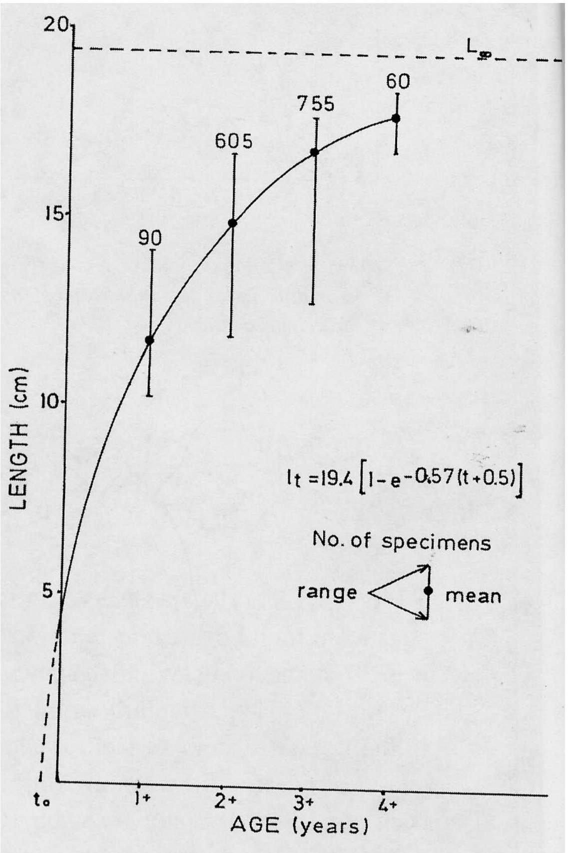
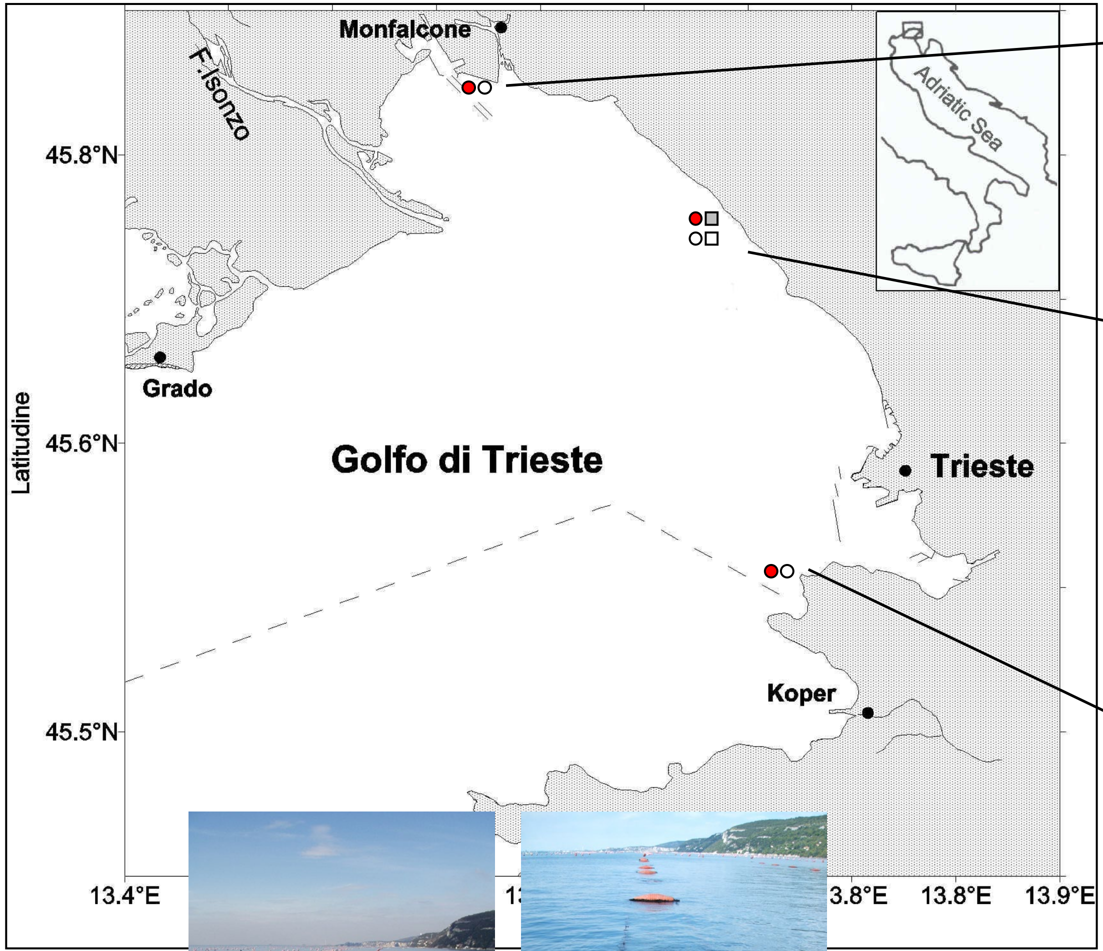


Fig. 30. Length growth curve of anchovy, Middle Adriatic, 1979

Time t of course is the age of the fish. While length and weight are easy to measure, more difficult is to measure age: usually from scales and otholiths

Sinovčić, 2000

Example: growth data



Panzano

Coorte 6: esterno, bi-ventia, adulti

Coorte 7: esterno, bi-ventia, giovanili

Santa Croce

Coorte 1: esterno, bi-ventia, adulti (**)

Coorte 2: esterno, bi-ventia, giovanili (**)

Coorte 3: interno, bi-ventia, giovanili (**)

