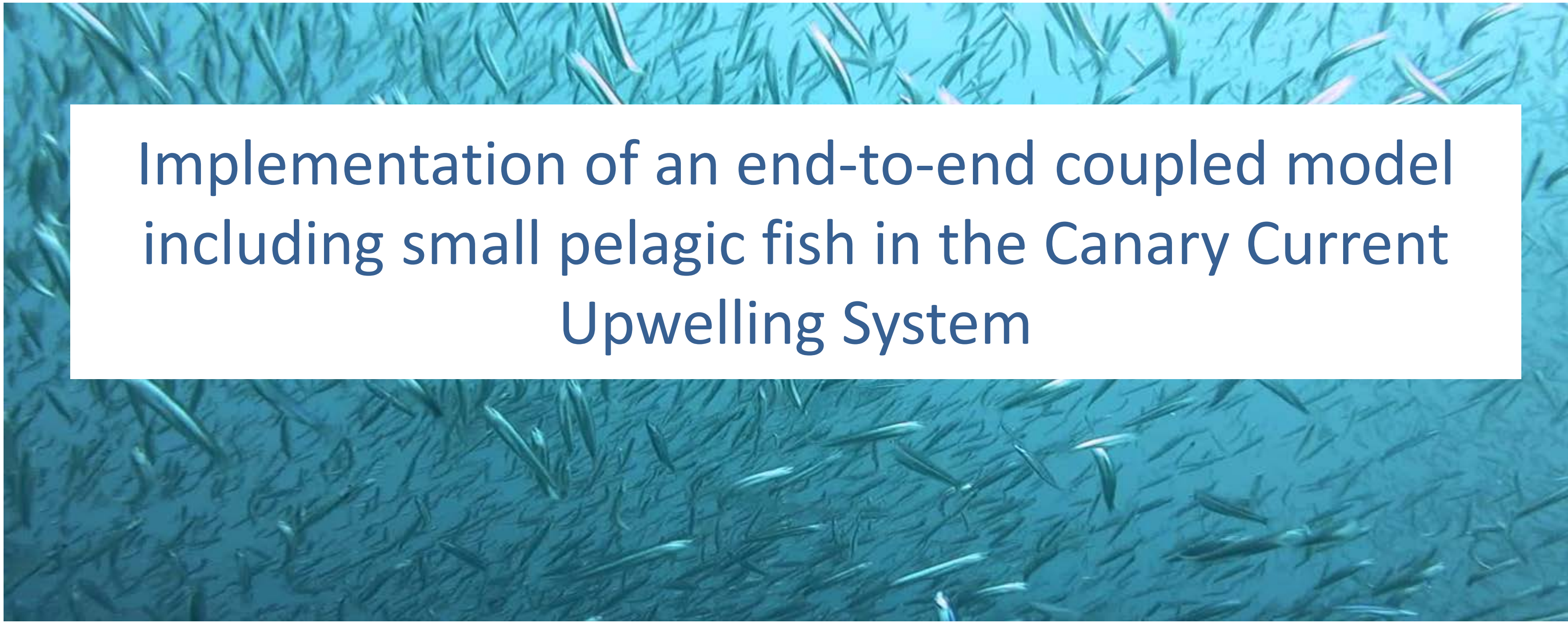
Implementation of an end-to-end coupled model including small pelagic fish in the Canary Current Upwelling System



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Workshop on Biophysical Models of Eastern Boundary Currents Upwelling Systems
Las Palmas de Gran Canarias, 17 de Febrero de 2016

Outline

- Origin of the initiative
- Similar works in the California Current
- The circulation model
- Biochemistry and Fish IBM model
- Current situation

Previous interest in multidisciplinary works in my usual region of study

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2015JC010885

Modeling the impact of tidal flows on the biological productivity of the Alboran Sea

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Key Points:

- Tidal flows fertilize the inflowing waters through the Strait of Gibraltar
- Nutrients pumped by tides reach the photic zone
- The nutrient supply explains ~40% of the productivity of the western Alboran Sea

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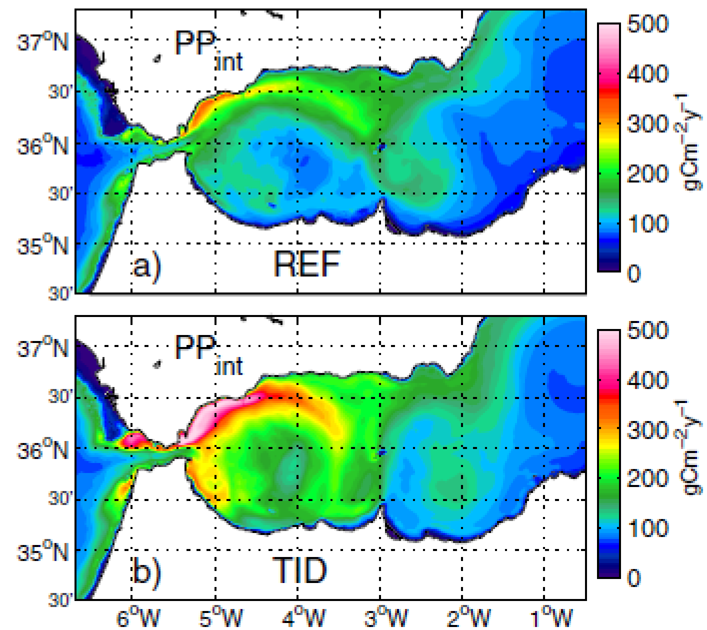
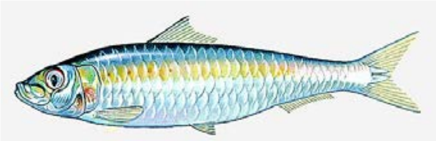
Abstract The control of phytoplankton production by tidal forcing in the Alboran Sea is investigated with a high-resolution ocean circulation model coupled to an ecosystem model. The aim of the modeling efforts was to elucidate the role of tides in sustaining the high biological productivity of the Alboran Sea, as compared with the rest of the Mediterranean subbasins. It is shown that tidal forcing accounts for an increase of phytoplankton biomass and primary productivity in the basin of about 40% with respect to a nontidal circulation, and about 60% in the western Alboran Sea alone. The tidal dynamics of the Strait of Gibraltar is shown to be the primary factor in determining the enhancement of productivity, pumping nutrients from depth to the photic zone in the Alboran Sea. Model results indicate that the biological implications of the propagating internal tides are small. These results imply that nutrient transports through the Strait of Gibraltar have to be parametrized in ocean models that do not resolve tides in order to properly represent the biochemical budgets of the Alboran Sea.

1. Introduction

The Alboran Sea (AS; Figure 1a) is the first subbasin that the jet of Atlantic Water (AW) entering through the Strait of Gibraltar (SoG) encounters in its way along the Mediterranean. Its surface circulation is fairly variable in both space and time, but its most typical and classically described configuration is that consisting of the Atlantic jet meandering around and feeding two mesoscale anticyclonic gyres, the so-called Western and Eastern Alboran Gyres (hereinafter WAG and EAG). Typical velocities along the jet are as large as 1–2 m s^{-1}, and to a first approximation can be assumed to be geostrophically maintained by the strong density front between the relatively fresh incoming AW and the saltier ambient water (modified AW). As elsewhere in the ocean, such fronts feature a secondary cross-front ageostrophic circulation characterized by large vertical velocities and with potential to sustain high levels of biological productivity [e.g., *Spall*, 1995; *Nagai et al.*, 2008].

