Colour Plate Legends

Plate 1: A snapshot (18 November 1991) of the simulated suitable spawning area for anchovy. Areas suitable for spawning are highlighted in white. See contribution by Roy *et al*., "Investigation of interannual dynamics of suitable spawning habitat for anchovy (*Engraulis encrasicolus*) in the southern Benguela using a 3D hydrodynamical model", for details see page 4.

Plate 2: Overlays of predicted (from a multivariate model that used single parameter quotient curves applied to satellite-derived observations of SST, ocean colour and wind speed, and water depth) and observed (from CalVET net samples) spawning habitats of anchovy in the southern Benguela in November 2000. See contribution by Drapeau and van der Lingen, "Predicting spawning habitat location of anchovy and sardine in the southern Benguela using remotely-sensed data", for details see page 6.

Plate 3: Average relative abundance of eggs spawned from 1999 to 2002 for anchovy (left) and for sardine (right). See contribution by Sagarminaga *et al*., "Characterization of the anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) spawning habitats in the Bay of Biscay from the routine application of the annual DEPM surveys in the southeast Bay of Biscay", for details see page 9.

Plate 4: The spatial distribution of anchovy length in the southern Bay of Biscay based on data collected during the period 1983-2002. From Petitgas *et al.*, (2003). Overlaid is the distribution of probability of presence of river plume water, as defined in Planque *et al.*, (2003). See contribution by Planque *et al*., "Tentative approaches to describe anchovy and sardine spawning habitats in the Bay of Biscay", for details see page 14.

Plate 5: Spatial distribution of eggs abundance (eggs/0.05m^2) of anchovy and common sardine in the central zone and southern sector of the study area in central Chile. See contribution by Cubillos *et al., "*Spawning, daily egg production and spawning biomass of common sardine, *Strangomera bentincki*, and anchoveta, *Engraulis ringens*, off central south Chile in 2002", for details see page 23.

Plate 6: Distribution of blue mackerel eggs along southeastern Australia during October 2003. Mean SST images from sampling periods were provided by CSIRO Marine Research, Hobart. See contribution by Neira *et al*., "Synthesis of early life-history dynamics and spawning habitat characterization of small pelagic fishes in south-eastern Australia: past and current research", for details see page 32.

Plate 7: Yolk sac length/ total length (R_1), at temperatures between 18 and 10°C. It is observed that the development time from hatching (age) is temperature dependent. See contribution by Riquelme *et al*., "A temperature-dependent model of yolk sac larval development and the effects of the addition of yolk sac larvae data on the estimations of P_0 in the DEPM", for details see page 55.

Plate 8: Distribution maps of anchovy *Engraulis encrasicolus*, sardine *Sardinops sagax* and round herring *Etrumeus whiteheadi*, eggs by stage category. See contribution by Dopolo *et al*., "Fine scale spatial variation of pelagic fish eggs in relation to ontogenetic variation over the Western Agulhas Bank, South Africa", for details see page 59.

Plate 9: Spatial distribution of Pacific sardine, anchovy and jack mackerel and sea surface temperature off California in 1998, 1999 and 2003 surveys. See contributions by Barbieri *et al*., "Spatial spawning strategy of jack mackerel (*Trachurus symmetricus murphyi*) off the central-south region of Chile", for details see page 73.

Plate 10: Spatial models of a) Spawning fraction, b) female weight, c) egg production and d) SSB estimates. The colors represent the fitted values, with dark blue means the lower values and red is the larger value. Circles represent the observations, with circle size proportional to the observed values. On panel d), the circles represent acoustic energy from the Portuguese survey (data from the Spanish survey was not available for this work). See contribution by Bernal *et al*., "Applying new statistical tools to improve DEPM-based estimates of spawning biomass of Ibero Atlantic sardine (*Sardina pilchardus*, Walb.)", for details see page 94.

