INDIVIDUAL BASED MODELLING (IBM) OF THE EARLY STAGES OF ANCHOVY IN THE SOUTHERN BENGUELA SYSTEM

Christian Mullon[1], Carolina Parada[2], Phillipe Cury[3], Jenny Huggett[4], Pierre Fréon[3], Carl Van der Lingen[4], Pierrick Penven[5], Coleen Moloney[6] and Anthony Richardson[2]

[1] GEODES and IRD, France, and Oceanography Department, UCT, Cape Town, South Africa
[2] UCT Oceanography Department, Cape Town, South Africa
[3] IRD, FRANCE, MCM, and Oceanography Department, UCT, Cape Town, South Africa
[4] Marine and Coastal Management, Cape Town, South Africa
[5] Laboratoire de Physique de Océans, UBO, Brest, France
[6] UCT Zoology Department, Cape Town, South Africa

Introduction

Individual based modelling (IBM) is *"a bottom up approach that is focused in the parts (i.e. individuals) of a system (i.e. population) and then tries to understand how the system's properties emerge from the interaction among the parts"* (Grimm 1996). The resulting model is neither descriptive nor predictive, but rather an exploratory model. In this case the IBM is intended to represent, at an individual level, the main processes involved in the population dynamics of anchovy (*Engraulis capensis*) in the Southern Benguela. The implications of the spatial distinction between the Agulhas Bank spawning and West Coast nursery areas exhibited by anchovy are explored. This approach attempts to make explicit the underlying dynamics of conceptual models arising from previous work on the subject (Hutchings *et al.* 1992, Bakun 1996).

An emphasis is put on methodology, and involves an experimental, step-by-step procedure in which the processes of spawning, transport, growth, feeding, cannibalism and swimming are examined sequentially (Fig. 1). The approach is collective, and includes several scientists from UCT and MCM who try to follow the "Keep it Simple, Stupid" (KISS) principle. The IBM is designed to explain and reproduce a set of "testing patterns", defined as part of a pattern orientated approach (POA).

Implementation

The IBM is coupled with a hydrodynamic model of the region known as PLUME (see Roy *et al.* this volume). This model provides a virtual environment giving an exhaustive and coherent representation of the 3D dynamics, including such features as upwelling, eddies, and filaments. This virtual environment is enough to represent processes, but is insufficient to provide validated conclusions (Penven 2000).

Several individual IBM experimental simulations have been conducted to date and are detailed below.

Transport - hypotheses about the main factors impacting on transport success from the spawning grounds to the nursery area were examined. Spatial and temporal variations in spawning affected recruitment success, whereas parameters such as spawning patchiness and spawning frequency each month were less important (Plate 8).

Transport and buoyancy - hypotheses concerning the impact of variability in horizontal and vertical distributions of anchovy eggs arising from differential buoyancy were tested. Whether changes in buoyancy generated a significant variation in the horizontal distribution of eggs, and whether positive egg buoyancy reduced recruitment success because of offshore advection were examined. Results suggest that there is an optimal egg density ($1.025 g.cm^3$) that promotes the highest recruitment success in all experiments, leading