Coorte 8: interno, mono-ventia, giovanili

Muggia

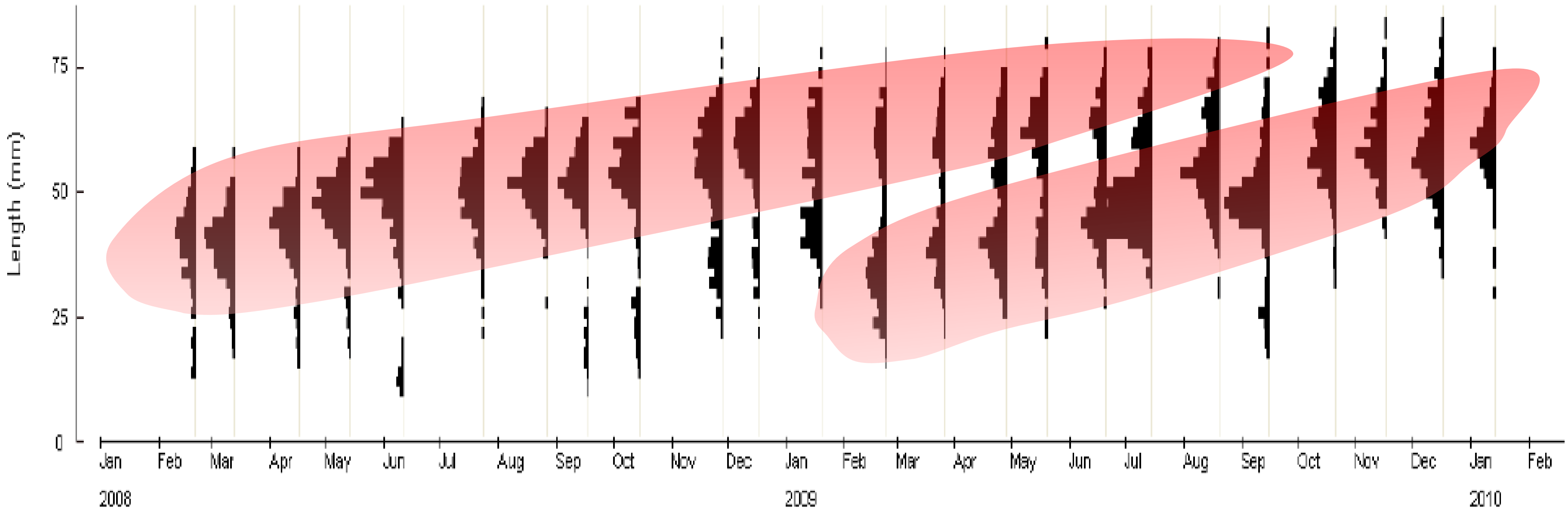
Coorte 4: esterno, bi-ventia, adulti

Coorte 5: esterno, bi-ventia, giovanili

(**) da seguire per due anni

Example: growth data

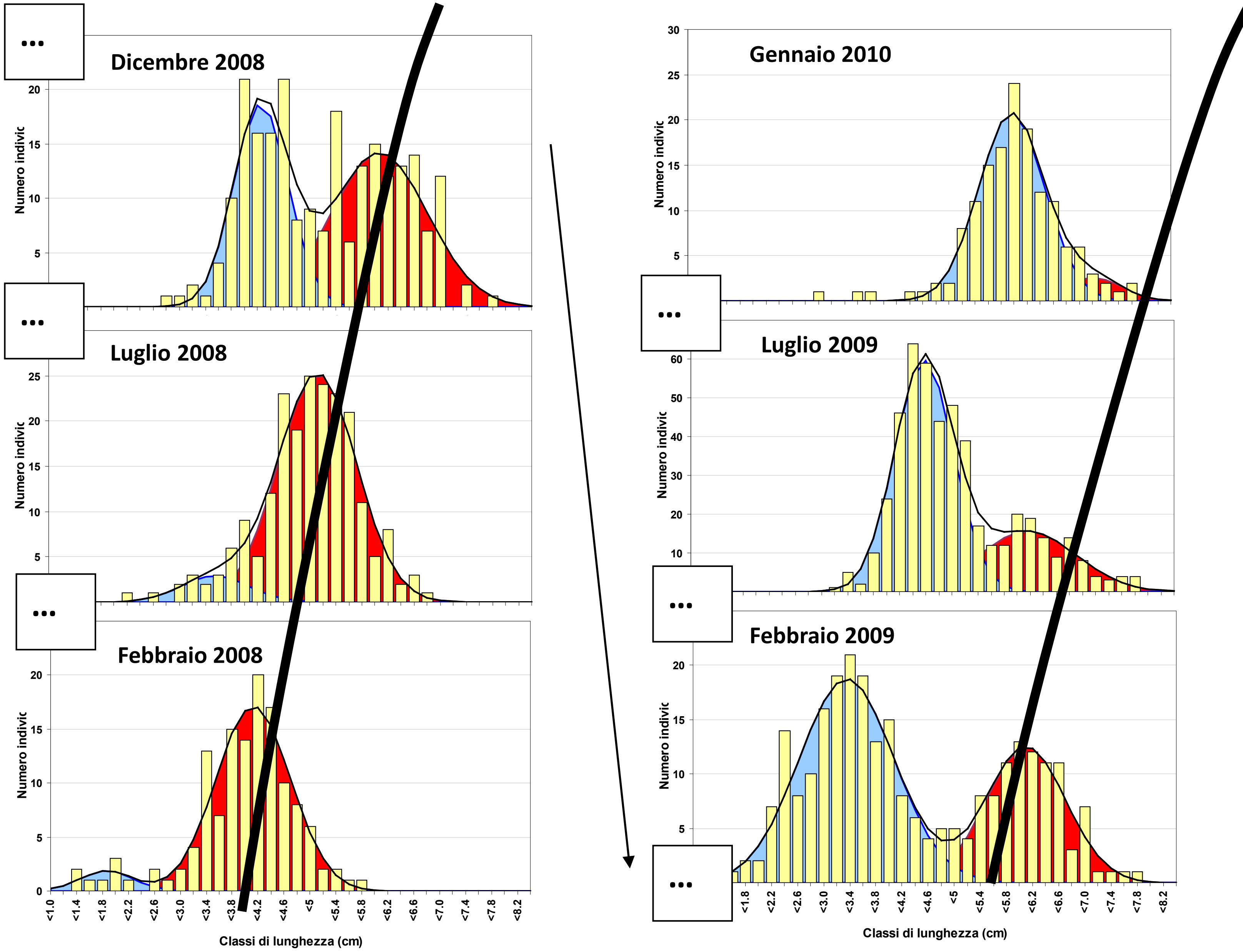
Nel campionamento sono naturalmente confuse le fdiverse generazioni di individui (coorti): questo succede sia perché le specie si riproducono piú volte durante l’anno, che per la presenza di individui di diversa etá. E’ importante separare le coorti per poter calcolare correttamente l’etá



Example: growth data

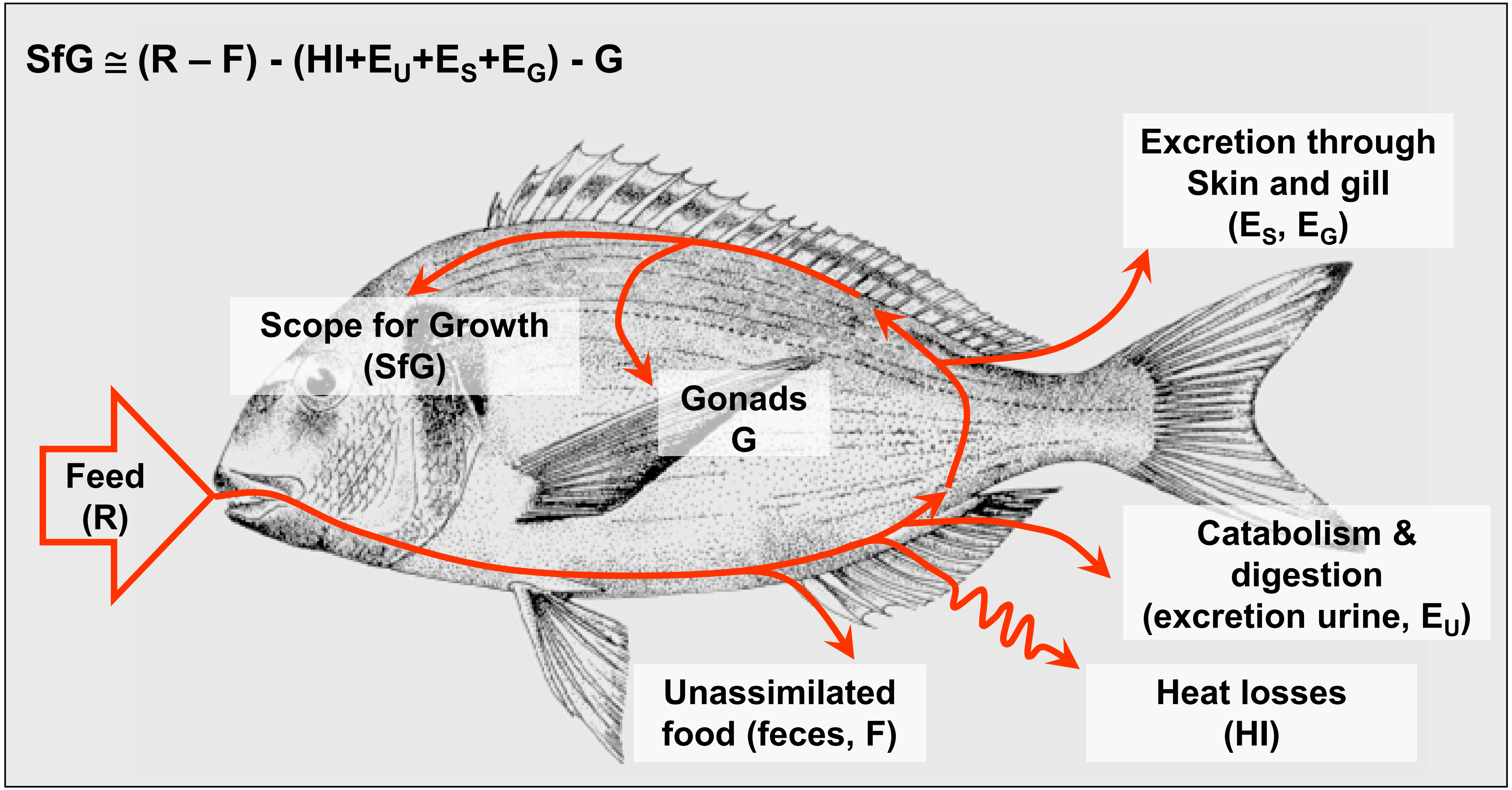
Da ogni campionamento è necessario distinguere gli individui nelle opportune coorti e calcolare la curva di crescita sugli individui della stessa coorte!

Software come ELEFAN e FISAT Aiutano a risolvere il problema



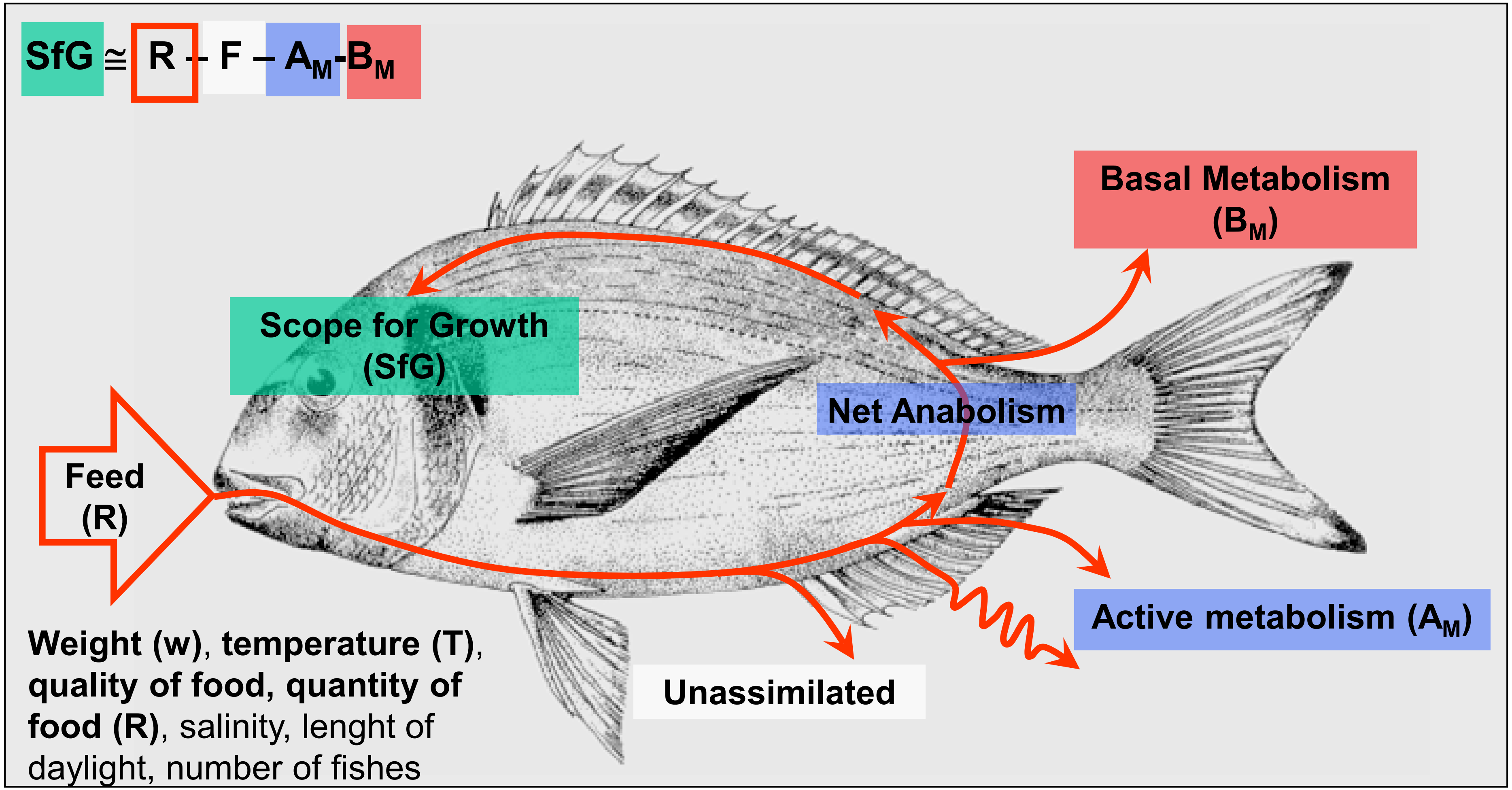
Growth: the bioenergetic approach

Growth is the result of anabolic (food assumption) and metabolic processes. Measuring these in lab or in controlled experiments one can have detailed information on growth.



