Effects of spawning patterns and larval mortality on survival to the juvenile stage: a modelling analysis on the anchovy population of the Bay of Biscay.

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Introduction

Fish populations show complex life cycles with successive dependent life stages, the spatio-temporal patterns of distribution at one stage impacting distribution, growth and mortality during the next stage. Here we propose to assess the relative effect of spawning (timing, duration, fecundity and spatial distribution, resulting from adult environmental conditions over autumn and winter) and larval mortality on the resulting survival at the age of metamorphosis.

We used a suite of models run sequentially :

- a coupled physical-biogeochemical model to provide the environmental forcing,
- a Dynamic Energy Budget (DEB) model for adult fish growth and reproduction (spawning timing, duration and fecundity),
- an Individual Based Model (IBM) for larval drift, growth and survival.

The experiment setup

- a simulation starts in September 1st with a 8 cm individual,
- the DEB model is run over one year with spatial-averaged environmental forcing of two distinct areas (see coloured areas of Fig. 2),
- the DEB model is run in 0-D
- the DEB model provides spawning timing and fecundity,
- the larval IBM is run for thousands of particles released in zones 1 and 2 (Fig. 2) every two weeks over the spawning season, April to August,
- 12 years (1996-2007) are simulated.

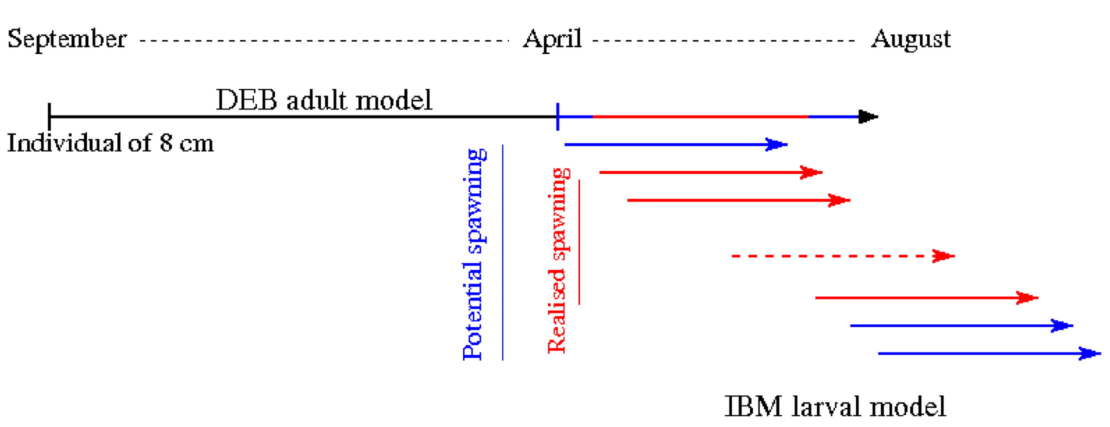

Figure 1: Schematic represention of the experiment with the two successive models. In blue the potential spawning, in red the realised spawning as determined by the adult DEB model.

