A space oddity: the case of the of anchoveta (*Engraulis ringens*) in southern Humboldt current system

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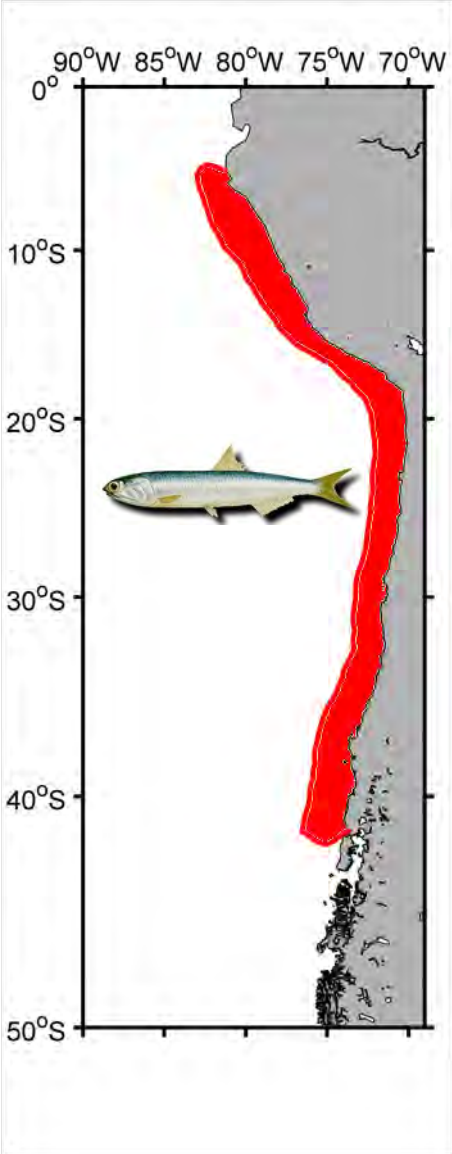
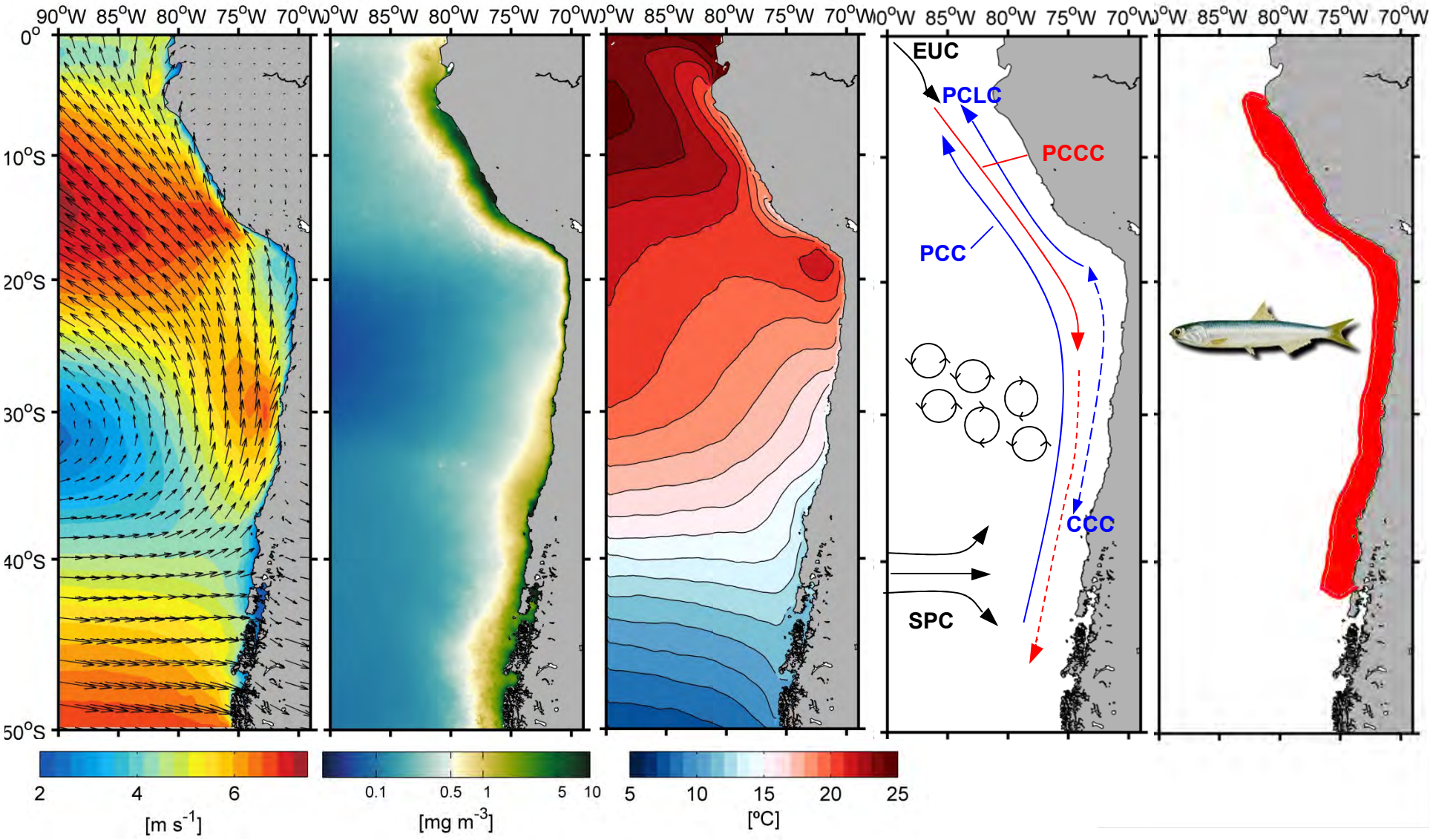
La anchoveta