Growth: the bioenergetic approach

The bioenergetic approach permits to explicit the effects of other factors, such as for example Temperature, salinity, food availability etc



Ursin, 1967.A *mathematical model of some aspects of fish growth, respiration and mortality.* J. Fish. Res. B. Can.

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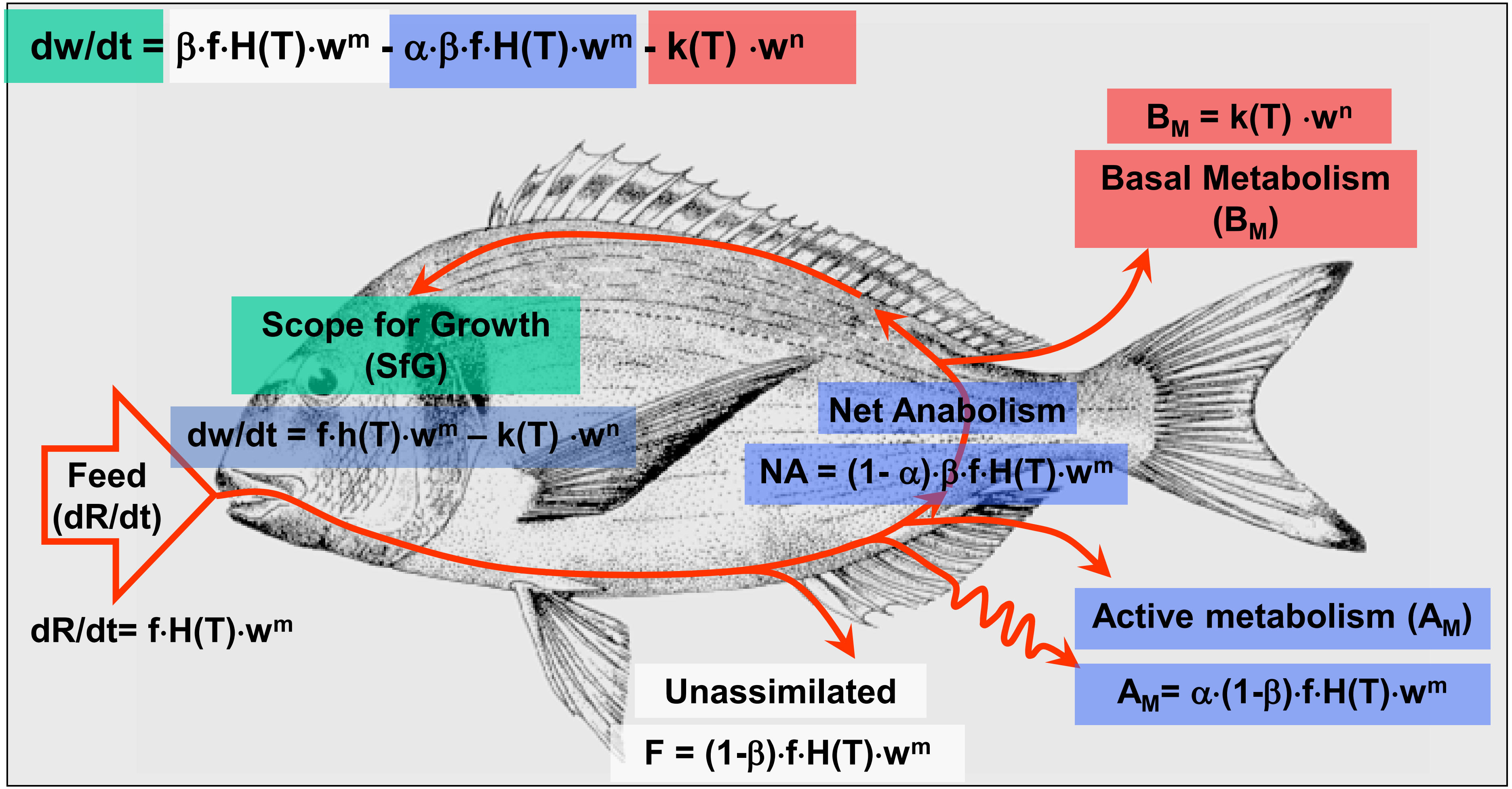


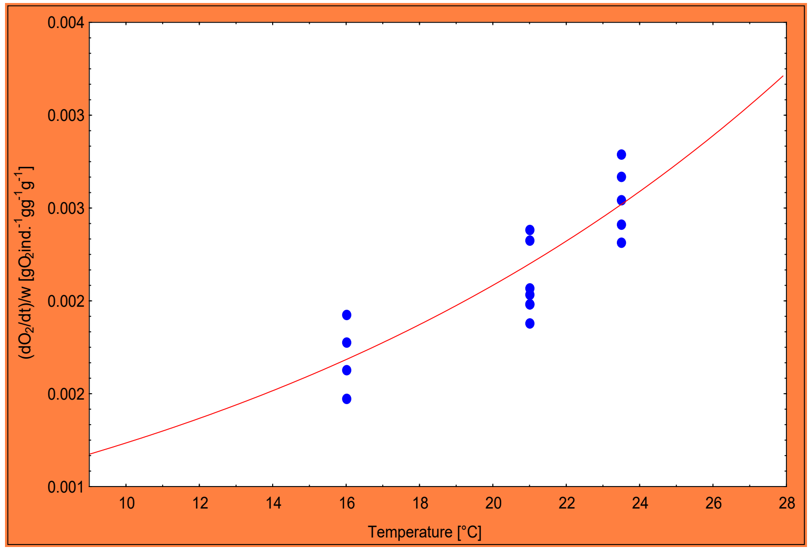
Application to Sparus aurata

Different data can be used to estimate the bioenergetic processes

Basal metabolism

The **basal metabolism** are the energy costs for keeping functional living activities and equal the energy spent for living when resting and fasting. Estimated from oxygen when fish are not feed: **respiration of fasting fish**. In these conditions:

$$\frac{dw}{dt} = -k(T)\cdot w^n = -k_0 \cdot e^{(pk\cdot T)} \cdot w^n \longrightarrow \frac{dO_2}{dt} = \omega \cdot \frac{dw}{dt} = -\omega \cdot k_0 \cdot e^{(pk\cdot T)} \cdot w^n$$



Guinea & Fernandez, Aquaculture, 1997. SPAIN:
Data oxygen consumption for fasting sea bream; specimen of weight 30-100 g; temperature 16, 21, 23.5 °C.

k_0 = 0.0012 ± 0.0002 [giorno-1]
p_k = 0.06 ± 0.01 [°C-1]

Guinea & Fernandez, Aquaculture, 1997. SPAIN:	**Q_{10} = 1.795**
Lemarie et al., *Icthyophysiologica Acta*, 1992. FRANCE:	Q_{10} = 1.738
Calderer-Reig, PhD Thesis, 2001. SPAIN:	Q_{10} = 1.79

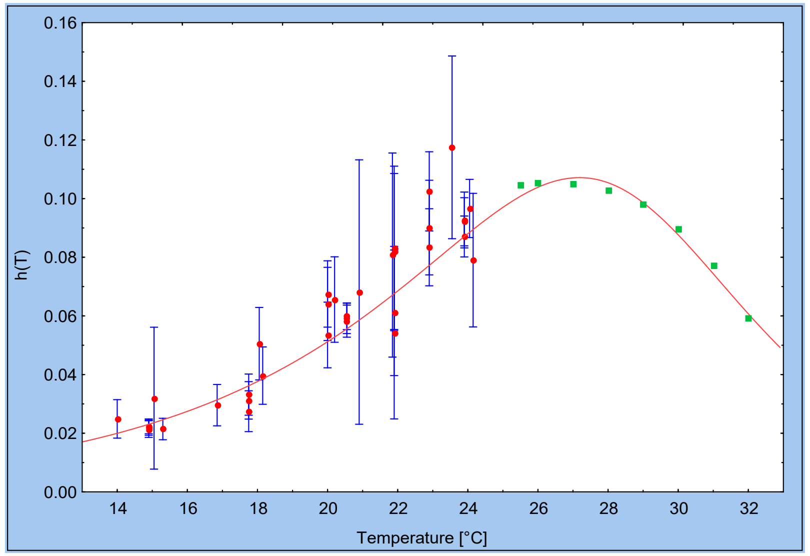
Different data can be used to estimate the bioenergetic processes

Feeding/active metabolism

The **active metabolism** are the energy costs for feeding and digest. This is function of quantity of feed find and taken but can be estimated from **growth data for fish feeding *at libitum***. In these conditions fish intake the maximum amount of feed needed thus f=1.

$$(1-\alpha)\cdot\beta\cdot f\cdot H(T)\cdot w^{m}=(1-\alpha)\cdot\beta\cdot f\cdot\frac{a_H\cdot e^{(ph2\cdot T)}}{1+b_H\cdot e^{((ph1+ph2)\cdot T)}}\cdot w^{m}$$