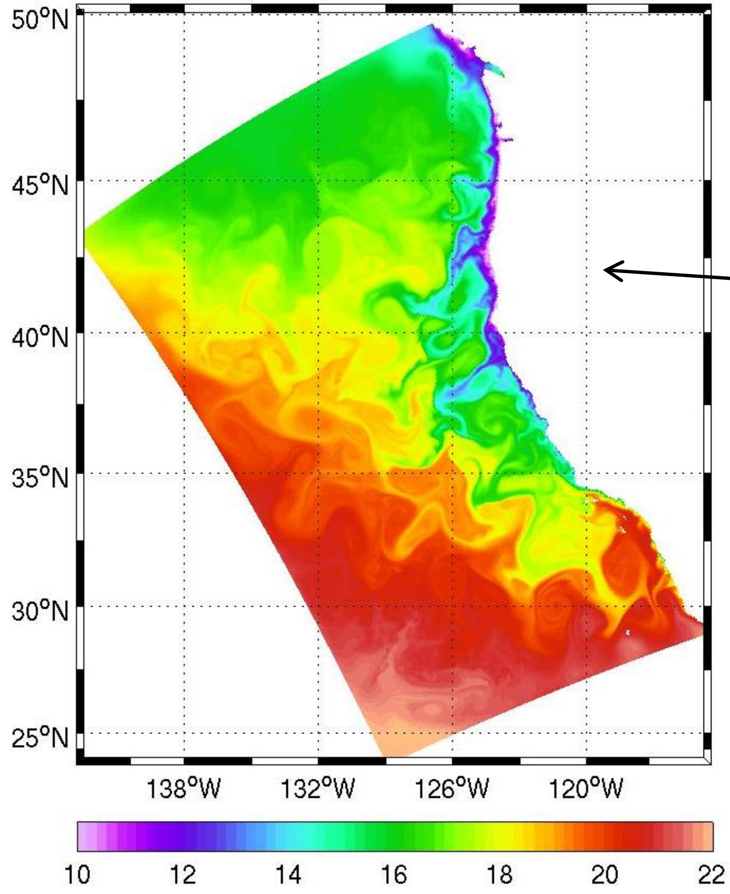


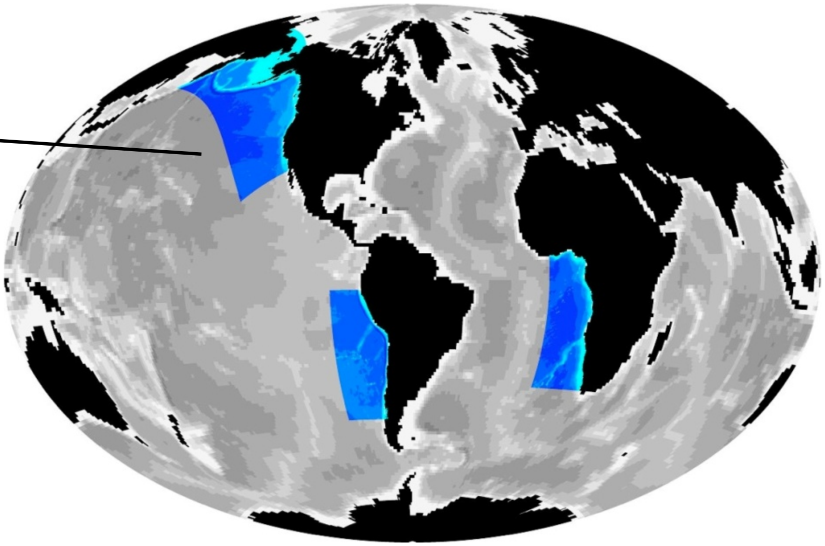
Visit NOAA Fisheries with the aim to incorporate a higher trophic level in the Alboran...



or the Canary Current Upwelling System too…

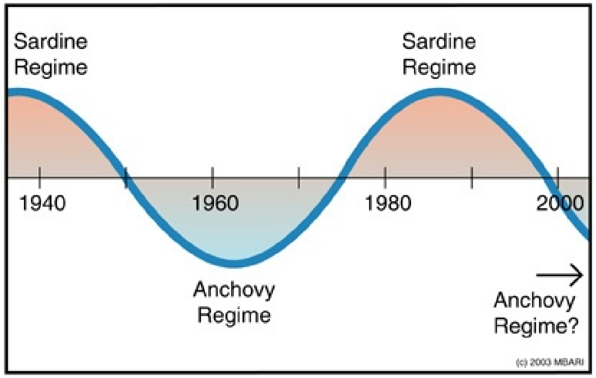
- Greater interest of Eastern Boundary Currents
- Models already applied to the California Current