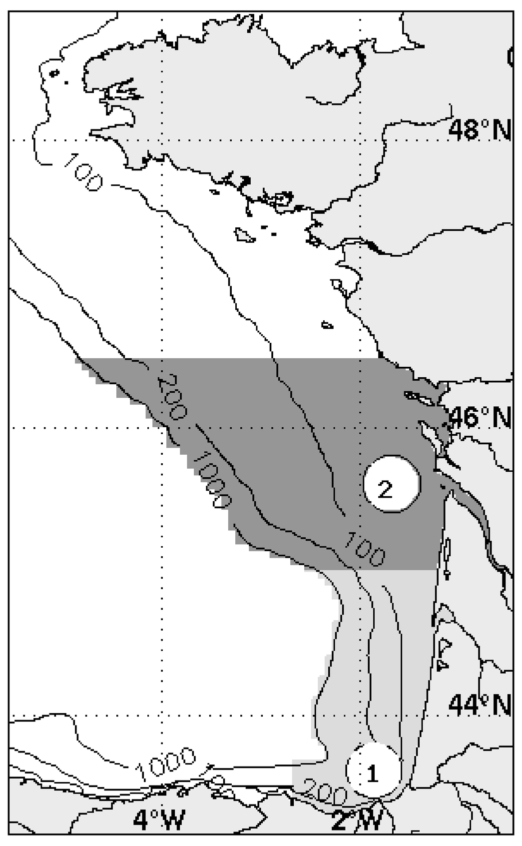

Figure 2: The two zones (in colour) over which environmental conditions are averaged to force the DEB, with corresponding release areas for the larval IBM model.

The adult DEB model for reproduction

The standard model of the DEB theory (Kooijman, 2000) describes the rate at which the organism assimilates and utilizes energy for maintenance, growth and reproduction. This model is based on the κ-rule which states that a fixed fraction k is allocated to somatic maintenance and growth, with priority for maintenance while $1-\kappa$ is allocated to gonadic development during the juvenile stage and reproduction and maturity maintenance during the adult stage.

Pecquerie *et al.* (2009) developed a DEB model for the anchovy of the Bay of Biscay to investigate what controls the variability in its spawning. Temperature and primary production from our coupled physical-biogeochemical model (Huret *et al.* 2007) are forcing variables to the anchovy bioenergetic model.

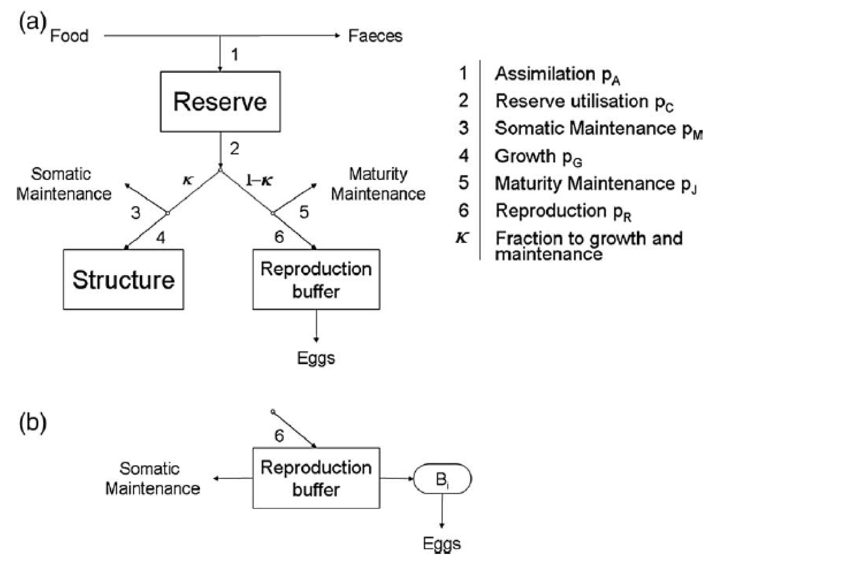

Figure 3: (a) Energy fluxes through an individual at the adult stage following DEB theory and (b) specific handling rules of the reproduction buffer (Pecquerie *et al.* 2009): somatic maintenance can be paid from the reproduction buffer if $\kappa p_C - p_M < 0$ and energy is allocated from the reproduction buffer to the successive batches of eggs located in the gonads during the spawning season (the i^{th} batch is represented).

The larval growth and survival model

A Langrangian particle tracking module is coupled to the MARS hydrodynamic model (Lazure and Dumas, 2009). An IBM of larval growth and survival, based on otolith daily ring analysis following Allain *et al.* (2007), relates otolith growth rate to age and temperature (Fig. 4), with a mortality model based on observed minimum growth rates at age (Fig. 5).