Petridis & Rogdakis, Aquaculture, 1997. SPAIN: Data of fish weight growing in the first year from 2 g to 200 g at variable temperature (known) between 13 and 26°C;
Muller-Feuga, 1990, FRANCE: data points till 31 °C:



b_H = 0.22 10^{-6}

p_{h1} = 0.30 [$°C^{-1}$]

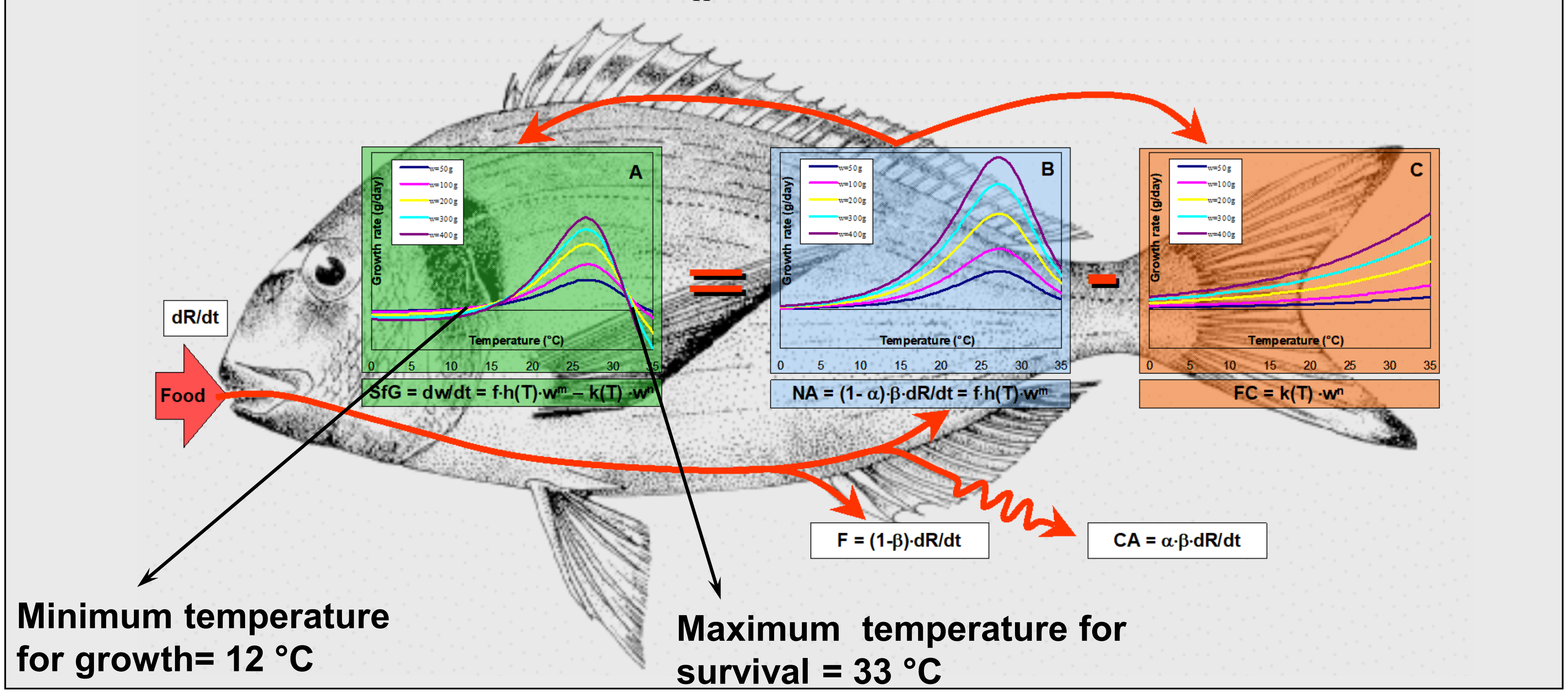
a_H = 0.0021 ± 0.0003 ($g^{1-2/3}$ day^{-1})

p_{h2} = 0.160 ± 0.006 ($°C_{-1}$)

Growth: the bioenergetic approach

Fitting to real data of anabolism as a function of temperature (food consumption at different temperatures) and basal metabolism (e.g., weight loss of fasting fish; or respiration in resting condition) permit to obtain apparently complex curves but…
For m=2/3 and n=1 this is exactly Von Beralanffy

$$\frac{dw}{dt} = (1-\alpha)\cdot\beta\cdot f\cdot\frac{a_H\cdot e^{(ph2\cdot T)}}{1+b_H\cdot e^{((ph1+ph2)\cdot T)}}\cdot w^m - k_0\cdot e^{(pk\cdot T)}\cdot w^n$$



Broad usefulness of bioenergetic model

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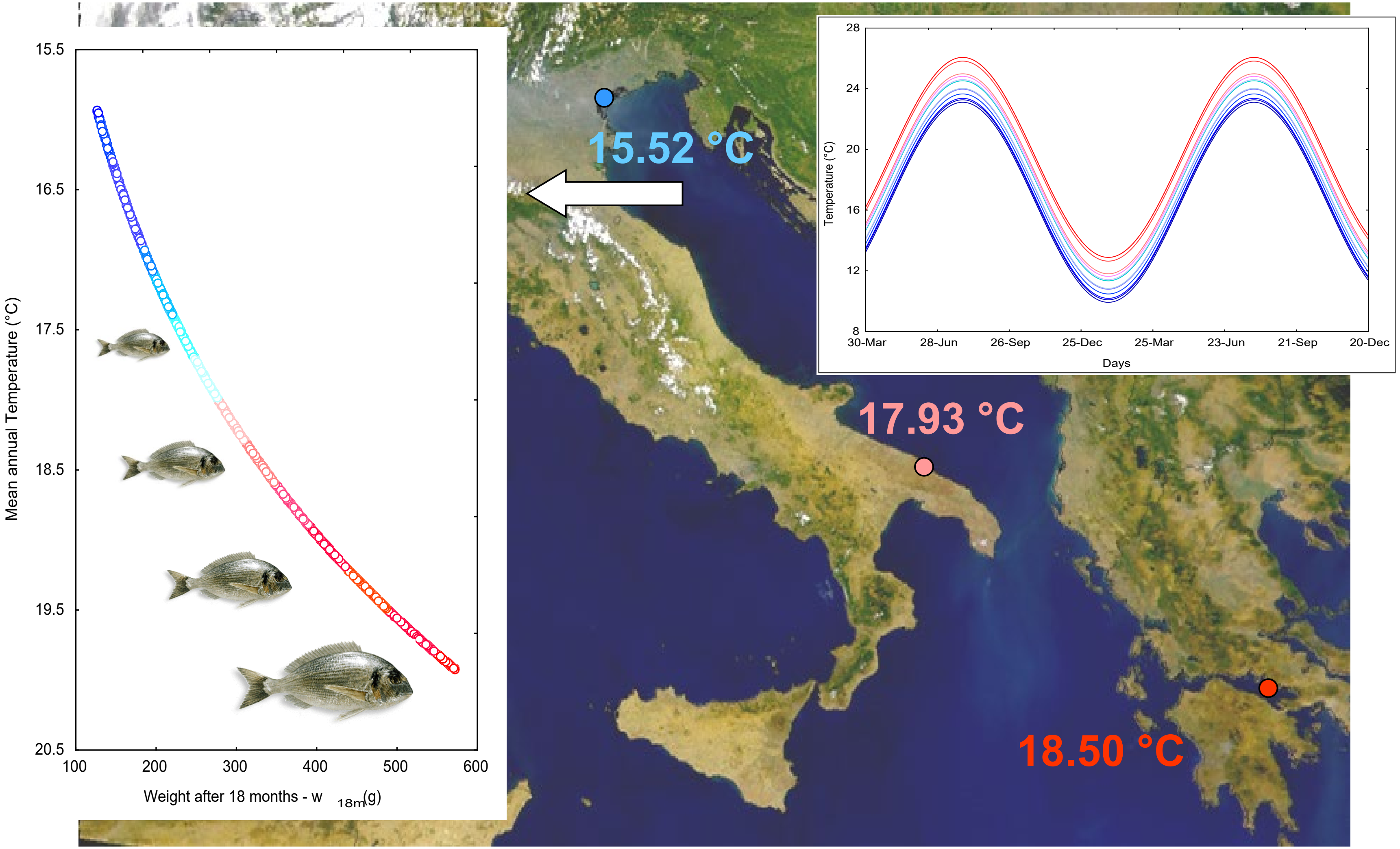
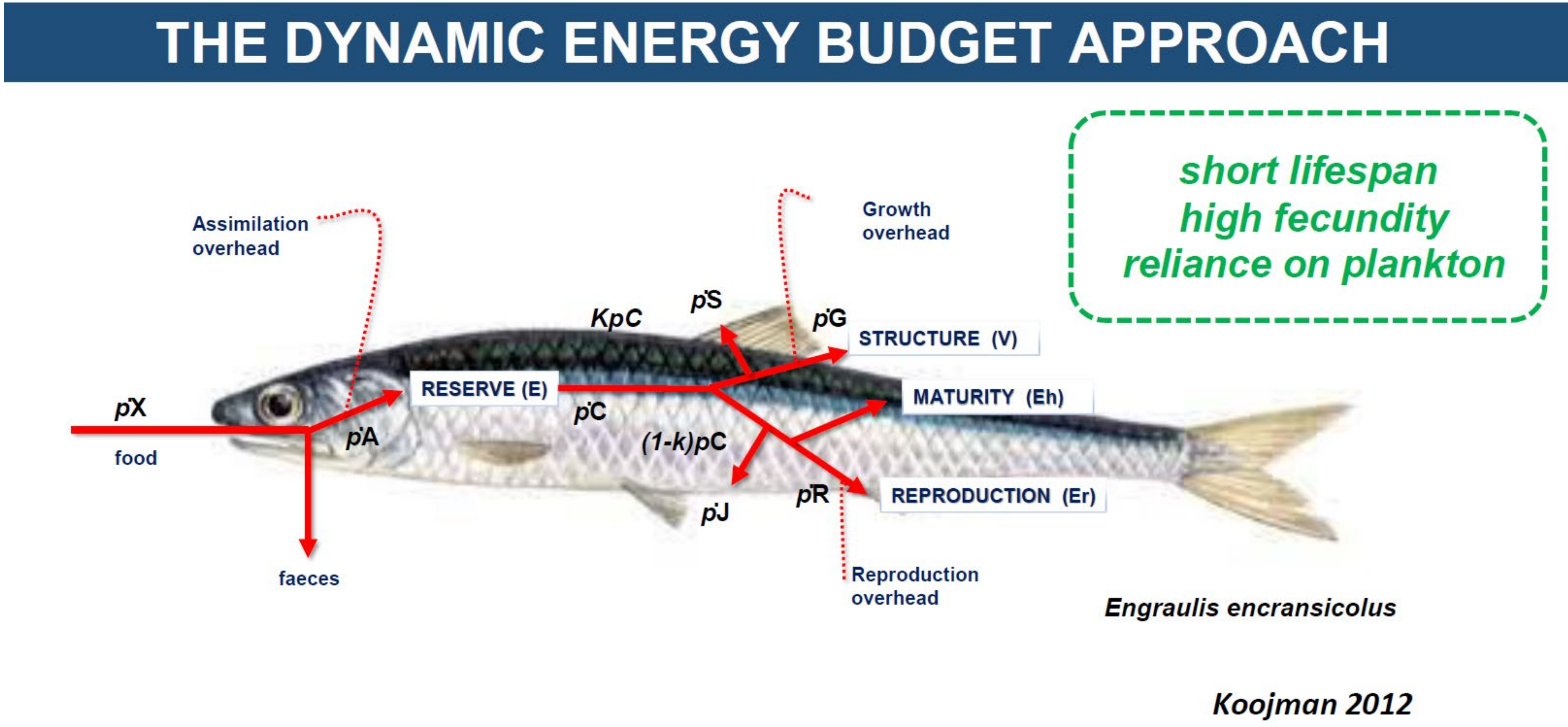