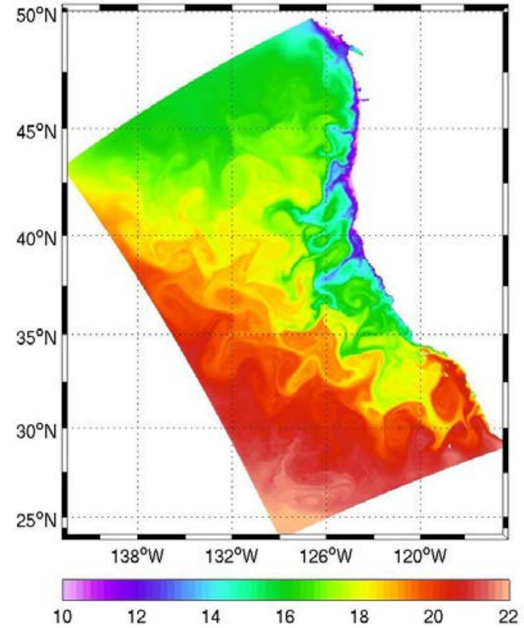


Hypotheses for low-frequency variability

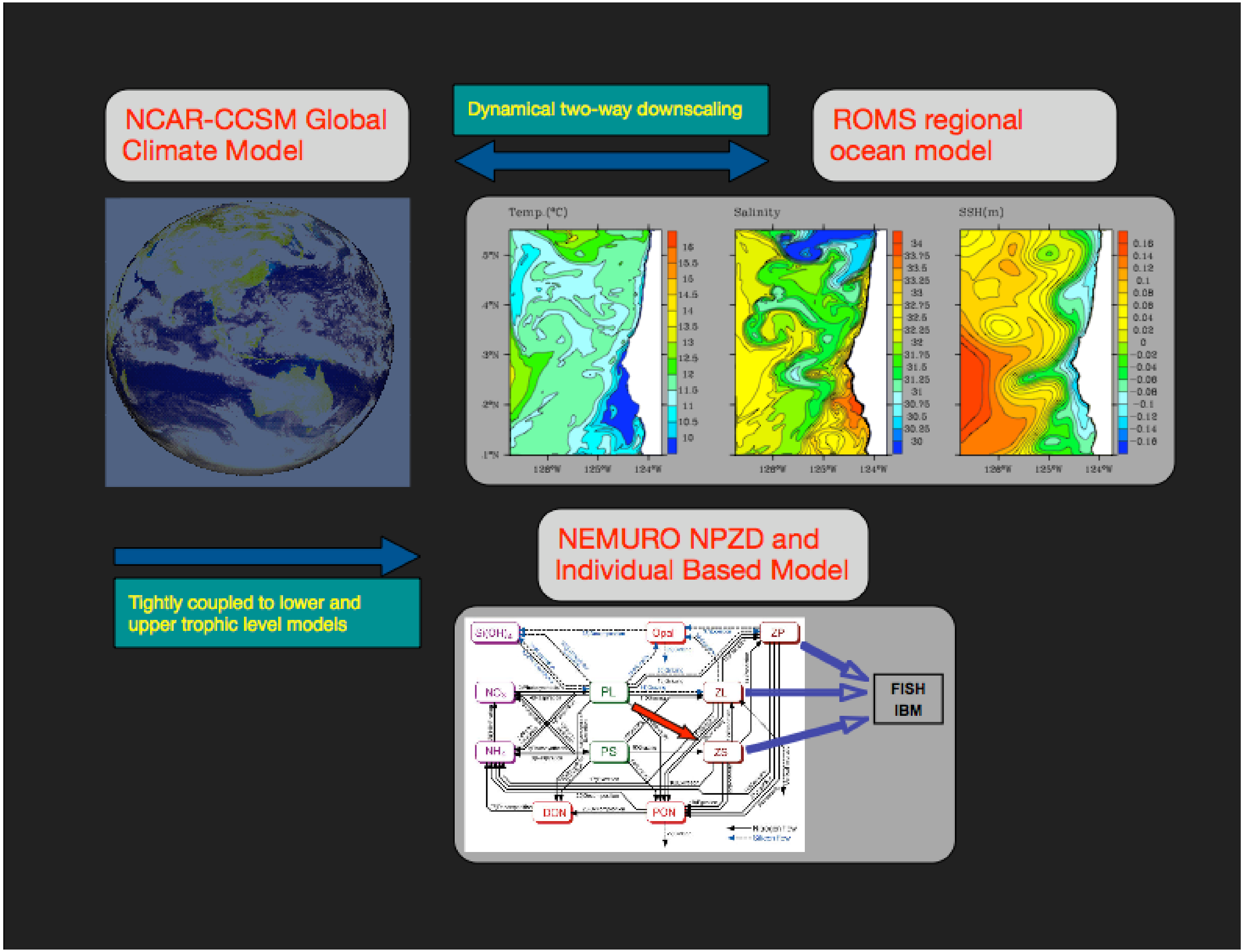
- **Environmental conditions (bottom up)**
  - **Temperature** controls population expansions and contractions via spawning behavior (e.g., Lluch-Belda et al., 1991).
  - Reproduction success linked to **mesoscale features** (MacCall, 2002).
  - **Food availability** and composition determines population success (e.g., Van der Lingen et al. 2001).



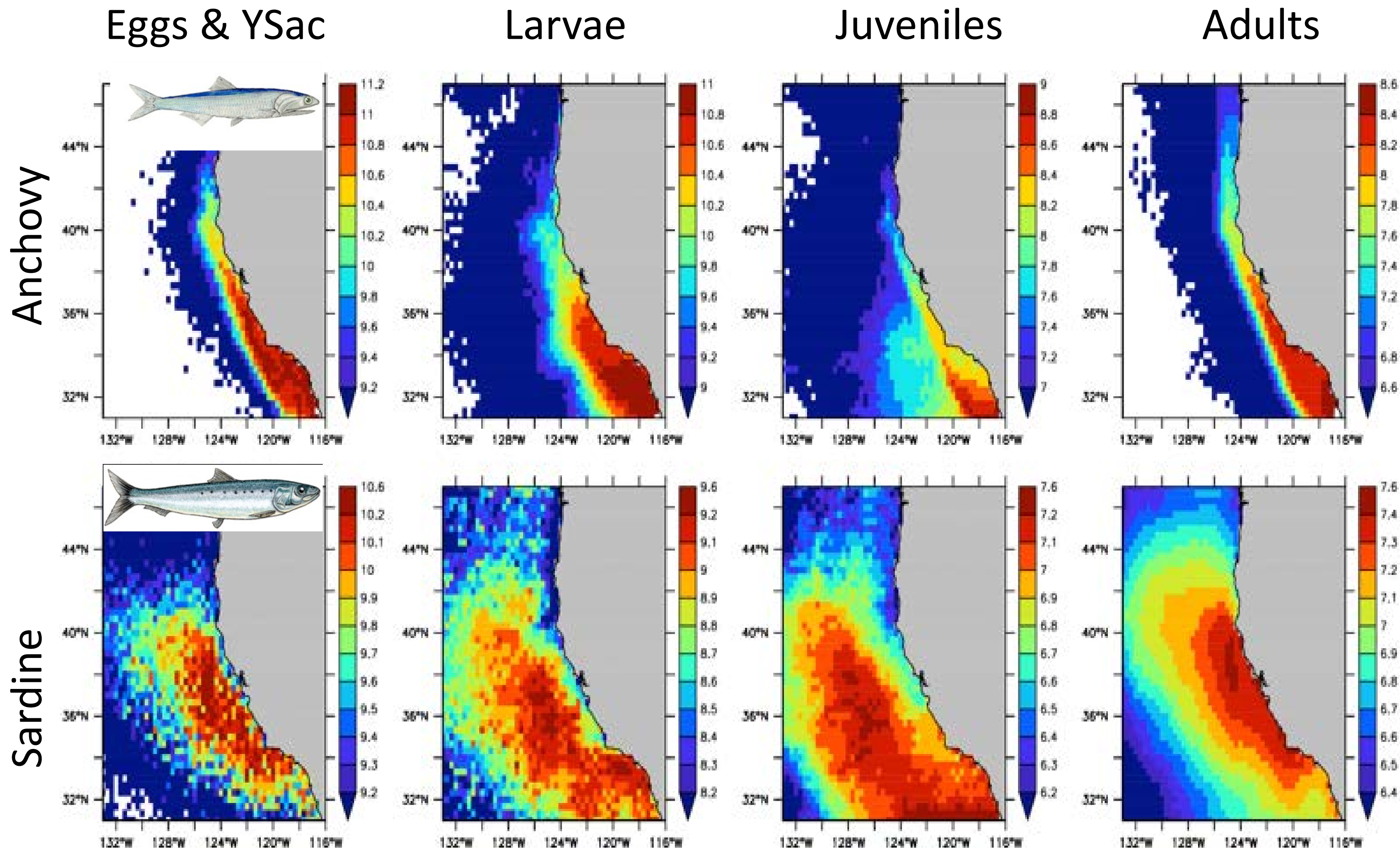
- **Fishing pressure (top down)**
  - Affects longevity--affects survival in adverse conditions.
  - Differentially preserve more fecund older fish and their migratory behavior.
  - Productivity depends on learned migratory behavior (Petigas et al. 2006).