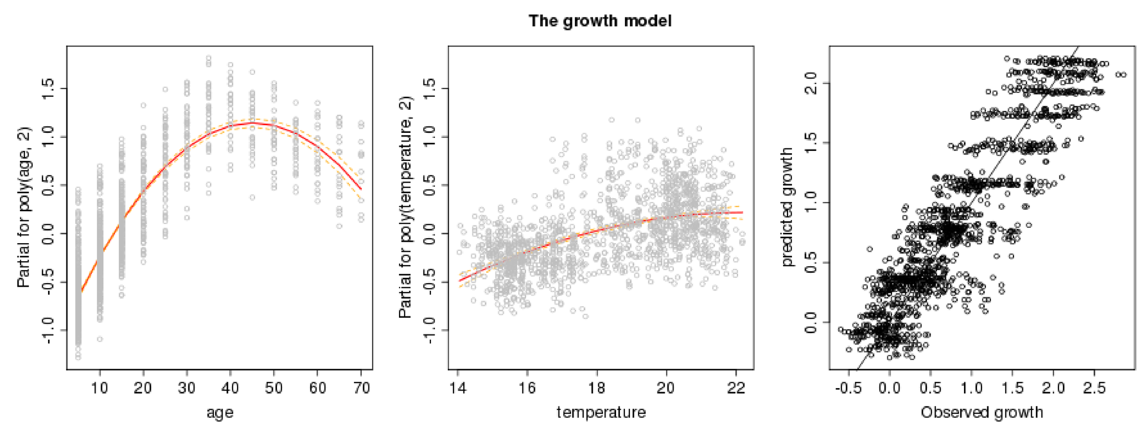

Figure 4: The partial responses of the GLM linking otolith growth rate with age (left) and temperature (middle). Predicted versus observed growth rate (right).

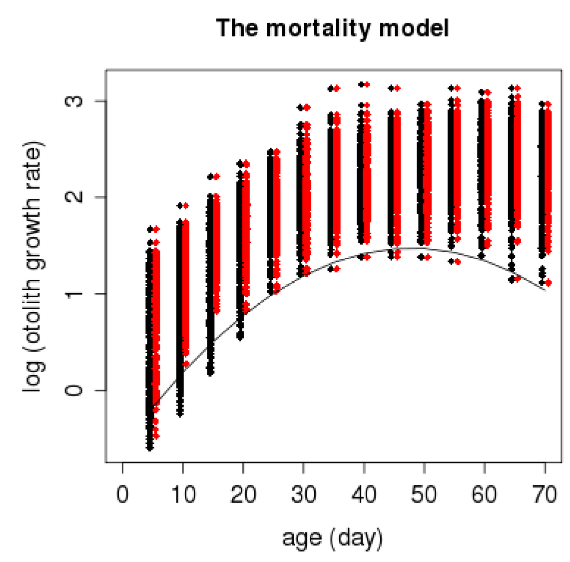

Figure 5: At each age (A), the minimum growth rate of survivors at age A+10 (red) among a pool of individuals (black) is calculated. Black line is fitted curve to the successive minimum growth rates.