Dynamic Energy budget (DEB) model

An important extension of the bioenergetic modelling of fish growth is the DEB model, in which it is assumed that assimilated energy is stored into reserves and THEN used for somatic and gonadic growth.

This result in a very important possibility to delay the use of energy but needs some additional data to fit (storage)



Mortality

When studying mortalities we are concerned with rates of change, and it is generally most convenient to deal with instantaneous rates of change; that is, the rate at which the numbers in the population are decreasing can be written as

$$\frac{dN(t)}{dt} = Z \cdot N(t)$$

where Z is defined as the instantaneous total mortality coefficient. From this equation the number Nt alive at any time will be given by:

$$Nt = N0 \cdot e^{-Zt}$$

where N0 = number alive at time = 0.

Note that Z is total mortality and include natural (M) and fishing (F) mortalities. Both follows the same law and thus can be demonstrated that mortalities are additive:

$$\frac{dN(t)}{dt}\text{natural} = M \cdot N(t) \qquad \frac{dN(t)}{dt}fishing = F \cdot N(t) \qquad M + \mathrm{F} = Z$$

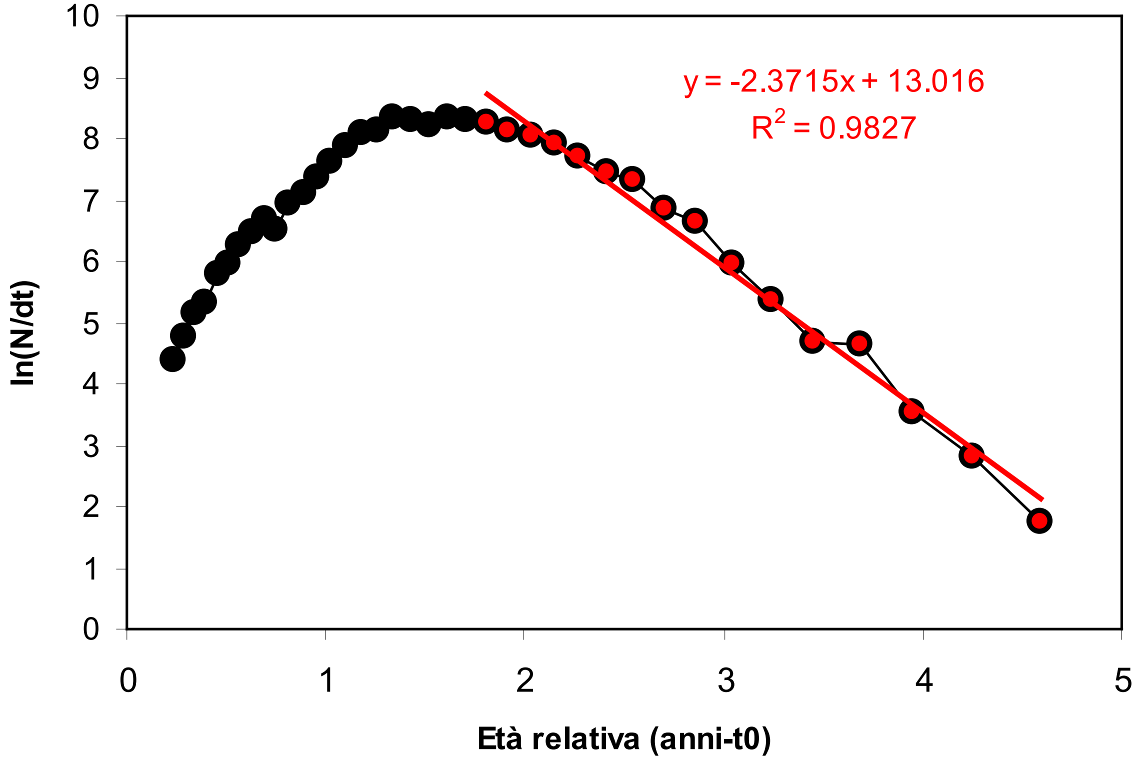
To estimate mortality

$$Nt = N0 \cdot e^{-Zt}$$

From the equation (exponential decline fo mortality) one can linearize (taking the log) and explicit the mortality ad the log of ratio between number of individuals at different age

$$\frac{Nt}{N0} = e^{-Zt} \qquad ln\frac{Nt}{N0} = -Zt \qquad ln\frac{N0}{Nt} = Zt$$

The total mortality, therefore, can be estimated considering the logarithm of the number of individuals at different age classes, just by calculating the slope.
However, while estimating Z is relatively easy, distinguishing between fishing mortality F and natural mortality M is quite difficult.



How to estimate natural mortality?

It is fundamental for any stock assessment. Typically, estimates arise from rationalized assumptions made by experts (often informed by information for other stocks or species), calculated from general empirical relationships, and/or are based on life history theory. M is also usually assumed to be constant over time, age, and (somewhat less often) sex to simplify model complexity— assumptions that are unlikely to be true for any stock. In some stock assessments, the value of M has been unchanged for decades at values based on little, if any, support from actual data. (Maunder et al., 2023)

Table 1a

Equations for representing or estimating natural mortality: theoretical approaches. M is the instantaneous rate of natural mortality, K is the growth rate, L_∞ is the asymptotic length, W_∞ is the asymptotic weight, t_0 is the theoretical age at which the fish would have length zero, t_m is the age at maturity, t_{m^*} is the age at the end of reproductive span (where senescence starts; Chen and Watanabe, 1989), L_m is the length at which 50% of a year-class reaches maturity, t_{max} is the maximum age, p is the proportion surviving to the maximum age, T is water temperature, GSI is the gonadosomatic index, L is length, W is body weight, M^* is the limiting value of M approached by the largest fish, β is the exponent of the weight-length relationship, t_c is the critical age (the time that the cohort achieves its maximum biomass, Zhang and Megrey, 2006).