Approach: coupled climate-to-fishers model

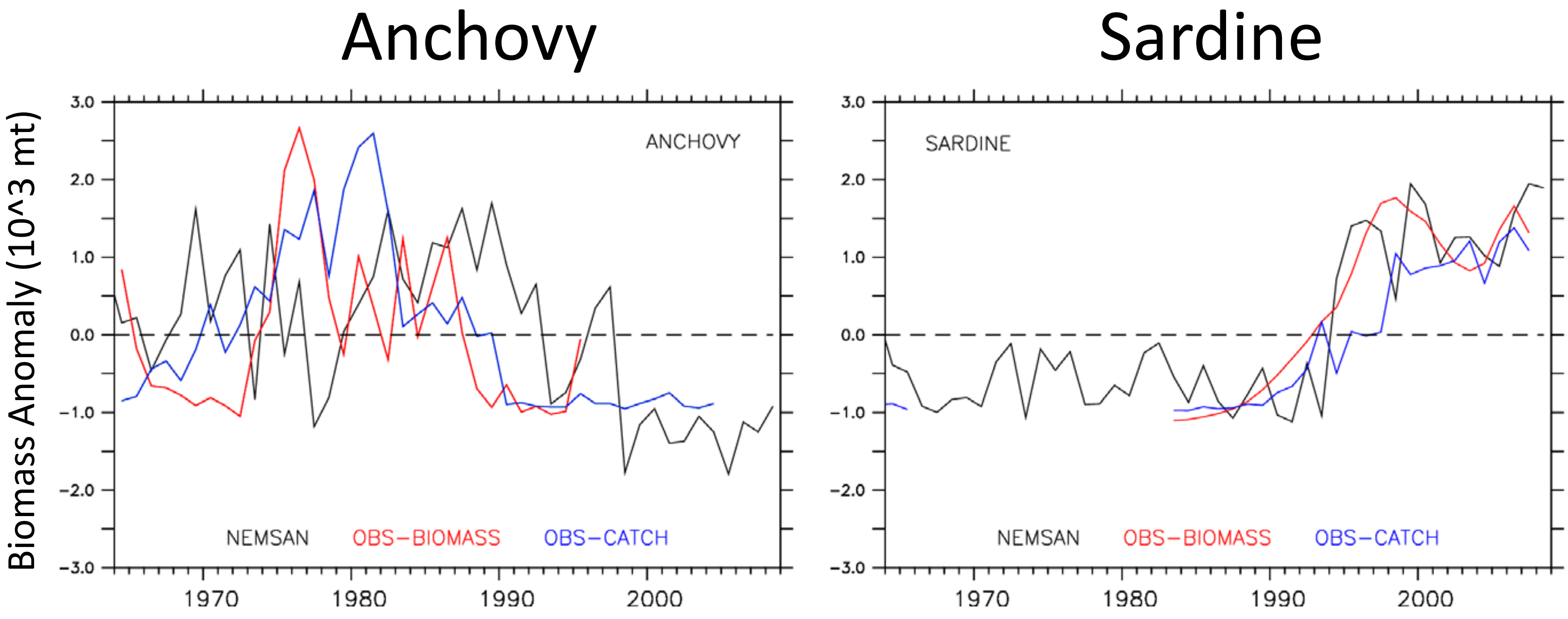


Mean (1964-2008) abundance by life stage (log_{10} of individuals); Anchovy (top) and sardine (bot.)



Rose et al. and Fiechter et al., Progress in Oceanography, 2015

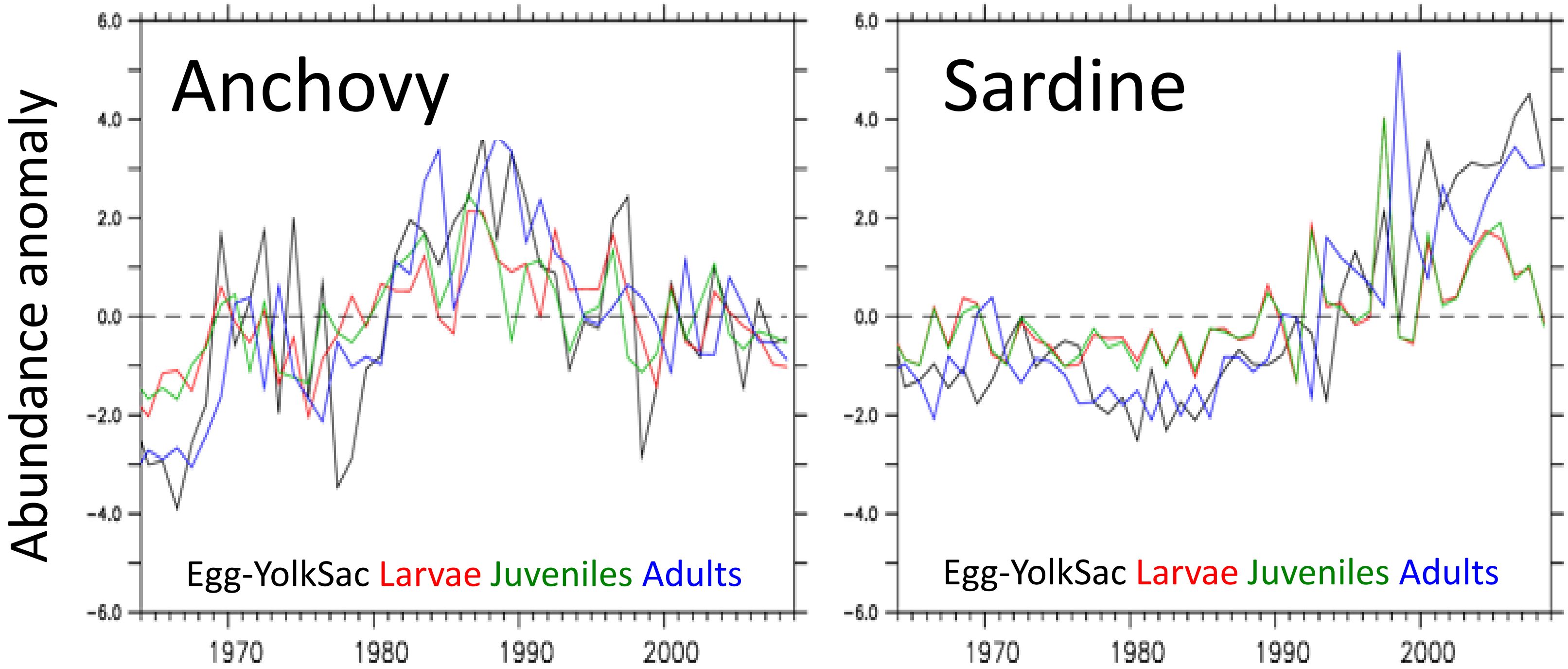
Population biomass fluctuations (seemingly) captured (shows encouraging resemblance to observations)