Results

Zone 1

Zone 2

Survival from potential spawning

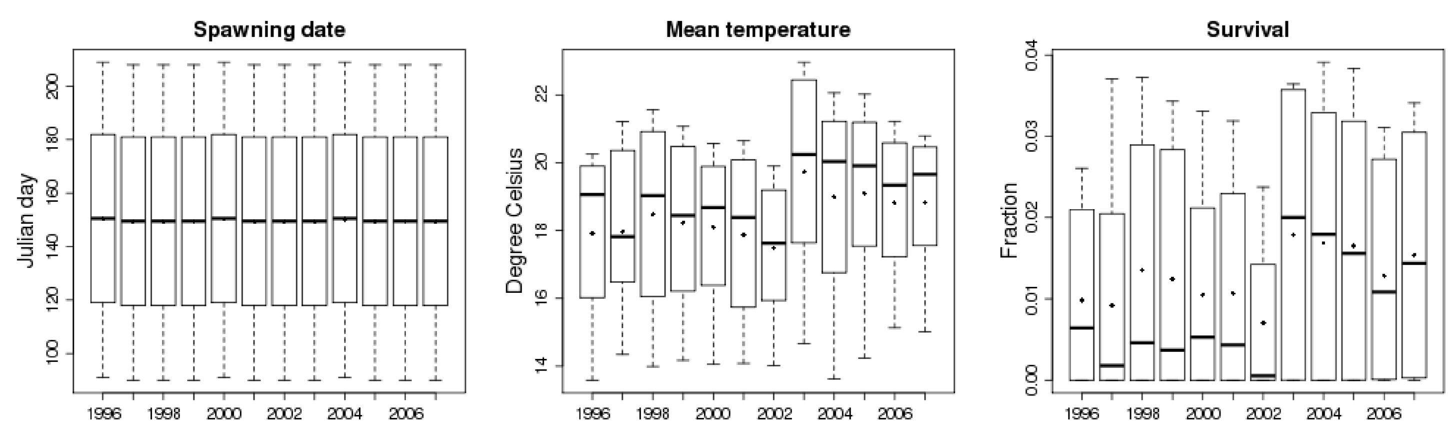

Figure 6: Box-plots of the spawning dates, mean temperature along the trajectories during larval development, and survival rates. Statistics are calculated for releases in spawning area 1 over the whole potential spawning season.

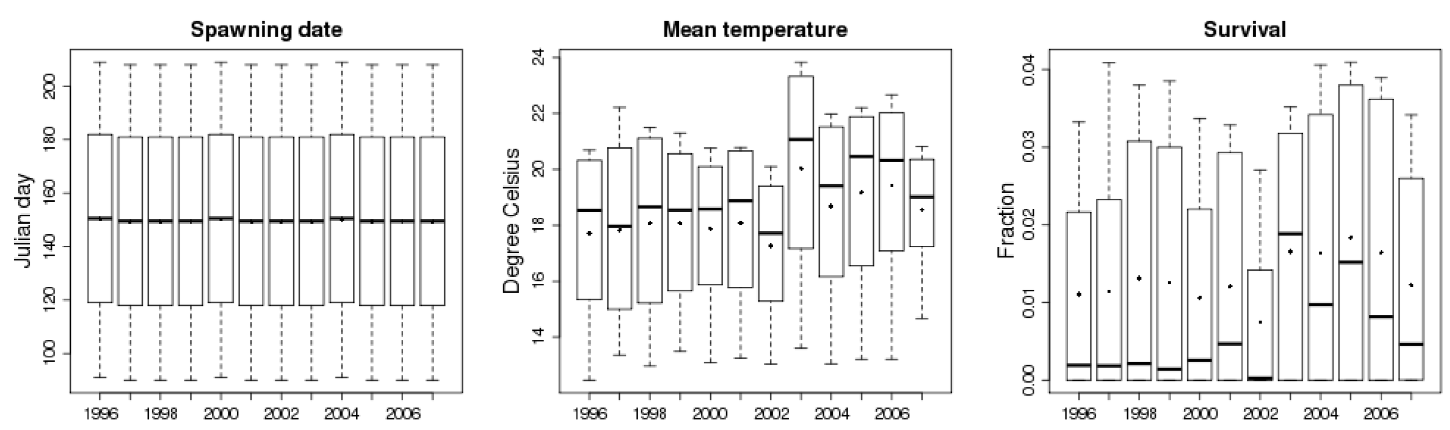

Figure 9: Same as Fig. 6 for spawning in zone 2.

Survival from realised spawning (i.e. resulting from the adult DEB model)