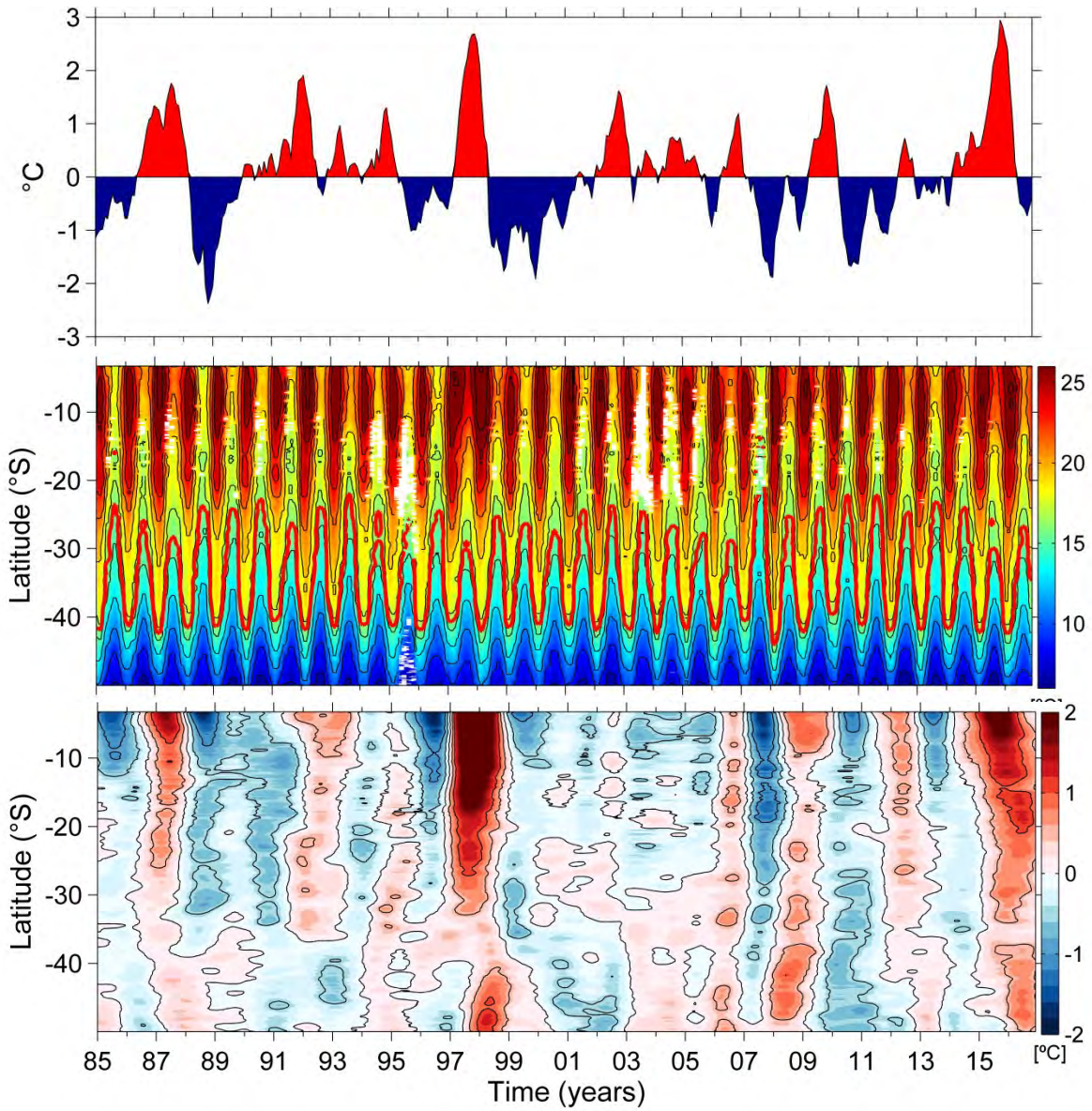
- Small pelagic coastal fish (de Vries y Pearcy, 1982; Mathisen 1989)
- Fast growth (Cubillos *et al*., 2007)
- Planktonic feeding habits and pelagic eggs (Krautz *et al*., 2010)
- Short life span: 4 - 5 years (Serra *et al*. 1979)
- Partial spawner: spawning throughout the year with maximum at the end of winter and beginning of southern spring (Cubillos *et al*., 2007)
- Highly variable population productivity (Arteaga & Cubillos 2007).
- Key species in the ecological system of the Humboldt Current (Espinoza, 2014)
- Species highly dependent on environmental fluctuations: seasonal (Espinoza & Bertrand, 2008) , interannual (Ganoza et al., 2000) and interdecadal (Chávez *et al*., 2003; Alheit & Ñiquen, 2004).
- Population size closely related to recruitment strength