A rather complex set of models including a wide range of processes were put together, with biological/physiological traits, and results of two species emerged showing differen ces at various scales, e.g., anchovy at higher frequency, decadal variability in both …

Rose et al. and Fiechter et al., Progress in Oceanography, 2015

The models allow for examination of annual abundance anomalies at various life-stages



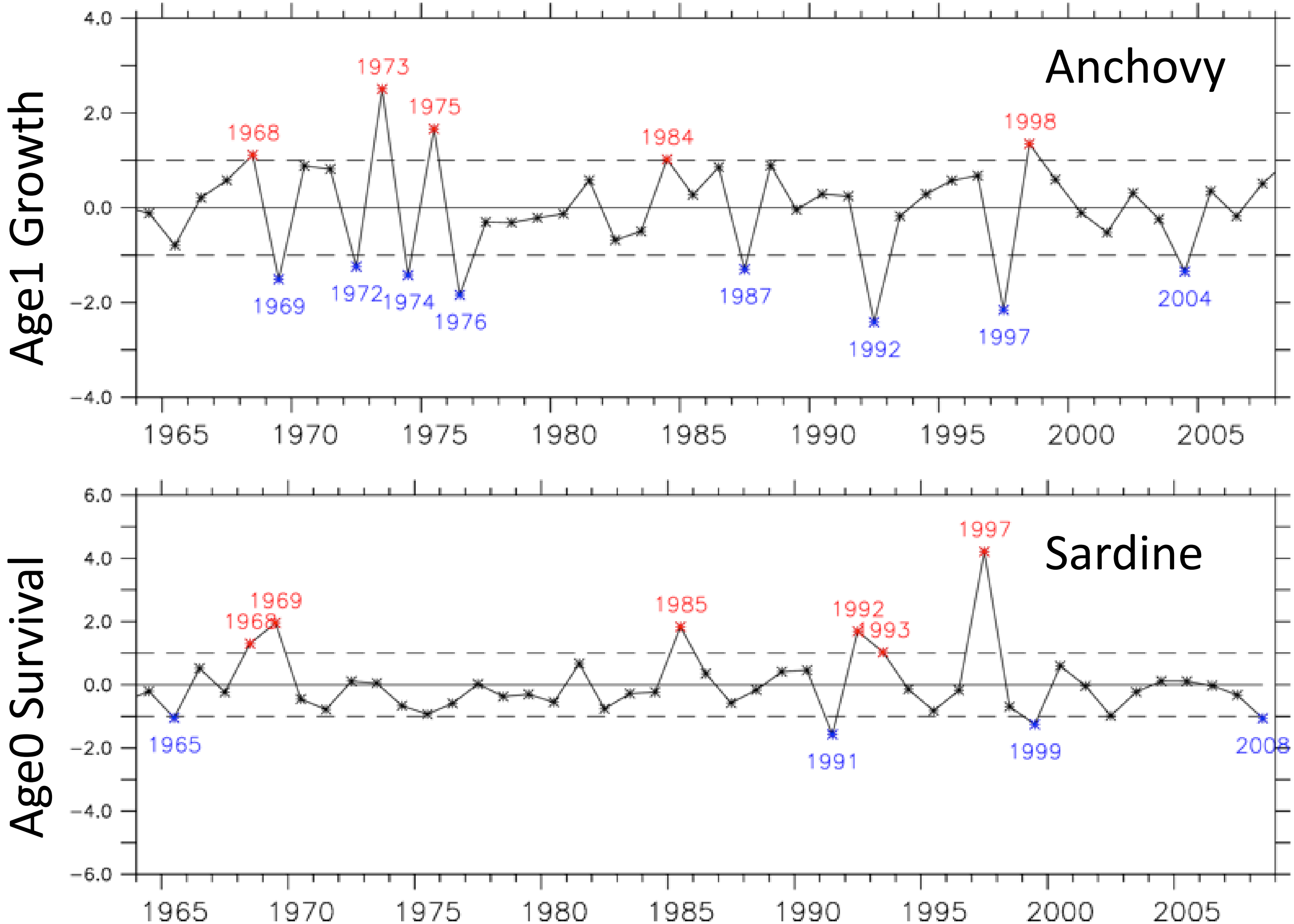
Rose et al. and Fiechter et al., Progress in Oceanography, 2015.

Lots of "wiggly" information… three steps to tease out the drivers

- Step 1: identify the biological processes that control adult sardine and anchovy population dynamics
  - Anchovy: adult population fluctuations are associated with age-1 growth and prey availability.
  - Sardine: adult populations correlated with temperature and age-0 survival.
- Step 2: link changes in processes to variations in environmental conditions
  - Anchovy: years of high growth related to enhanced upwelling in the southern CCS (more productive lower tropic levels)
  - Sardine: years of high age-0 survival related to high temperatures
- Step 3: correlate environmental conditions experienced by the individuals in the model to regional and climate-scale variability in the CCS using ROMS and NEMURO output directly.