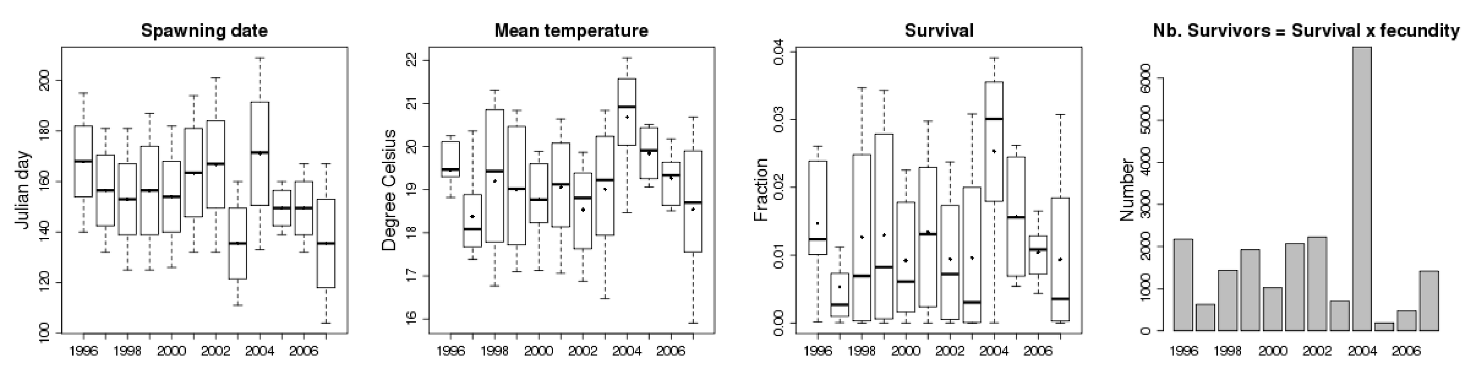

Figure 7: Box-plots of the spawning dates, mean temperature along the trajectories during larval development, survival rates and number of survivors. Statistics are calculated for releases in spawning area 1 over the spawning season resulting from the adult DEB model. Number of survivors is the product of survival by the fecundity given by the DEB.

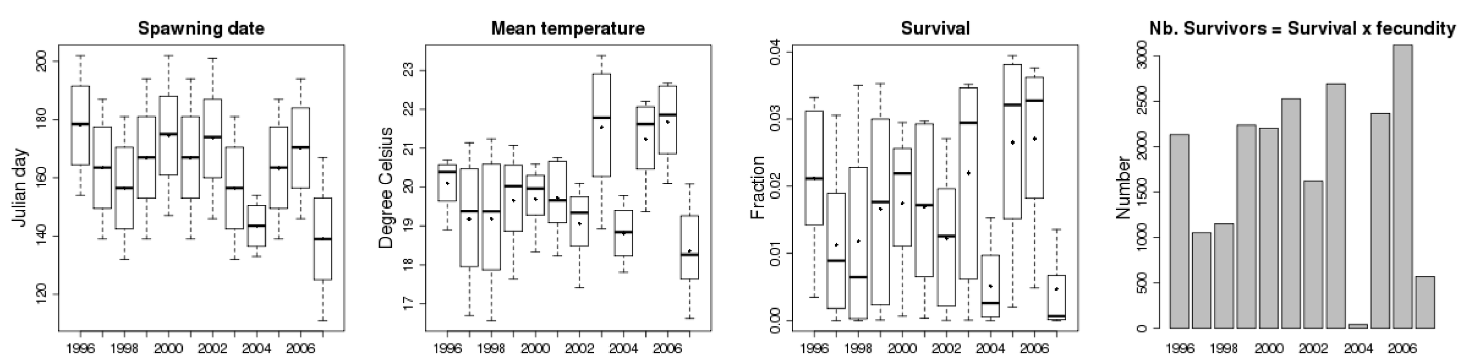

Figure 10: Same as Fig. 7 for spawning in zone 2.

- Mean temperature during the larval development season highest in 2003 (Fig. 6),
- Potential survival rate highest in 2003 (Fig. 6),
- Realised spawning simulated earlier in 2003 (Fig. 7),
- Mean temperature during the realised larval season lower in 2003 than 2004 (spawning earlier), leading to a lower survival (Fig. 7),
- Number of survivors very low in 2005 despite a quite good survival rate (Fig. 7). Due to the low fecundity,
- Earlier spawning in 2003 than 2004 gives higher retention on-shelf (Fig. 8).

