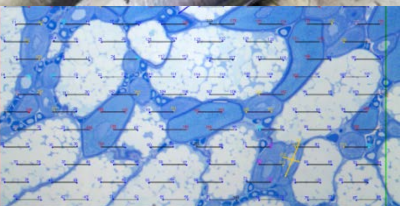
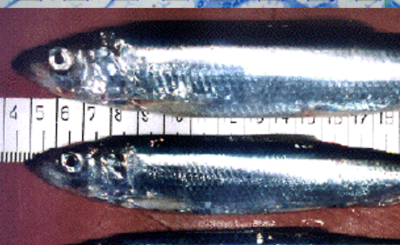
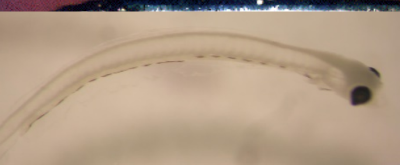
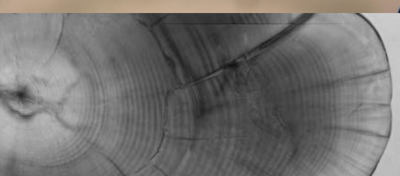
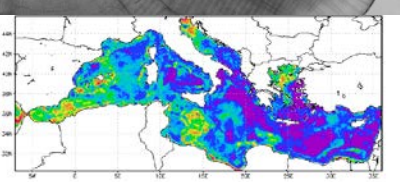
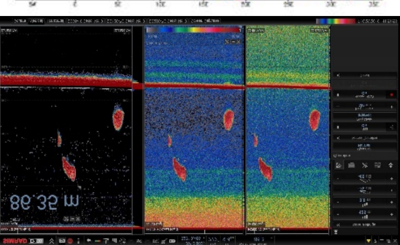
Drivers of dynamics of small pelagic fish resources

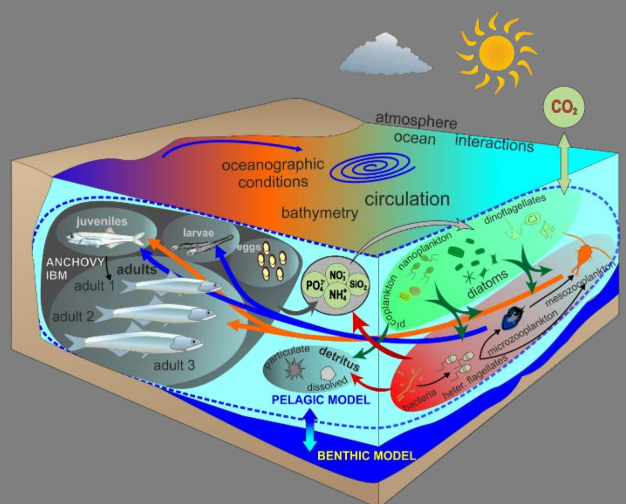
International Symposium, Victoria, BC, Canada, March 6-11 2017

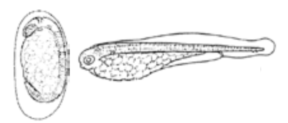
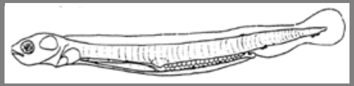
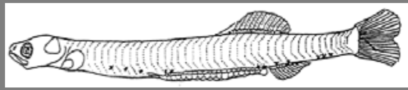
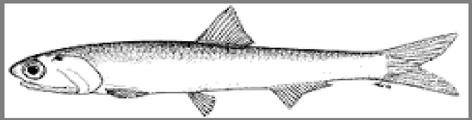








From egg production to year class strength: A full life cycle perspective of small pelagic fish recruitment

Stylianos (Stelios) Somarakis

Hellenic Centre for Marine Research (HCMR)
Crete, Greece

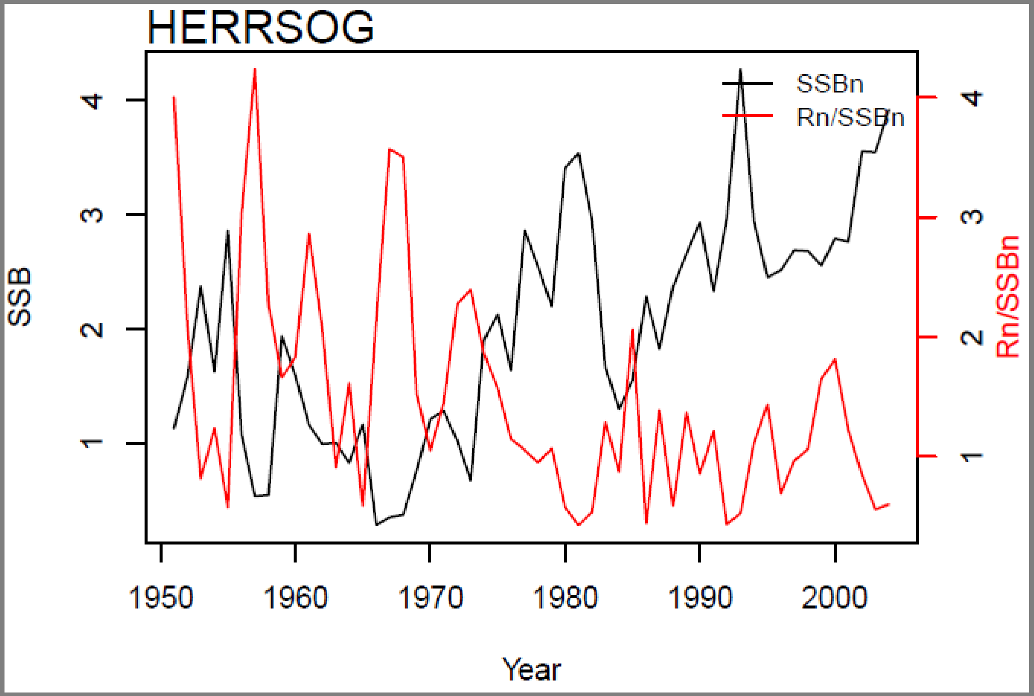


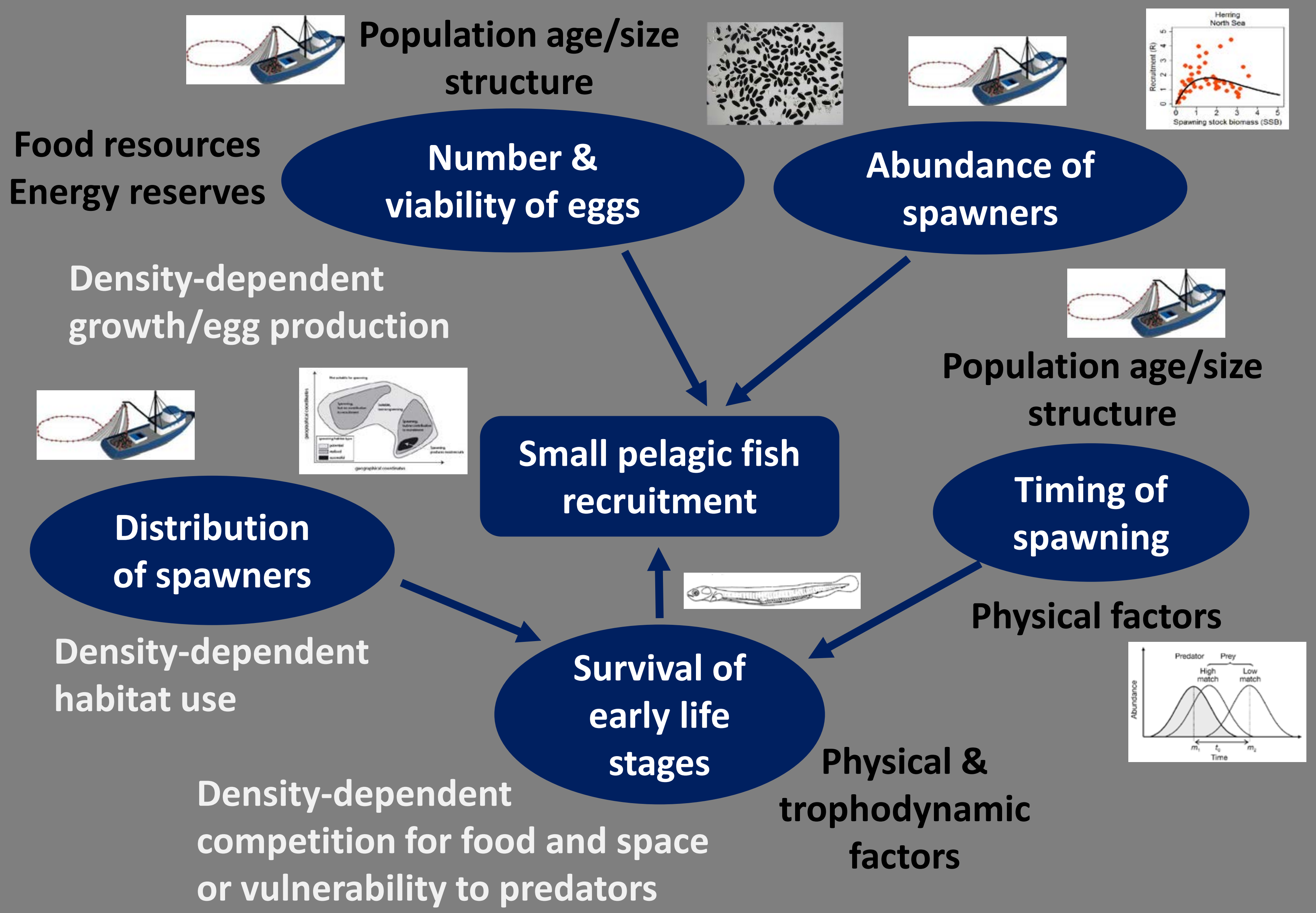






Recruitment in SPF

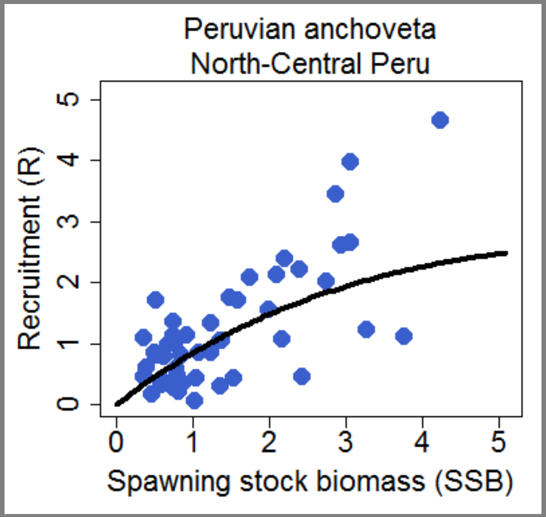
Large inter-annual fluctuations

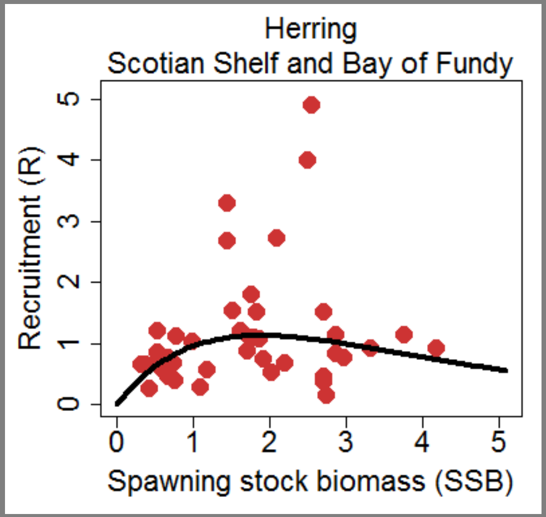
often superimposed on decadal trends …





Population age/size structure
Herring
North Sea
Recruitment (R)
Spawning stock biomass (SSB)
Food resources
Energy reserves
Number & viability of eggs
Abundance of spawners
Density-dependent growth/egg production
Population age/size structure
Small pelagic fish recruitment
Distribution of spawners
Timing of spawning
Physical factors
Predator
Prey
High match
Low match
Abundance
Time
Density-dependent habitat use
Survival of early life stages
Physical & trophodynamic factors
Density-dependent competition for food and space or vulnerability to predators

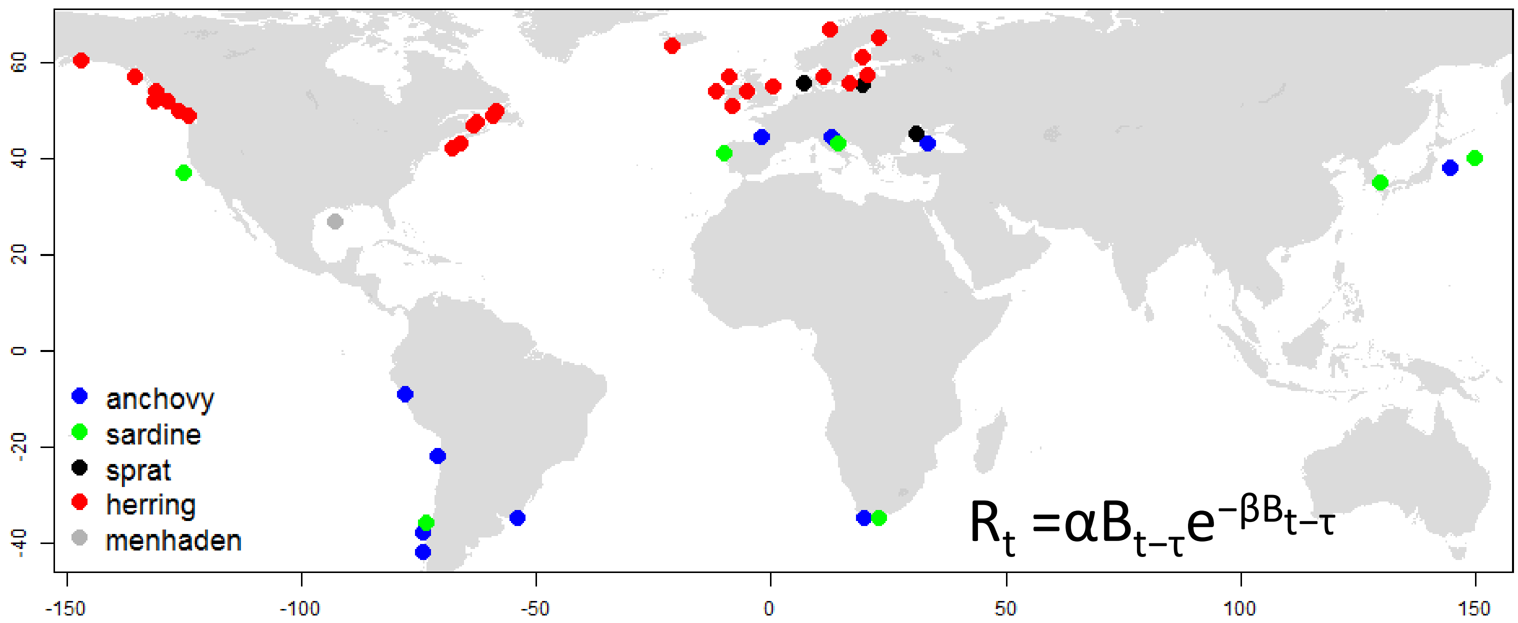




The effect of SSB on recruitment cannot be discounted

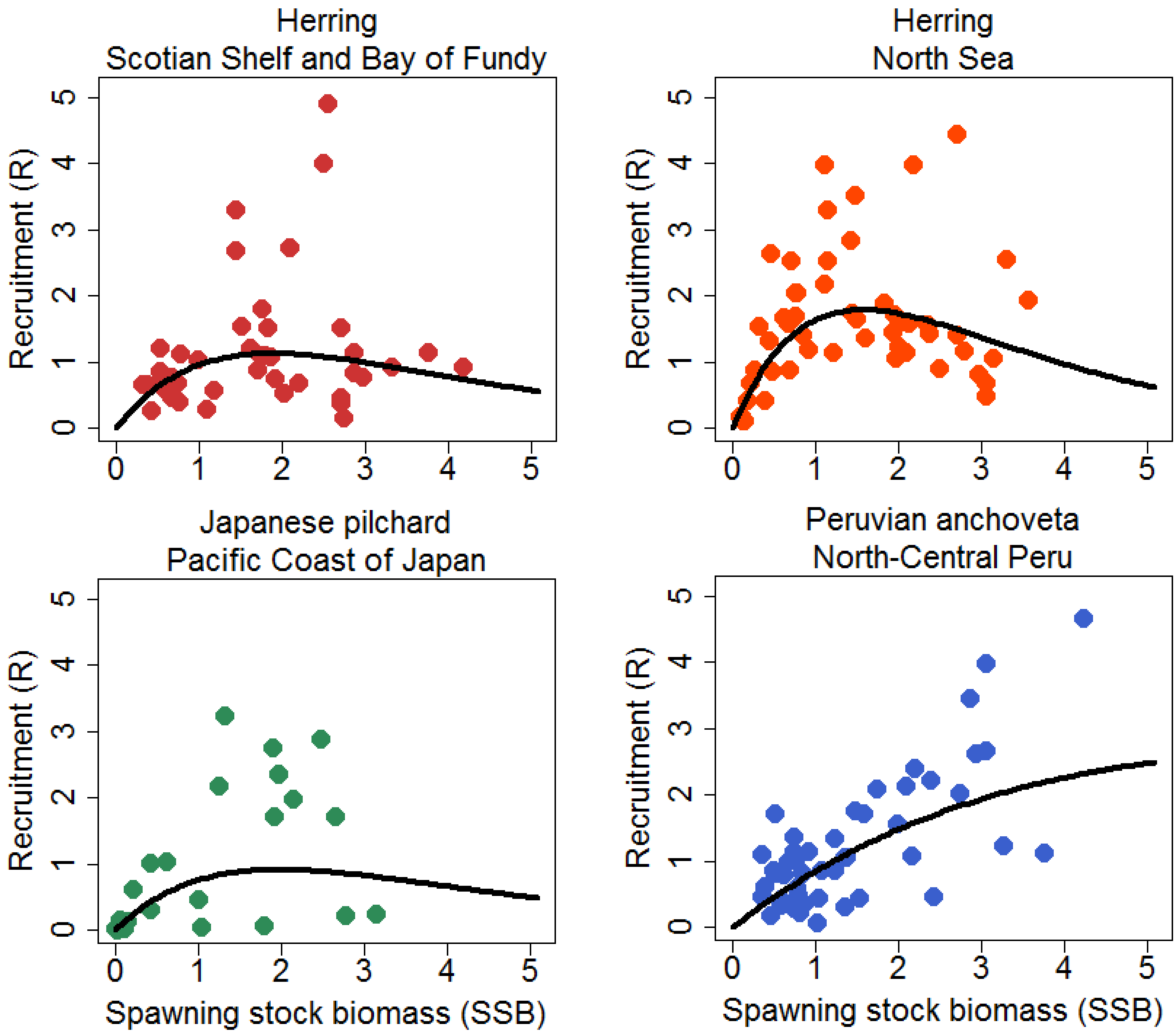
1. THE EFFECT OF ADULT STOCK

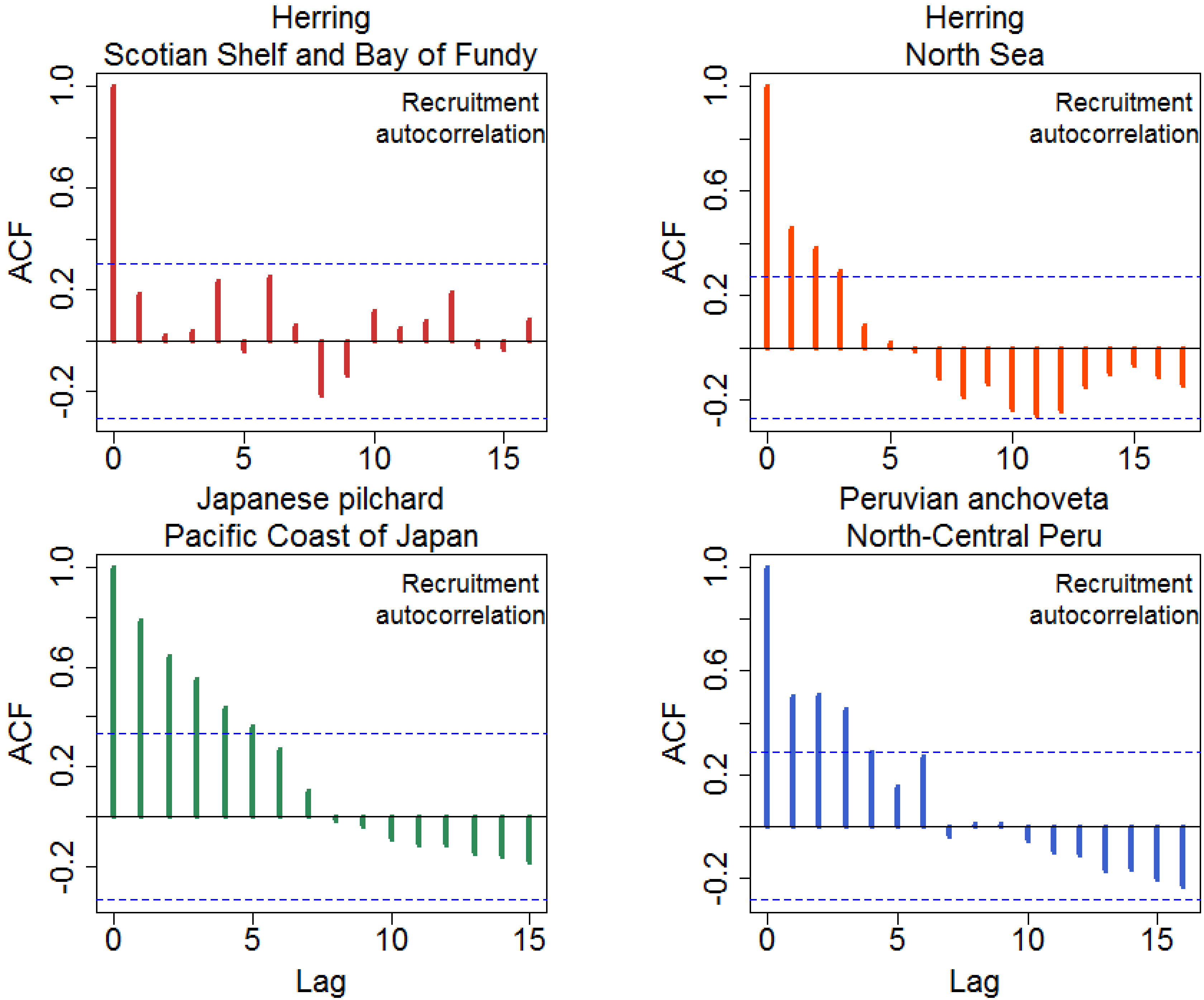
The stock-recruitment relationship



$$R_t = \alpha B_{t-\tau} e^{-\beta B_{t-\tau}}$$

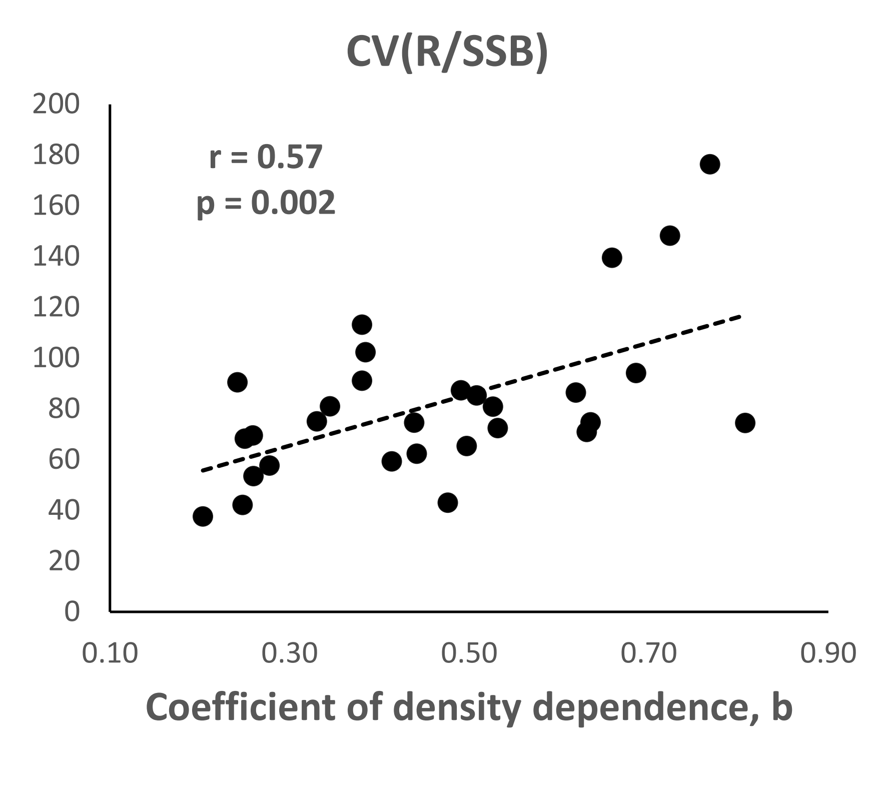
- 46 stocks mainly from the RAM Legacy Stock Assessment Database (25 herrings, 7 sardines, 10 anchovies, 3 sprats, 1 menhaden)
- Series normalized to unit variance for easy comparison across stocks/regions
- 29 out of 46 stocks had acceptable fits (significant Ricker coefficients and/or no obvious structure in residuals)