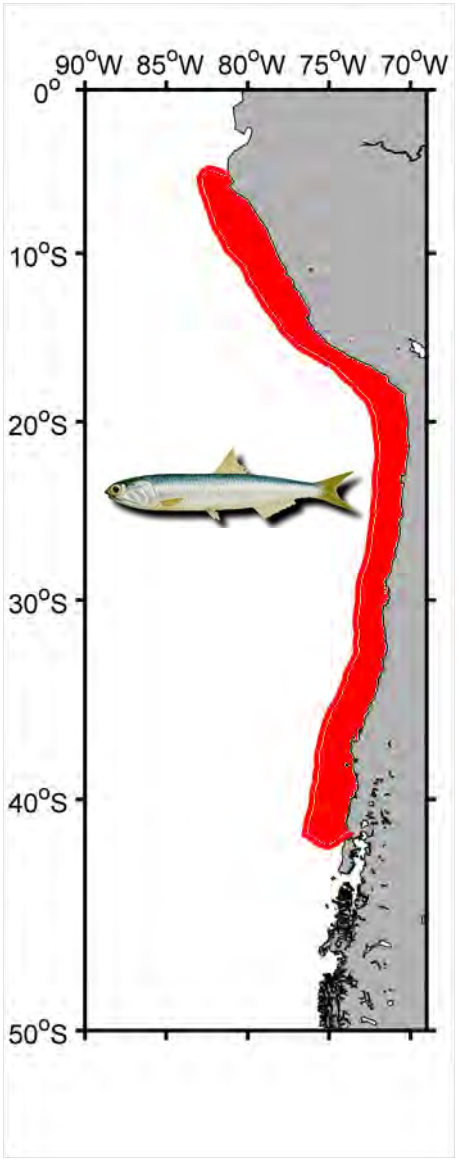


Habitat conditions



Habitat variability – stock size



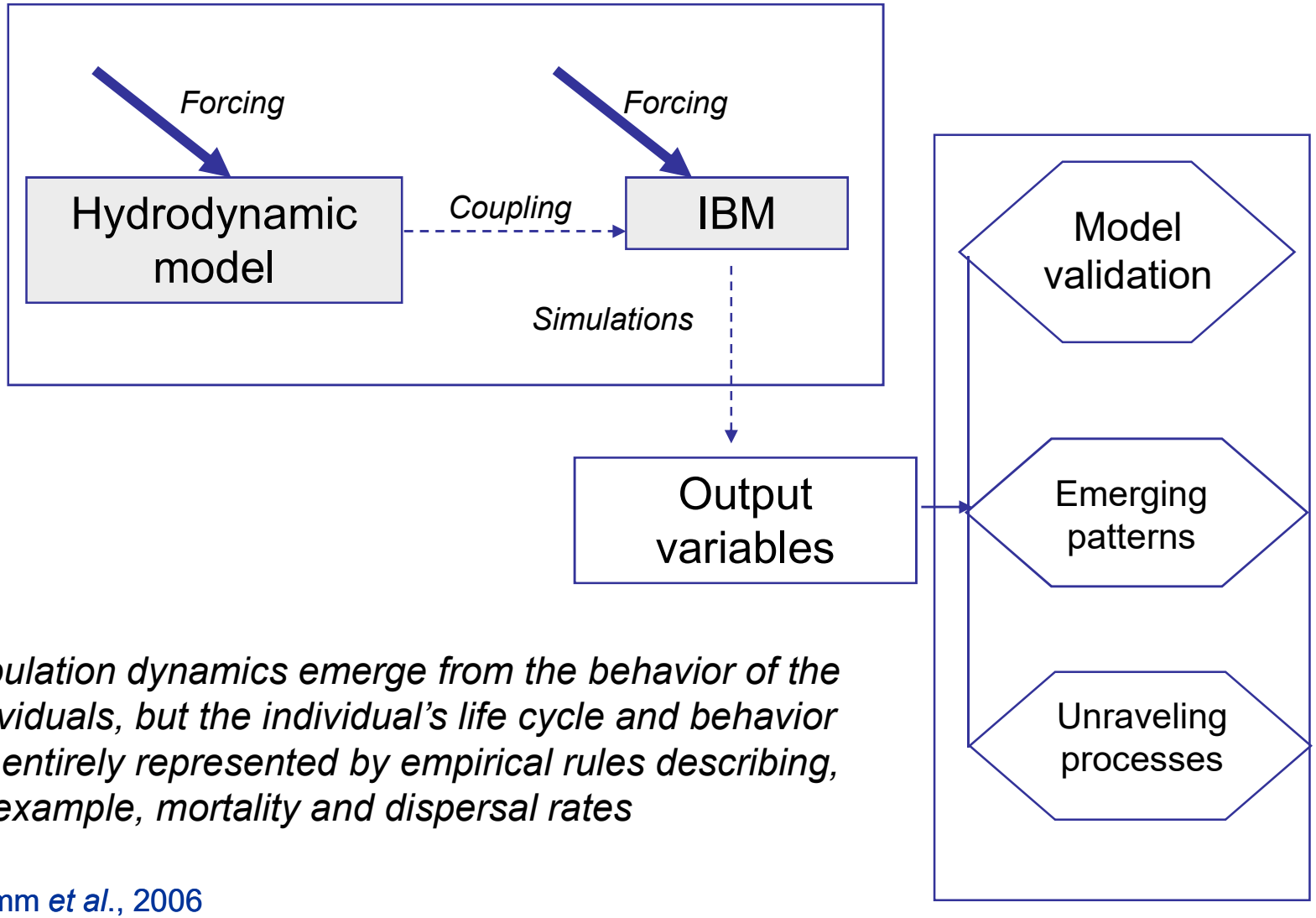


Aims

What are the main atmospheric-oceanographic controllers for the survival of early anchoveta stages and ultimately the success of recruitment? How does environmental variability modulate the spatial pattern of recruitment?

We analyzed simulated patterns of juvenile distribution and paths using a methodological approach that combines numerical and statistical modeling. These analyses aimed to make inferences about the factors affecting anchoveta reproductive success and its relationship to the main environmental drivers involved in early survival.

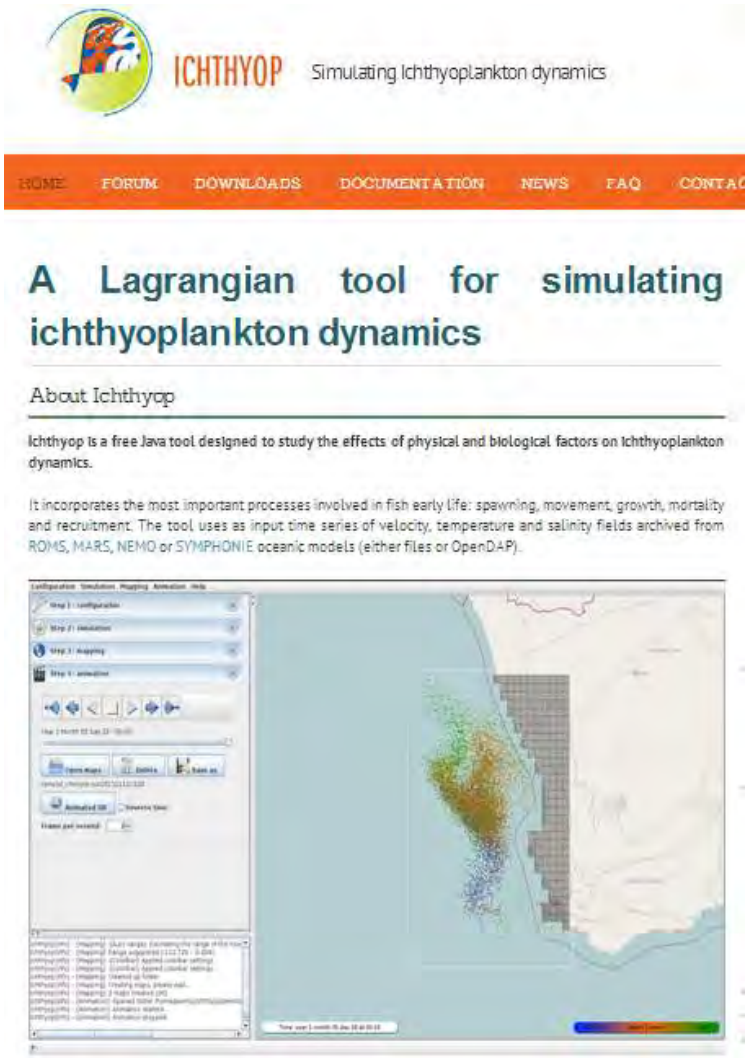
Biophysical modeling



Population dynamics emerge from the behavior of the individuals, but the individual's life cycle and behavior are entirely represented by empirical rules describing, for example, mortality and dispersal rates