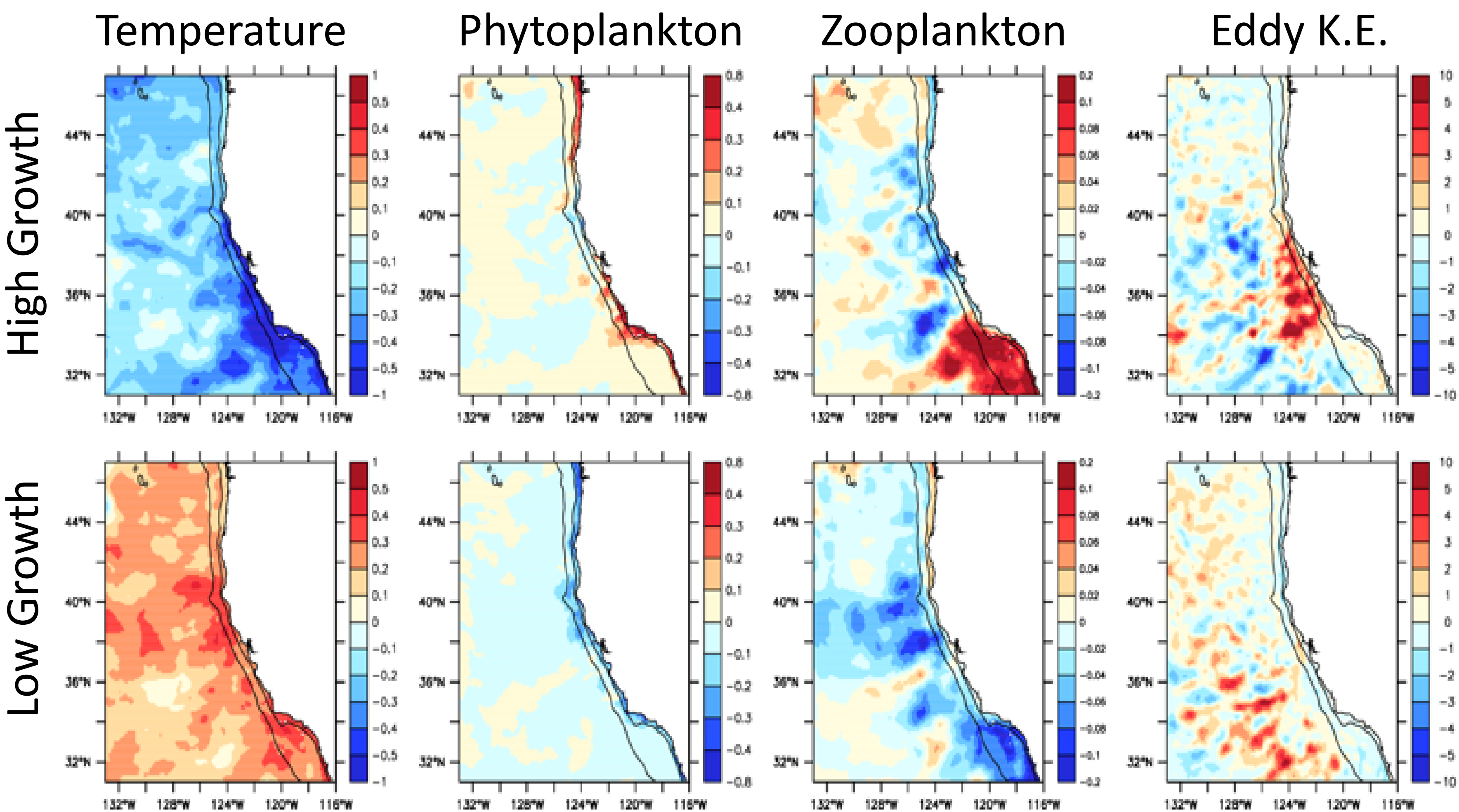
Annual anomalies

Top: Age-1 growth. Bot.: Age-0 survival



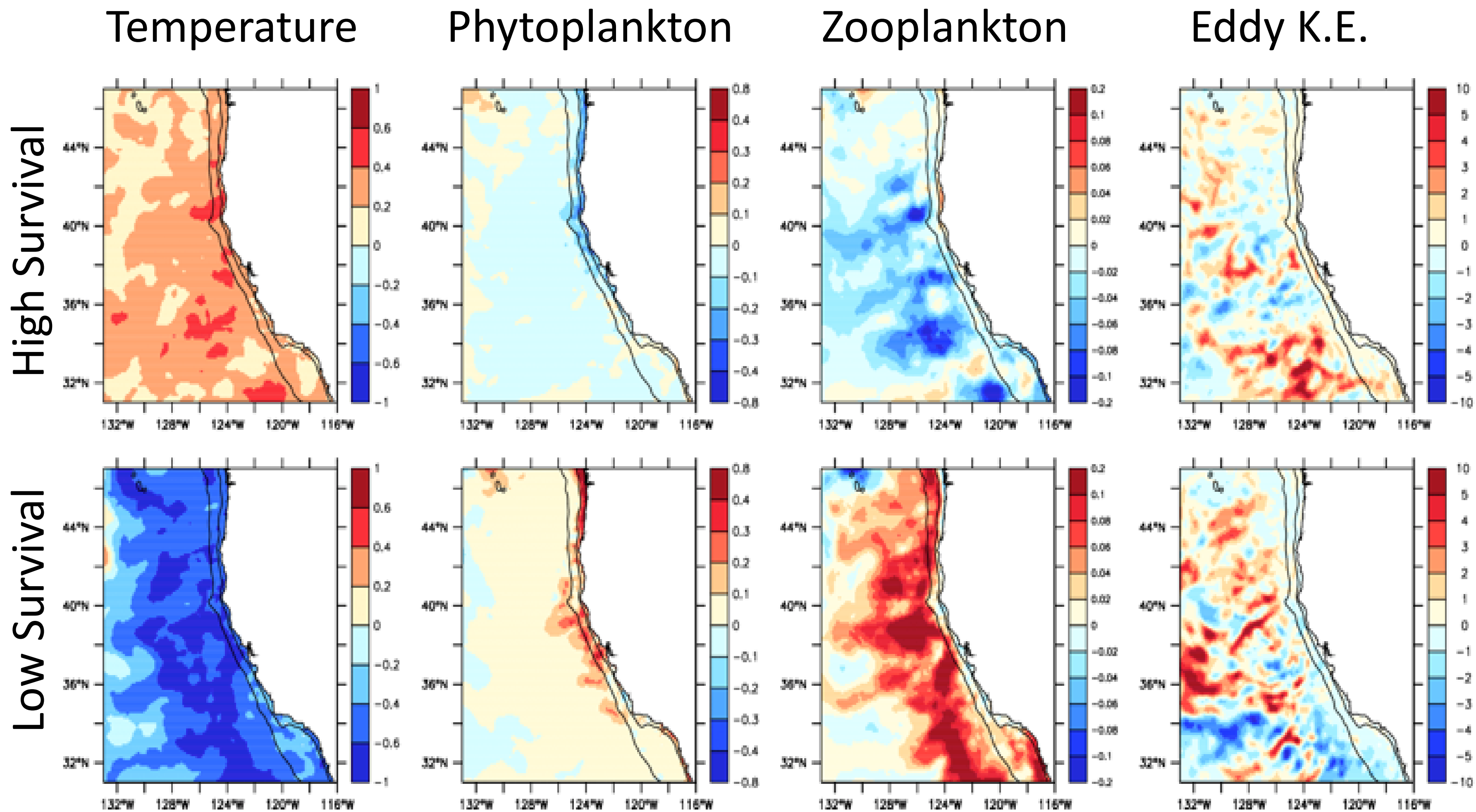
Rose et al. and Fiechter et al., Progress in Oceanography, in press.

Environmental drivers: Anomalies for high- and low-years of anchovy age-1 growth



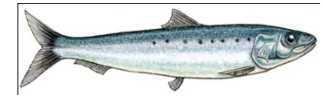
Rose et al. and Fiechter et al., Progress in Oceanography, 2015.

Environmental drivers: Anomalies for high- and low-years of sardine age-0 survival



Rose et al. and Fiechter et al., Progress in Oceanography, 2015.