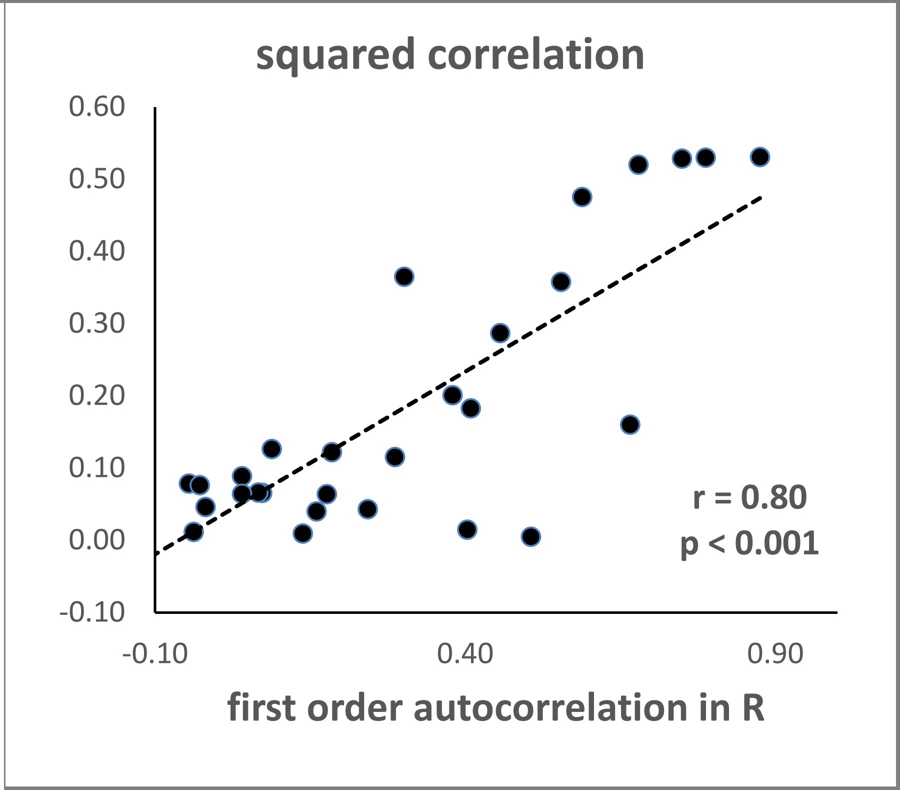

Herring
Scotian Shelf and Bay of Fundy
Herring
North Sea
Japanese pilchard
Pacific Coast of Japan
Peruvian anchoveta
North-Central Peru
Recruitment (R)
Spawning stock biomass (SSB)
0
1
2
3
4
5



Herring
Scotian Shelf and Bay of Fundy
Recruitment autocorrelation
Herring
North Sea
Recruitment autocorrelation
Japanese pilchard
Pacific Coast of Japan
Recruitment autocorrelation
Peruvian anchoveta
North-Central Peru
Recruitment autocorrelation
ACF
Lag

The Ricker S/R relationship

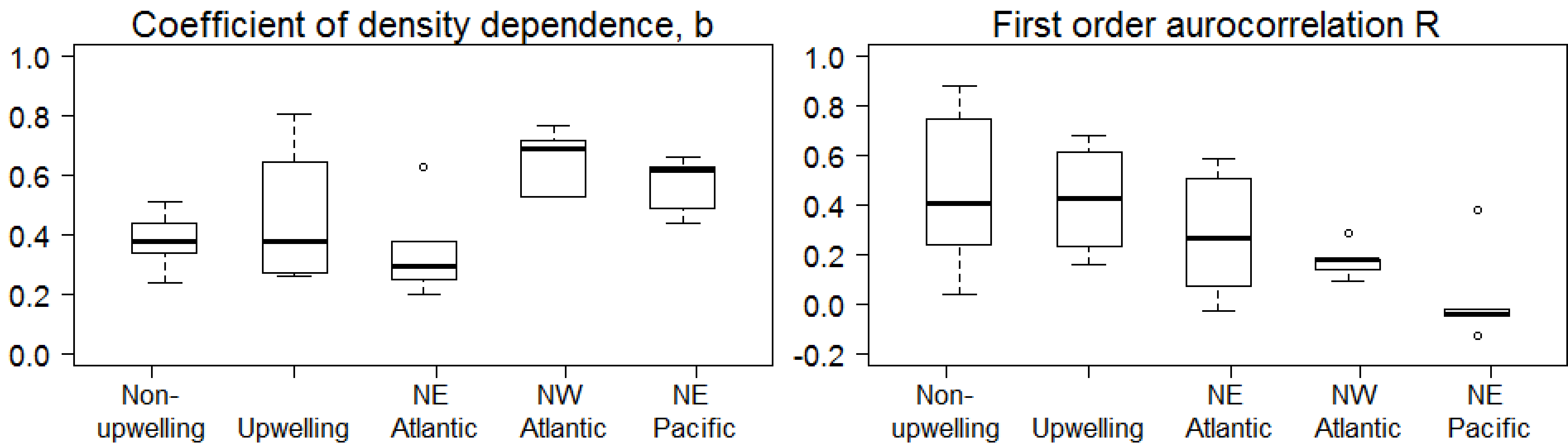




… the degree of density dependence controls the recruitment rate

…. recruitment is governed by low frequency variability in ecosystem regime (e.g. temperature or food)

The Ricker S/R relationship



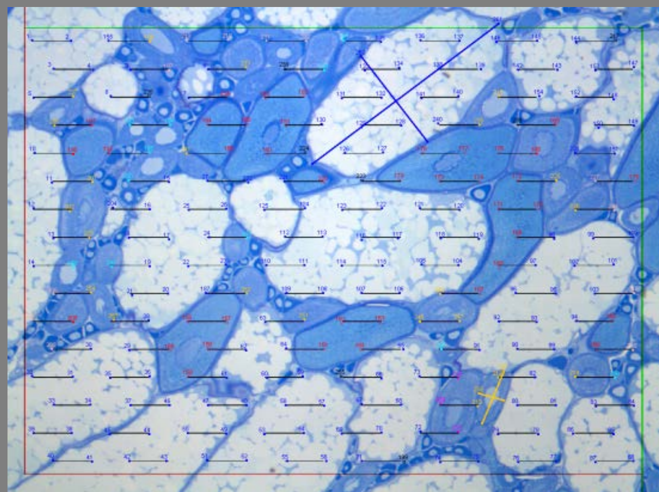
Anchovies
Sardines
Sprats

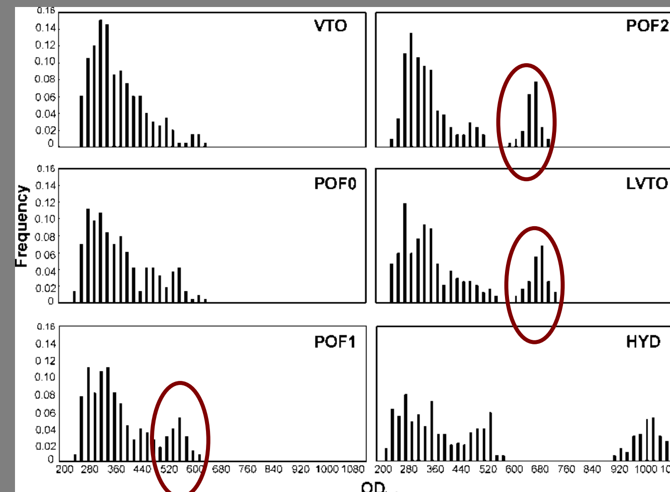
Herrings

Anchovies
Sardines
Sprats

Herrings

… recruitment in American herrings is dominated by high frequency (inter-annual) variability





The potential effect of SRP has received limited attention

2. STOCK REPRODUCTIVE POTENTIAL

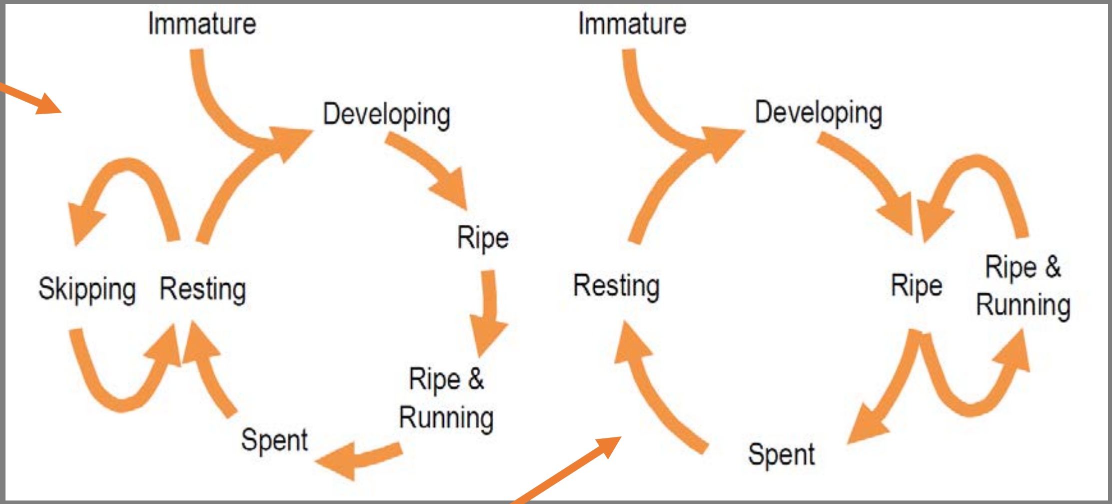
Reproductive strategies

Herring

Total spawner that ovulates and spawns demersal eggs in a single wave and skip spawning in some years. **Extreme capital breeder (store energy for use later in reproduction)**

McBride RS, Somarakis S,et al. (2015)

Fish and Fisheries



Anchovy, sardine, sardinella, sprat

Batch spawner that ovulates and spawns pelagic eggs in discrete intervals (biorhythm) over a relatively prolonged spawning season. **Capital-to-extreme income breeder (feed during the spawning season)**

Capital-income breeding is a conditional strategy: an individual's genotype is capable of moving along the capital-income continuum in response to its own physiological condition and the environment

Female nutritional condition & recruitment

Evidence from Iberian sardine, Japanese sardine, Californian sardine

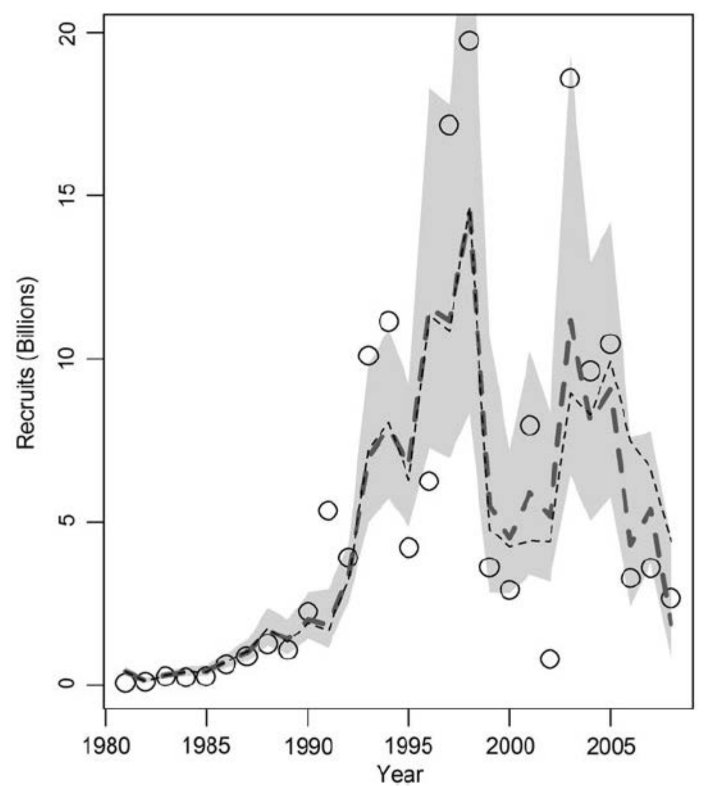


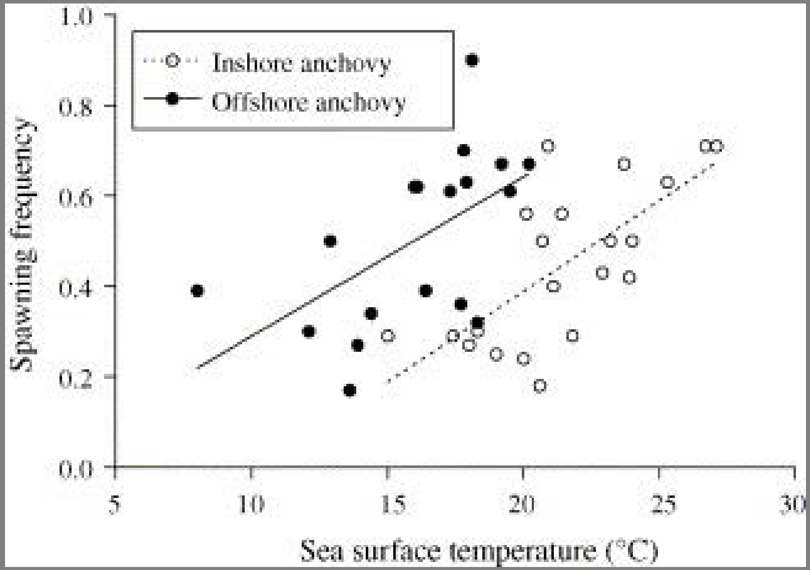
Figure 3. Reconstruction of the recruitment time-series for the sardine stock from 1981 to 2008 (circles) using the best environmental Ricker model [Equation (2); Table 2; black dashed line]; and the best environmental Ricker model with *k* [Equation (3); grey dashed line] with 95% confidence intervals (grey area). The inclusion of *k* provides a better fit to the data after 2000.

Sardines are more close to the **CAPITAL BREEDING mode**

… to predict Californian sardine recruitment, Zwolinski and Demer (2014) proposed a "dual-phase" model based on seasonal PDO-based indices and a condition factor:

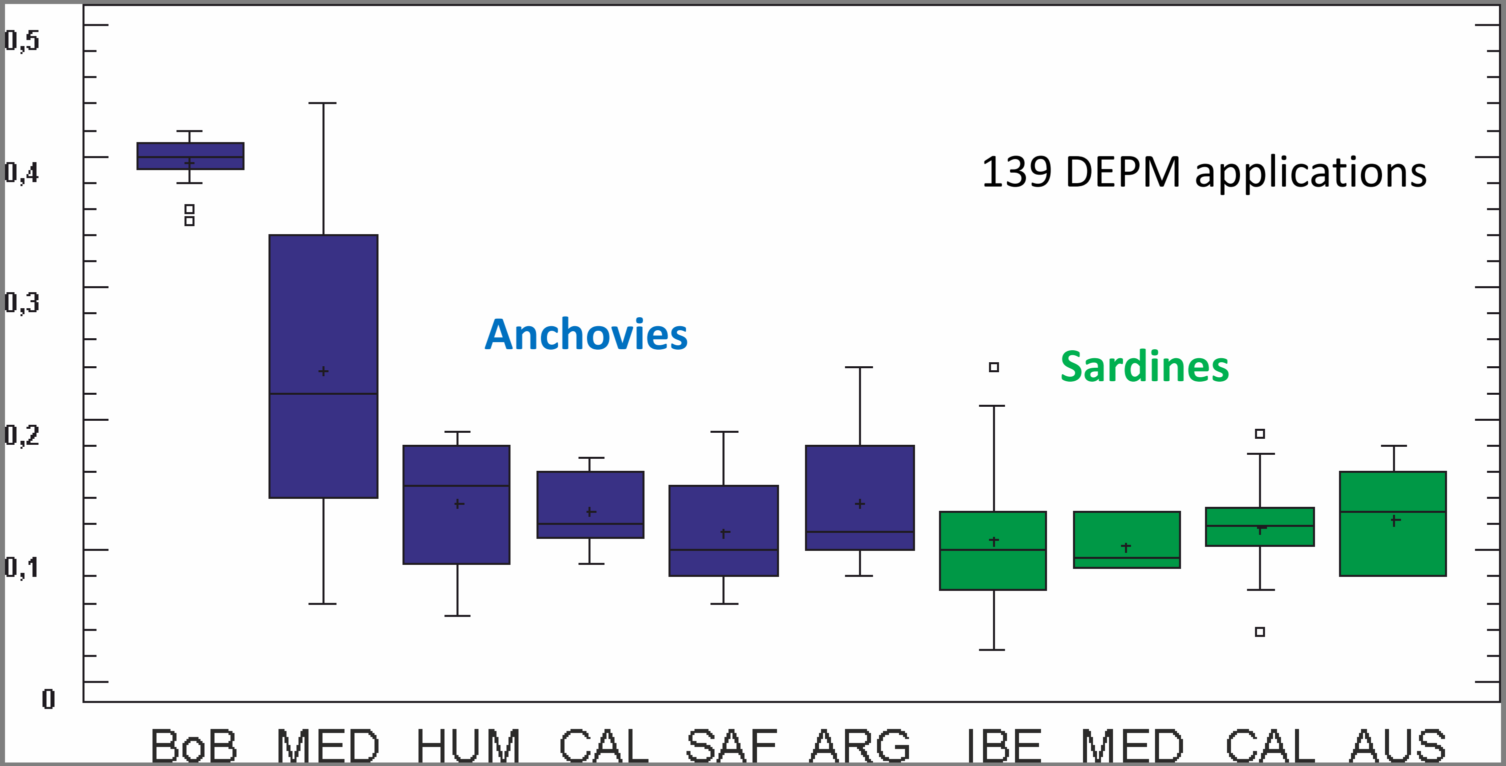
- summer feeding conditions favorable to a good pre-spawning adult condition contributes significantly and positively to recruitment

The rate of vitellogenesis and inter-spawning interval are temperature dependent



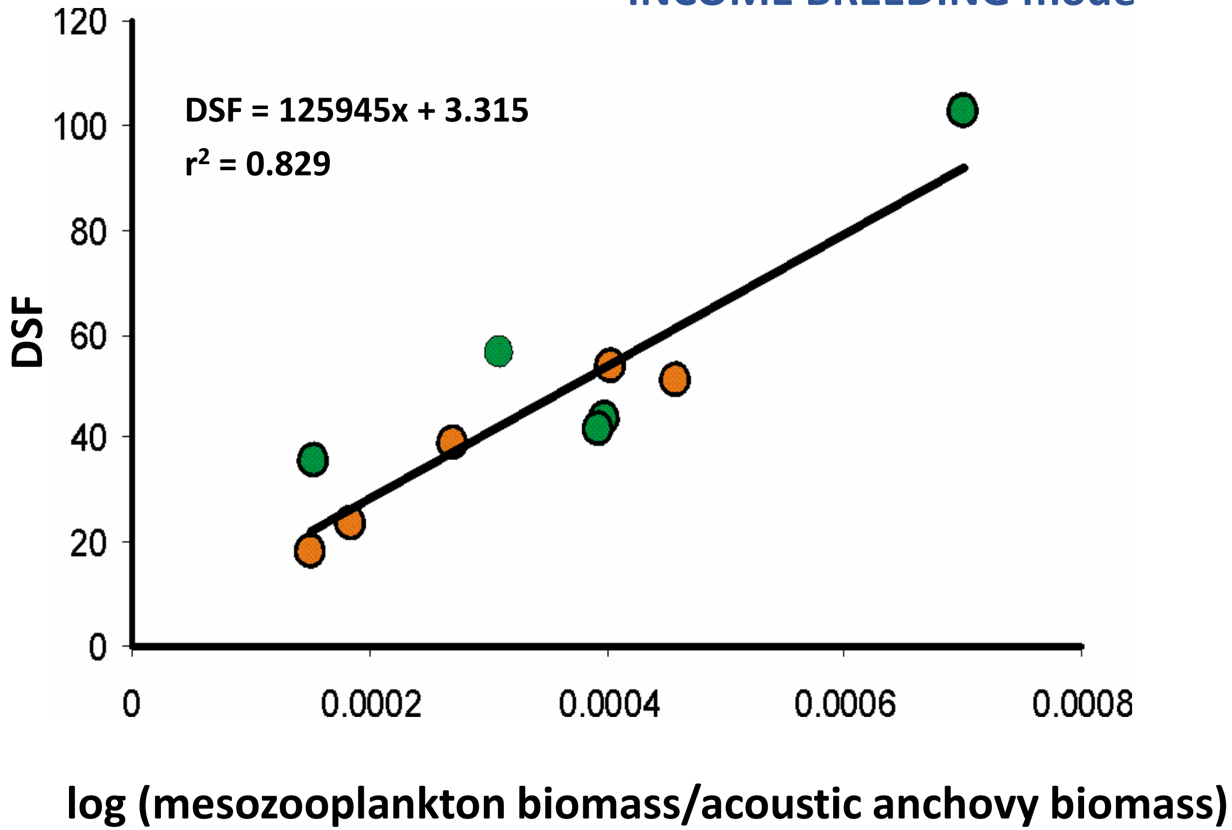
Takasuka et al. 2005

Spawning frequency (S)



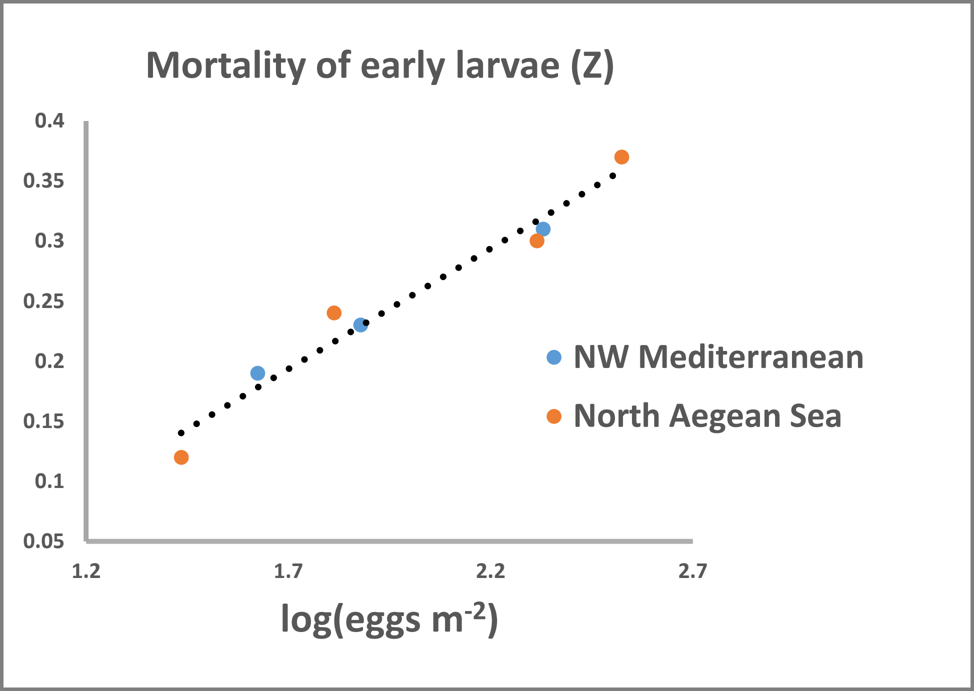
BoB: Bay of Biscay
MED: Mediterranean Sea
HUM: Humboldt Current
CAL: Californian Current
SAF: Benguela Current
ARG: Argentine Sea
IBE: Iberia
AUS: Australia

Mediterranean anchovy is more close to the **INCOME BREEDING mode**



Somarakis et al. 2012. Fisheries Research

Density dependent larval mortality



Mediterranean anchovy
(Somarakis et al. 2007. Mar Biol)

….direct predation, increased attraction of zooplanktivorous nekton

Density dependent habitat use

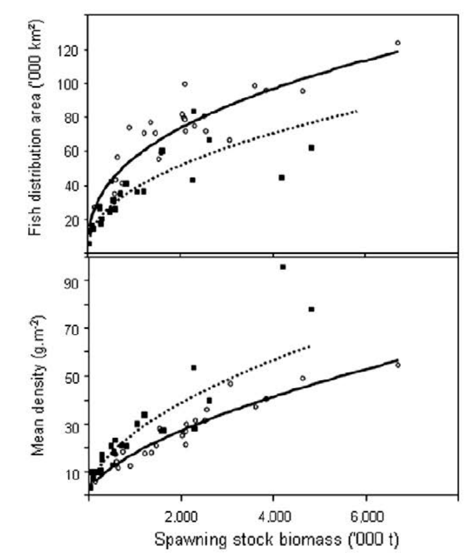


Fig. 4. Relationship between anchovy (open circles, solid line) and sardine (closed squares, dotted line) spawning stock biomass, fish distribution area (top panel) and average packing density (bottom panel), off South Africa (1984–2007).