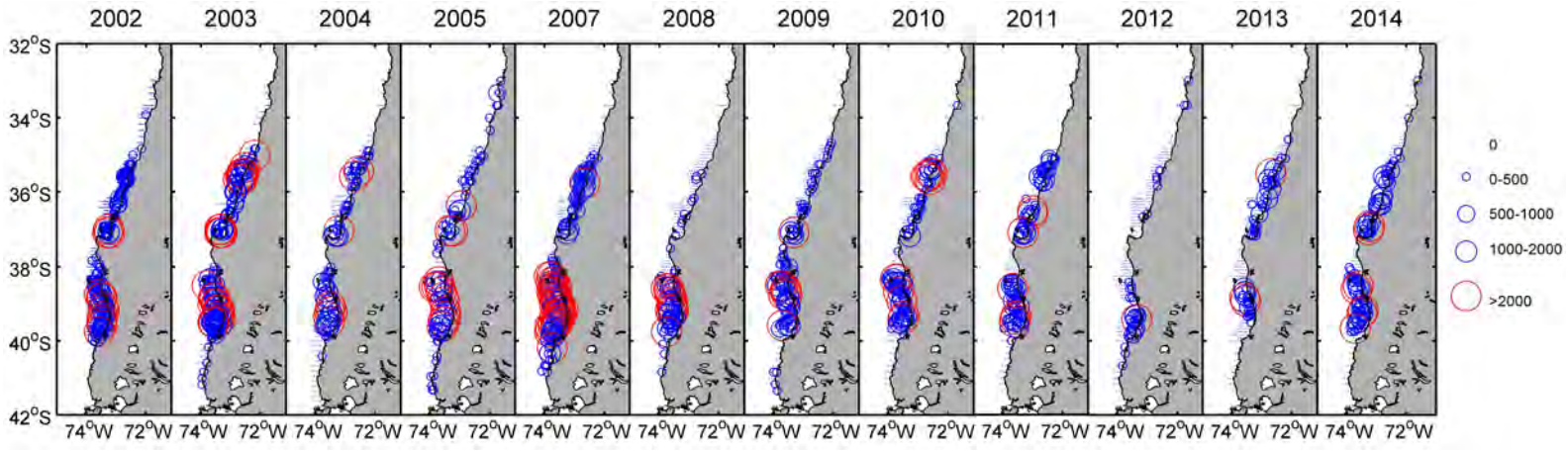
Grimm *et al.*, 2006

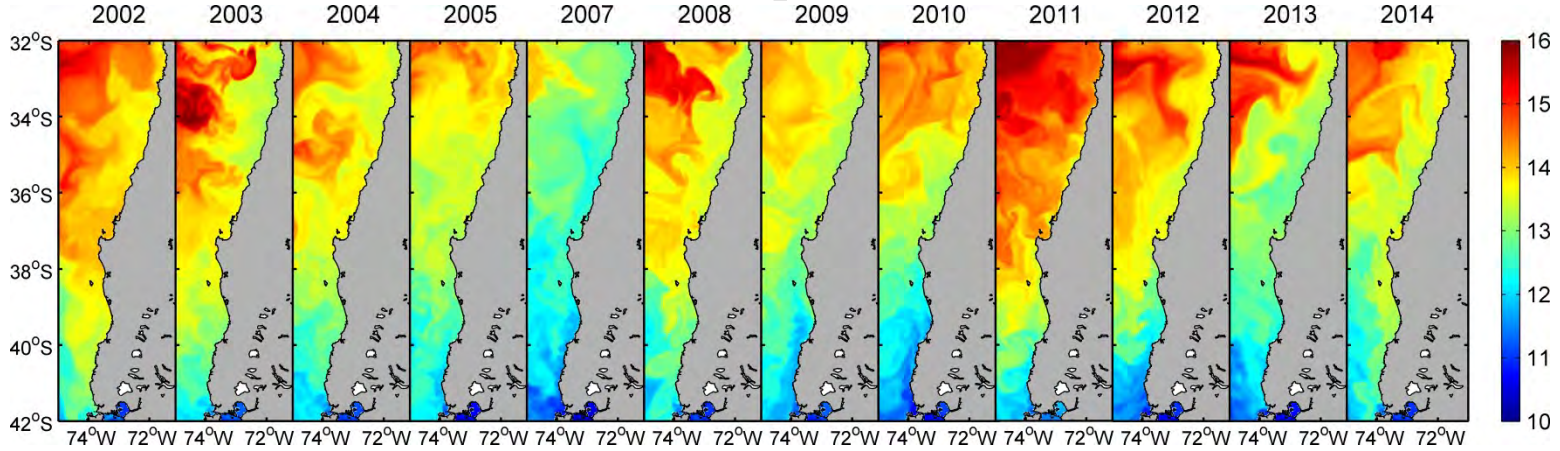
Modeling tool



- Customized version of the open source modeling tool ICHTHYOP (Lett *et al*., 2008)
- Study period: 1994-2014
- Egg buoyancy (Parada *et al*., 2008)
- Diel vertical migration (DVM) scheme structured by length (Ospina-Alvarez et al., 2012)
- Real distribution of eggs (based on egg distribution data from surveys)
- Timing of spawning: based on observed data of the adult fraction
- Temperature-dependent growth scheme (Sepúlveda *et al.*, 2000; Llanos-Rivera, 2005)
- Mortality: temperatures below 9°C for eggs; below 10°C over 20°C for larvae results in either death or severe growth retardation (Sepúlveda et al., 2004).

Spawning distribution

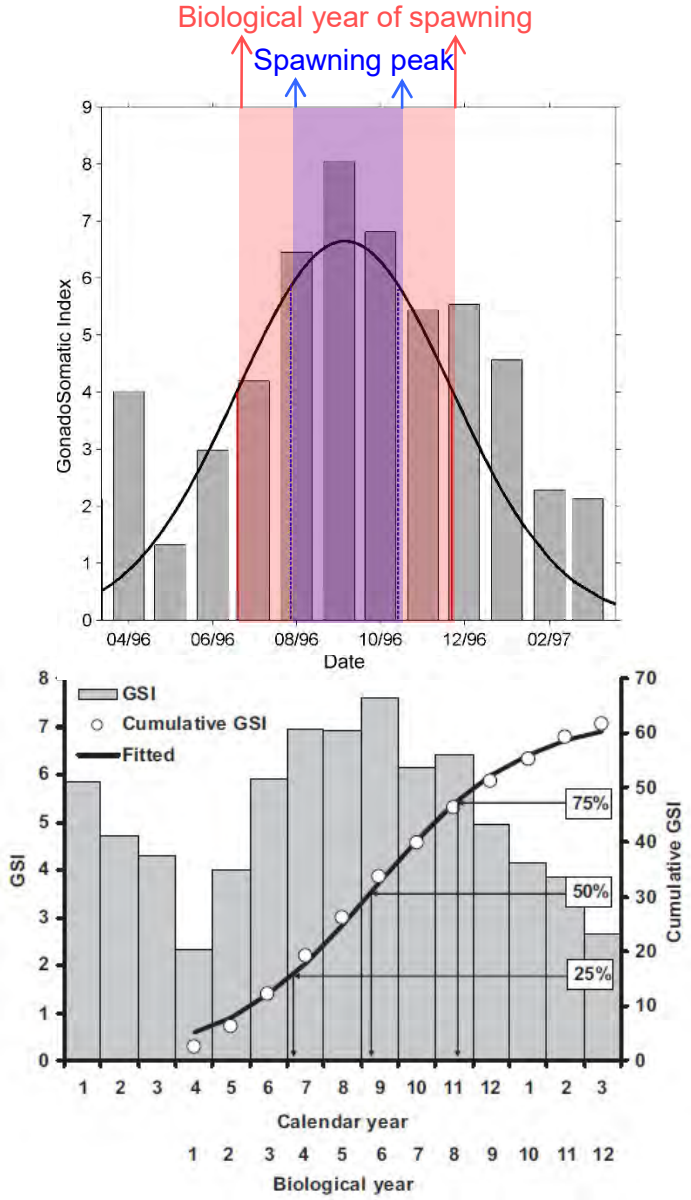




Generalized Additive Model

Bernal et al., 2007

Spawning season



•Cumulative area under the IGS curve as a function of time is consistent with a sigmoid trend.

$$G_t = \frac{a}{1 + e^{b - c \cdot t}}$$

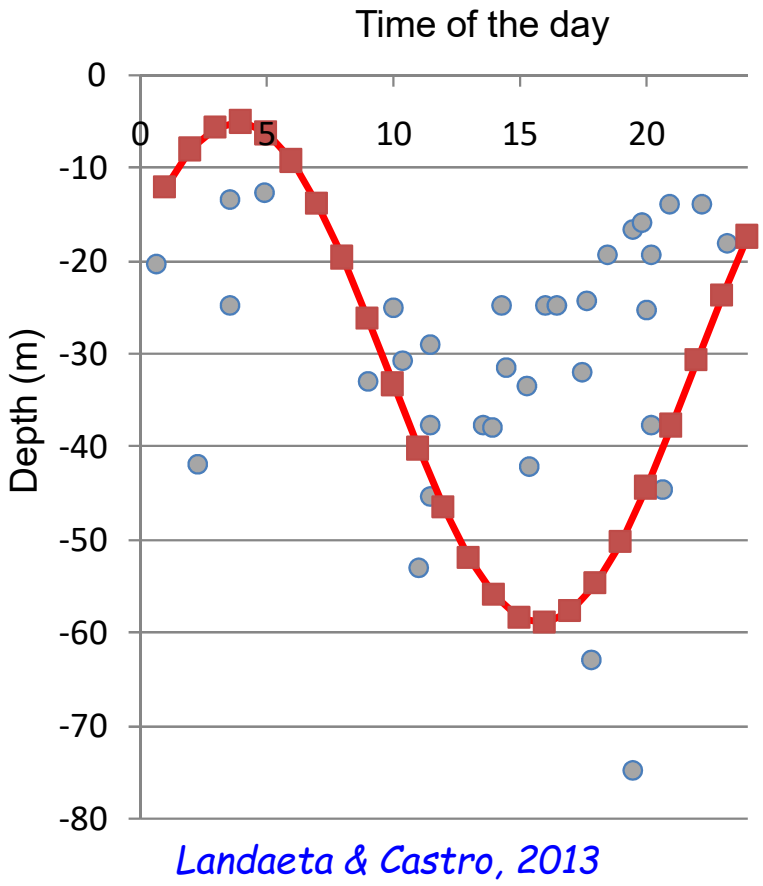
Gt: Area under G at time t, which is a proxy for the number of spawnings. *a*, *b* and *c*: parameters

b: position parameter, such that b / c is the time at which the half of the asymptote is reached and that corresponds to the time at which the maximum is reached (= reproductive peak)

c: related to the rate at which the asymptote is reached

Claramunt et al., 2013

Movement



Landaeta & Castro, 2013

- Density of the egg decreases slightly through its development and ascends slightly towards the surface (positive buoyancy).