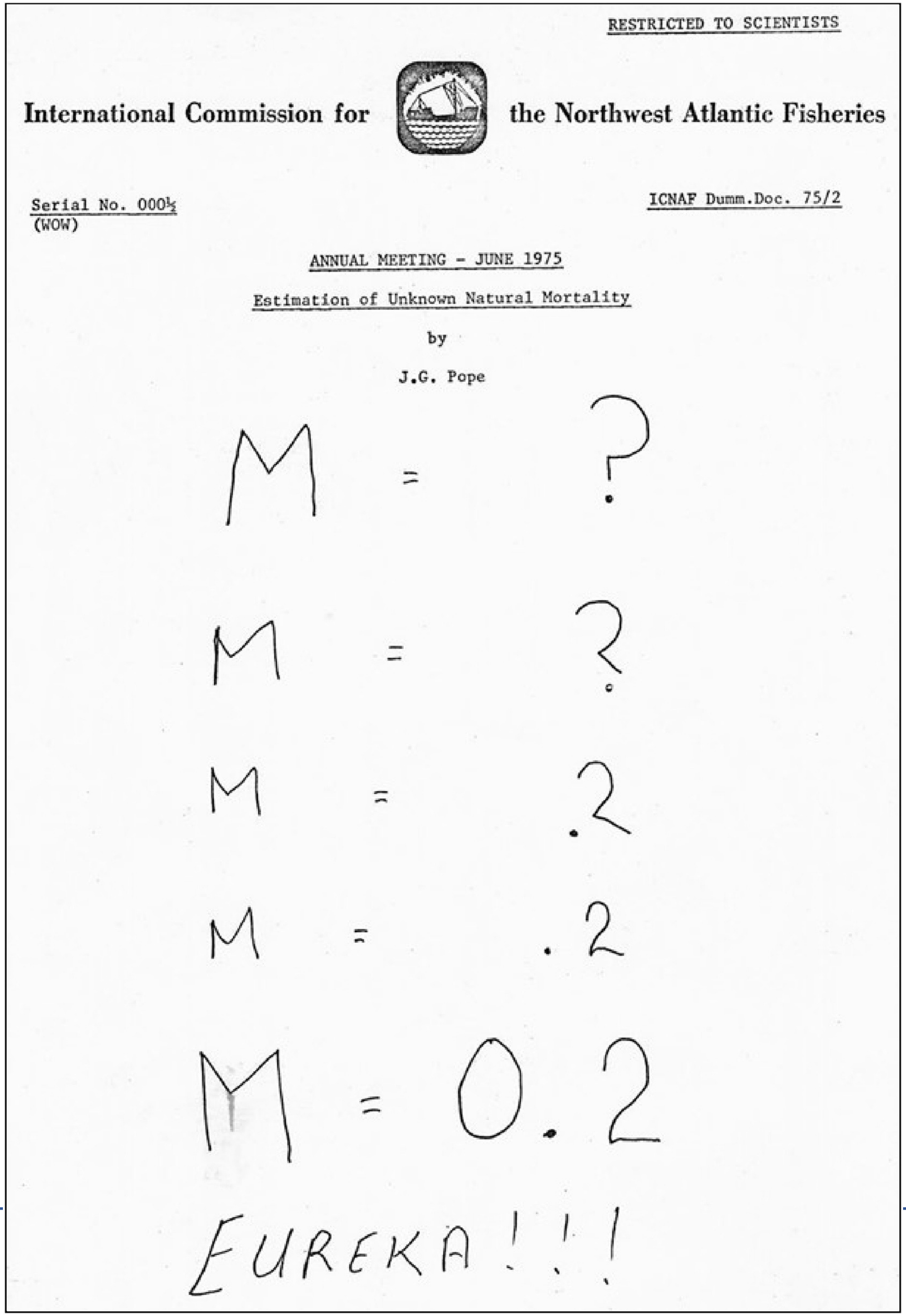
Approach	Reference	Notes	Equation	Eqn No
Life history approaches				
Jensen t_m	Jensen (1996)		$M = 1.65/t_m$	T1.1.1
Jensen K	Jensen (1996)		$M = 1.5\,K$	T1.1.2
Roff	Roff (1984)		$M = 3K/(\exp(t_m K) - 1)$	T1.1.3
Zhang and Megrey	Zhang and Megrey (2006)	t_c could be t_m or a fraction of t_{max}	$M = \beta K/(exp(K(t_c - t_0)) - 1)$	T1.1.4
Beverton	Beverton (1992)	$L_m/L_\infty = 3/(3 + M/K)$	$M = K\left(\frac{3L_\infty}{L_m} - 3\right)$	T1.1.5
Chen and Watanabe	Chen and Watanabe (1989)	$t_{m^*} = -\frac{1}{K} ln\left[1 - e^{Kt_0}\right] + t_0$ $a_0 = 1 - e^{-K(t_{m^*} - t_0)}$ $a_1 = Ke^{-K(t_{m^*} - t_0)}$ $a_2 = -\frac{1}{2}K^2 e^{-K(t_{m^*} - t_0)}$	$M = \begin{cases} \frac{K}{1 - e^{-K(t - t_0)}}, & t \le t_{m^*} \\ \frac{K}{a_0 + a_1(t - t_{m^*}) + a_2(t - t_{m^*})^2} & t \ge t_{m^*} \end{cases}$	T1.1.6
Maximum age				
Proportion surviving to maximum age		p = proportion remaining	$M = -ln(p)/t_{max}$	T1.2.1
Rule of thumb		$p = 5\%$	$M = 3/t_{max}$	T1.2.1a
M correlations				
Gulland-W	Gulland (1987)		$M = M(L/L_\infty)^{-1.5}$	T1.3.1
Gulland-L	Gulland (1987)		$M = M(W/W_\infty)^{-0.5}$	T1.3.2

Natural mortality estimate is important for stock assessment

The natural mortality is an important input parameter for stock assessment, but often is a number quite difficult to know precisely.

It is often reported how John Pope provided an ingenious solution to the problem when ICES had to estimate the value for the north Atlantic groundfish stocks.

The best available justification in 1975 for M = 0.2
(Pope et al., 2021)


RESTRICTED TO SCIENTISTS

International Commission for the Northwest Atlantic Fisheries

Serial No. 000½
(WOW)

ICNAF Dumm.Doc. 75/2

ANNUAL MEETING – JUNE 1975

Estimation of Unknown Natural Mortality

by

J.G. Pope

M = ?

M = ?

M = .2

M = .2

M = 0.2

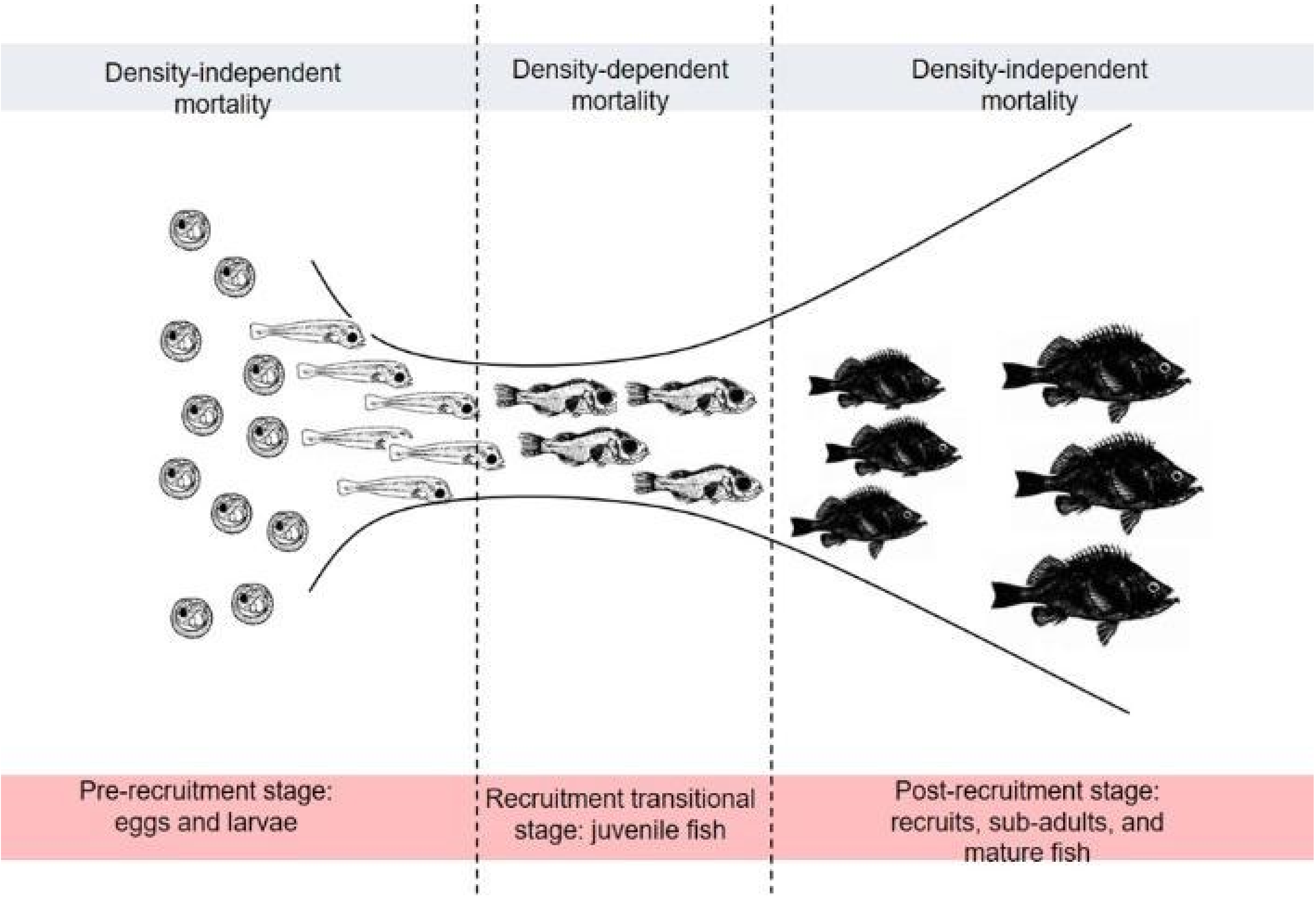
EUREKA!!!

Reproduction

Scientists showed that peaks in abundance of juveniles in a year, affect catches for several years after. Importance of some coorts.

Recruitment is probably the most important process that regulates populations of fish, but it is complicated to understand. Recruitment refers to the process of small, young fish transitioning to an older, larger life stage. What is so important is that during the recruitment period, natural mortality is density-dependent in a compensatory manner. This means that whether a greater or a lesser number of eggs and larval fish are produced, the number of fish surviving to the subadult populations will be approximately the same.

The term recruitment that we use here refer (and mostly in fisheries science) is when the fish is becoming vulnerable to harvest (e.g., reaching legal size).