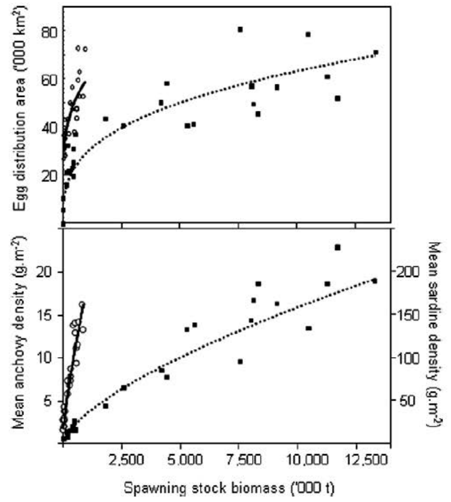
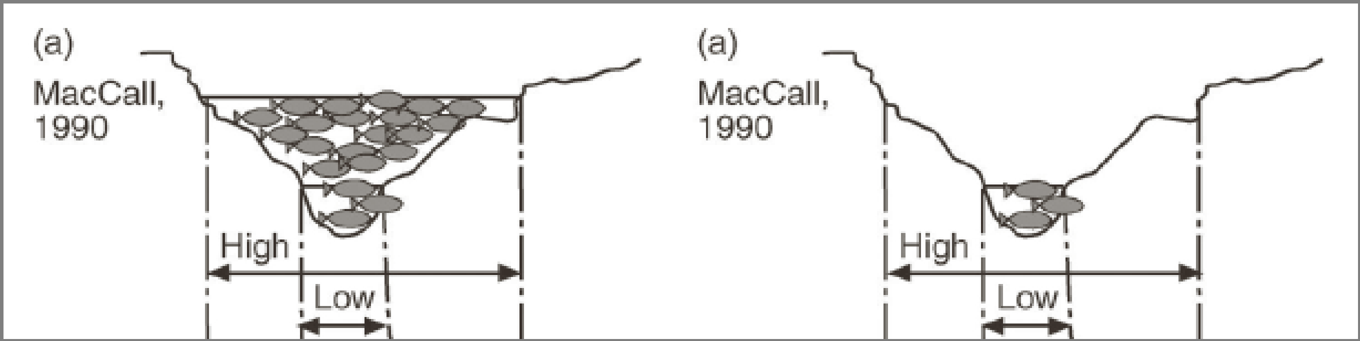


Fig. 5. Relationship between anchovy (open circles, solid line) and sardine (closed squares, dotted line) spawning stock biomass, egg distribution area (top panel) and average packing density (bottom panel, assuming that the egg distribution area reflects the distribution of adult fish, Fig. 2), off Japan (1978–2004). Distribution area computed on the peak spawning month, February for sardine and June for anchovy (from Oozeki et al., 2007).

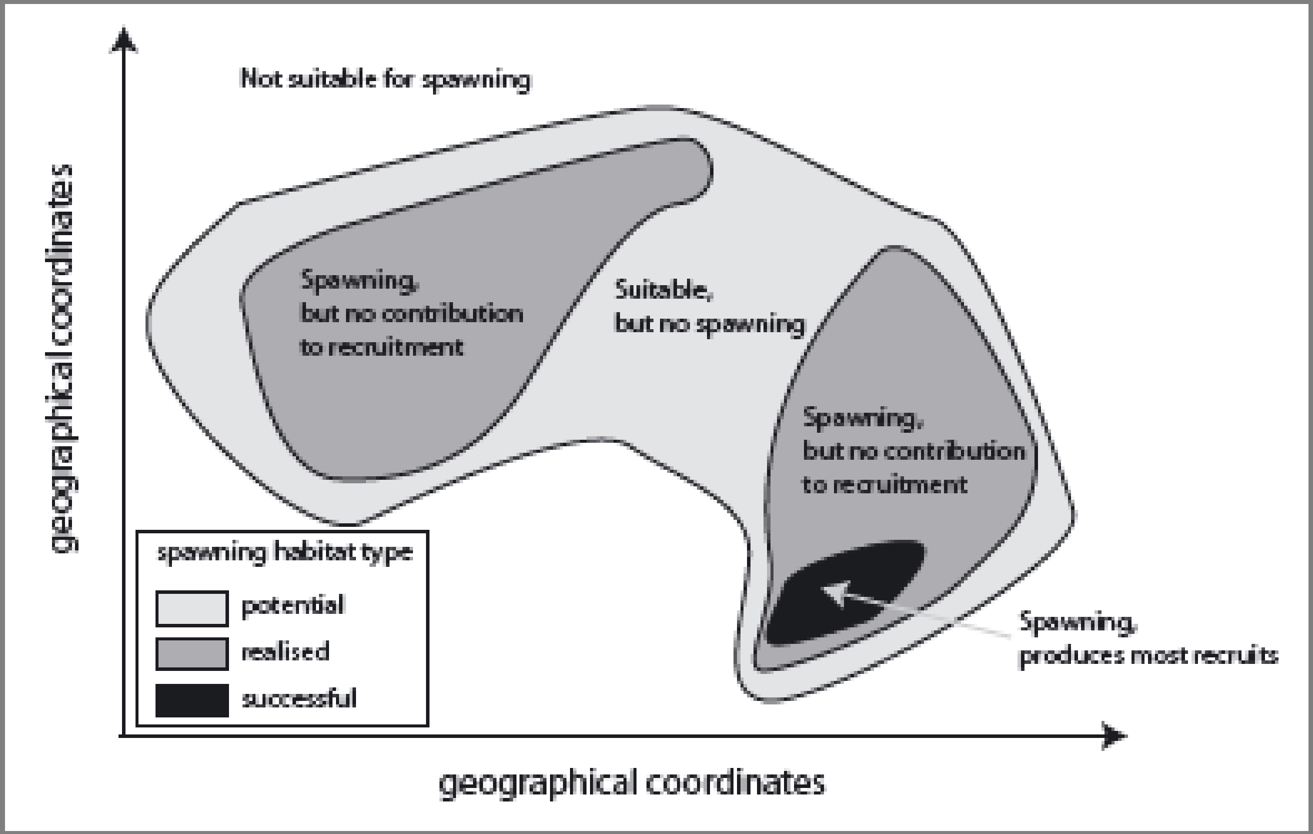
Barange et al. 2009. Prog Oceanogr



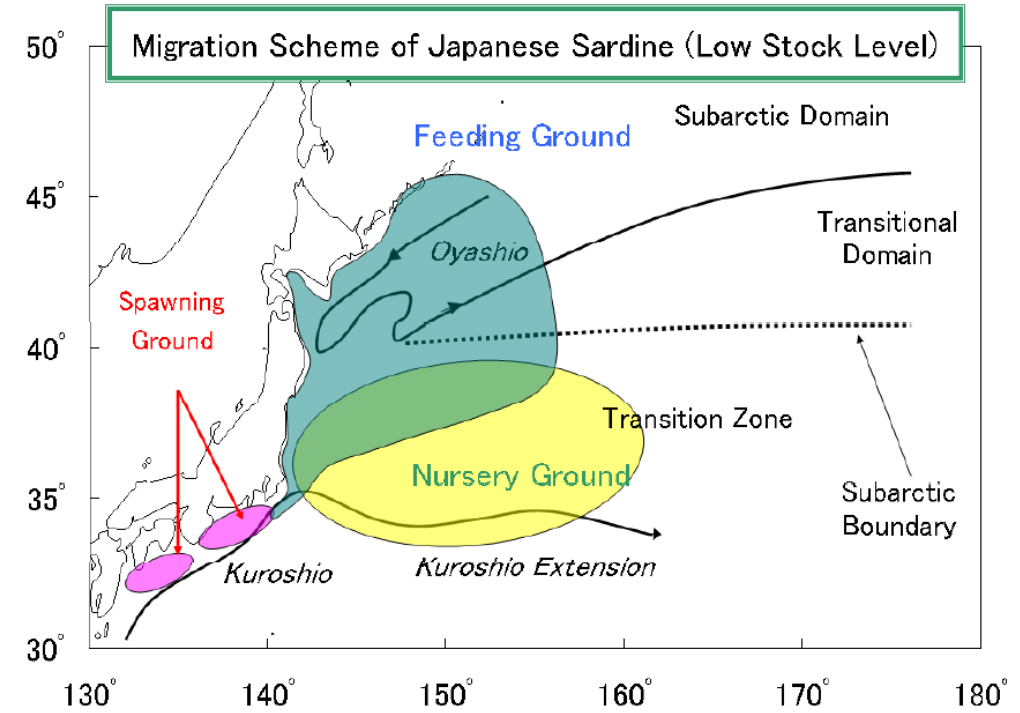
Freon et al. 2005. Bull Mar Sci

Large expansions and contractions of range associated with levels of abundance

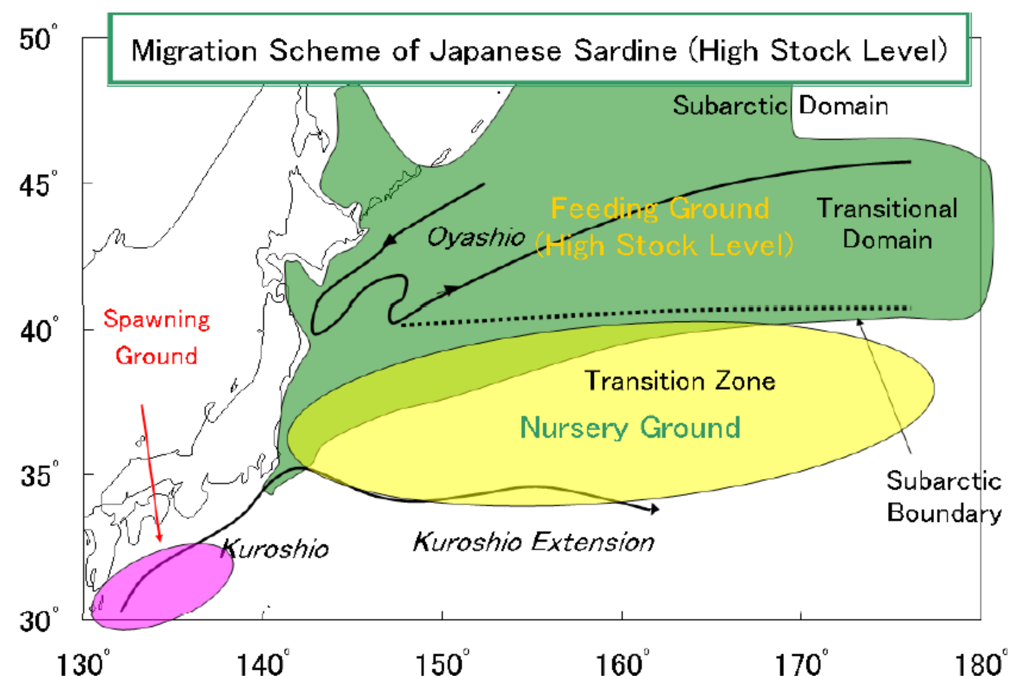
Realized vs successful spawning habitats



Planque et al. 2007. Fisheries Oceanography



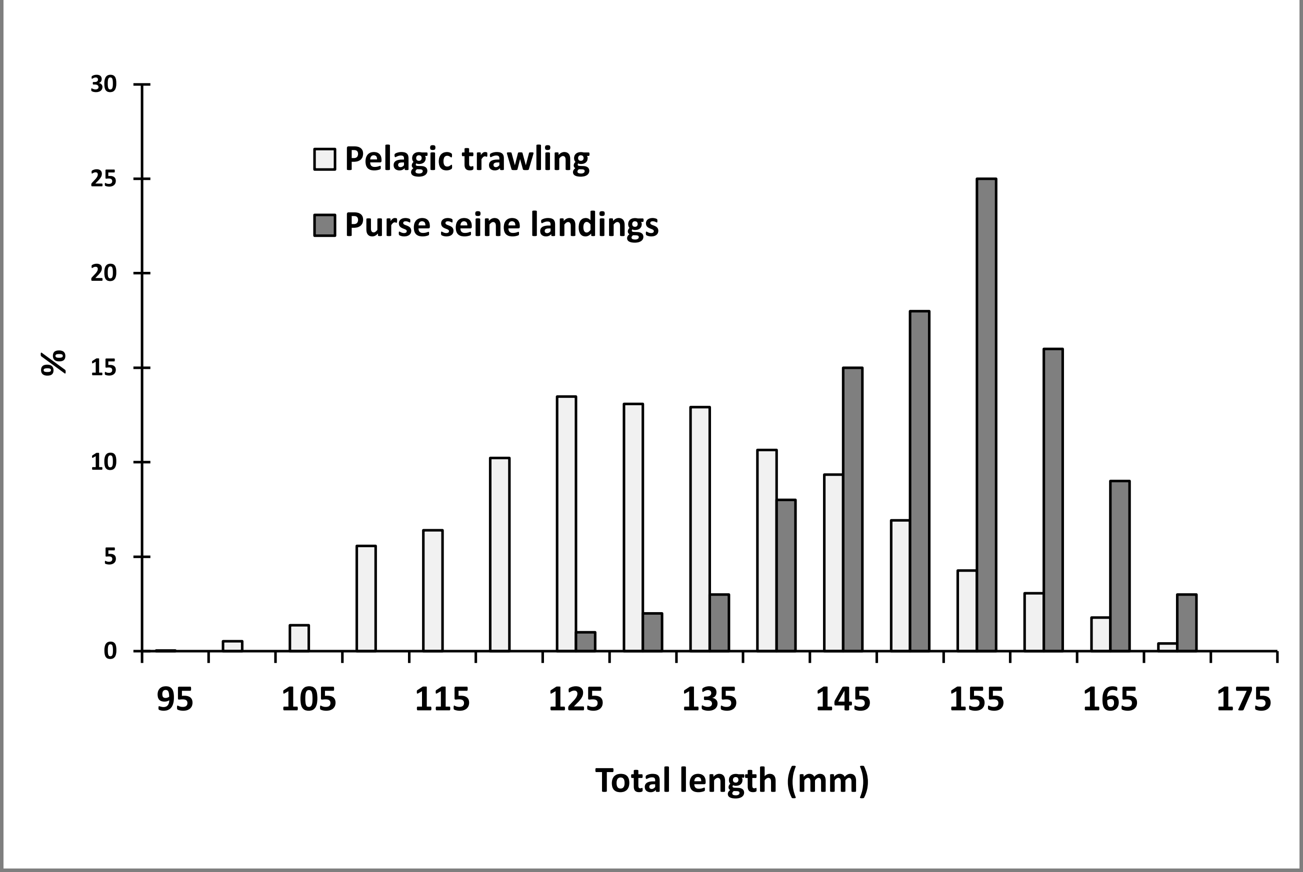
<u>Low stock periods</u>:
Spawning grounds confined within inshore areas



<u>High stock periods</u>:
Spawning grounds extend across Kuroshio current -> -> increased transport to Kuroshio Extension

drawn by Yatsu et al.

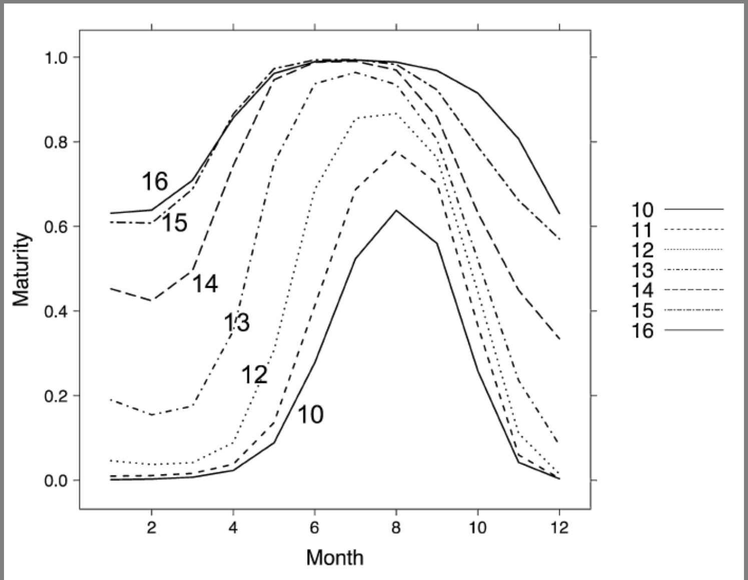
Reproductive potential and size selective fishing



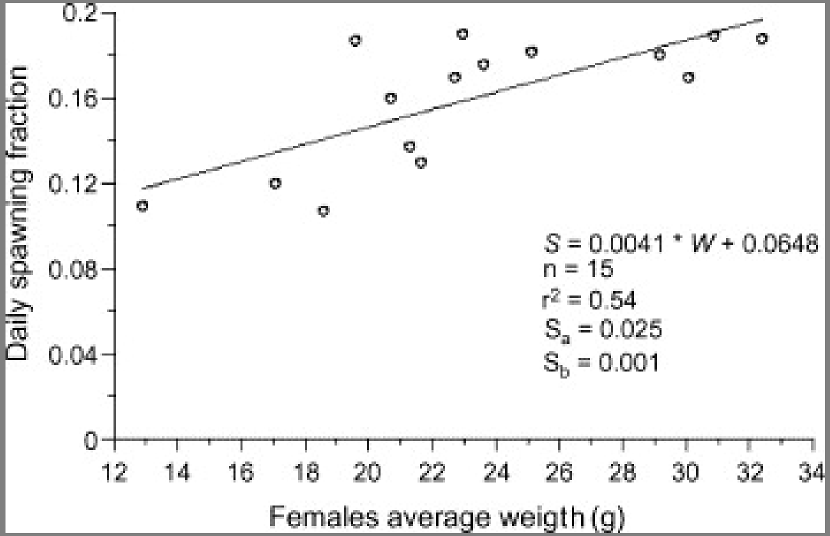
North Aegean Sea – June 1995

Age/size effects

- **R**ecruit spawners often become sexually mature later in the year or the duration of the spawning period is shorter in smaller fish
- The **spawning fraction (S)** and **relative batch fecundity (F/W)** may increase with size



Cubillos LA, Claramunt G, 2009. Mar Biol

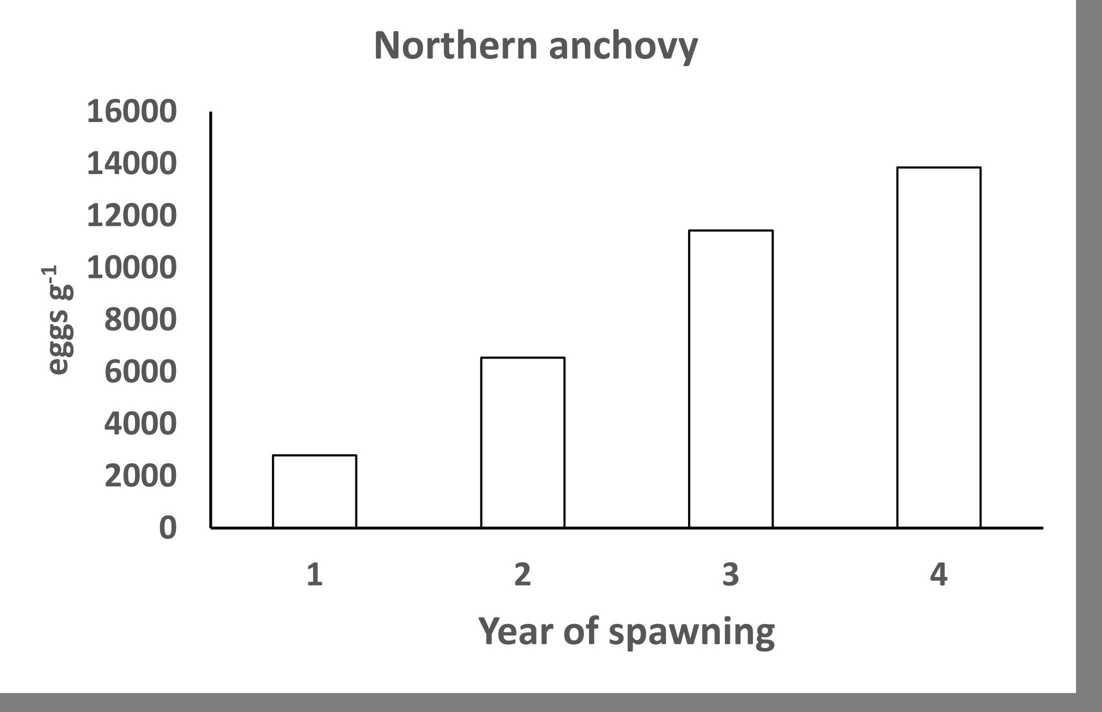


Claramunt et al. 2007. Fish Res

Age/size effects
Annual fecundity

The few existing estimates of annual fecundity in anchovies and sardines indicate **a strong size-/age- dependency of AF**

Parrish et al. 1986. Fish Bull



Size-selective fishing by its effect on population size structure may affect the **timing of spawning**

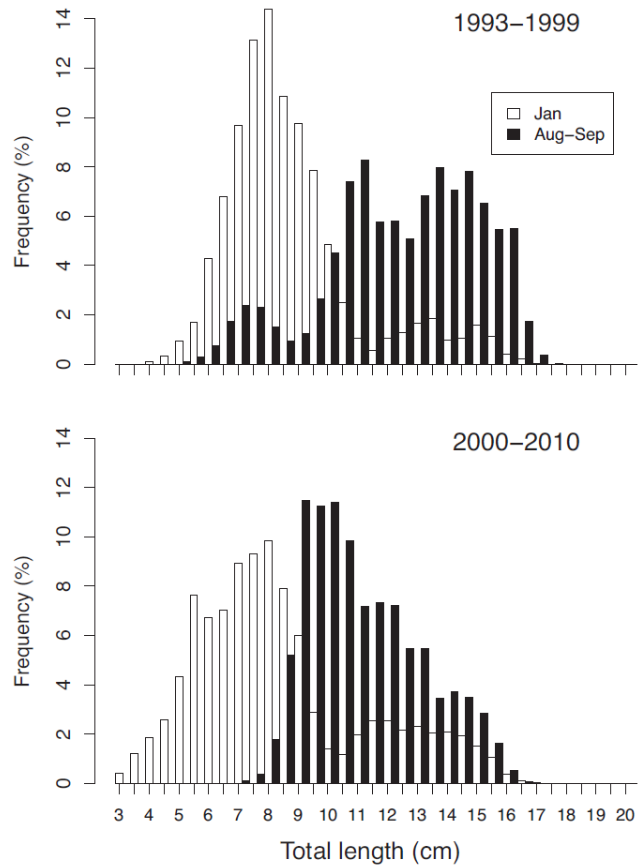
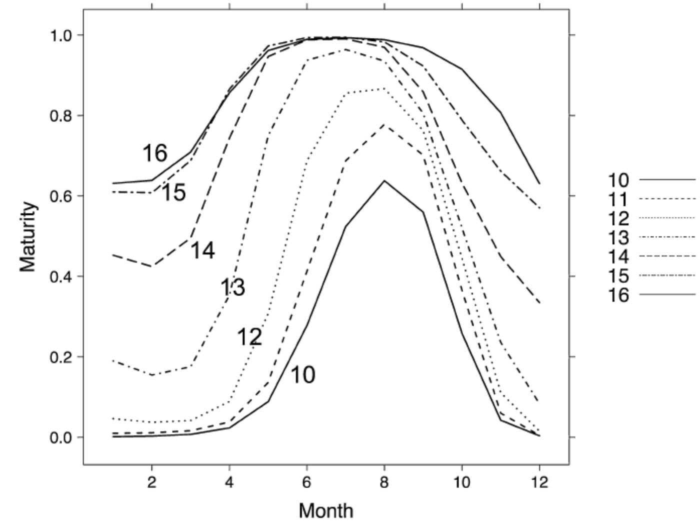


Fig. 6. Observed catch-at-length composition of common sardine in January and August–September during the periods 1993–1999 and 2000–2010 in central southern Chile.