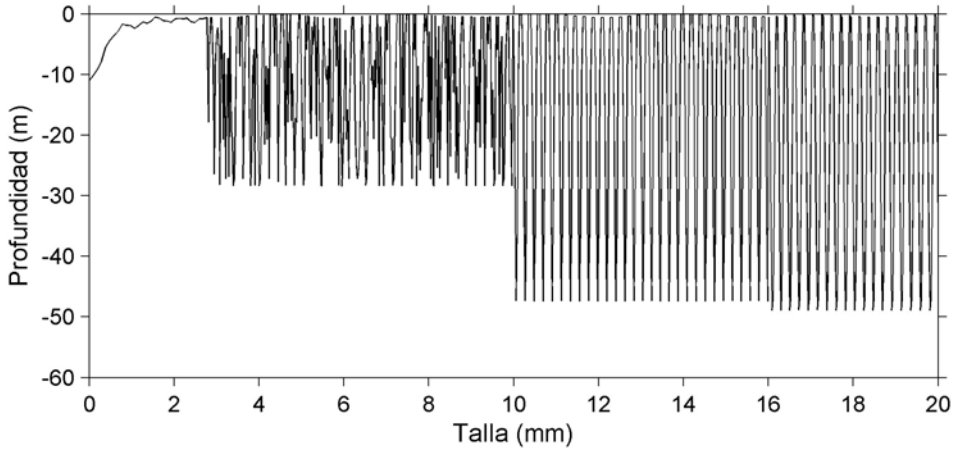
- Hatching: 2.78 mm to 10 mm, do not perform DVM and their vertical movement is random between 0 and 30m.

- Larvae bigger than 10mm always migrate reaching 50m maximum depth until the end of the simulation.

$$x(t+\Delta t) = x(t) + V_u * \Delta t$$

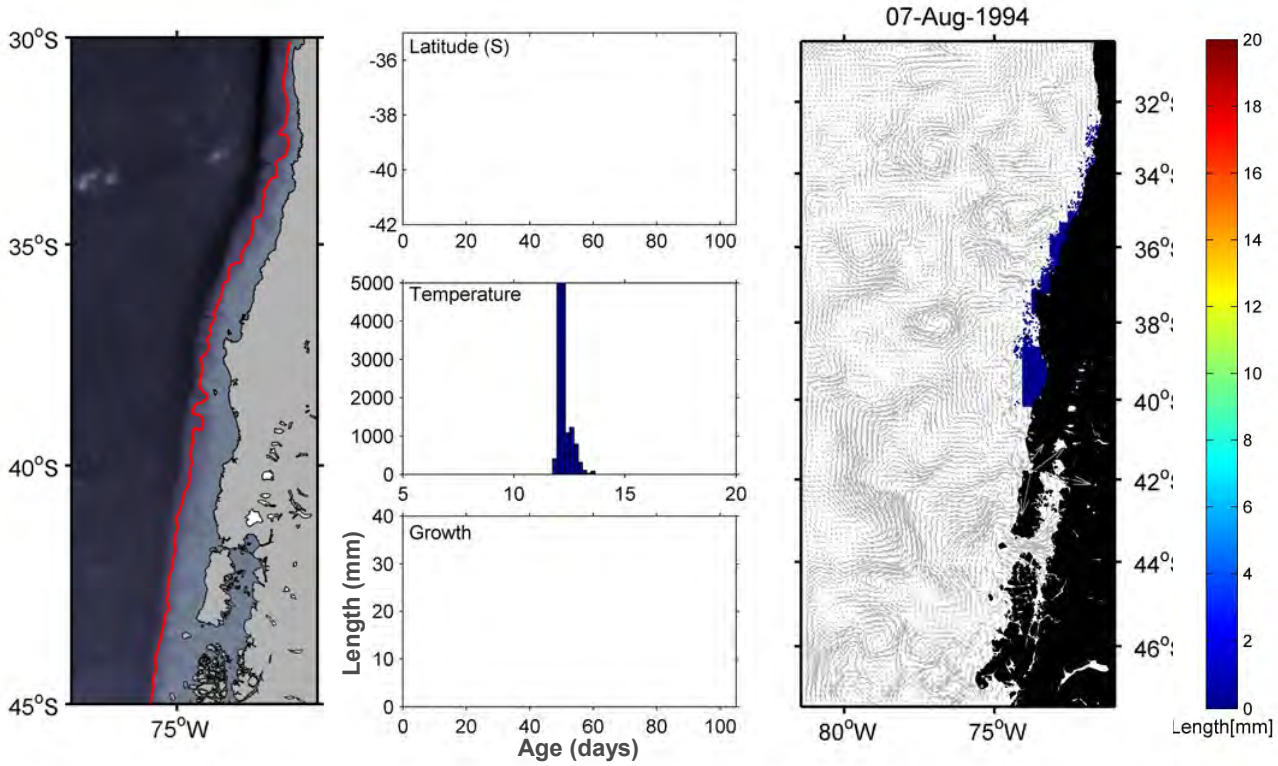
$$y(t+\Delta t) = y(t) + V_v * \Delta t$$