Credit: Kai Lorenzen, UF/IFAS

Recruitment

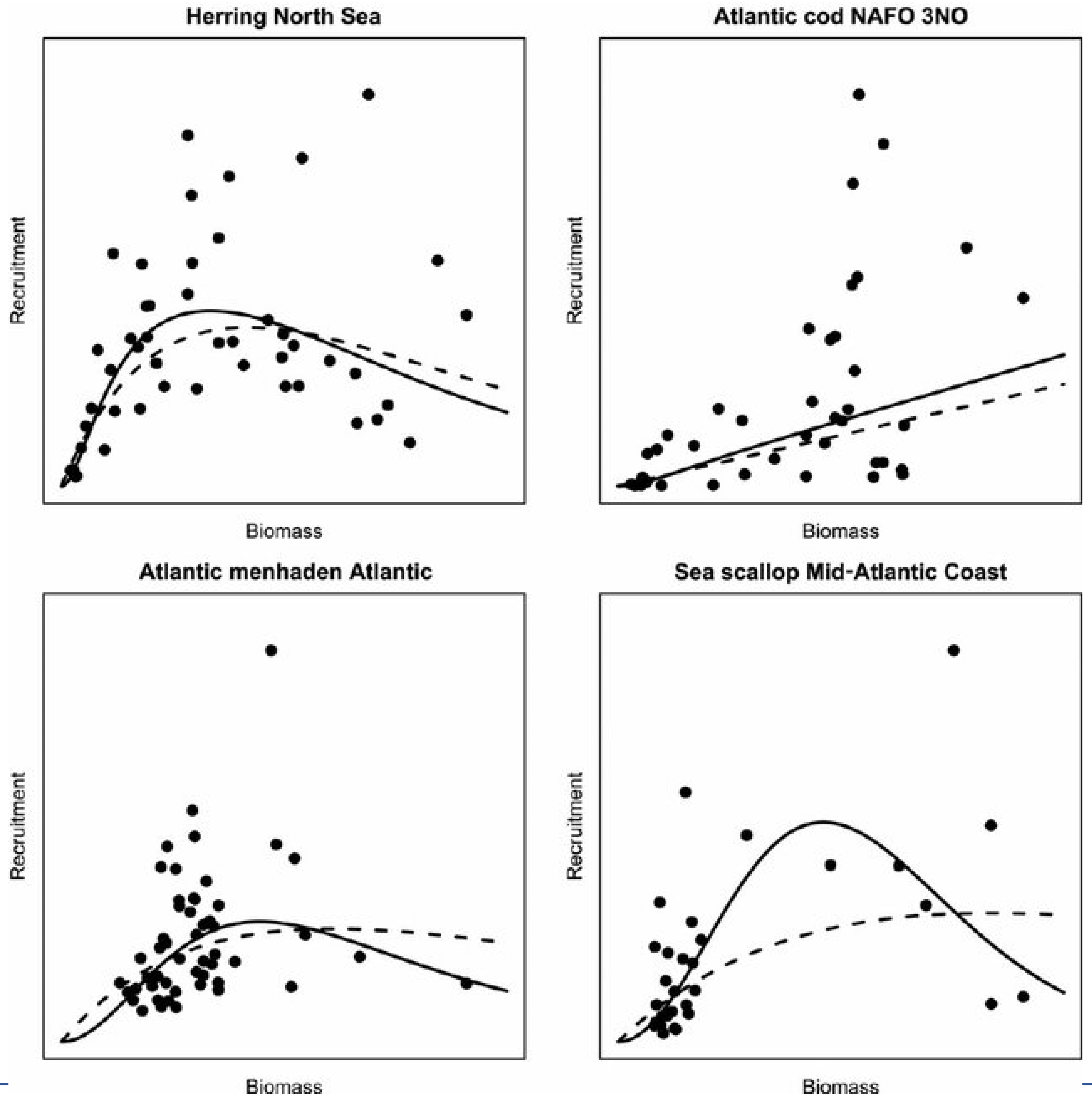
Example of stock-recruit data.

Recruitment is highly variable and is highly dependent on environmental variability.

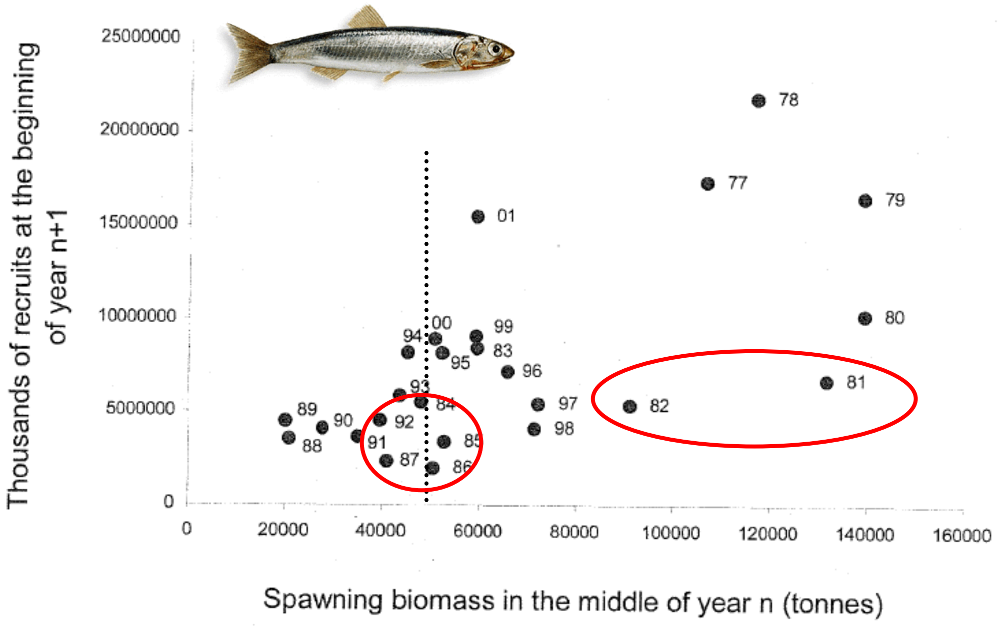
It is one of the most difficult part to treat in the fish population dynamics

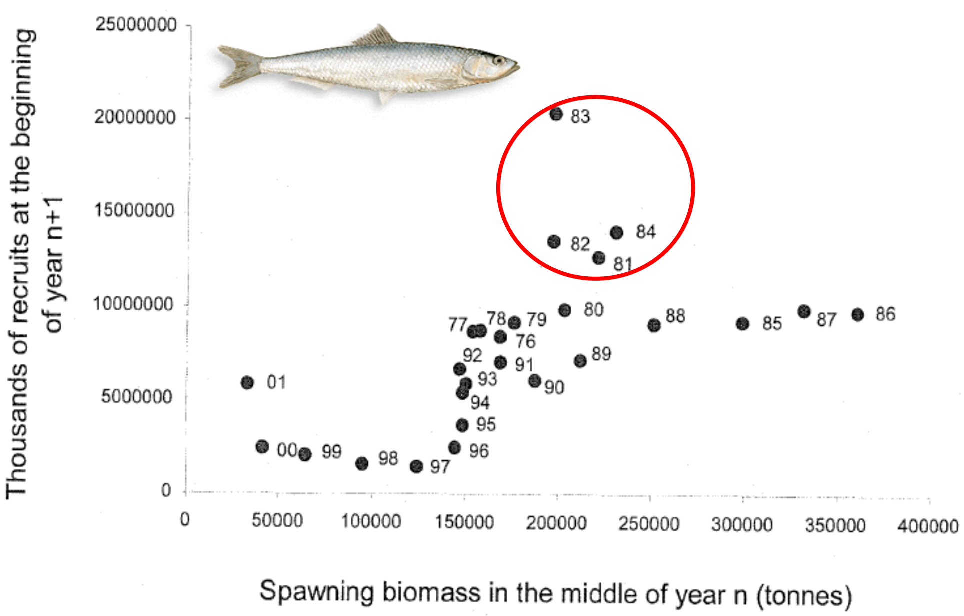
Note that usually recruits are number of individuals at a given age but this recruit age can change across species.

For short living species it is usually age0
For long living species (e.g., tuna) can be also age 1 or age 2.



Recruitment





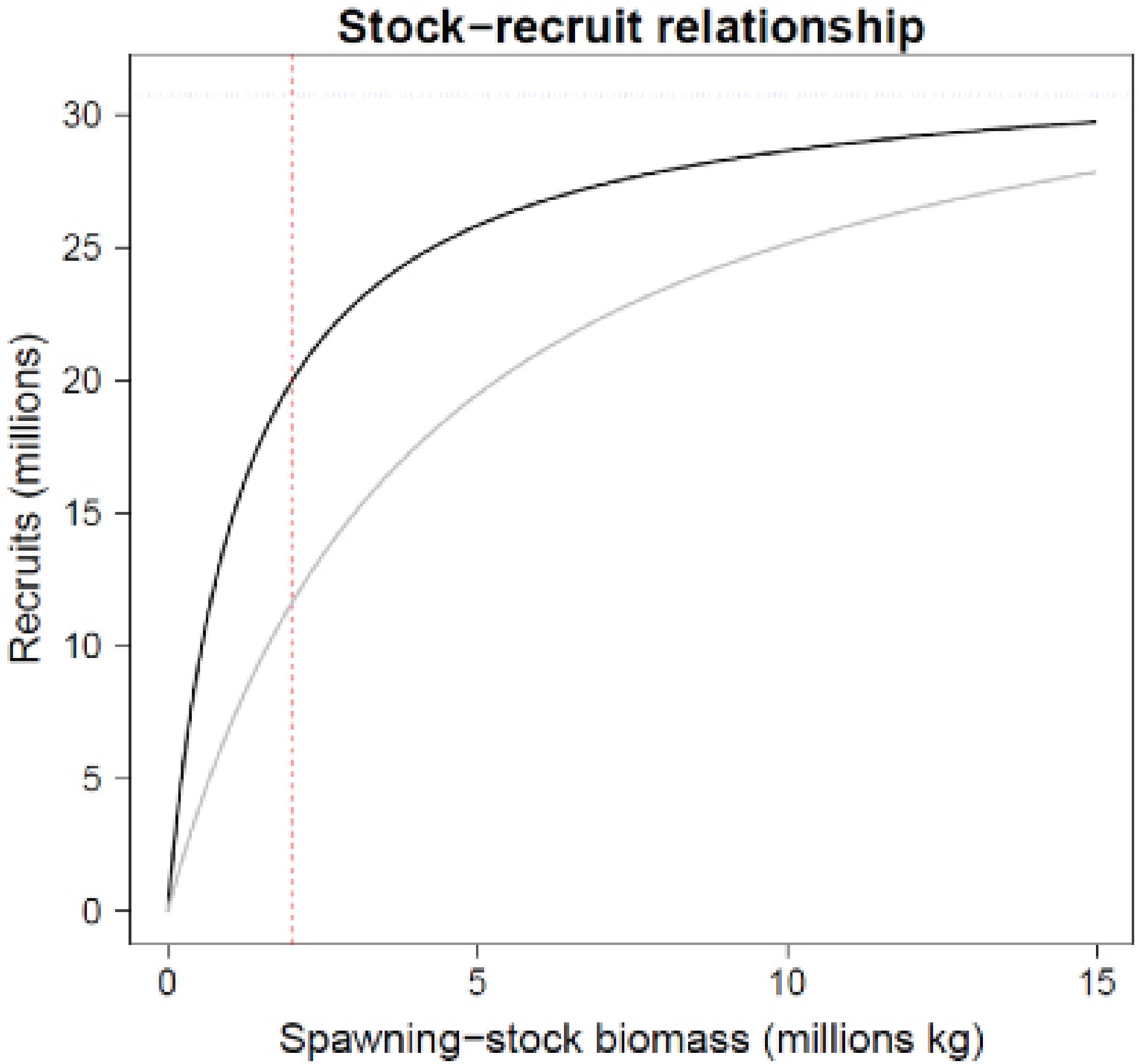
Example of stock-recruit relationship for small pelagics in Adriatic Sea
(Santojanni et al., Biol.Mar.Medit. (2006) 13, 98-111.)