Plate 1

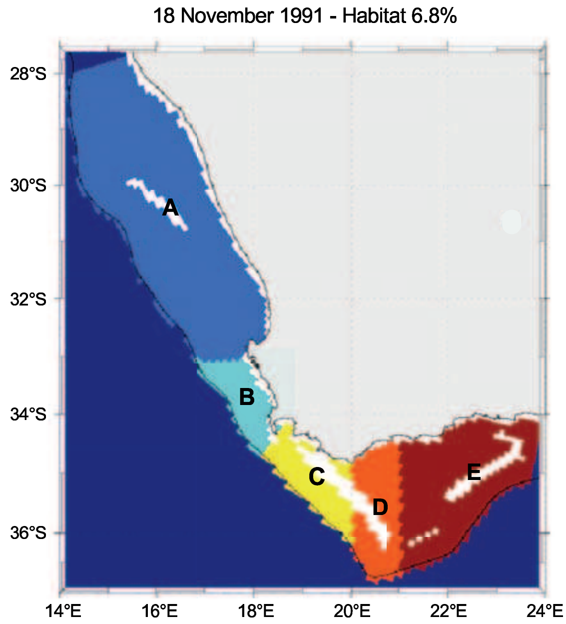


Plate 2

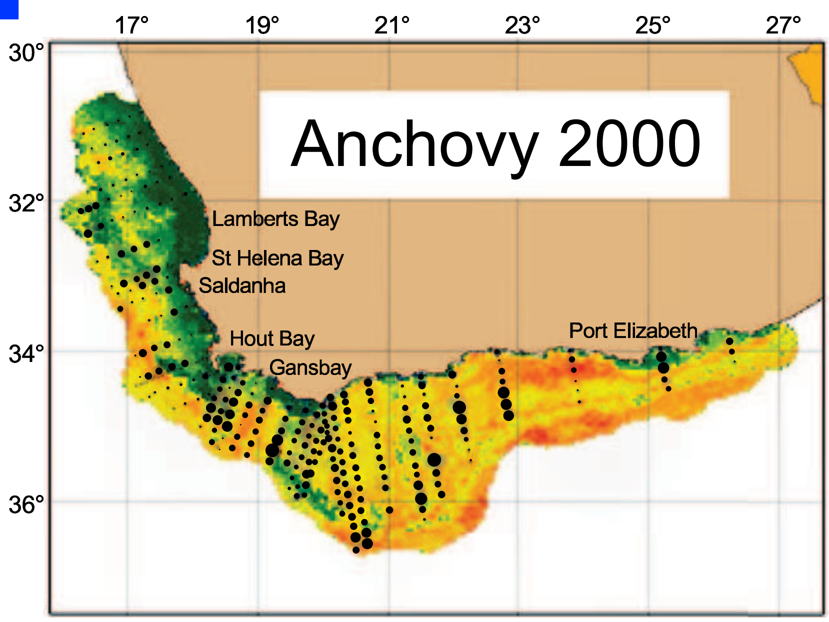
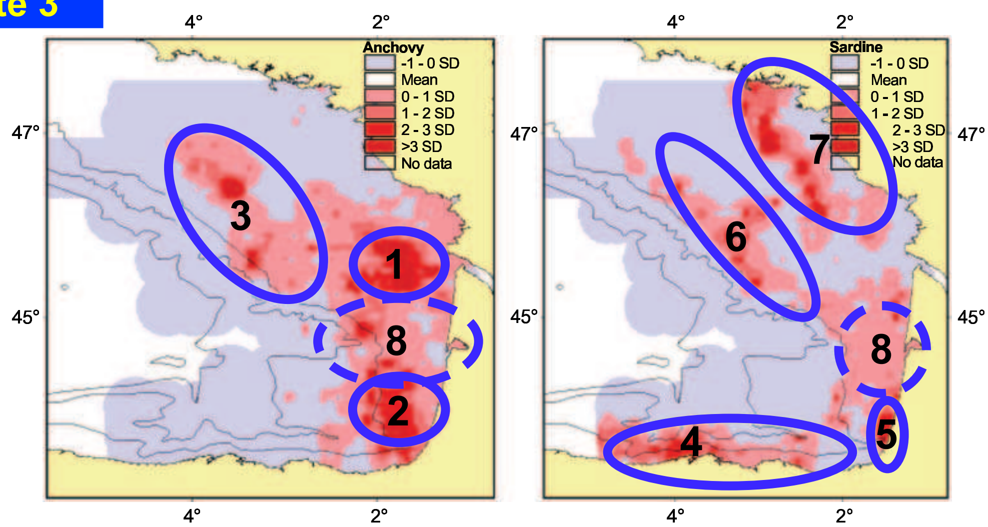


Plate 3



INVESTIGATION OF INTERANNUAL DYNAMICS OF SUITABLE SPAWNING HABITAT FOR ANCHOVY (*ENGRAULIS ENCRASICOLUS*) IN THE SOUTHERN BENGUELA USING A 3D HYDRODYNAMIC MODEL

Claude Roy[1], Pierric Penven[1] and Carl D. van der Lingen[2]

[1]Centre IRD de Bretagne, 29280 Plouzané, France.

[2]Marine and Coastal Management, Pvt Bag X2 Rogge Bay 8012, South Africa.

Environmental characterization of the spawning habitat of anchovy in the southern Benguela through single parameter quotient analysis has identified ranges of environmental variables within which this species "prefers" to spawn (Twatwa *et al.*, 2004). The objective of this work is to test the potential of using simulations from an hydrodynamic model as a surrogate for direct measurements of the physical environment to explore the interannual variability of the potential anchovy spawning habitat. Once validated, it is thought that this approach could provide a methodology to diagnose the impact of future climate change on anchovy spawning habitat.