$$z(t+\Delta t) = z(t) + (V_z + V_{buoy}(a) + B(a)) * \Delta t$$



Ospina-Alvarez et al., 2012

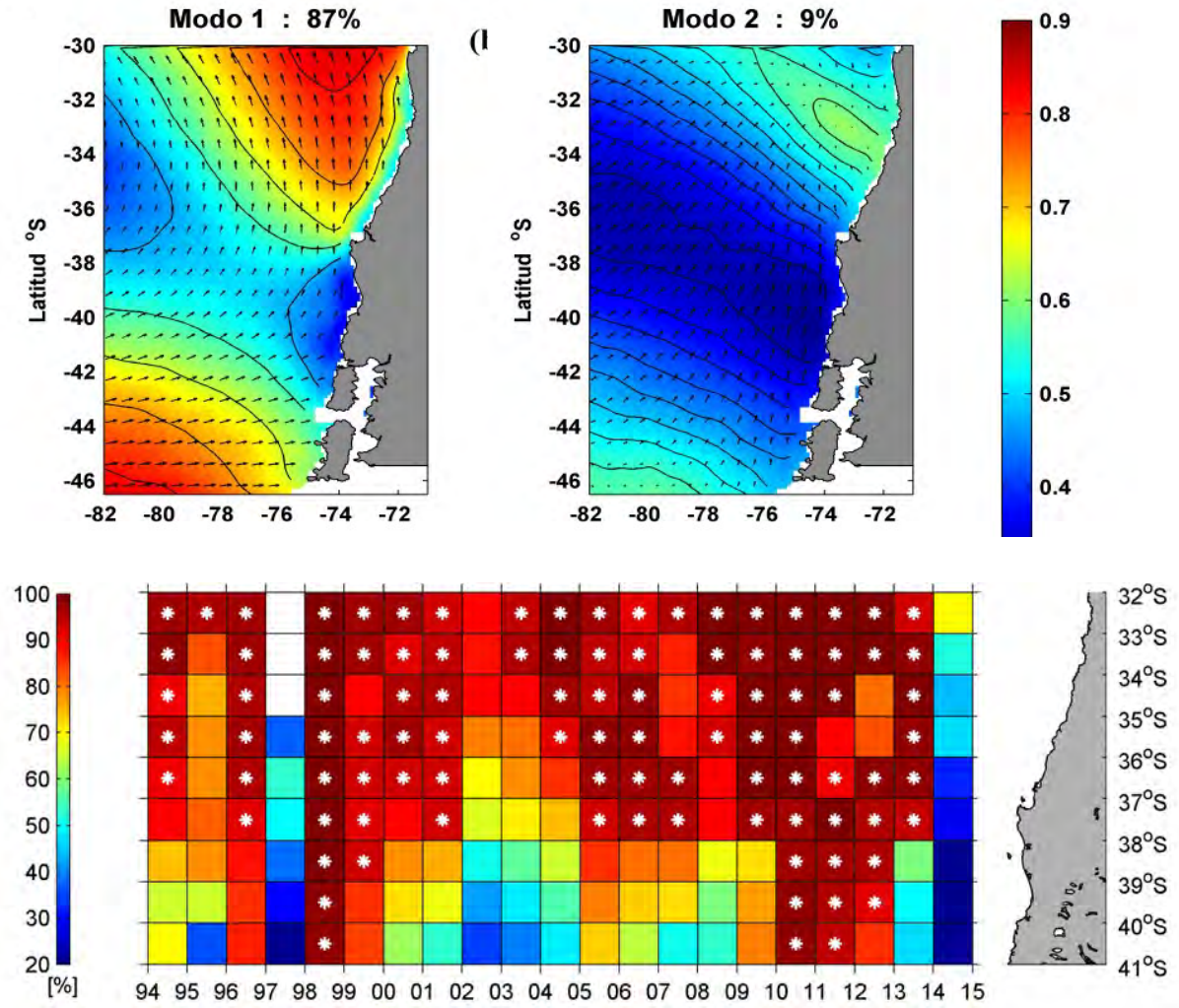
Biophysical coupled model



• For each year of the period 1994-2014, 20,000 individuals were released every 5 days (spawning frequency, Alarcón, 2013). The releases were performed from the beginning to the end of the spawning season. **282 simulations.**

• Survival Criteria: Individuals within the continental shelf that have reached **20 mm** in length (Claramunt *et al*., 2011)

Biophysical coupled model



•The biophysical model showed latitudinal differences in the levels of coastal retention (associated with survival).

•Coastal retention levels revealed marked interannual differences.

•The surface wind pattern reveals a coastal area of lower activity between 38° and 42°S (main spawning area).

• Differences in surface wind impact on the vertical structure of the water column and on the local circulation pattern.

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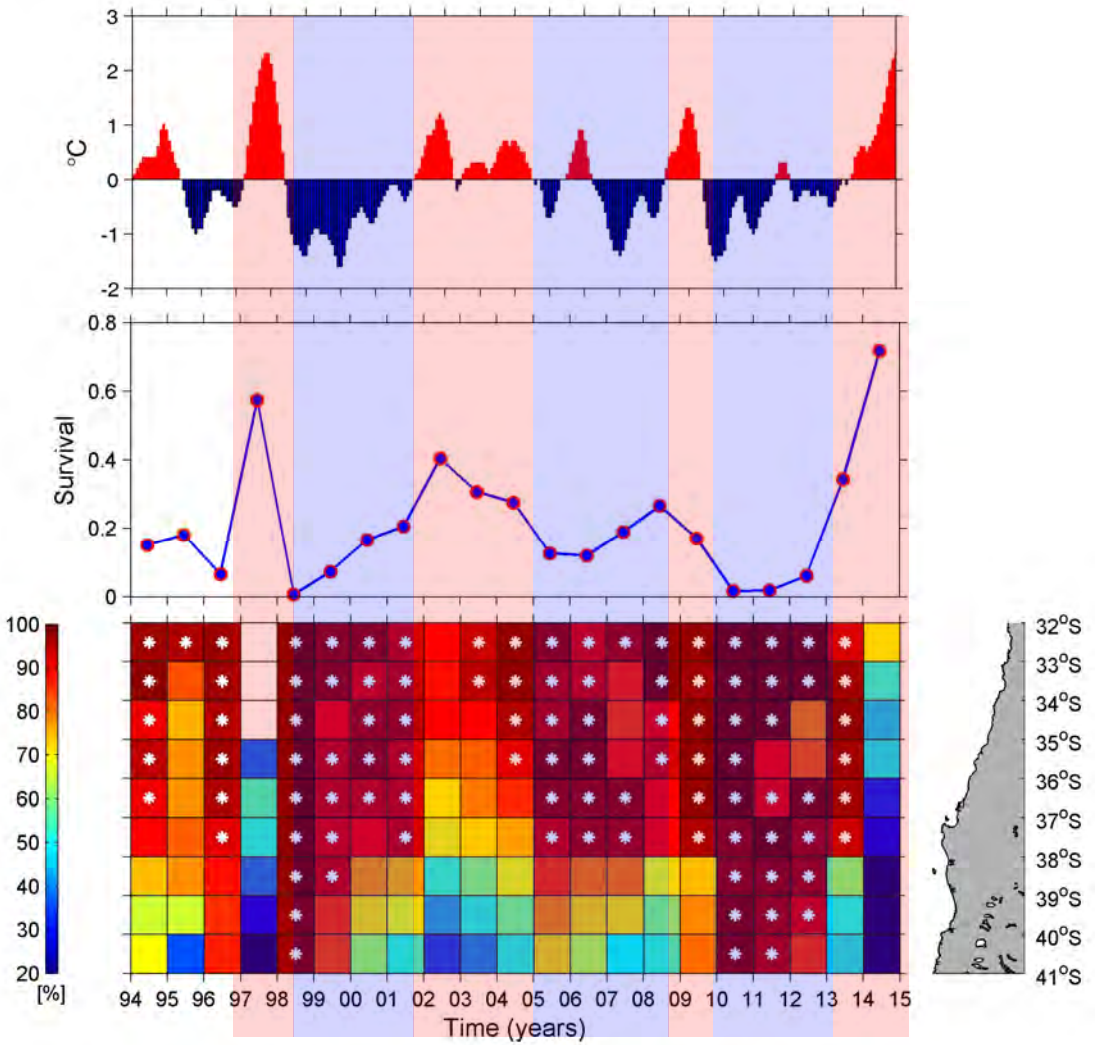