Cubillos et al. 2014. Fish Res



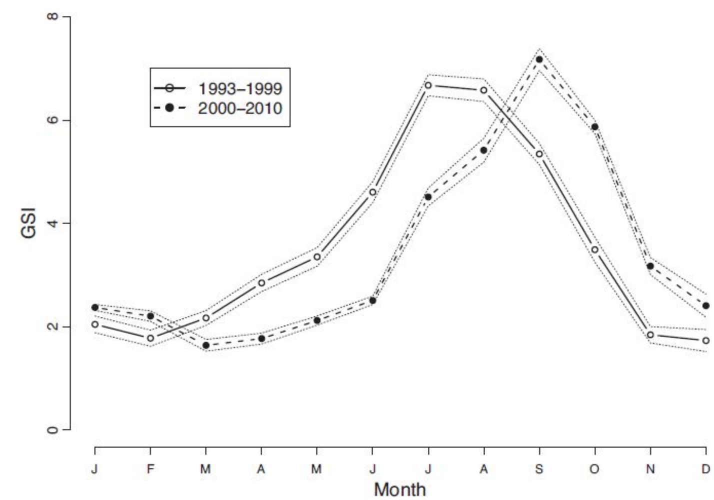
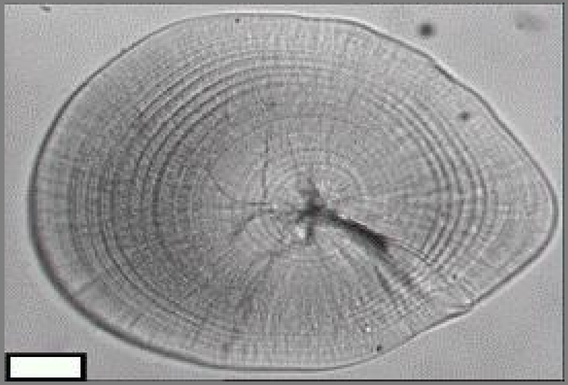
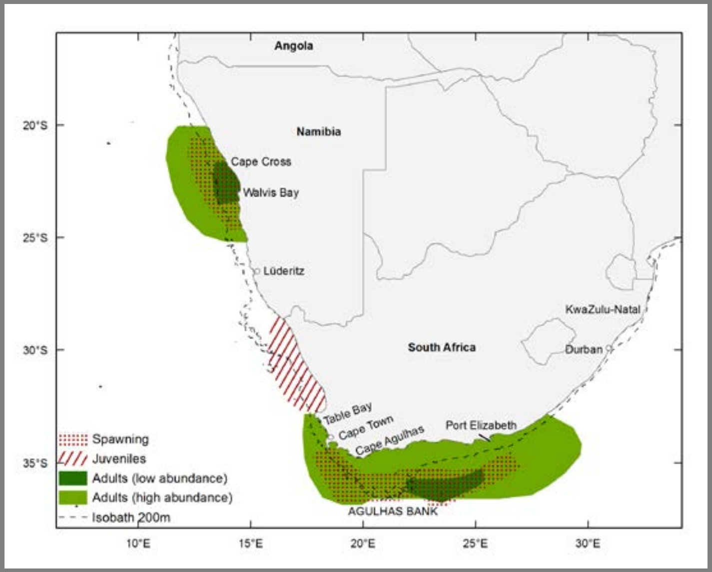


Fig. 7. Observed seasonal changes in the gonadosomatic index of common sardine during the periods 1993–1999 and 2000–2010 in central southern Chile. Confidence limits at 95% are drawing around each seasonal pattern.

Selection for fast growing juveniles or fish produced at the begging of the spawning period



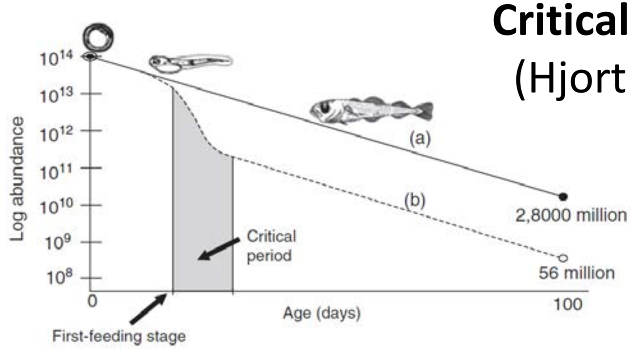


Mostly focused on the survival during the larval stages

3. RECRUITMENT HYPOTHESES

Recruitment hypotheses

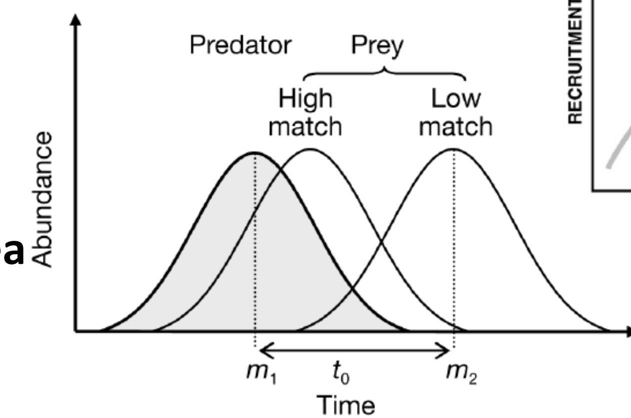
Critical period
(Hjort 1914)

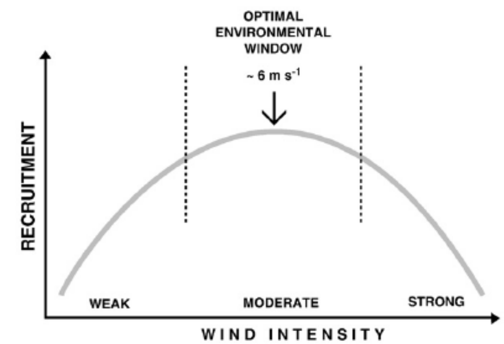


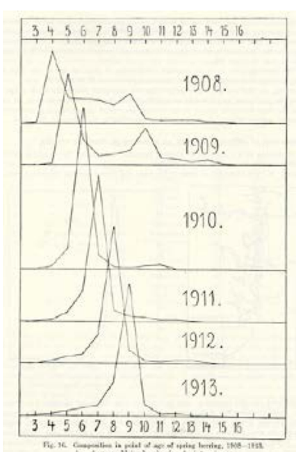
Stable Ocean
(Lasker 1975)

Abberant drift
(Hjort 1914)

Member-vagrant or Larval retention area
(Iles & Sinclair 1982)







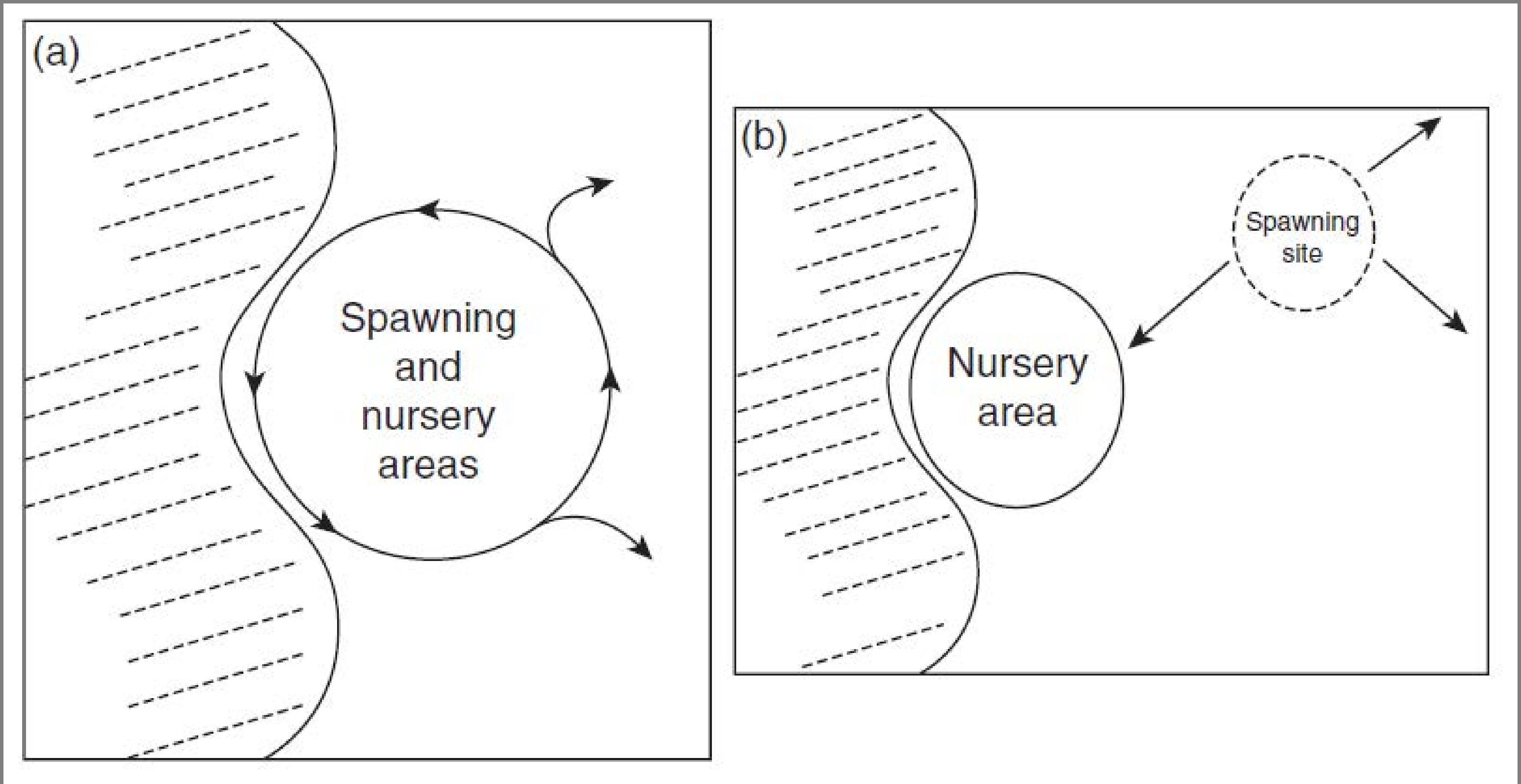
Stage duration
(Houde 1987)

Match-mismatch
(Cushing 1974)

Optimum environmental window
(Cury & Roy 1989)

The coupling of biological and physical mechanisms is the determinant of year class strength

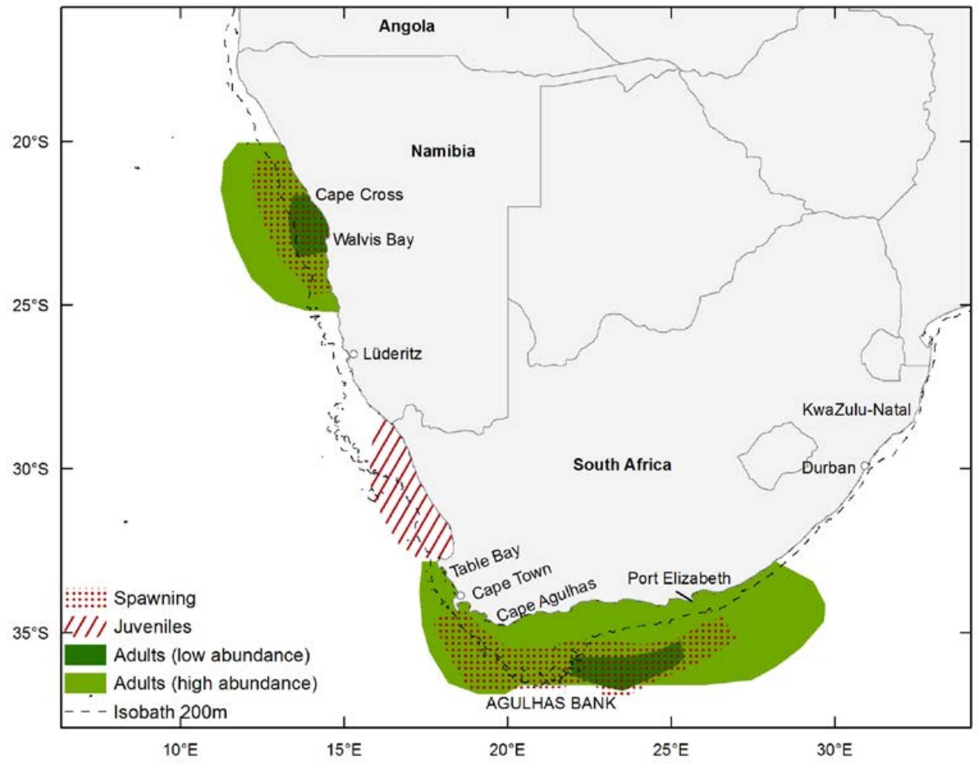
Transport, dispersal & retention processes



Dependent on features such as land enclosure, gyres, shelf break fronts

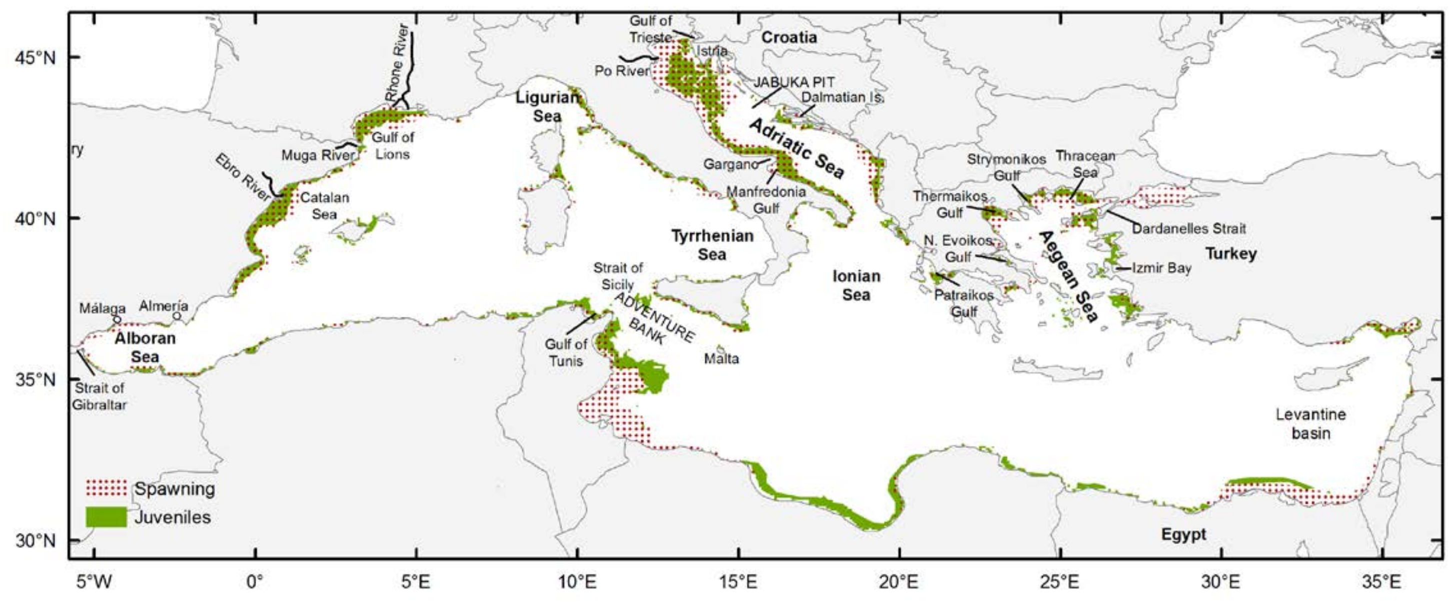
Dependent on specific circulation pathway

(Houde 2009)



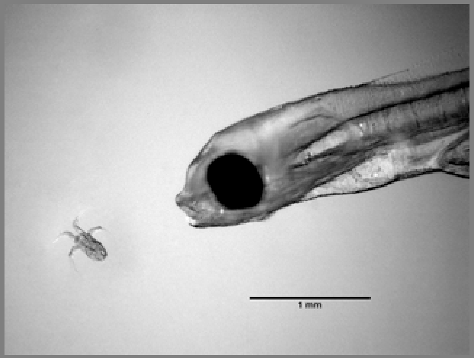
Engraulis encrasicolus

drawn in Giannoulaki et al. 2014

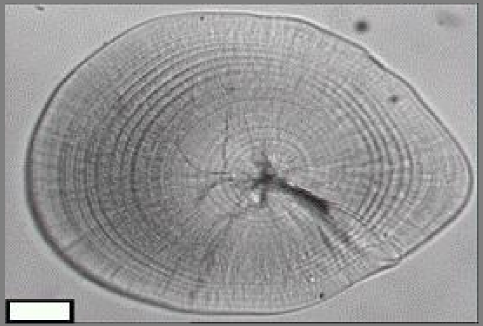


Prey – predator (trophodynamic) interactions

Feeding and predation rates …



Stage duration hypothesis



Good feeding conditions

↓

Fast growth

↓

Low cumulative mortality

↓

High recruitment

The growth/survival paradigm

Faster growing larvae are more likely to survive

The “growth–survival” paradigm has been given much attention in studies on recruitment dynamics of fish

Stage duration

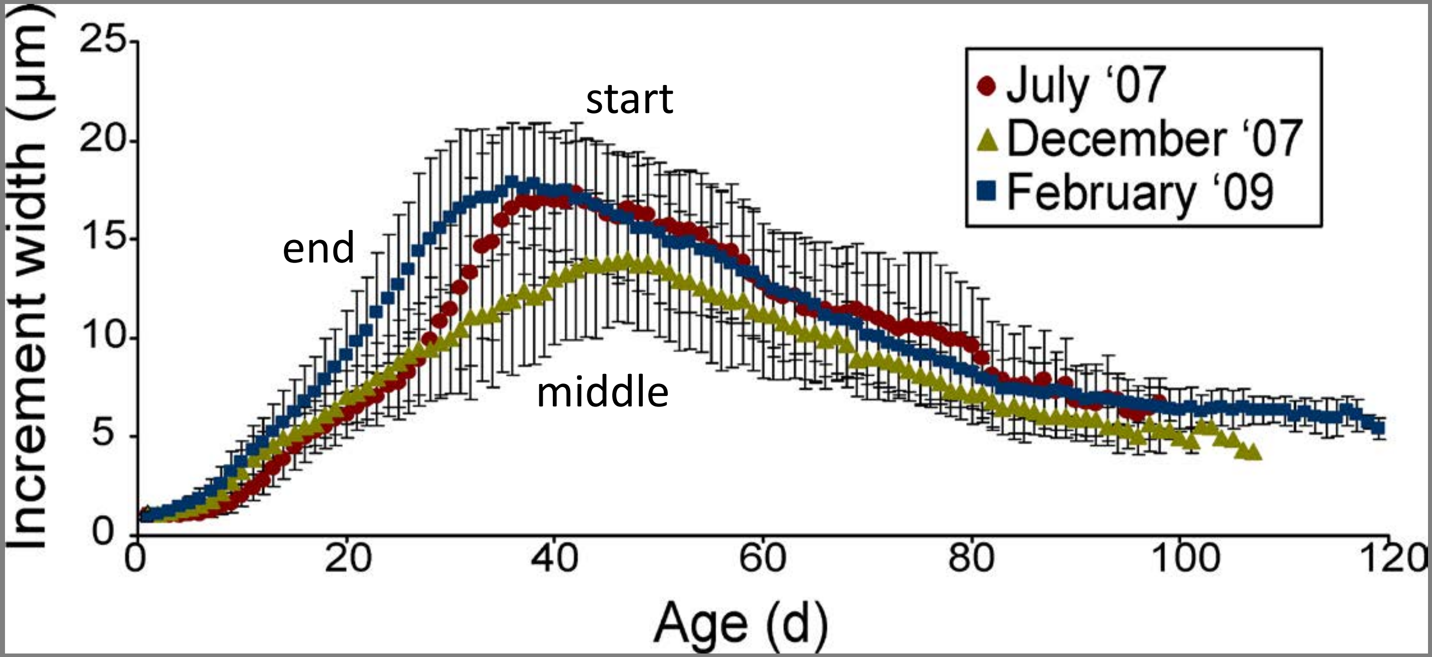
Bigger is better

Faster is better

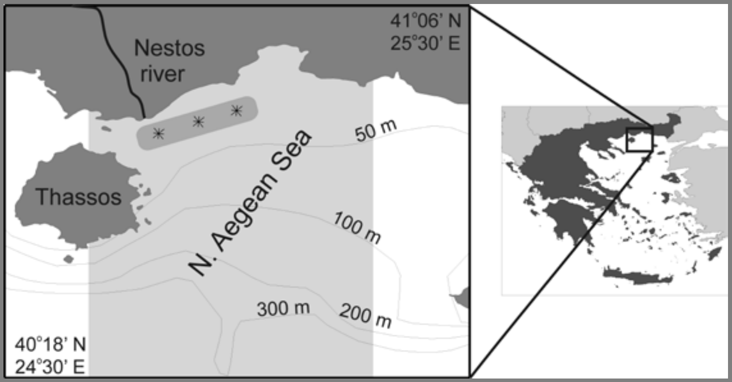
Implications of the bigger and faster hypotheses:

- Mortality rates are inversely related to size
- Smaller and/or slower-growing larvae are more susceptible to predation than larger or faster growing larvae