A ten year simulation (1991 to 2000) of the physical environment of the southern Benguela has been produced using an hydrodynamic model based on the ROMS numerical code. The model is forced at the surface with realistic weekly wind. Details of the configuration are given by Penven *et al.* (2001) and Blanke *et al.* (2002). The simulation provides modeled fields of temperature, salinity and currents in 3D with a spatial resolution ranging from 9 km inshore to 18 km offshore and with a temporal resolution of two days. The quotient analysis gives the ranges of temperature, salinity, current speed and water depth within which anchovy select to spawn, using observations made during annual cruises conducted in November (the peak anchovy spawning period). At each time step of the simulation, the Boolean combination of temperature, salinity and current speed ranges given by the quotient analysis is compared to surface values of those parameters given by the model over the whole domain, and areas meeting the criteria ranges are identified. Incorporation of the depth range identified by the quotient analysis provides a means of defining the area that is suitable for anchovy spawning. The resulting output is a ten year simulation with a two day time-step of the location and size of suitable anchovy spawning habitat in the southern Benguela. Plate 1 (page xi) presents a snapshot of suitable spawning habitat that corresponds to 18 November 1991.

A validation of the simulated suitable spawning habitat is performed by comparing the number of anchovy eggs collected during November surveys from 1991 to 1998 with the suitable spawning areas calculated by the model (Fig. 1). A positive correlation is found for area A (the west coast) and for the major anchovy spawning ground that corresponds to the combination of areas B+C+D (the

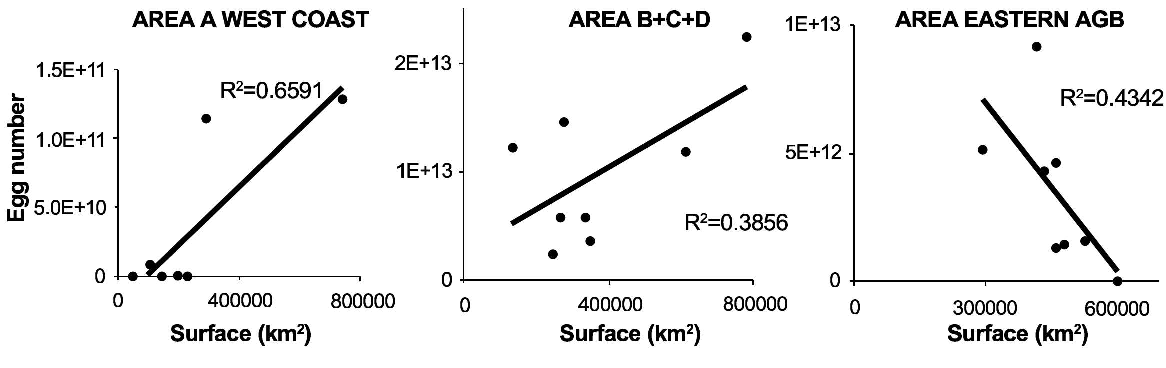


Figure 1. The relationship between the simulated suitable spawning surface and observed anchovy egg number during the November surveys from 1991 to 1998.

southwest coast, and western and central Agulhas Bank, respectively). In those areas, an increase in the simulated suitable spawning area corresponds to an increase in the observed abundance of anchovy eggs. An unexplained negative correlation is found on the eastern Agulhas Bank.

Using a simple combination of environmental parameters deduced from data collected during November surveys, the hydrodynamic model is able to partly reproduce the observed interannual variability in the distribution of anchovy spawning. This result gives us some confidence in the ability of such tools to investigate the impact of climate changes on spawning habitats. Future work will include a new configuration of the model with a southward and eastward extension of the oceanic boundary of the south-east corner of the domain. This will allow a better representation of the Agulhas retroflexion and of the influence of the Agulhas current on the Agulhas bank. Further development will include a realistic forcing at the oceanic boundaries in order to integrate the impact of remote events such as ENSO.

References

Blanke B., C. Roy, P. Penven, S. Speich, J. McWilliams and G. Nelson. 2002. Linking wind and interannual upwelling variability in a regional model of the southern Benguela, Geophysical Research Letters 29(24): 2188, doi:10.1029/2002GL015718.

Penven P., C. Roy, G. Brundrit, A. Colin de Verdière, P. Fréon, A. Johnson, J. Lutjeharms and F. Shillington. 2001. A regional hydrodynamic model of the Southern Benguela upwelling. South African Journal of Science 97: 472-475.

Twatwa N.M., C.D. van der Lingen, L. Drapeau, C.L. Moloney and J.G. Field. 2004. Characterizing and comparing the spawning habitats of anchovy (*Engraulis encrasicolus*) and sardine (*Sardinops sagax*) in the southern Benguela upwelling ecosystem. African Journal of Marine Science 27(2): 487-499.