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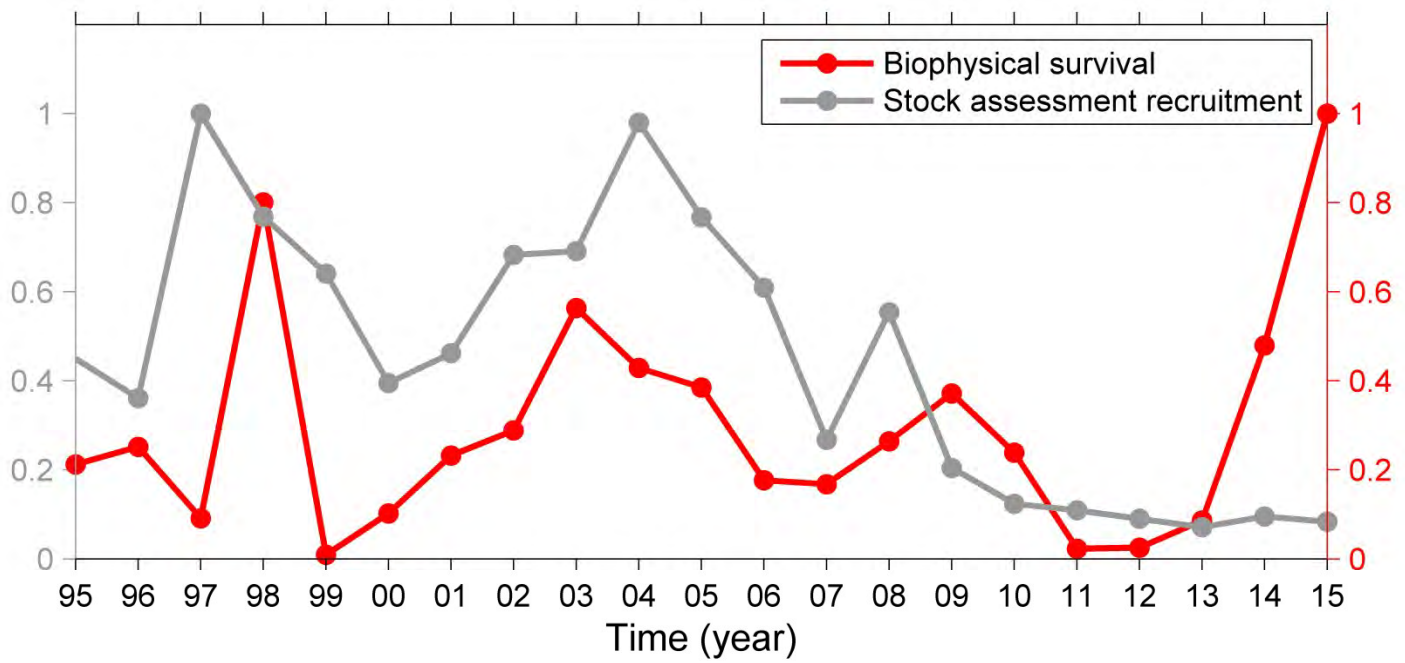
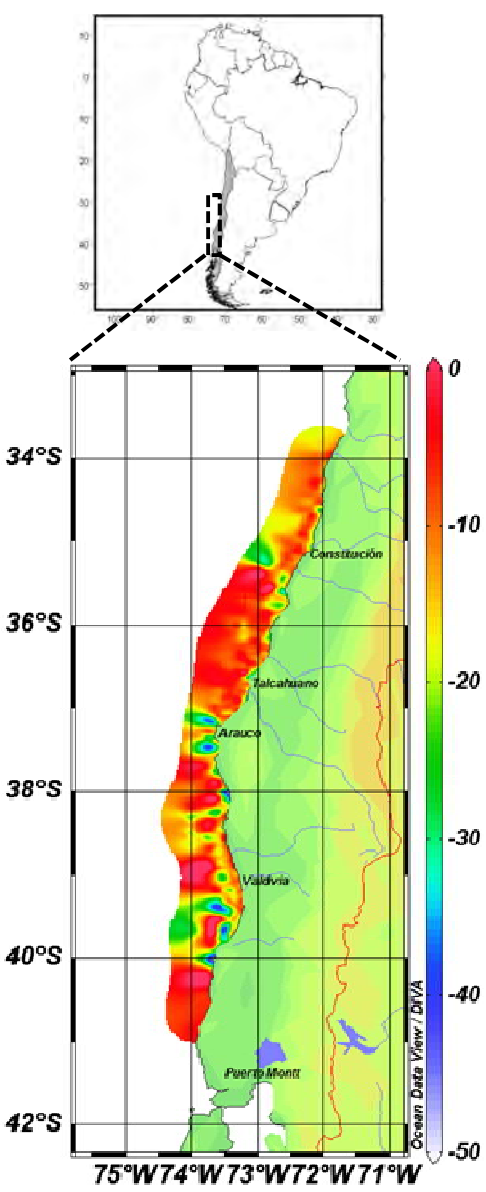
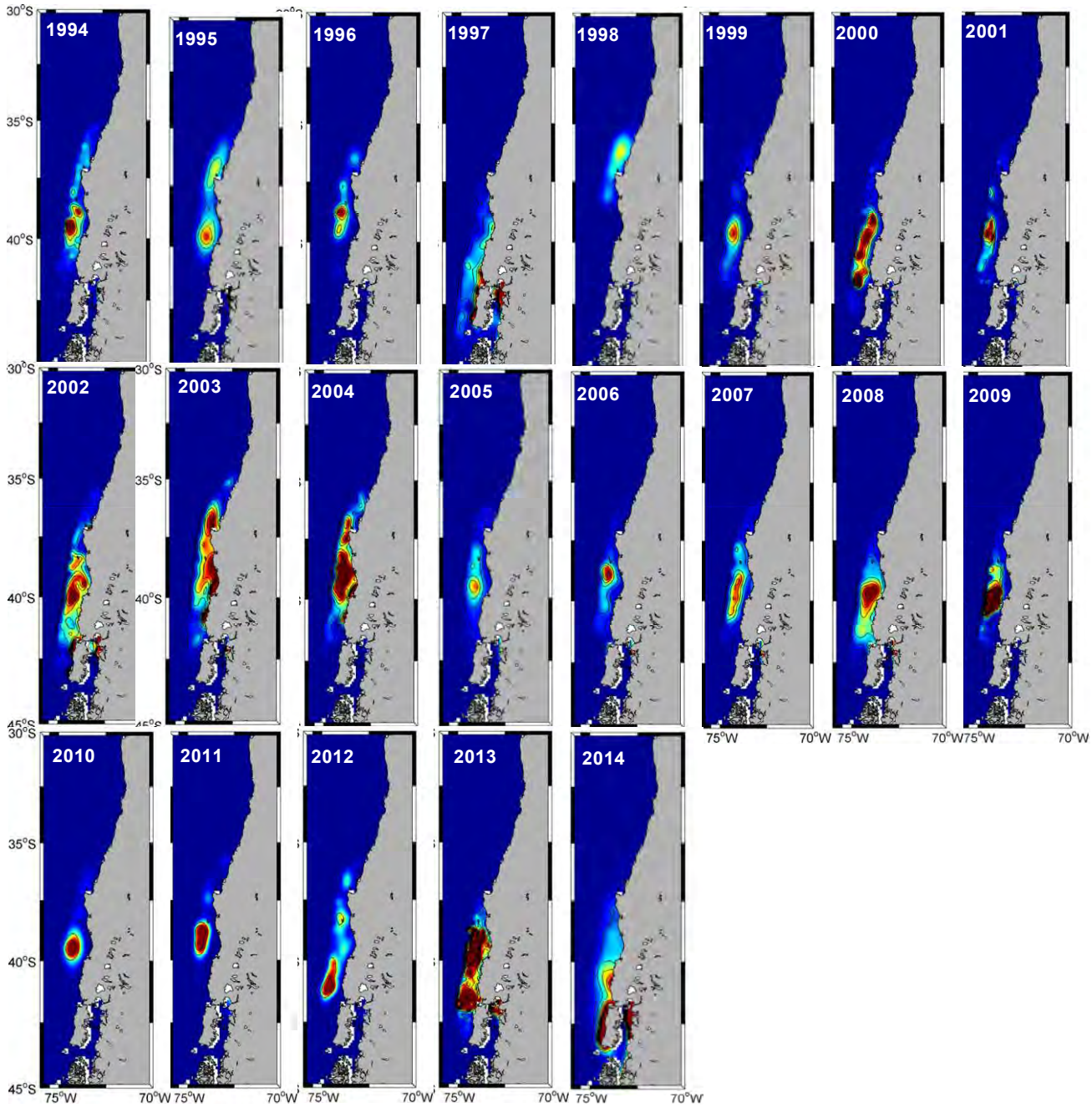
An early indicator of recruitment?