The growth/survival paradigm

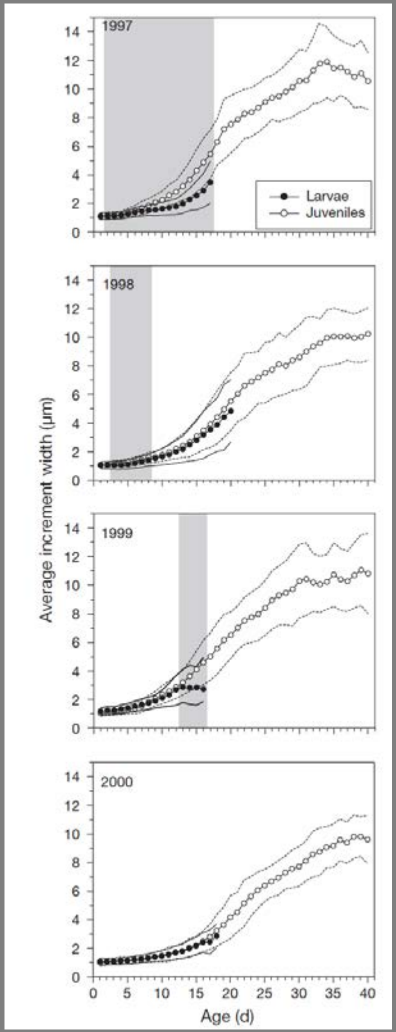


Schismenou et al. 2014. MEPS



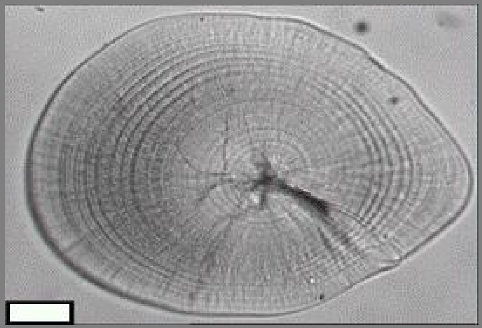
The growth/survival paradigm

Bigger and faster selection



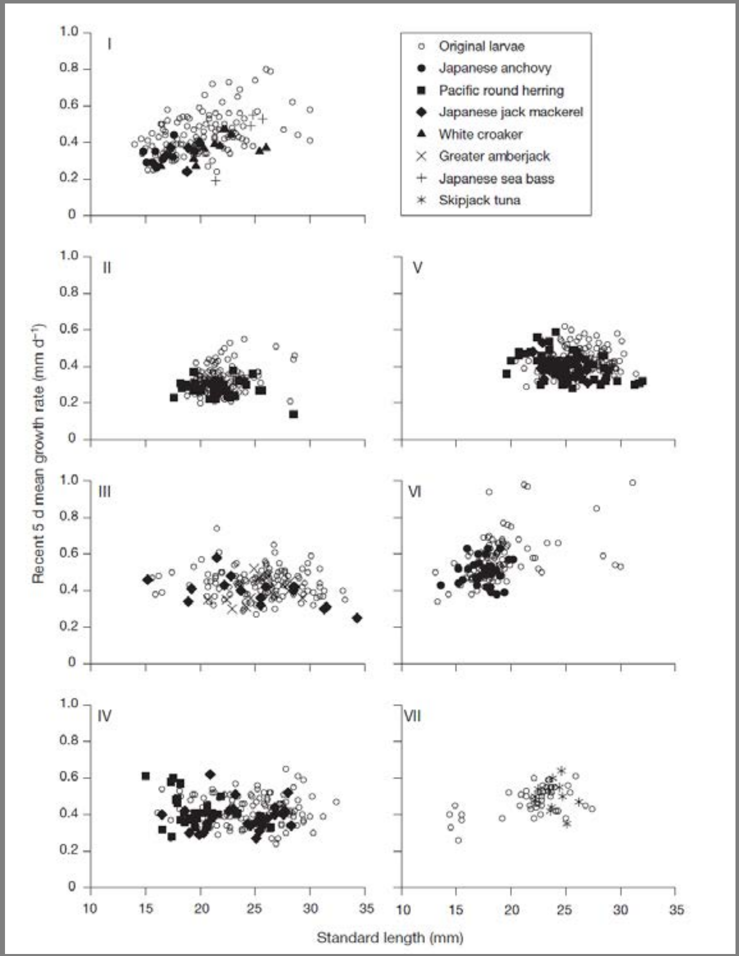
Robert et al. 2007

Bigger is better



Faster is better

comparisons between original populations with survivors

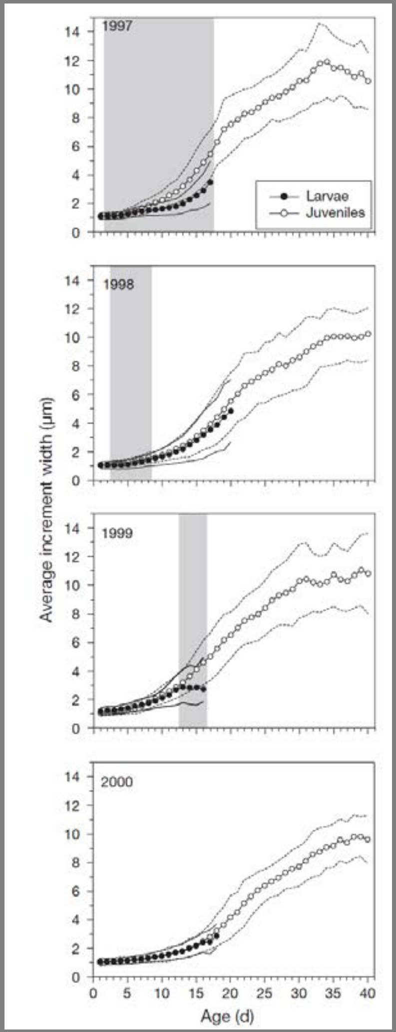


Takasuka et al. 2007

between original populations
and larvae from predators stomachs

The growth/survival paradigm

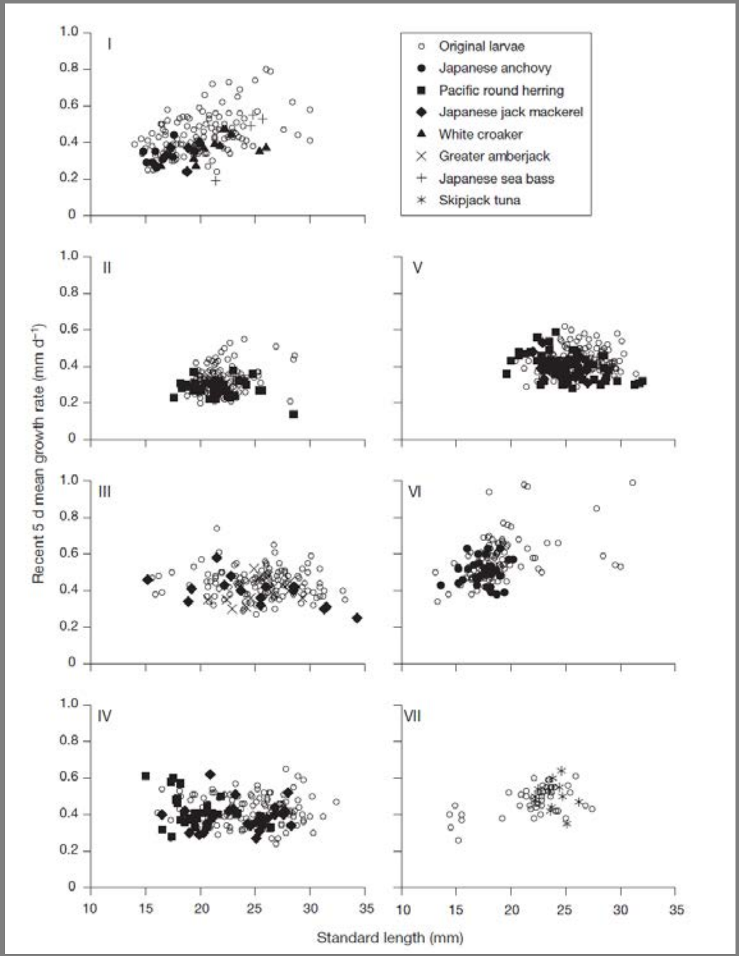
Bigger and faster selection



Robert et al. 2007

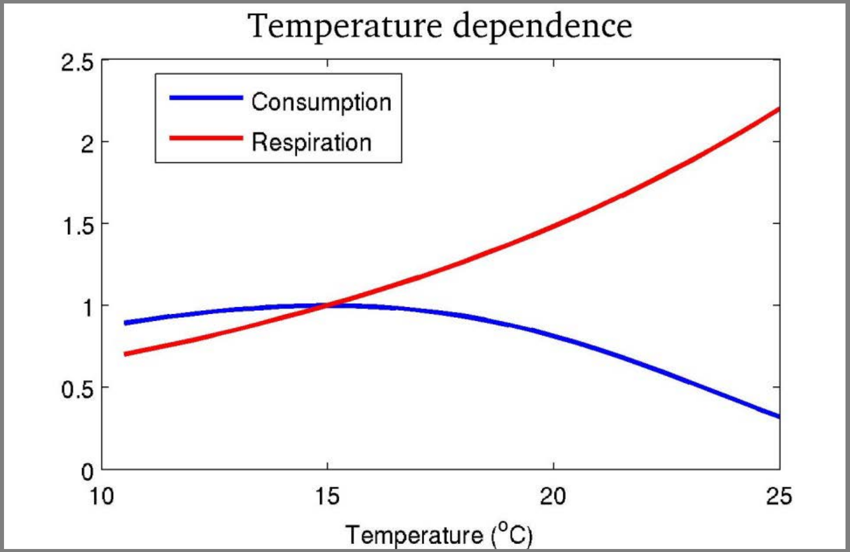
- **Contradictory evidence** from field, laboratory, and modeling studies across systems and taxa

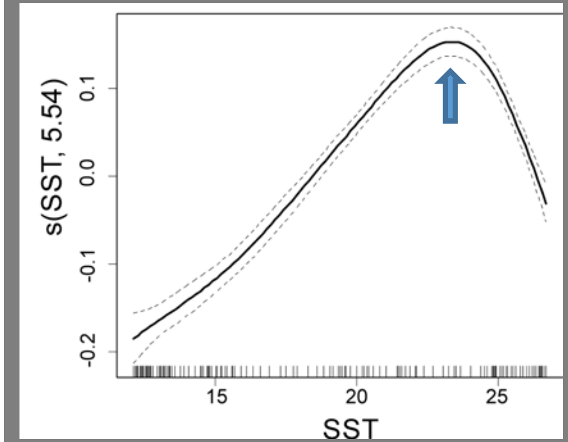
- The size-or growth-selectivity may occur in brief periods or particular stages/years whereas it depends on the size and taxon of predators



Takasuka et al. 2007

MORE discussions in WORKSHOP 4 …





Can control prey availability (levels and timing of planktonic production)

4. TEMPERATURE EFFECTS

Temperature effects

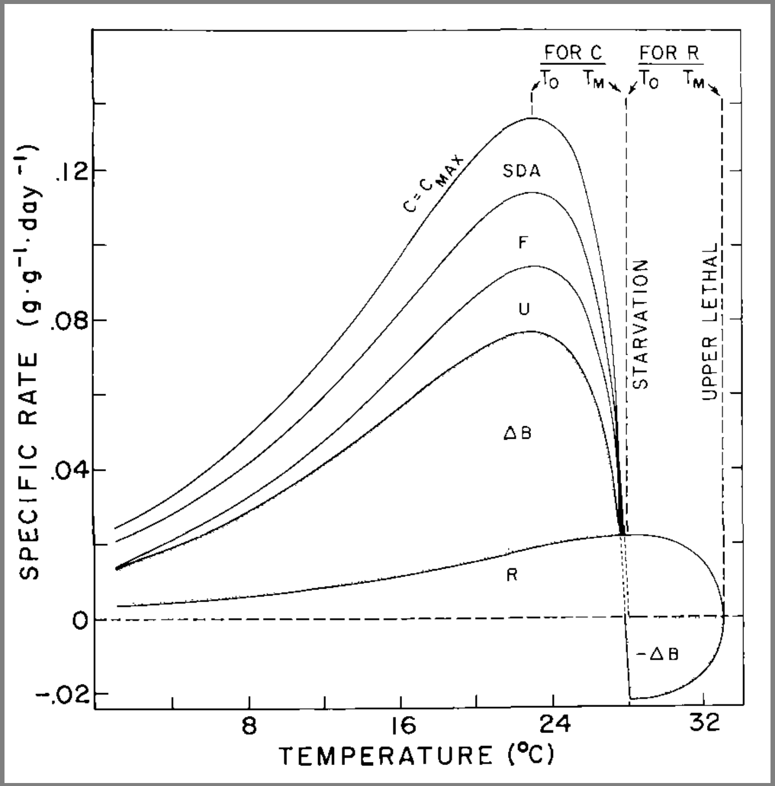
Temperature and component rates of the energy budget

Wisconsin-type bioenergetics model

Consumption $C_{max} = a \times W^{b} \times f(T)$

Swimming speed (levels of activity) $U = a \times W^{b} \times e^{cT}$

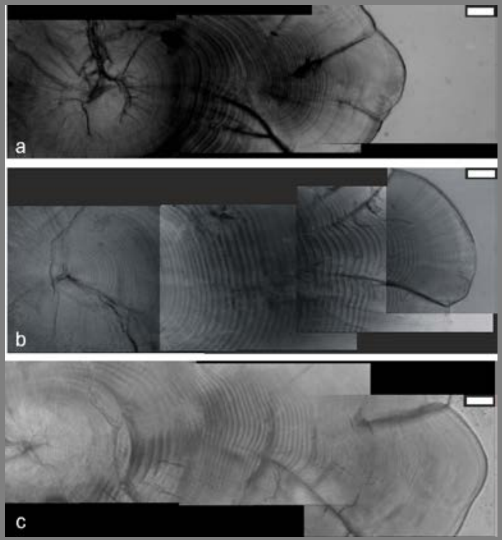
Respiration rate (metabolism) $R = a \times W^{b} \times f(T) \times A$

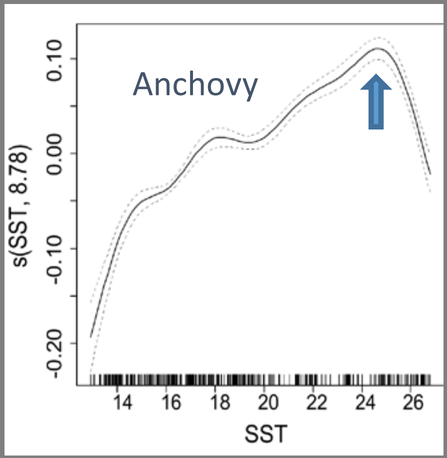


Kitchell et al. 1977

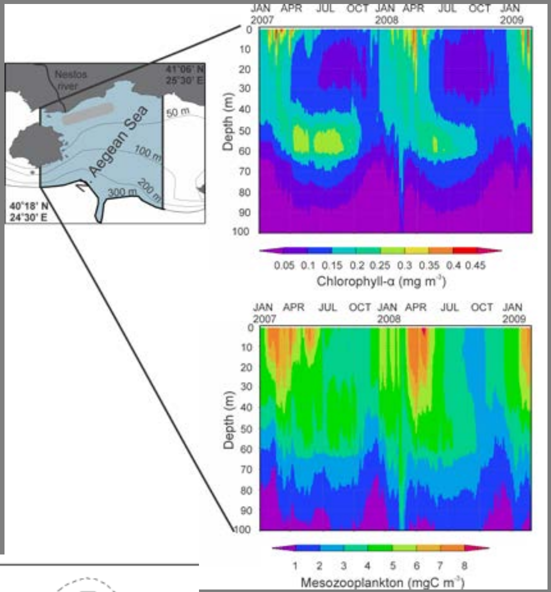
Temperature effects

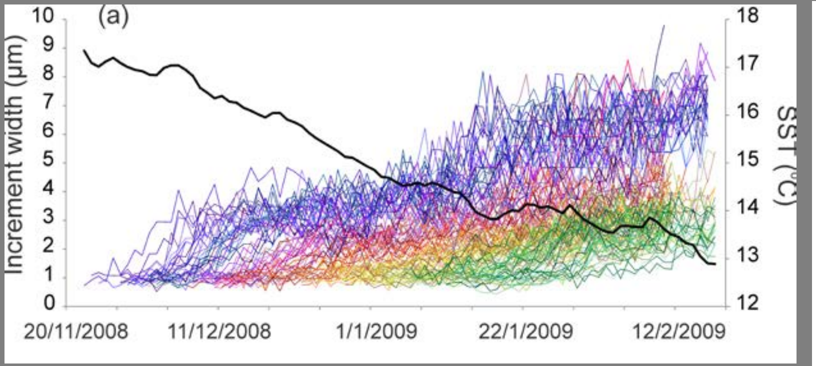
Temperature effect on growth

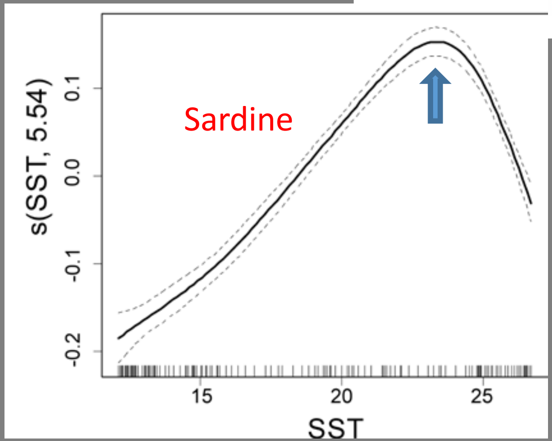




POM-ERSEM







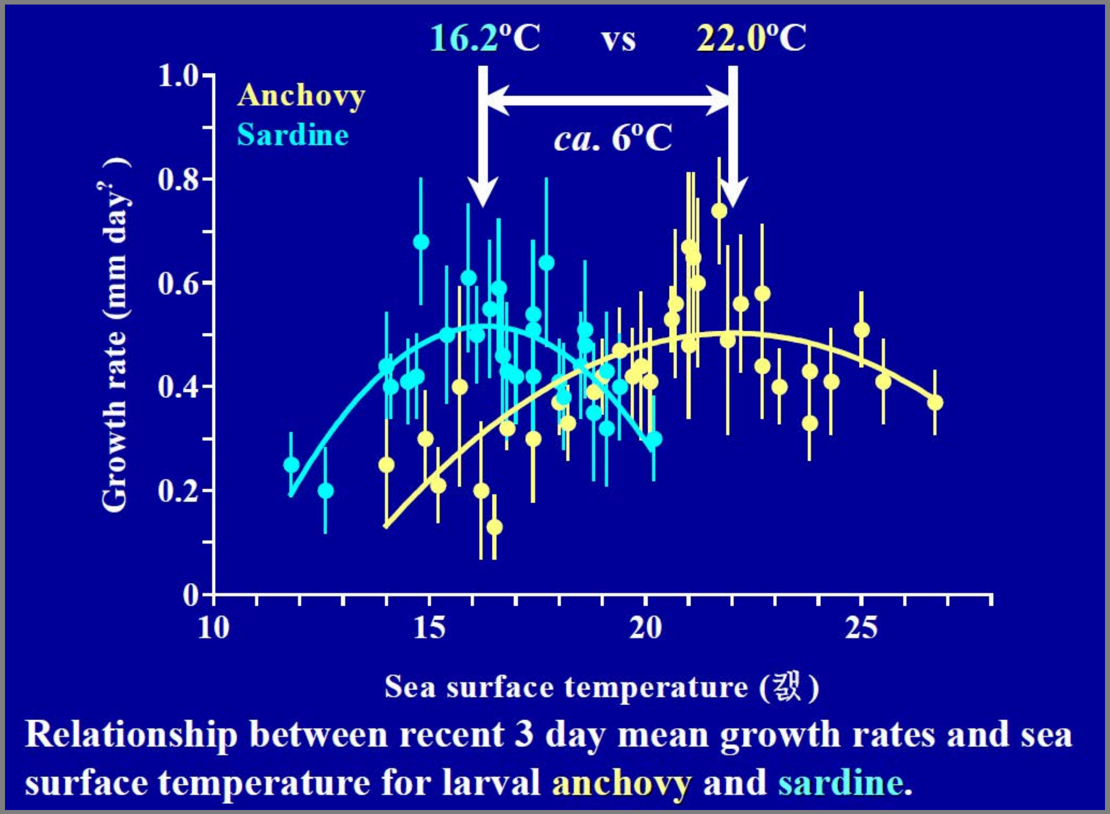
Uncoupling of O-S

- Temperature effects
- Ontogenetic effects
- Growth rate effects

Schismenou et al. 2014, 2016

Temperature effects

Temperature effect on growth

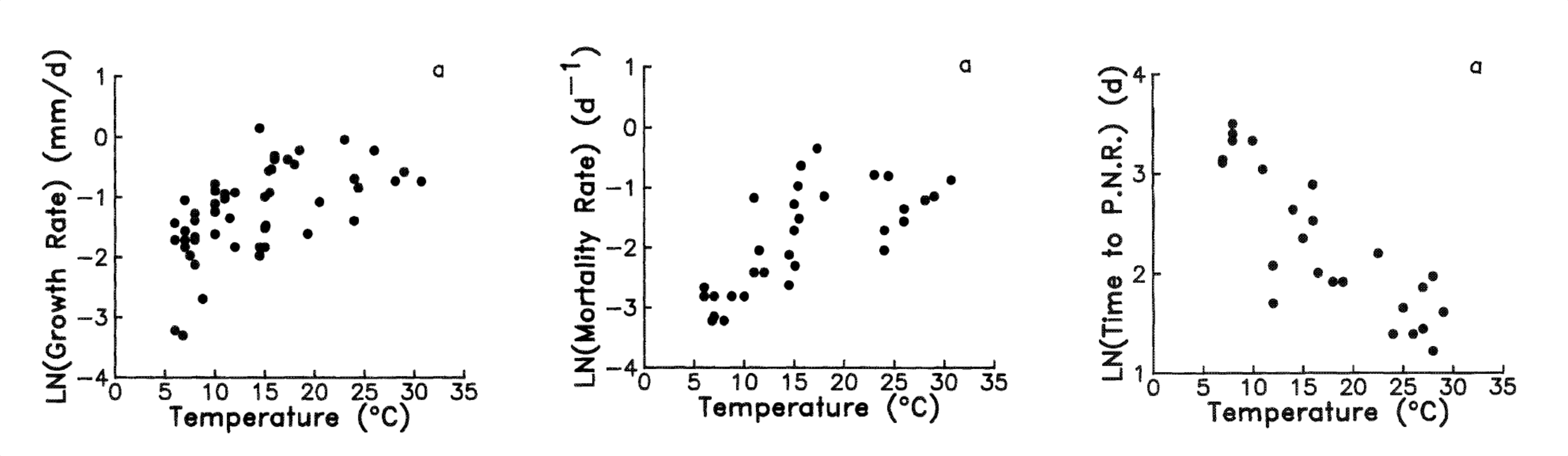


drawn by
Akinori Takasuka

Optimal growth temperature hypothesis (Takasuka et al. 2007)

Temperature effects

Temperature effects on growth, mortality, PNR

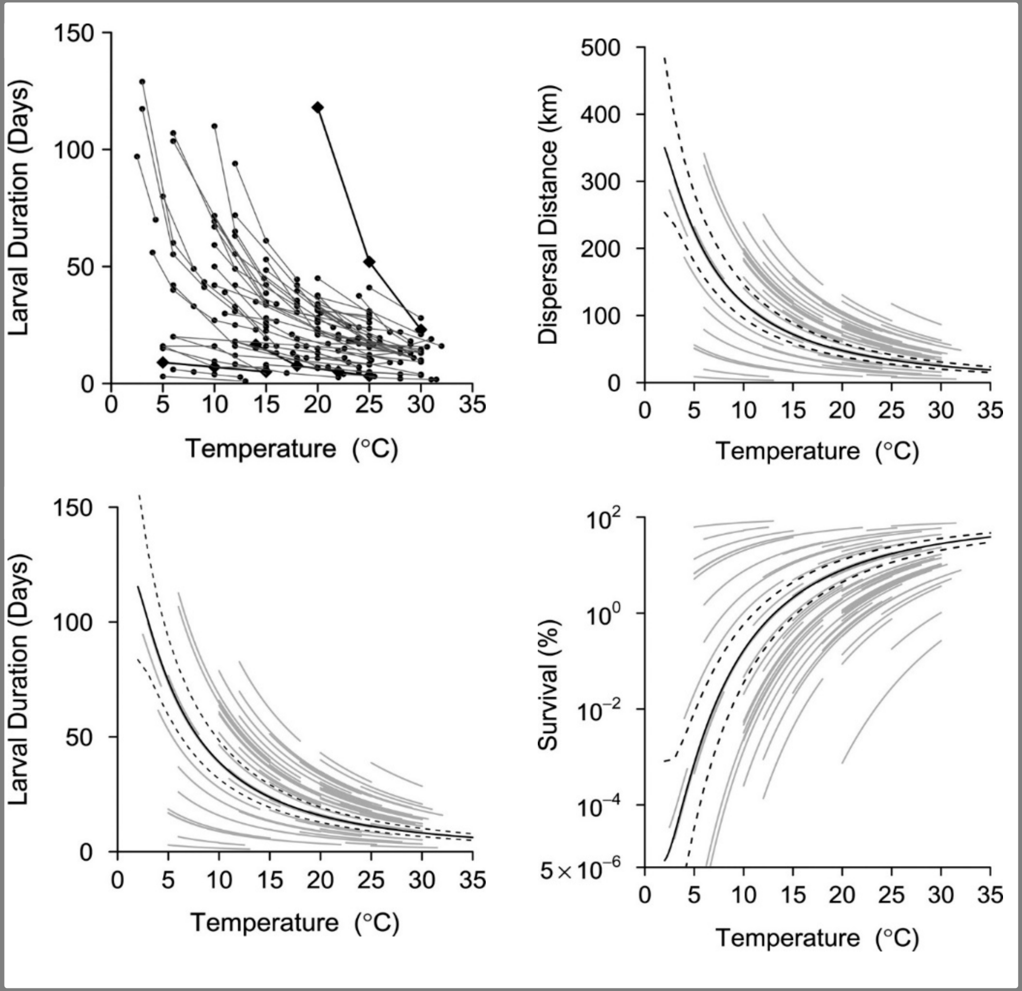


Pepin 1991

<u>PNR (point-of-no-return)</u>:
the time required for a first feeding larva to feed exogenously before irreversible starvation