Summary on sardine & anchovy dynamics in the CCS



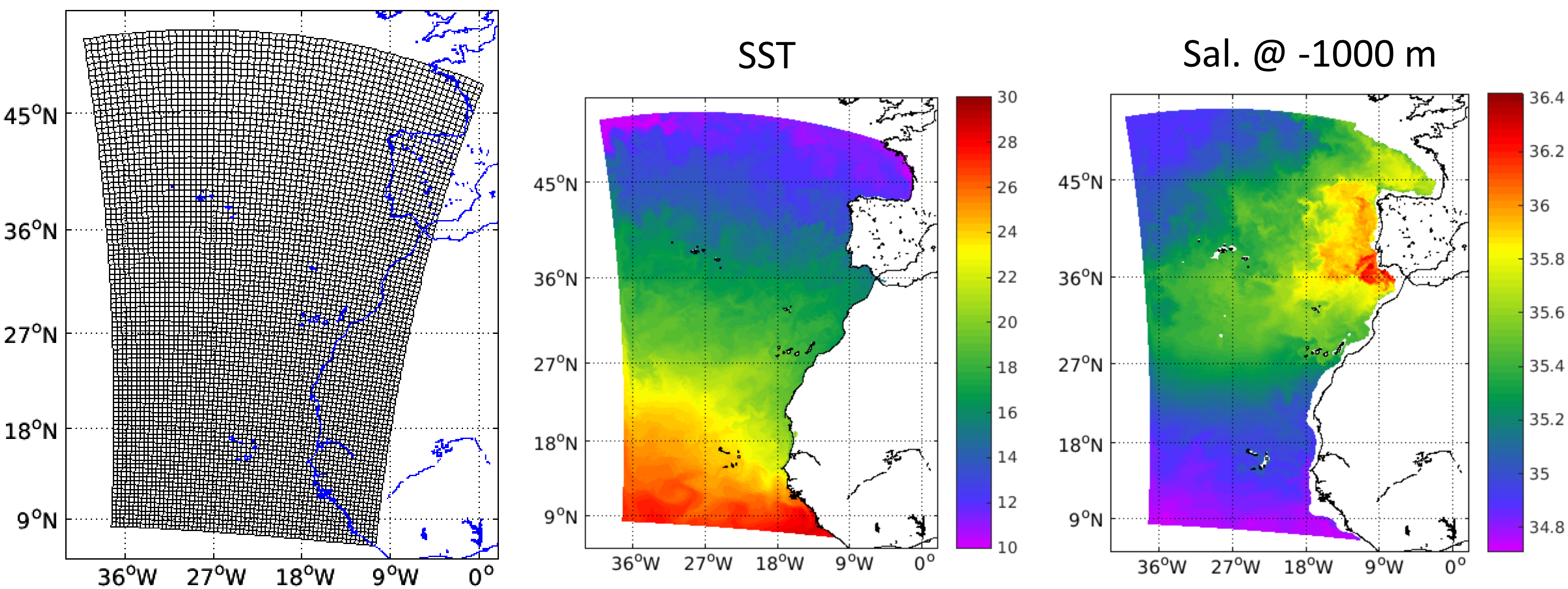
- Climate-to-fishing: Encouraging proof of concept of the modeling approach

- Results hint at potential linkages to known modes of climate variability, with anchovy responding to ENSO and sardine to the PDO.

- Sardine vs. anchovy out-of-phase cycles: adult populations favor prey for anchovy and temperature for sardines and these are out of phase in the CCS.

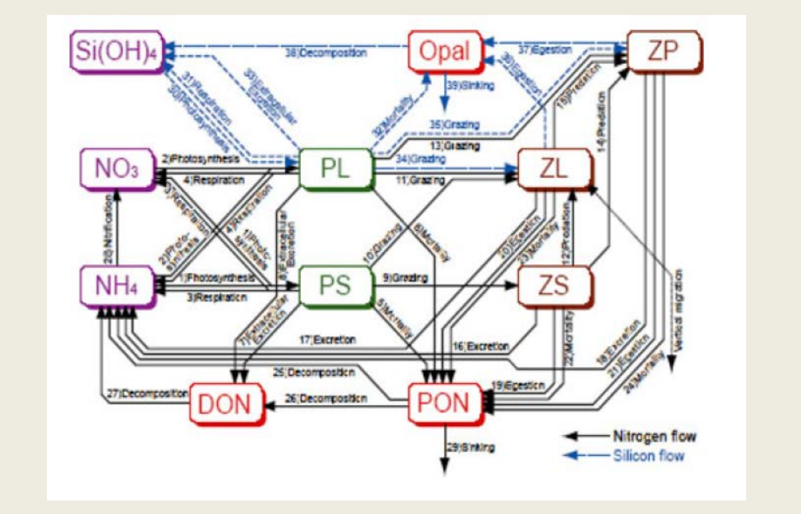
… returning to the Canary Current System: **circulation model** based in **ROMS**

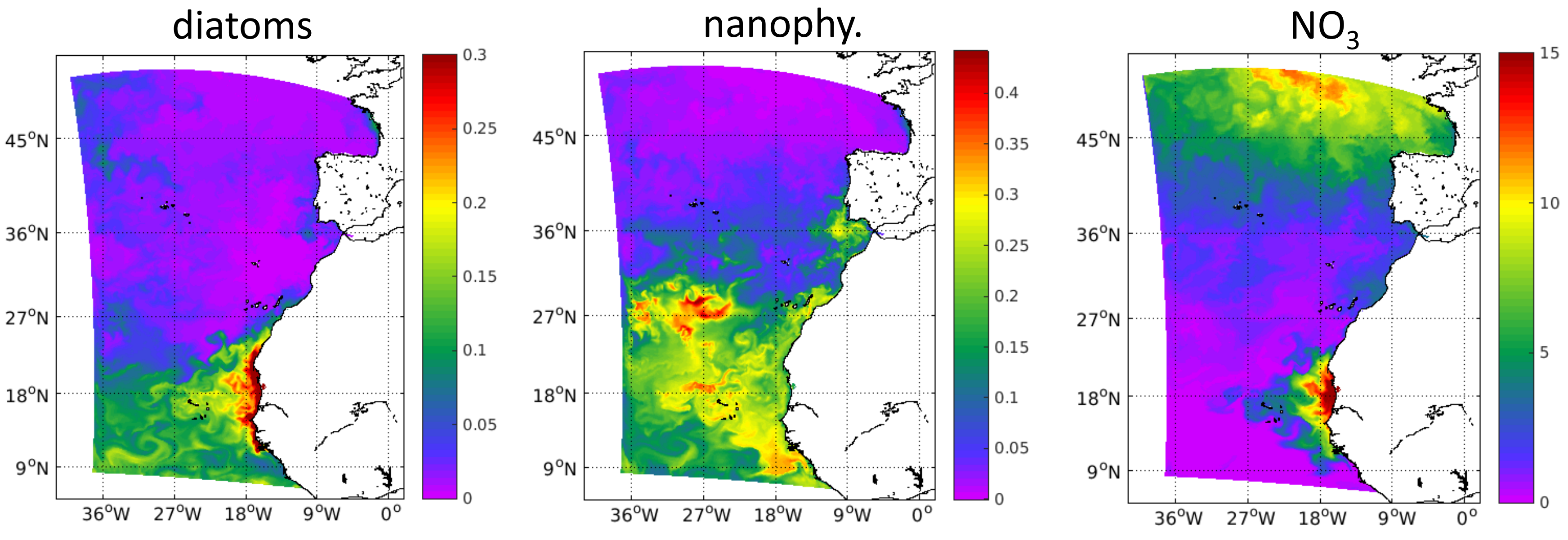
- Hindcast simulation of 1958-2007
- Model resolution of Δx=Δy=12 km; with 38 σ-levels in the vertical.
- Atmospheric and lateral boundary forcing from reanalysis (same products as in the California Current).