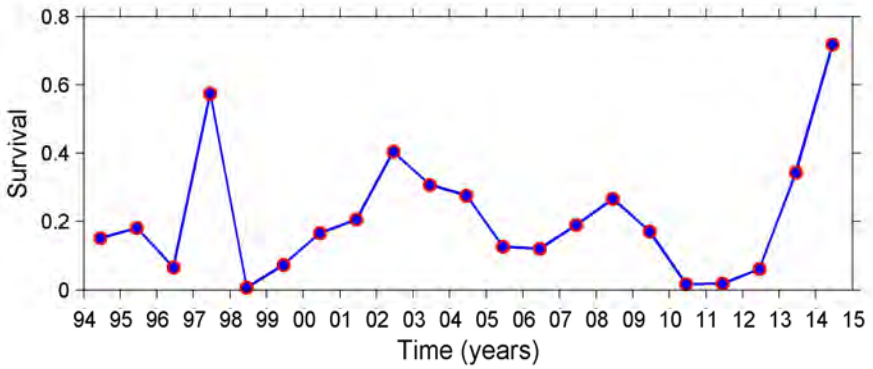
- Pre-recruitment indicator not linked to information from the catches nor correlated a priori with the stock assessment model.
- Integrative indicator of demographic characteristics of the population and environmental variability at different scales.
- Recruitment predictor ability in the year after modeling.
- Ecosystem-based pre-recruitment indicator.
- Spatially explicit pre-recruitment indicator

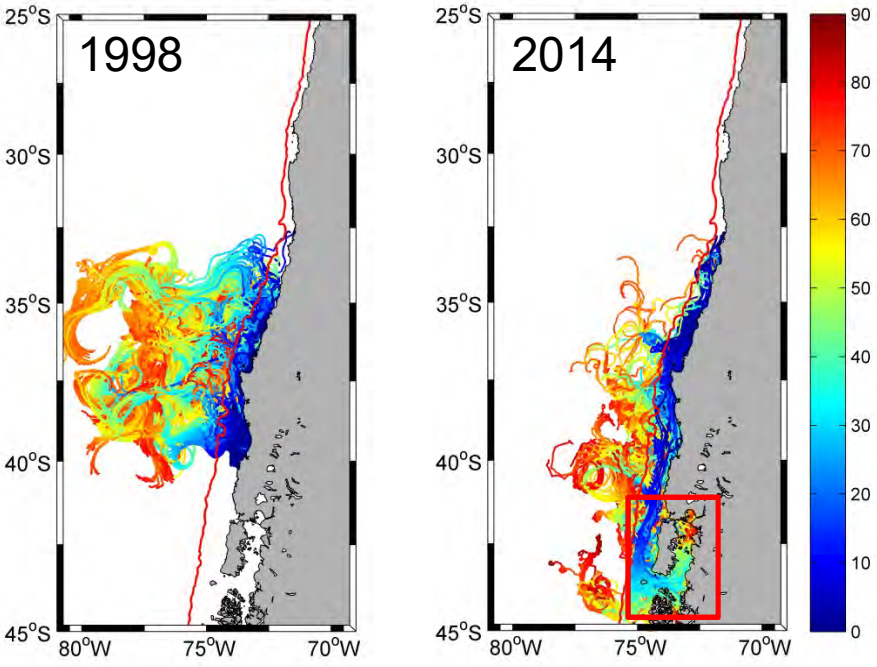
Spatial pattern of recruitment

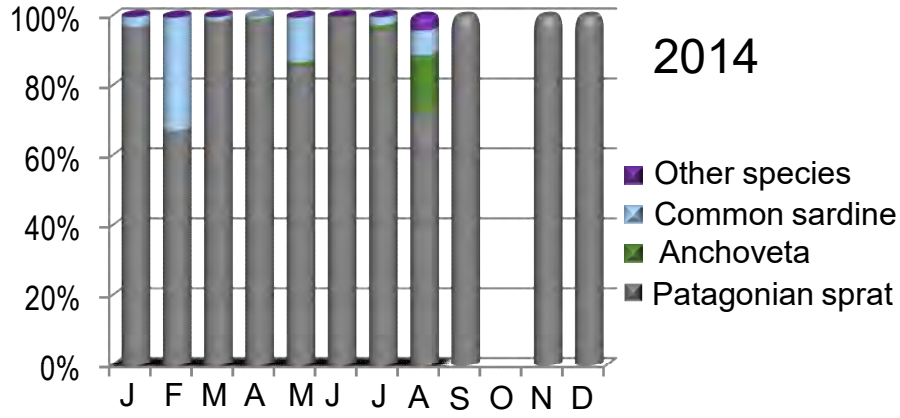


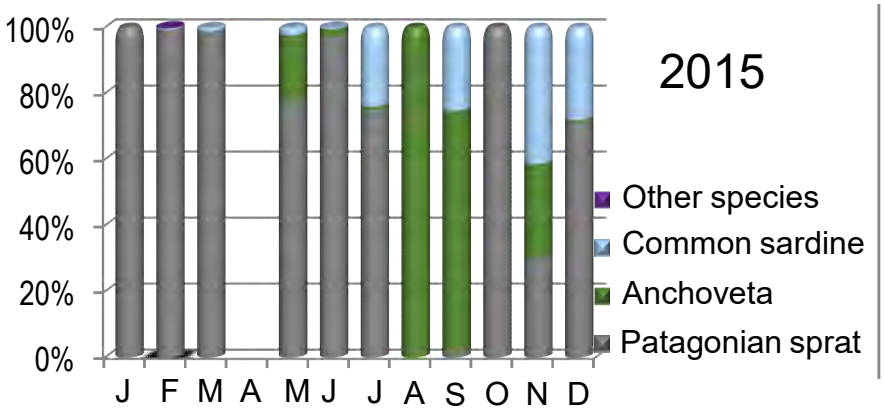


Expanding the anchovy habitat?









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Concluding remarks

- Coastal retention seems to play a major role as a driver of the survival of early anchoveta states.

- The interannual variability of coastal retention levels in central-southern Chile could be linked to larger-scale atmospheric and oceanographic changes (i.e. El Niño).

- The modeling of the early life history of the anchoveta provides early signs of recruitment under an operational scheme.

- Under extreme El Niño events the anchoveta connectivity patterns change, suggesting a southward extension of its distribution reaching fjord and estuary ecosystems.

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Thank you!

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