Temperature effects

Temperature effect on stage durations



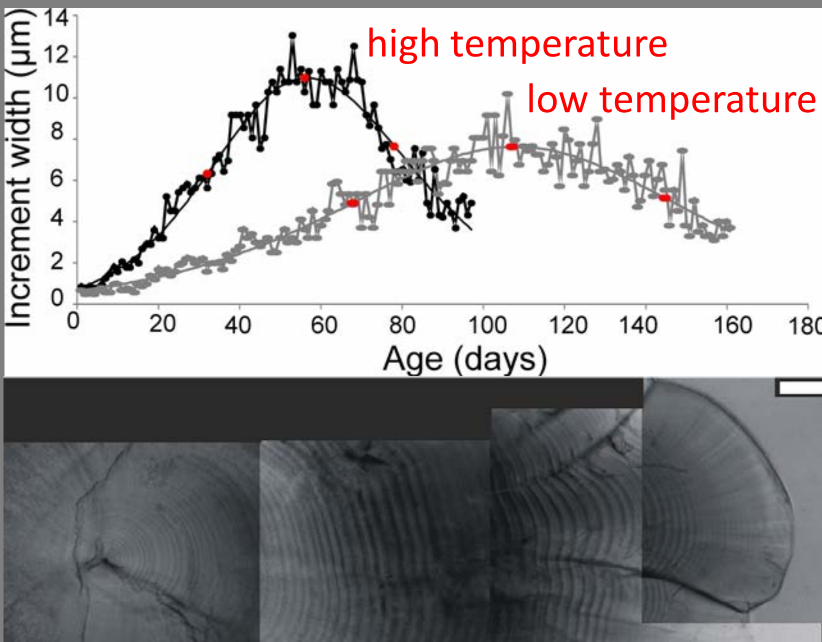
O'Connor et al. 2007 PNAS

Temperature effects	Boreal ecosystems (herrings)	Upwelling & mixed (winter) water columns	Thermally stratified (summer) waters
Rate of vitellogenesis	Very slow	Moderate	Fast
Frequency of spawning	Once	Low	High
Egg & larval size	Large	Small	Smaller
Planktonic durations	Long	Short	Short
Maintenance costs	Low	High	Very high
Time to PNR	Long	Short	Very short
Larval growth & mortality	Low	High	High
Ontogenetic & behavioral development	Slow, gradual	Fast	Fast, saltatory

Temperature effects

Temperature effect on ontogeny: Size & abruptness of transitions

Ontogenetic change in otolith growth



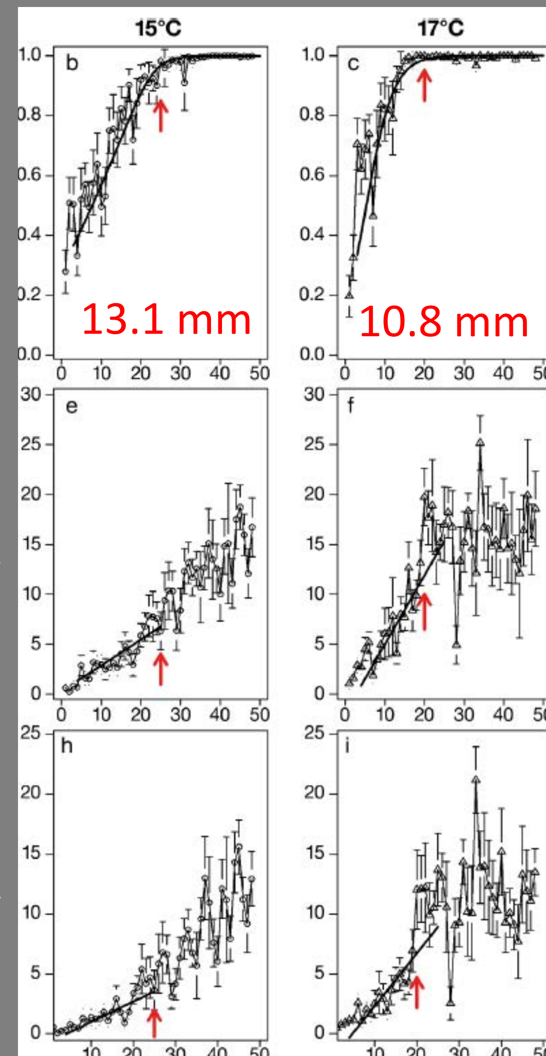
Schismenou et al. 2016

Competion of notochord flexion

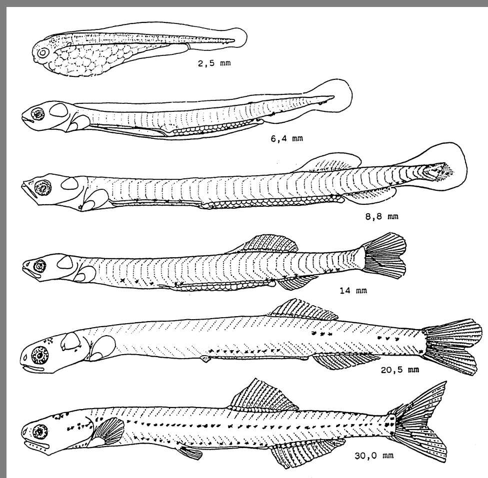
Time swimming (%)

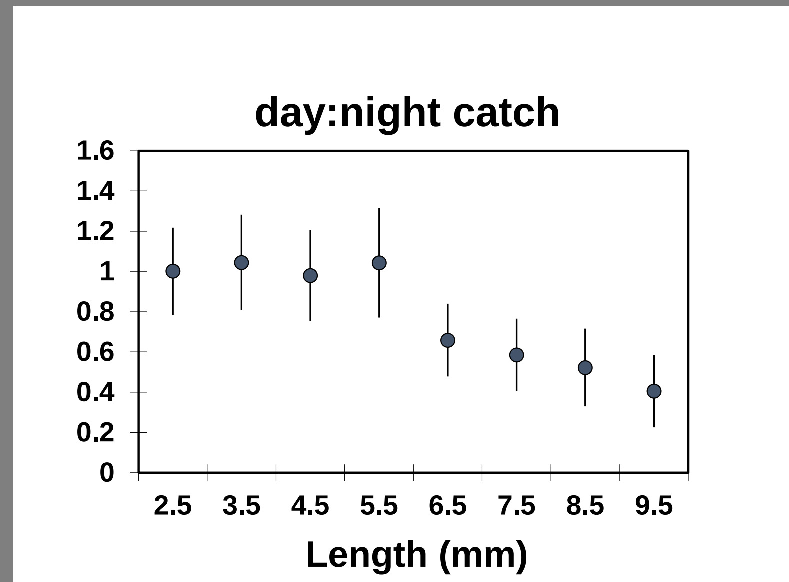
Fixations min^{-1}

Attacks min^{-1}



Garrido et al. 2016

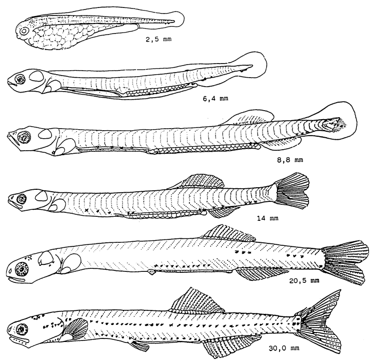


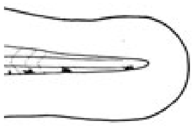


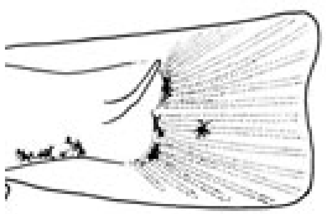
Mortality levels may change at specific developmental milestones

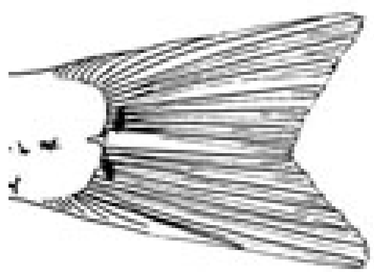
5. ONTOGENETIC THRESHOLDS

Fish Ontogeny









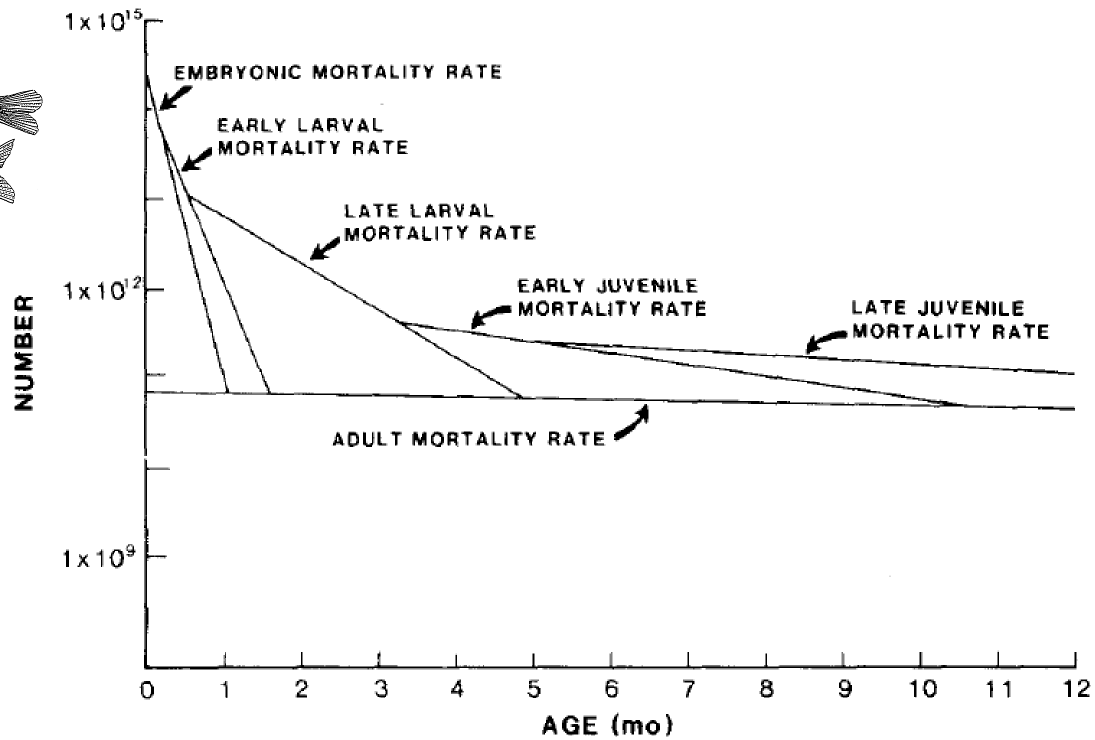
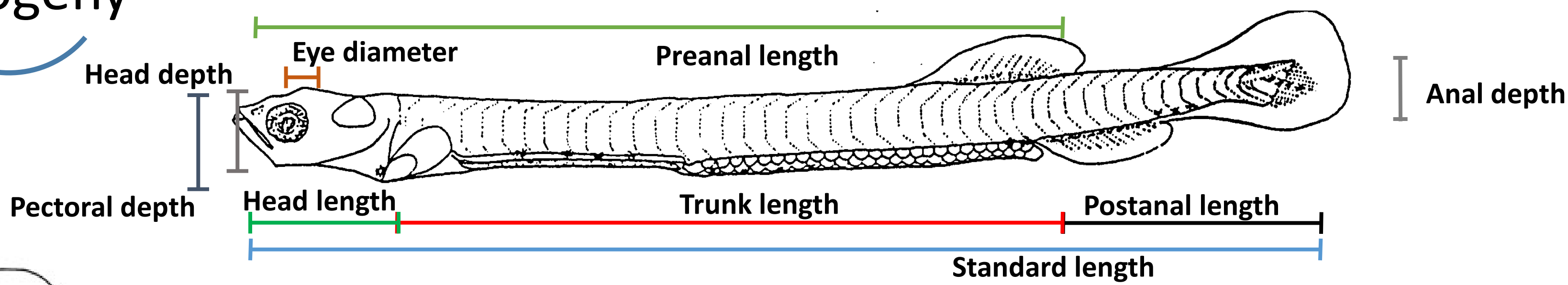


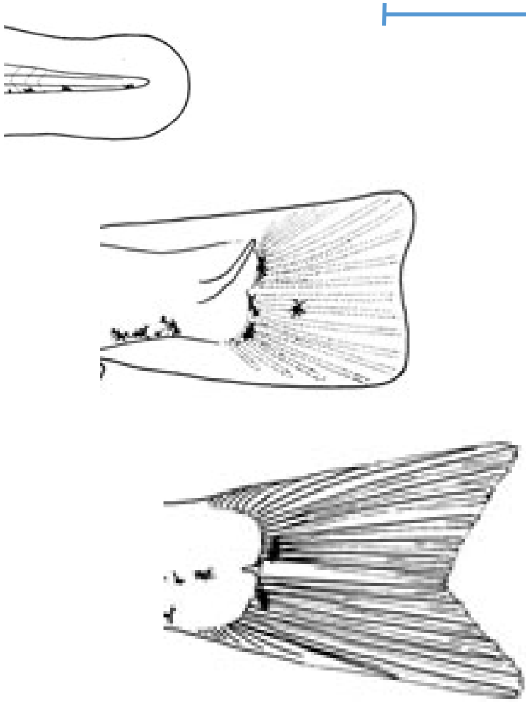
FIG. 4. A diagram of the O-group mortality curves to compare the joint effects of stage duration and stage mortality rate on the resulting adult population of northern anchovy central subpopulation.

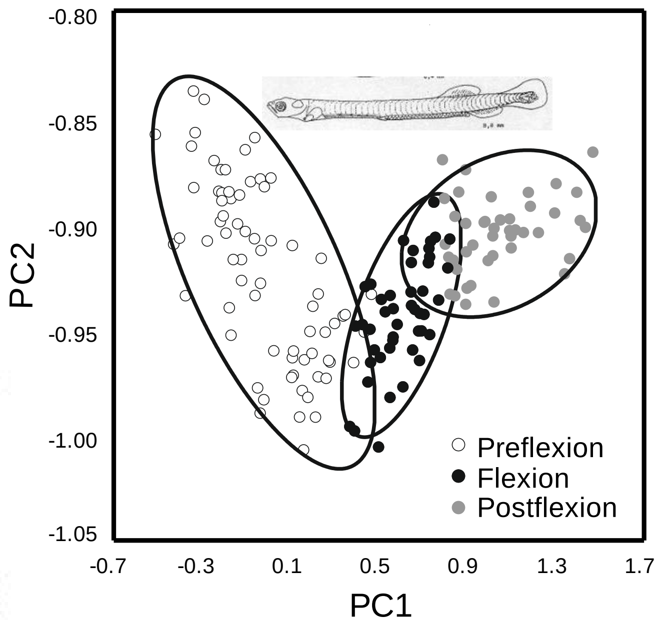
Smith 1985

Notochord flexion - Development of the caudal fin

Fish Ontogeny







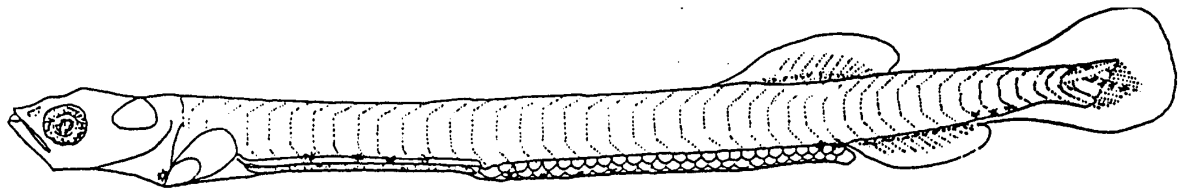
Change in functional morphology

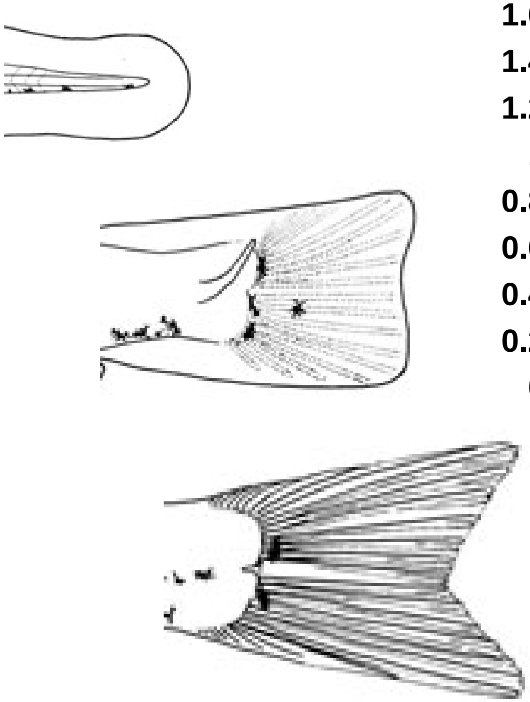
Multivariate allometry

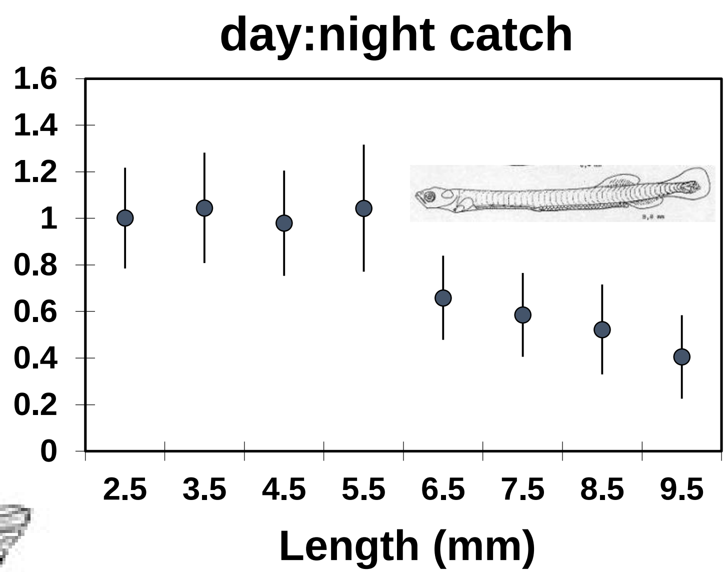
The development of the caudal fin seen as a milestone in fish ontogeny

Somarakis & Nikolioudakis 2010, Journal of Plankton Research

Fish Ontogeny





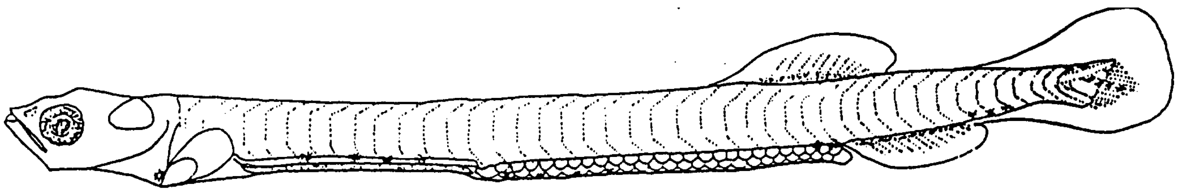


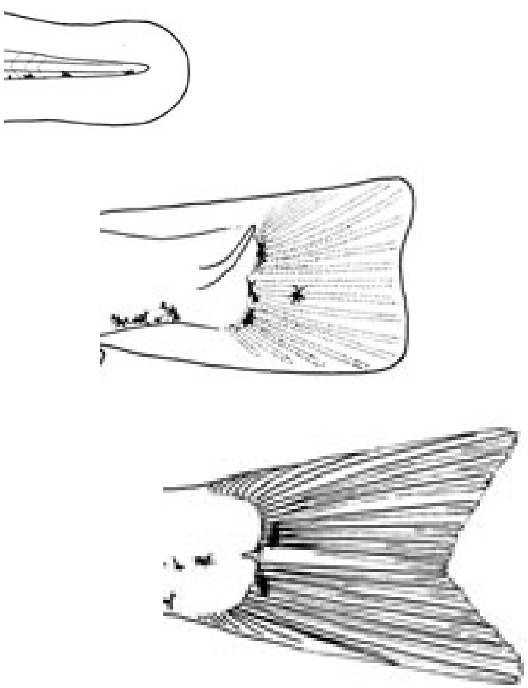
Somarakis et al. 1998. Fish Bull

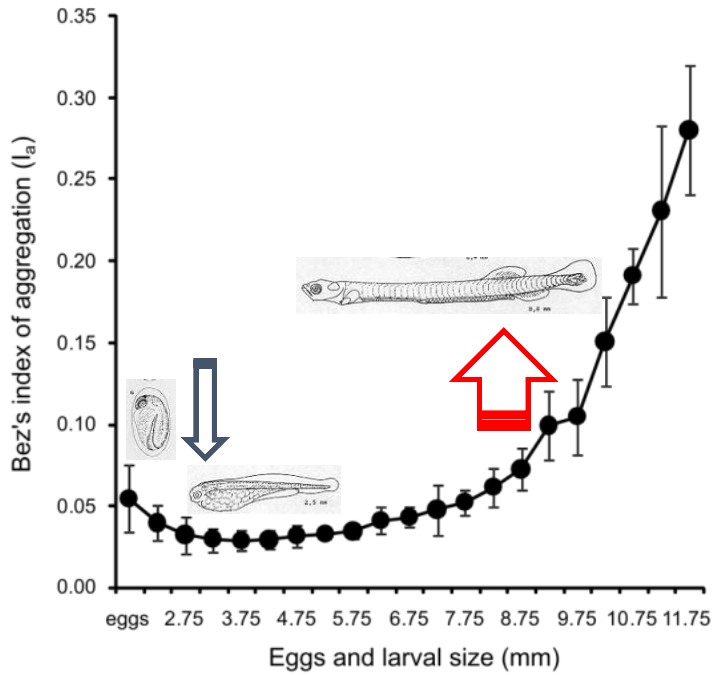
Change in catchability with plankton nets