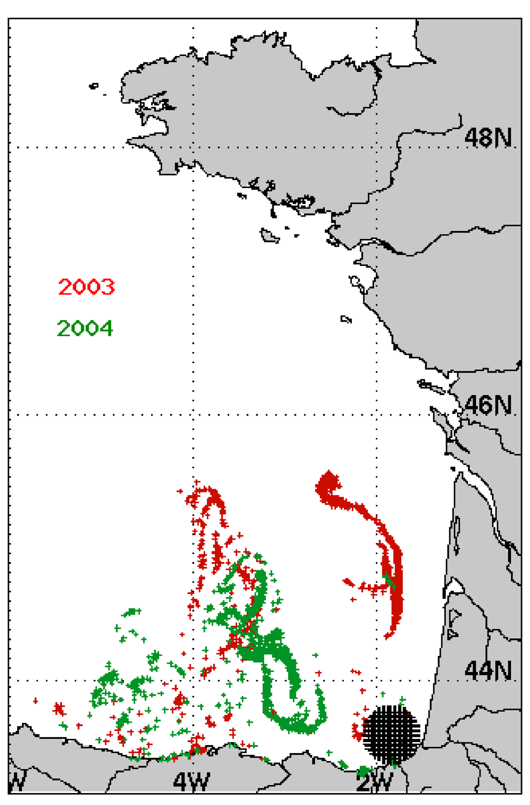

Figure 8: Distribution of particles at 60 days from releases at peak spawning of zone 1 for 2 contrasted years.

Test of the effects :
Number of survivors = N $\sim$

fecundity R^2=0.61 ***
realised survival R^2=0.47 ***
spawning duration R^2=0.42 ***
mean spawning date R^2=0.35 ***
first spawning date R^2=0.03
potential survival R^2=0.0

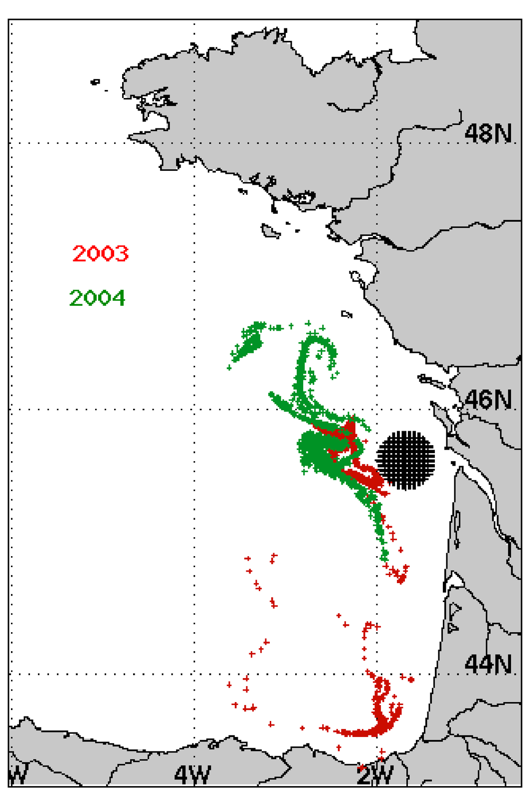

Figure 11: Distribution of particles at 60 days from releases at peak spawning of zone 2 for 2 contrasted years.

- Only slight changes in interannual variability of potential survival between zone 1 and 2 (Fig. 9 and 6),
- Realised spawning later than in zone 1 (Fig. 10 and 7),
- Realised spawning simulated earlier in 2004 (Fig. 10).
- Mean temperature high in 2003, 2005 and 2006 during the realised larval season (Fig. 9), with good survival rates for these 3 years,
- Drift to the south in 2004 (earlier spawning) and to the north in 2003 (Fig. 11).

Conclusions - Future work

- Factors acting at both the adult and larval stages have an impact on the resulting survival at metamorphosis
- Fecundity and spawning phenology have dominant effect on this survival
- Non-linear responses due to uncoupling between phenology, drift patterns, and winter-adult vs. spring-larval environmental conditions
- Integration of spatial dynamics for the adult individuals
- Improvement of the mortality formulation in both the DEB and larval IBM
- Similar study with climate change scenarios to assess the response over the life cycle

References

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