Results highlight great variability of recruitment for the same values of stock of spawners

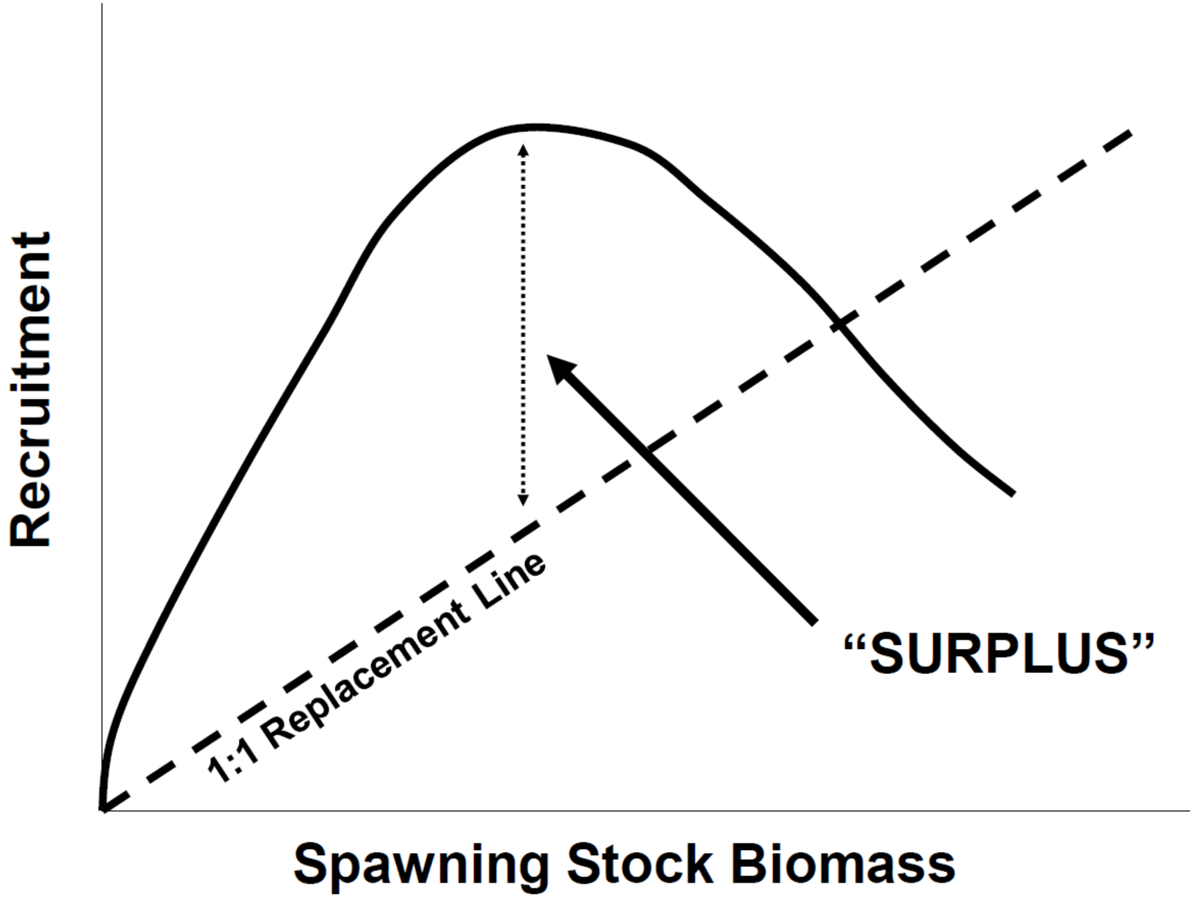
At the same time, there has been years with extremely high success in recruitment (e.g., sardine in middle 80s)

Spawners and Recruitment function

Example stock-recruit relationships. The gray line shows a lower improvement in the survival rate (from egg to juvenile) at low spawning stock biomass, whereas the black line shows a greater improvement in the same survival rate. In stock assessment terms, the black line shows a greater "steepness," and the grey lines shows lesser "steepness." The dotted blue line shows the "recruitment at unfished conditions," and the dashed red line shows roughly the "overfishing limit"— where if spawning stock biomass falls below (i.e., to the left of the line), the stock may be overfished.



The meaning of the S-R function

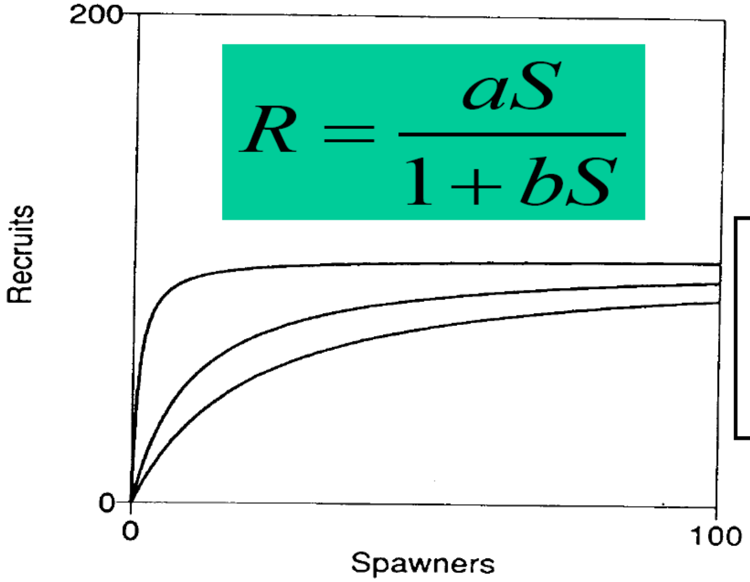


Above the 1:1 line (replacement line): there is surplus in number of individuals and thus population is in expansion

When below the 1:1 curve it means that are values od SSB for which compensatory effects start having effects on small individuals (e.g., cannibalism)

Stock-Recruitment functions

Beverton-Holt



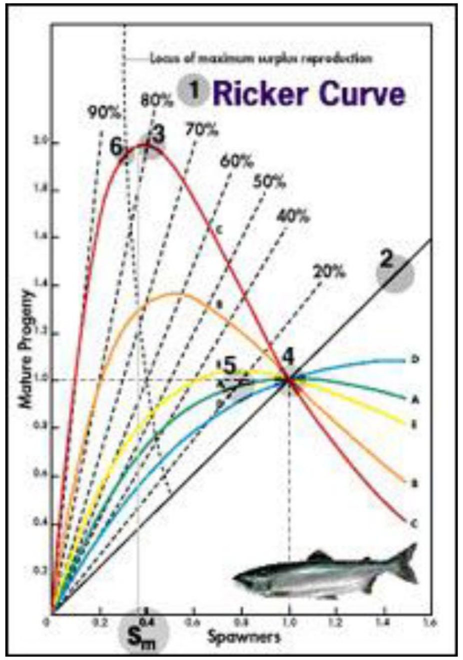
$$R = \frac{aS}{1 + bS}$$

a/b = max R at high S

a = max R/S at low S i.e. initial slope

Figure 7.9. Beverton-Holt stock-recruitment curves.

Stock-recruitment curves: Ricker



$$R = aSe^{-bS}$$

b = rate of decline in R as S increases

a = max R/S at low S i.e. initial slope

Beverton-Holt

– Recruitment asymptotic
– Intra-year feedback
– Recruits limited by food/habitat
–many Marine species

Ricker

–Recruitment declines at high stock sizes
–Inter-year feedback
–Recruits limited by cannibalism, egg superimposition
–Anadromous species

iv) Le specie ittiche: crescita, riproduzione, mortalità: esercizio modelli e dati.

Processi di base della dinamica di popolazione

Informazioni di base per gestire lo sfruttamento delle risorse alieutiche

Crescita, riproduzione, mortalitá

v) Stock assessment basi: dalla cohort analysis e virtual population analysis ad oggi (esercizi). Le attività di pesca: selettività, catturabilità, impatto sugli habitat. Dati fishery dependent e fishery independent per la gestione: uso, limitazioni, problematiche.