The development of the caudal fin seen as a milestone in fish ontogeny

Fish Ontogeny





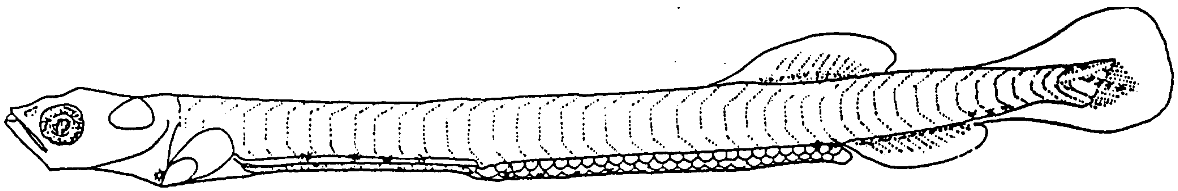


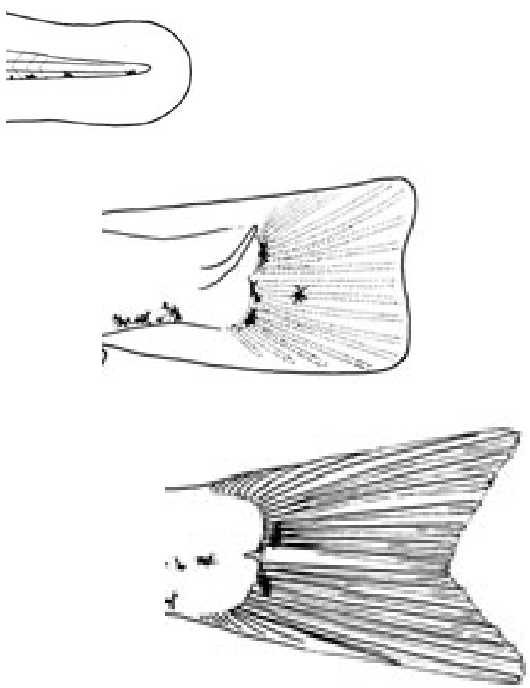
Increase in spatial patchiness

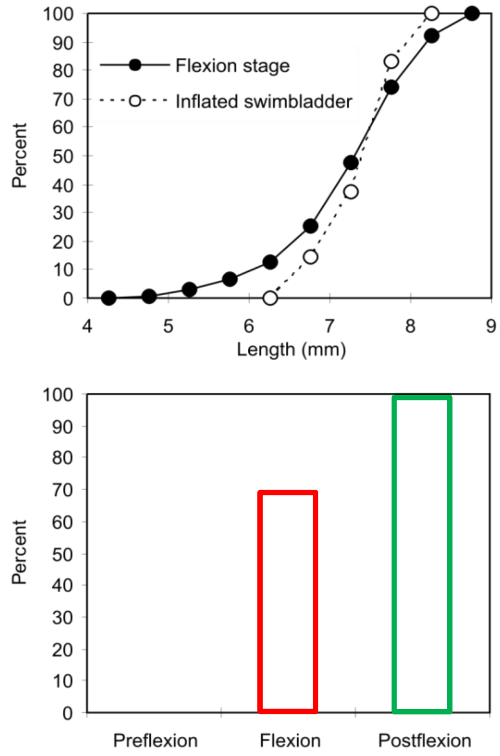
Bez's index of aggregation

The development of the caudal fin seen as a milestone in fish ontogeny

Fish Ontogeny

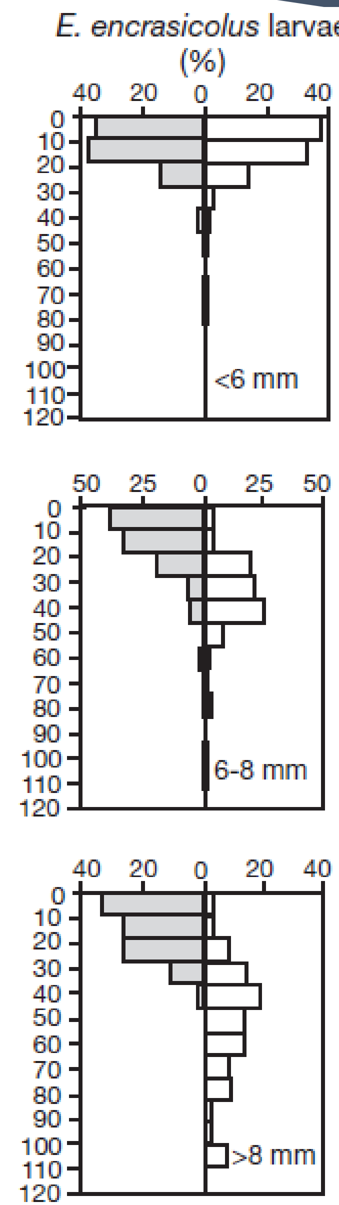






Onset of swim-bladder Inflation & diel vertical migrations

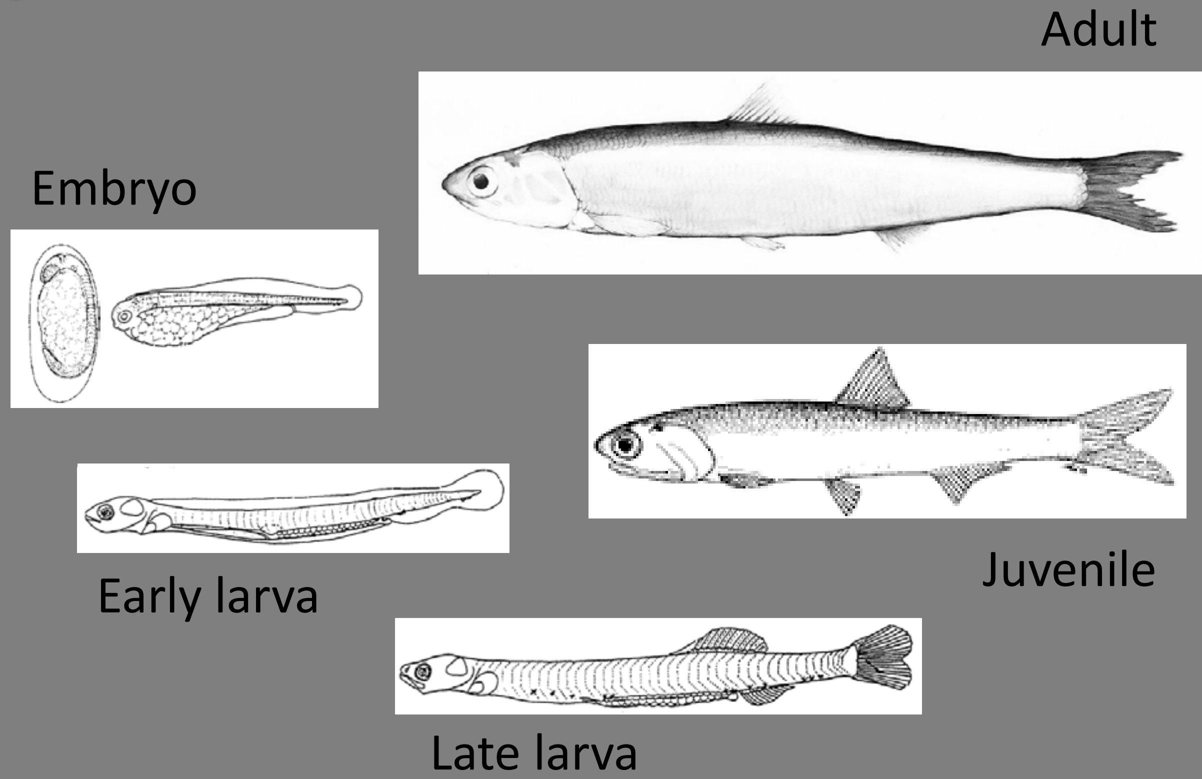
Onset of schooling behavior



Sabatés et al. 2008

The development of the caudal fin seen as a milestone in fish ontogeny

In addition to stage-specific features determining changes in growth and survival levels …



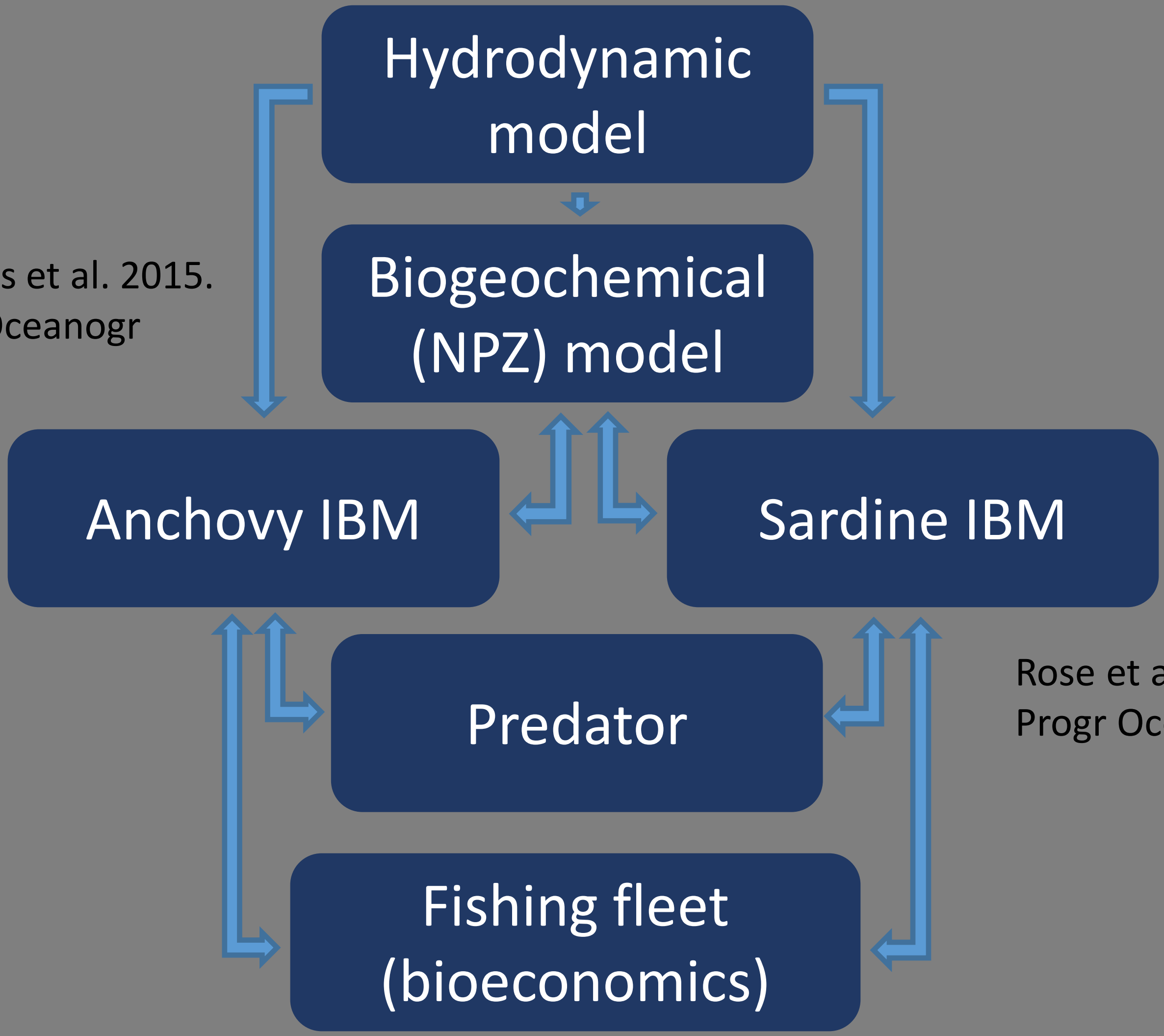
… in order to disentangle the relative contributions of the different factors involved in the recruitment process …

… the FULL LIFE CYCLE has to be adequately considered …

5. FULL LIFE CYCLE IBMs

Full life cycle IBMs

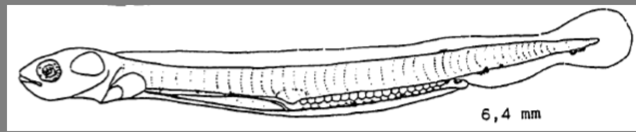
Politikos et al. 2015. Progr Oceanogr

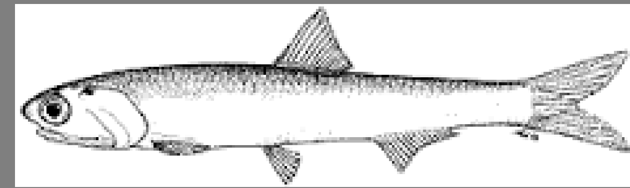


Rose et al. 2015. Progr Oceanogr

Full life cycle IBMs

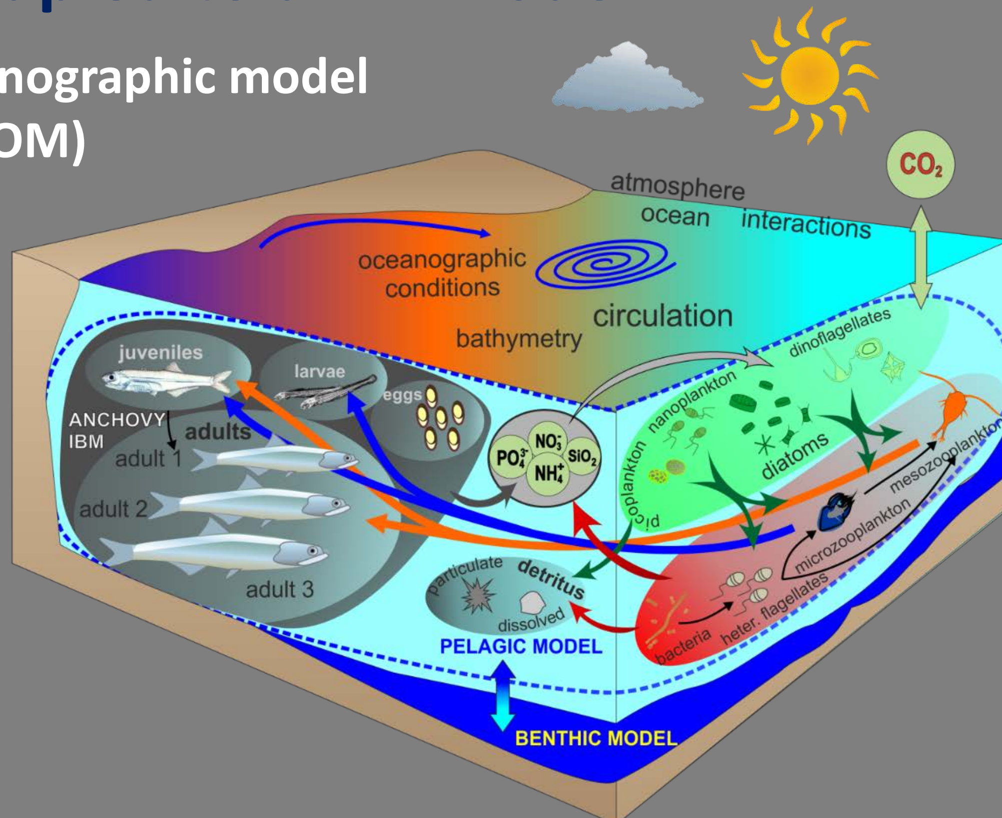
- Allow for straightforward linking of growth, mortality, movement and spawning processes to the detailed spatial and temporal scales of the hydrodynamic/biogeochemical model
- Can be used in multigenerational simulations in order to investigate (forecast) the effects of climate and fishing



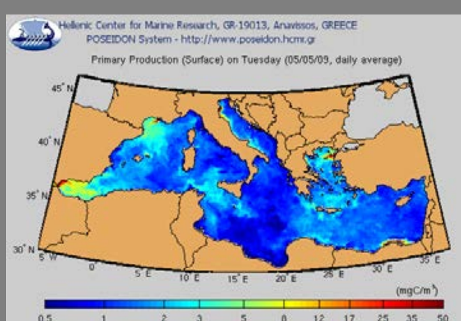


3-D full life cycle model for anchovy in the Aegean Sea coupled to a LTL model

Princeton Oceanographic model (POM)

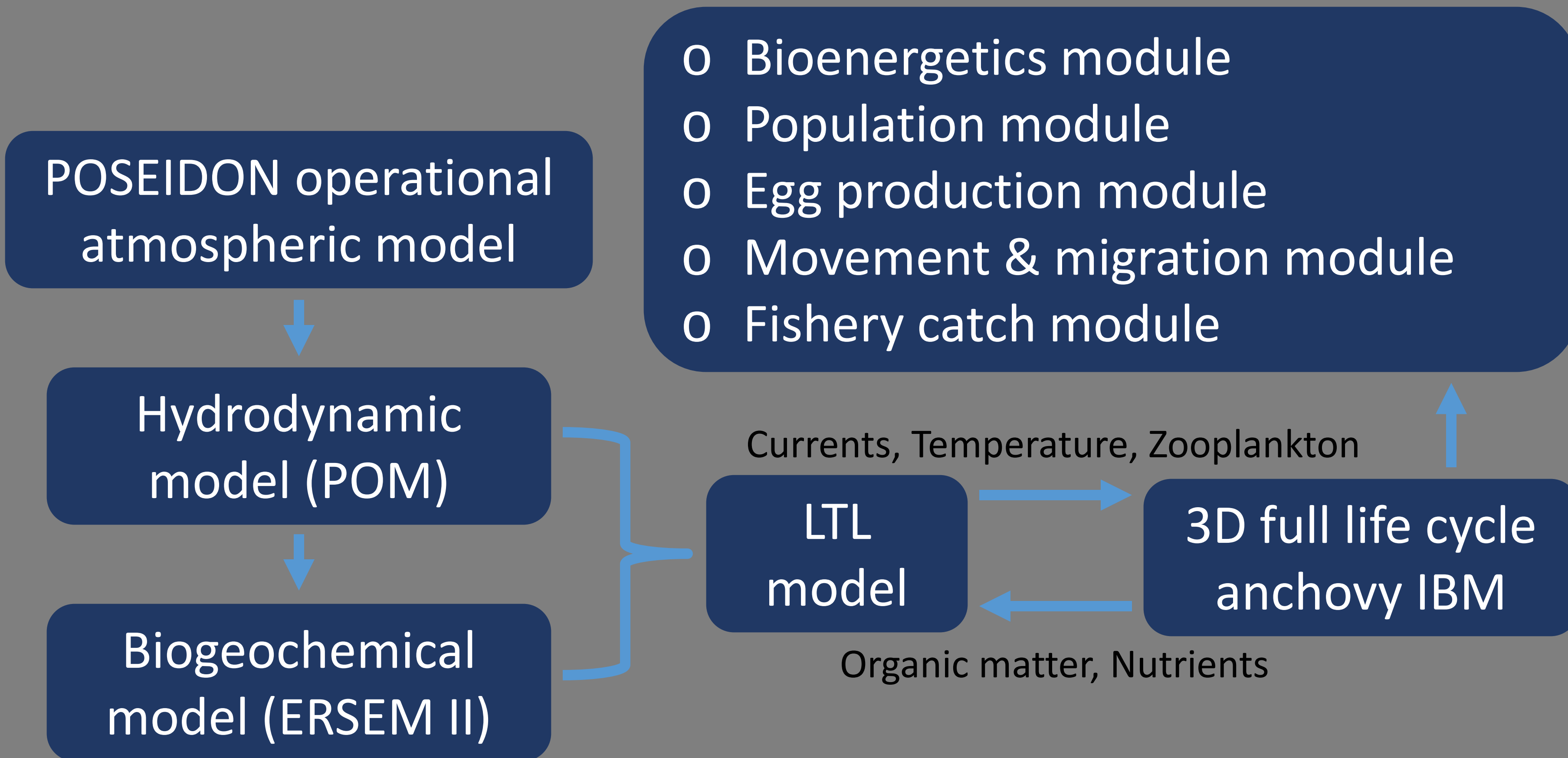


HCMR POSEIDON FORECASTING SYSTEM



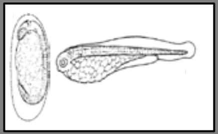
European Regional Seas Ecosystem Model (ERSEM II)

Suite of sub-models



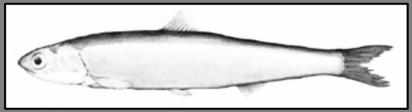
Stage- & age- specific model

Embryos



passive particles

fishing mortality



Adults

age 1, 2 & 3

DVM + horizontal movement

mesozooplankton

Full life cycle IBM

Early larvae

passive particles

microzooplankton

Late larvae

DVM + horizontal movement

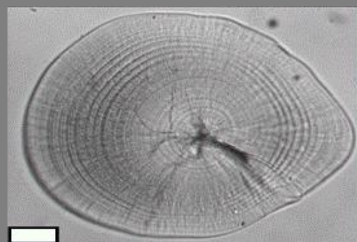
micro- + mesozooplankton

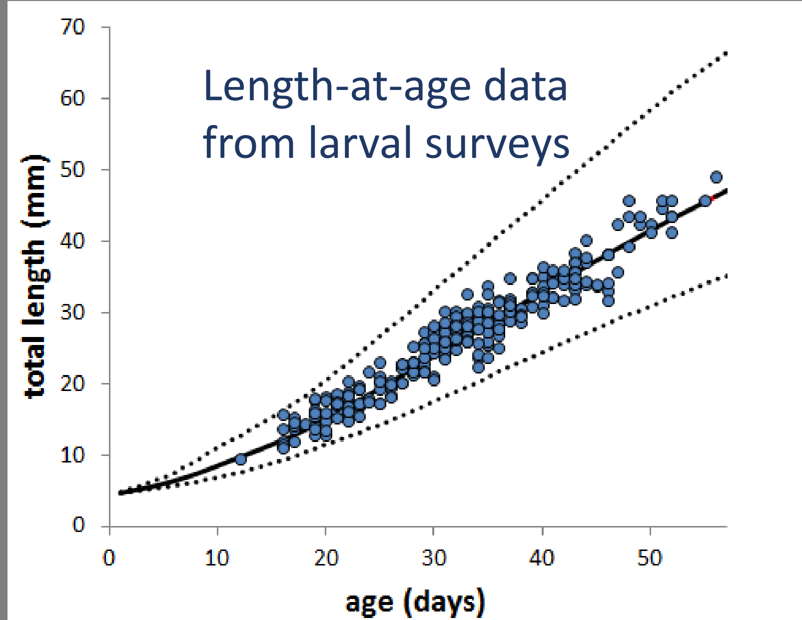
Juveniles

DVM + horizontal movement

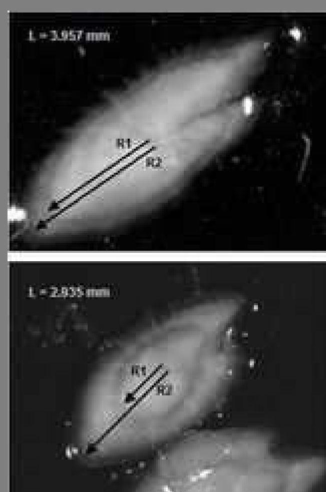
mesozooplankton

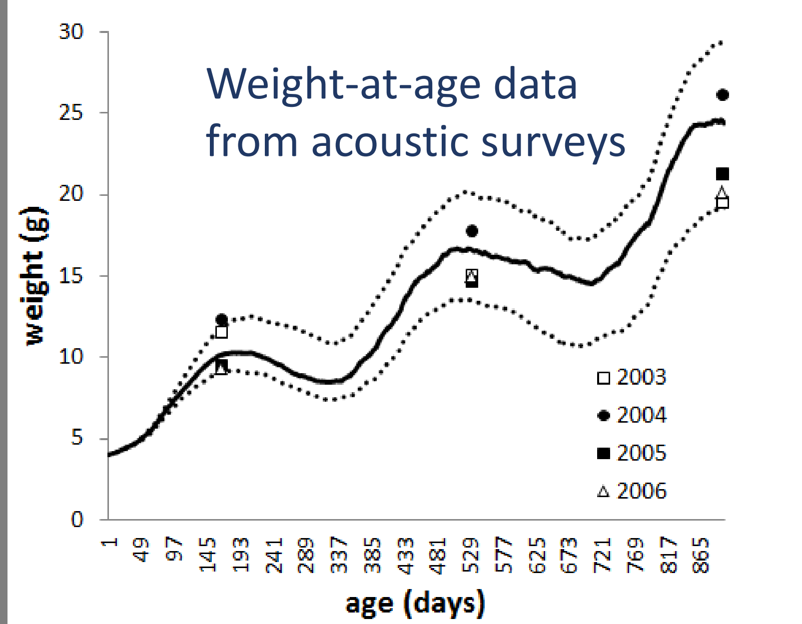
Model skills – Somatic growth





Larvae

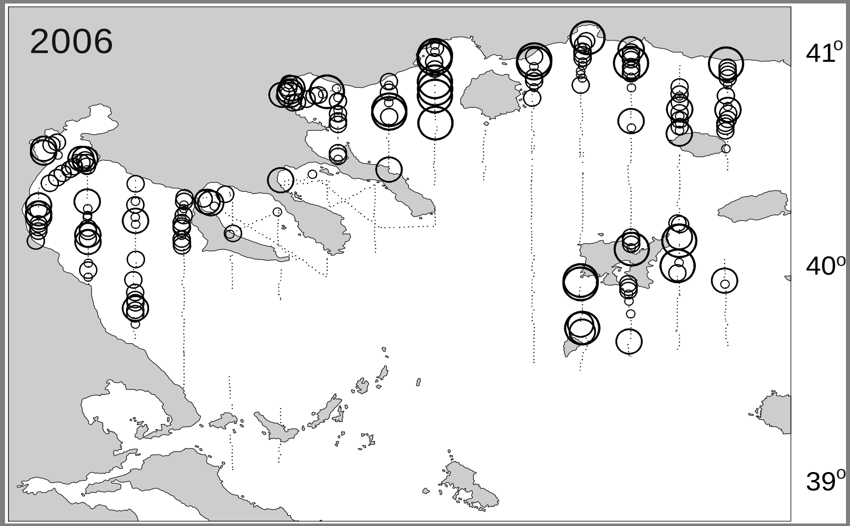


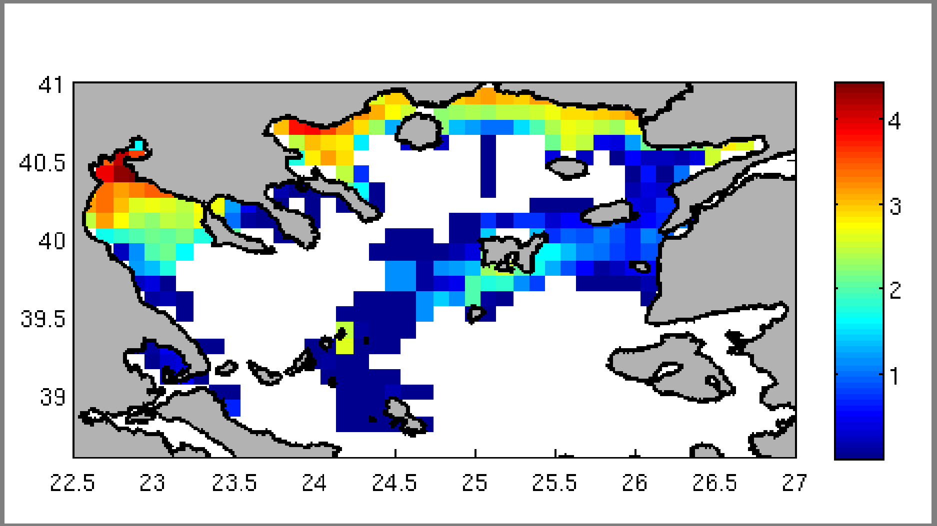


Adults

Model skills – Distribution & abundance

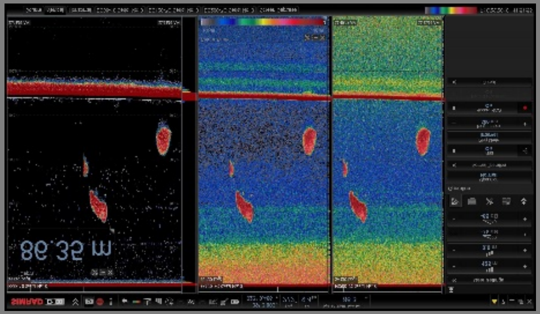
Comparison with distributions from **acoustic** and **egg production surveys** or **habitats from statistical models**