NEMURO biochemistry model

- Two phytoplankton types
- Two limiting nutrients (Si & NO_3)
- Three zooplankton types: large, small, and predatory





Fish model:

- Multi-species , with individual based modeling approach (IBM)

- Species can compete for common prey and eat each other.

- Explicit model growth, mortality, reproduction and movement.

- One species can represent a fishing fleet as individuals.

Bunch of parameters to model fish bioenergetics and behaviour

Table 2

Symbols, units, and definitions of model variables and parameters for anchovy and sardine. The equation the variable or parameter appears in is also noted. The order of the variables and parameters in the table as they first appear in the text; state variables or calculated variables are noted as a blank in the column labelled "Calibration." Grams are in wet weight. Units denoted as "fraction" means values are between zero and one, and units denoted as "–" means the units have no units or are complicated and not easily interpreted. Key aspects of how the parameter values were determined are listed under "Calibration": (A) derived directly from the literature on sardine or anchovy or closely related species, (B) new formulations that used parts and parameter values from other studies, (C) calibrated with the simplified 2-dimensional grid or simulation of an average individual, (D) re-calibrated in full model, or (E) not species-specific but based on general literature review. The superscripts refer to references listed in the table footnote.

Symbol	Units	Definition	Eq.	Calibration
Development of eggs and yolk-sac larvae				
D_T	Fraction	Fractional development of eggs and yolk-sac larvae per Δt	(1)	
d_1, d_2, d_3	–	Coefficient for hours of development in one time step	(1)	A[1]
$\alpha_1, \alpha_2, \alpha_3$	–	Coefficient determining hours for complete development	(1)	A[1]
Bioenergetics				
W	g	Weight of an individual	(2)	
A	Fraction	Assimilation efficiency	(2)	A[2,3,4,5,6]
C	$g\ g^{-1}\ d^{-1}$	Realized consumption rate (g prey per g fish)	(2) and (10)	
R	$g\ g^{-1}\ d^{-1}$	Respiration rate (g prey per g fish)	(2)	E[7,8]
e_f	$J\ g^{-1}$	Energy density of fish	(2)	A[9]
e_z	$J\ g^{-1}$	Energy density of zooplankton prey	(2)	
E	$J\ d^{-1}$	Losses due to reproduction	(2)	C[10,11]
L	mm	Length of an individual	(3)	
ΔL	$mm\ \Delta t^{-1}$	Change in length	(3)	
k_t	d^{-1}	Von Bertalanffy growth coefficient	(3)	C[10,11]
L_∞	mm	Maximum length for Von Bertalanffy	(3)	C[10,11]
a_r	–	Multiplier for allometric effect on respiration	(4)	B[2,3]
b_r	–	Exponent for allometric effect on respiration	(4)	B[2,3]
$G(T)$	Fraction	Temperature effect on respiration	(4) and (5)	B[2,3]
a_a	–	Activity multiplier for respiration	(4)	B[2,3]
R_Q	–	Q10-related effect of temperature on respiration	(5)	B[2,3]
T_r	°C	Reference temperature for effect on respiration	(5)	B[2,3]
d_r	–	Multiplier in exponent for swim effect on respiration	(6)	B[2,3]
U_B	$BL\ s^{-1}$	Swimming speed	(6)	B[2,3]
a_t	–	Multiplier for allometric effect on assimilation efficiency	(7)	B[2,3]
b_t	–	Exponent for allometric effect on assimilation efficiency	(7)	B[2,3]
A_M	Fraction	Maximum assimilation efficiency	(7)	A[2,3,4,5,6]
C_m	$g\ g^{-1}\ d^{-1}$	Maximum consumption rate	(8)	
a_c	–	Multiplier for allometric effect on C_m	(8)	B[2,3]
b_c	–	Exponent for allometric effect on C_m	(8)	B[2,3]
$F(T)$	Fraction	Temperature effect on C_m	(8)	B[2,3]
$CK1$	Fraction	Multiplier effect at temperature CQ on C_m	Text	B[2,3]
CQ	°C	Temperature at which effect on C_m is $CK1$	Text	B[2,3]
TO	°C	Cooler temperature at which effect on C_m is 0.98	Text	B[2,3]
TM	°C	Warmer temperature at which effect on C_m is 0.98	Text	B[2,3]
$CK4$	Fraction	Multiplier effect at temperature TL on C_m	Text	B[2,3]
TL	°C	Temperature at which effect on C_m is $CK4$	Text	B[2,3]
Z_j	$g\ m^{-3}$	Concentration of the j^{th} zooplankton type	(9)	
V_{sj}	Fraction	Vulnerability of prey type j to fish life stage s	(9)	C, D
K_{sj}	$g\ m^{-3}$	Half-saturation constant (stage s feeding on prey type j)	(9)	C, D
Reproduction				
T_b	°C	Minimum temperature for spawning	Text	A[12,13]
T_T	°C	Maximum temperature for spawning	Text	A[12,13]
P_M	Fraction	Probability of maturity based on length	Text	
P_A	–	Additive coefficient for length dependence of maturity	Text	C[14,15]
P_B	–	Multiplier coefficient for length dependence of maturity	Text	C[14,15]
S	J	Energy content of a new batch of eggs	(13)	
F	$Eggs\ g^{-1}$	Fecundity of an individual	(13)	A[16,17,18]
e_e	$J\ g^{-1}$	Energy density of an egg	(13)	A[8,19]
m_e	g	Weight of an egg	(13)	A[8,19]
D_e	d	Expected duration of a batch of eggs	(14)	C, D[8,17,18,20]
a_e	–	Multiplier for temperature effect on batch development	(14)	C, D[8,17,18,20]
b_e	–	Exponent for temperature effect on batch development	(14)	C, D[8,17,18,20]
T_e	°C	Reference temperature for batch development	(14)	A[12,13,21]
Q	J	Expected energy intake over duration of the batch	(15)	C, D
–	Fraction	Resorption efficiency of eggs undergoing atresia	Text	A, E[22]
Constant mortality				
M	d^{-1}	Natural daily mortality rate	Text	A, C, D[16,17]
Movement				
V_x	$m\ s^{-1}$	Velocity of individual in x direction	(16) and (28)	
I_x	$m\ s^{-1}$	Inertial contribution to velocity in x direction	(16)	
R_x	$m\ s^{-1}$	Random contribution to velocity in x direction	(16)	
V_y	$m\ s^{-1}$	Velocity of individual in y direction	(17) and (29)	
I_y	$m\ s^{-1}$	Inertial contribution to velocity in y direction	(17)	
R_y	$m\ s^{-1}$	Random contribution to velocity in y direction	(17)	
$f(T)$	Fraction	Weighting factor of temperature to inertial component	(18)	
H_1	Fraction	Height of function for temperature relative to T_o	(18)	C, D[23,24]

Current situation:

- Physical model is ready
- Biochemistry model is ready too, but, suitable for the CANC?
- We need to work on the Fish model. Species? Parameters?
- Need to be more specific regarding research questions
- Possibility to apply for a project (jóvenes investigadores)