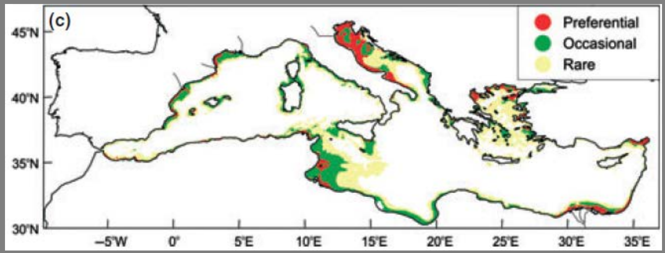




Anchovy biomass from acoustics

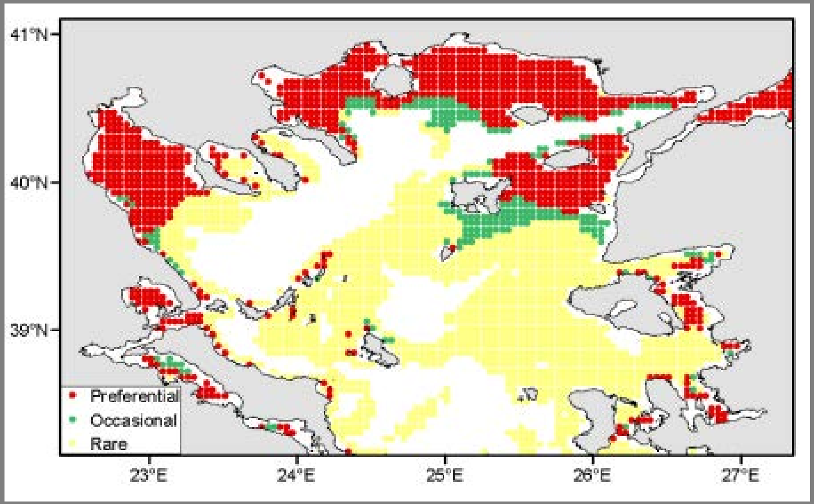
Anchovy biomass from IBM

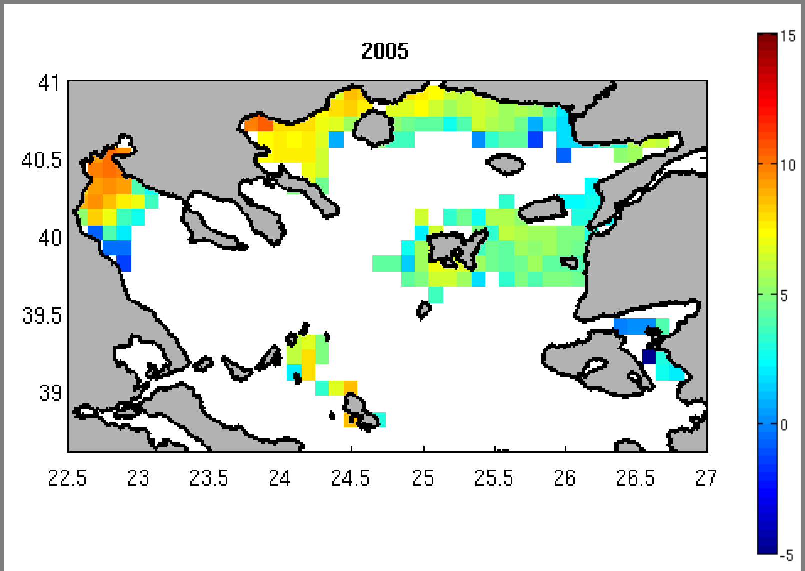




Model skills – Distribution & abundance

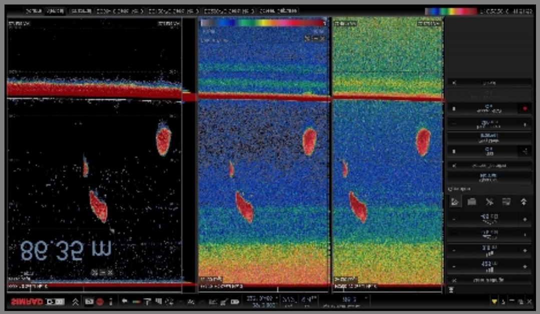
Comparison with distributions from **acoustic** and **egg production surveys** or **habitats from statistical models**

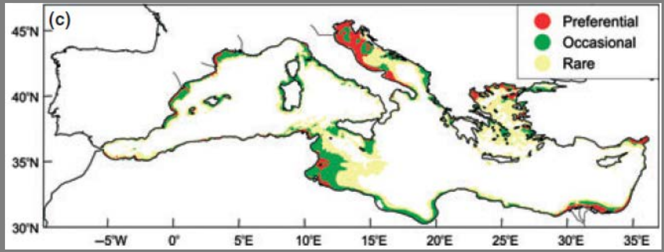




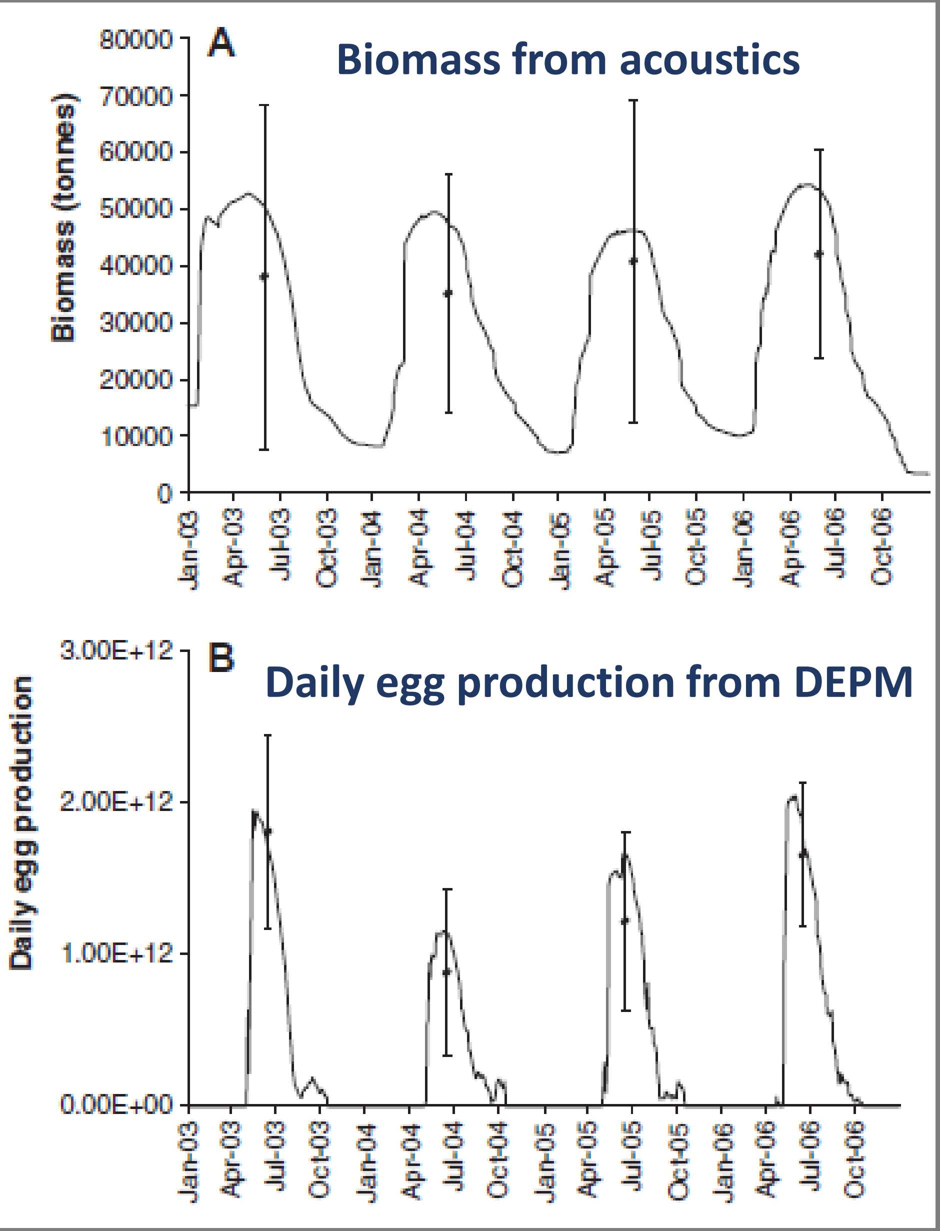
Preferential spawning habitat

Egg abundance from IBM





Model skills – Population biomass & daily egg production



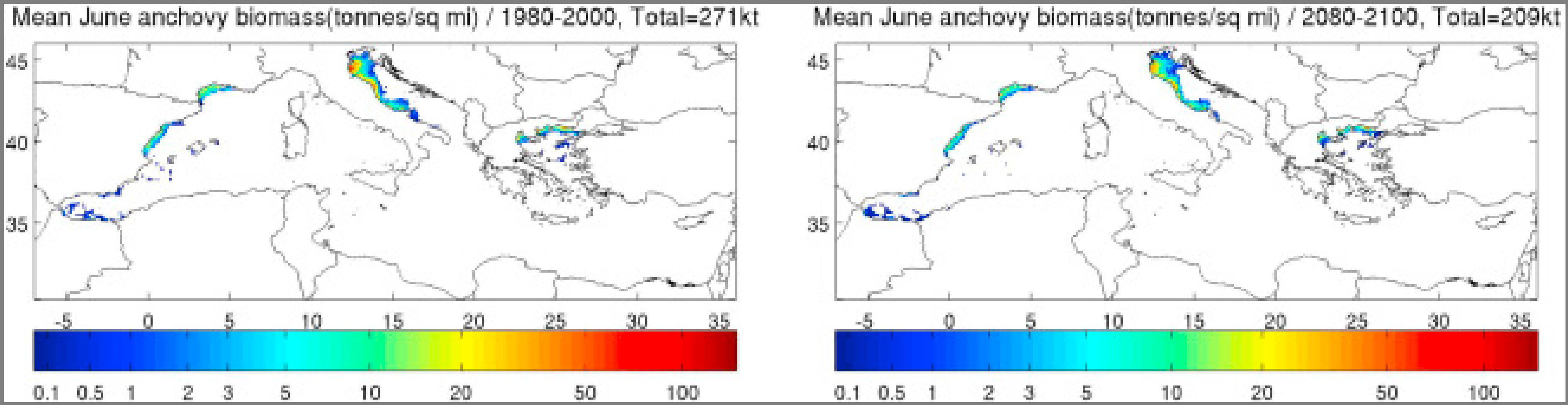
MEDIAS surveys
June 2003-2006

Hindcast inter-annual simulation

Mediterranean future climate simulations

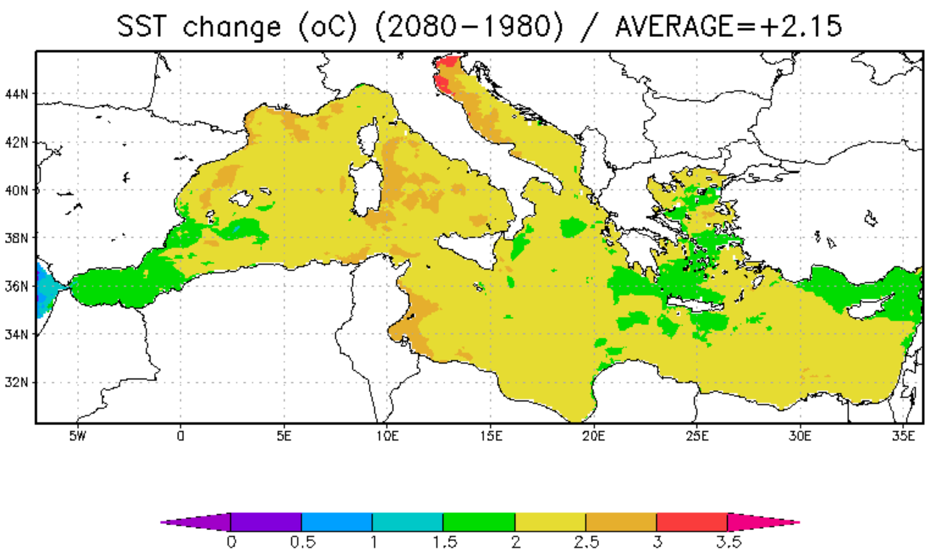
SIMULATION SETUP

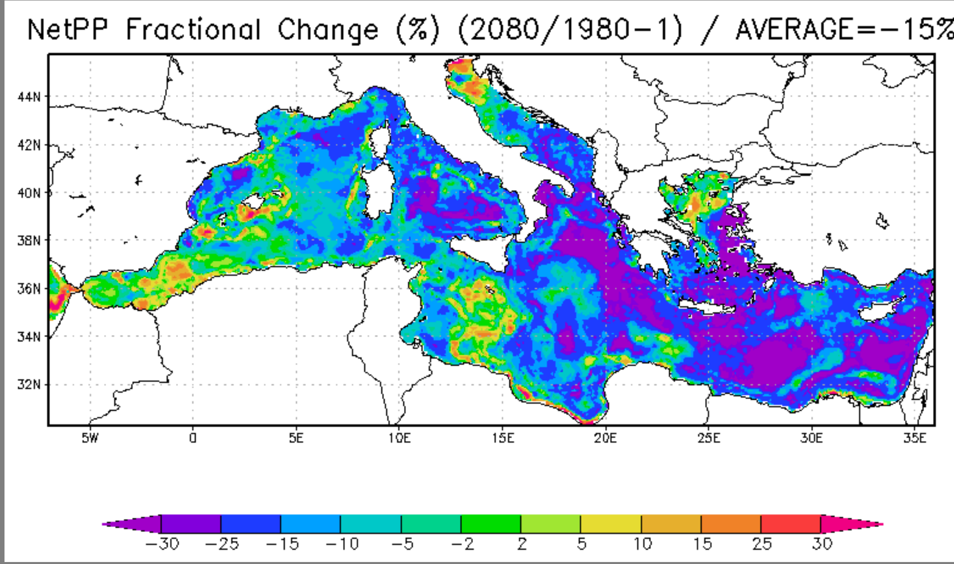
- Atmospheric Forcing: IPSL-CM4 coupled climate model (Hourdin et al. 2006)
- Periods compared: **1980-2000** & **2080-2100** (**A1B IPCC scenario**)
- Anchovies SIs along Spanish & French coasts, the Adriatic Sea and the North Aegean Sea

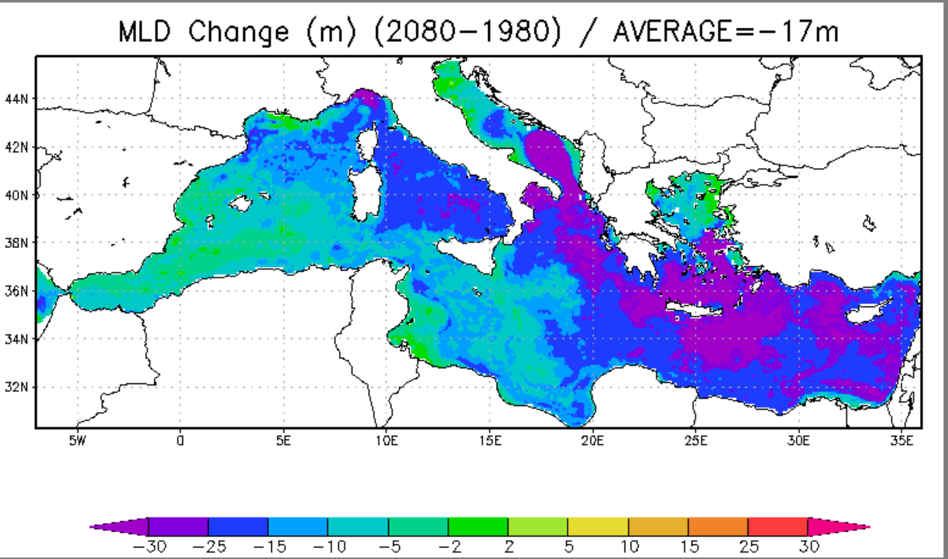


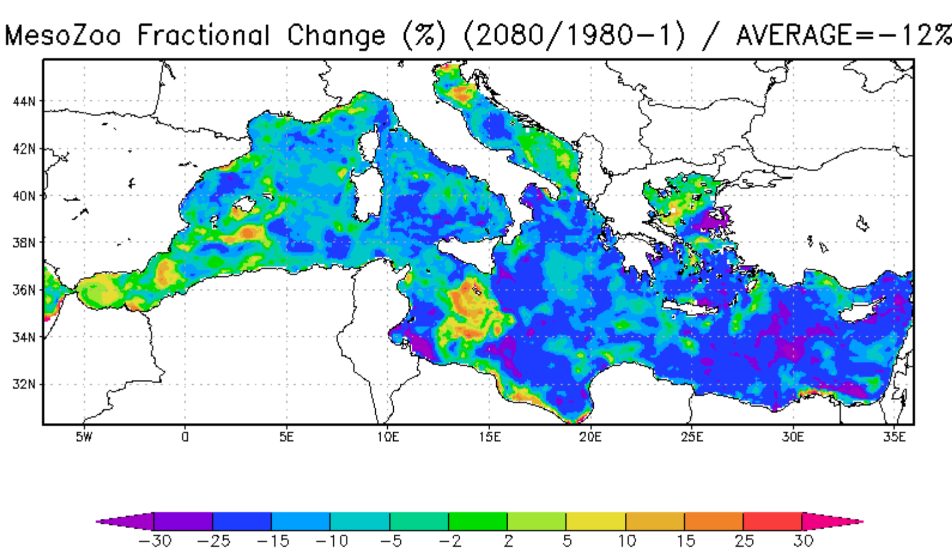
… close association of this species with productive, continental shelf areas, influenced by freshwater discharges

Mediterranean future climate simulations

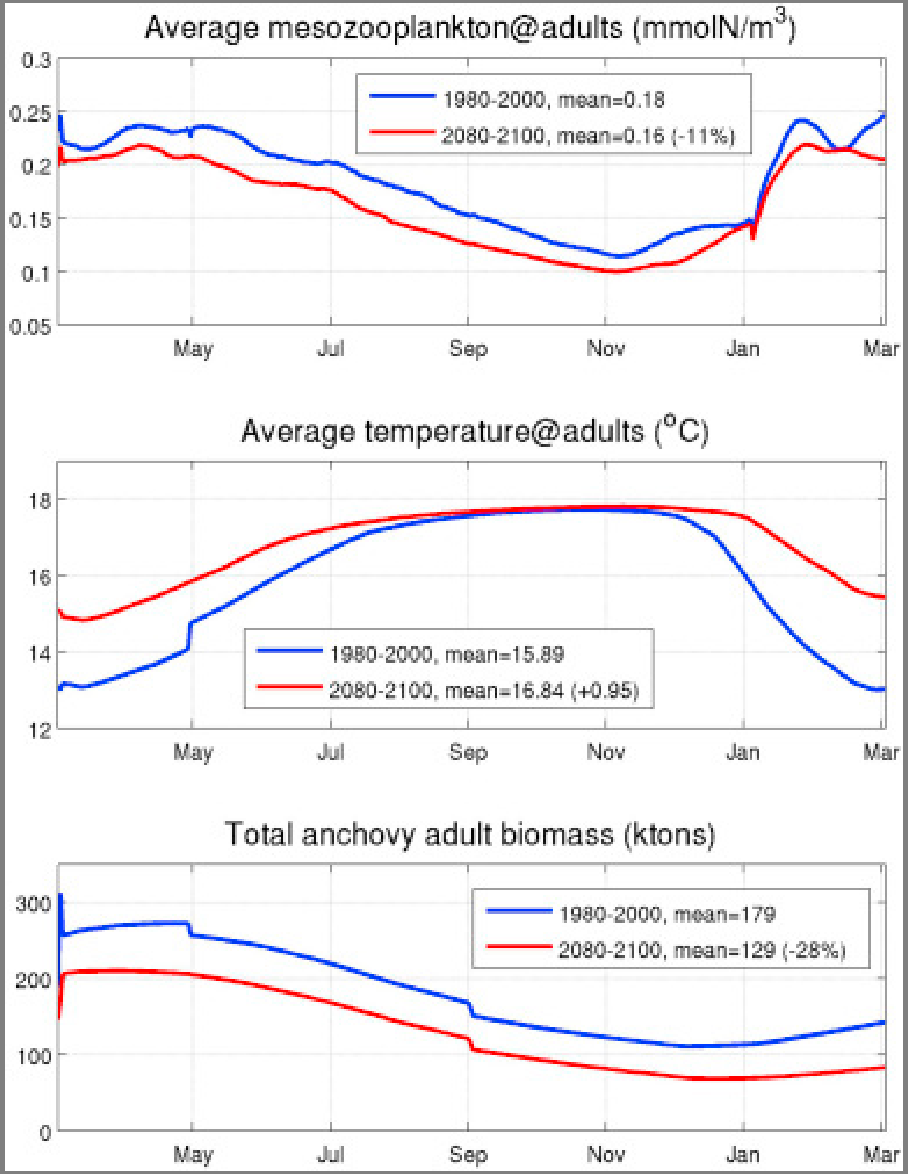








Mediterranean future climate simulations

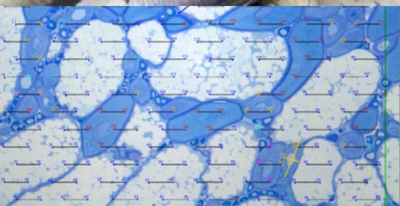


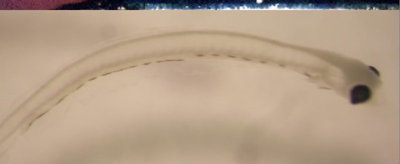
Biomass decrease

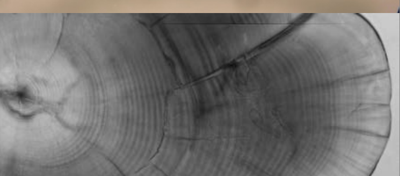
- Increased maintenance costs
- Decrease in net somatic growth
- Decrease in egg production
- Increase in larval starvation mortality

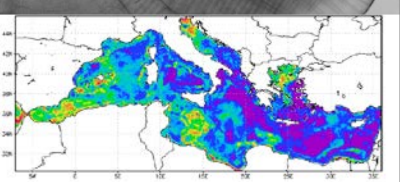
Drivers of dynamics of small pelagic fish resources

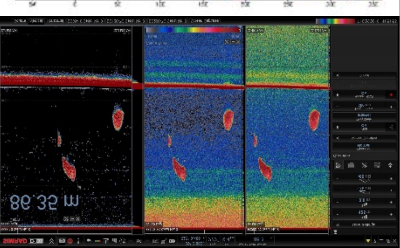
International Symposium, Victoria, BC, Canada, March 6-11 2017











Full life cycle perspective of small pelagic fish recruitment

THANK YOU FOR LISTENING !!!