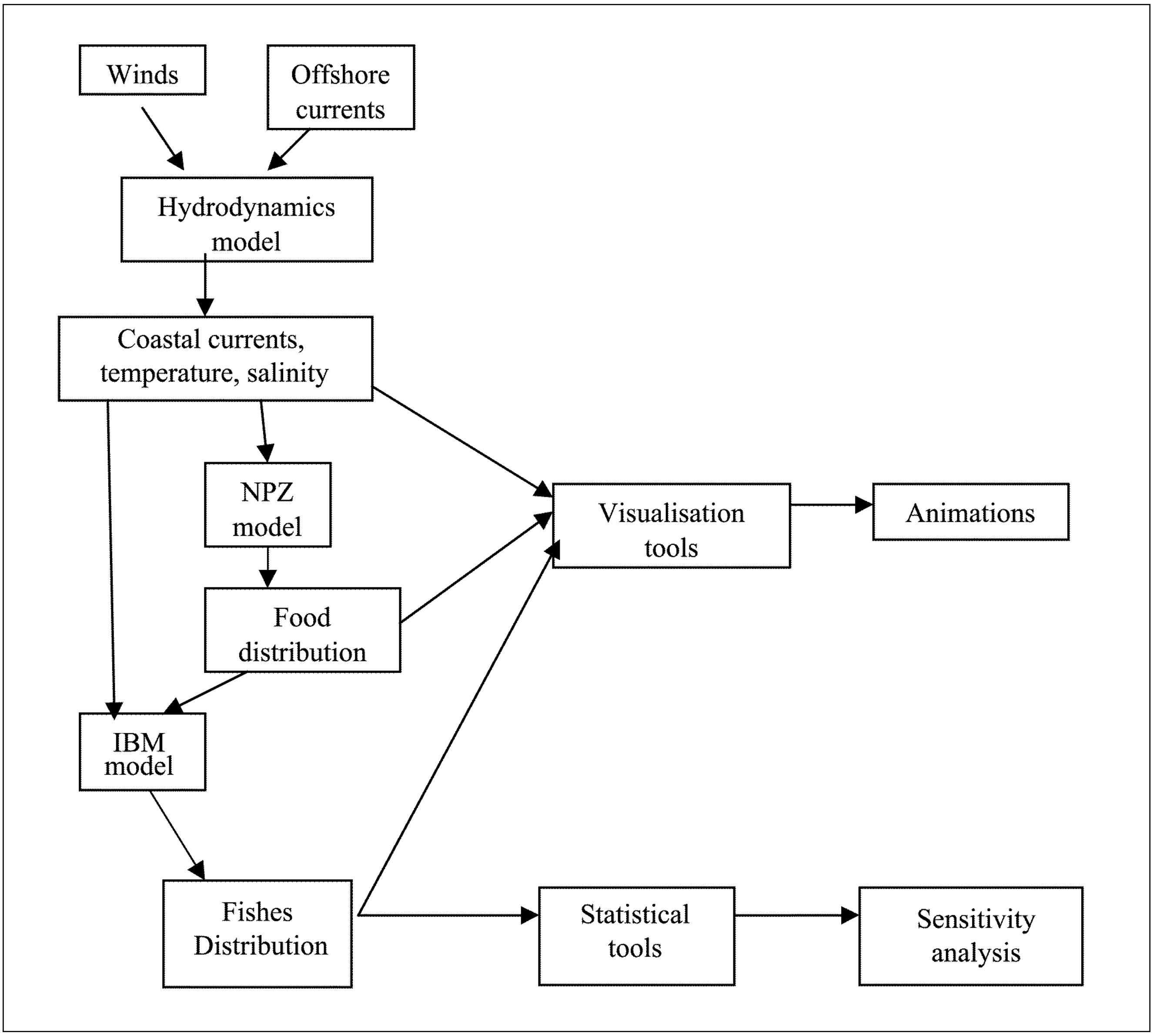

Fig. 1

to hypotheses of a trade-off between buoyancy properties and the efficiency of transport through the jet current (Parada *et al.* submitted.).

Growth - the effect of temperature on the mortality and growth of early stages of anchovy was examined. This IBM is based on a Gompertz equation which expresses the length of anchovy at each stage. The model relates independent variables (year, area, season of spawning, and feeding probability) to dependent variables (number of dead eggs and larvae due to temperature, and number of larvae at a feeding stage reaching the nursery area). Simulations show a trade-off between transport, temperature and feeding probability. If transport is too fast, eggs or young larvae arrive at the nursery area but cannot survive in the cold water. If transport is too slow, development occurs rapidly in the jet current, which may lead to food limitation (Table 1; Parada *et al.* in prep.).

Fronts and food availability - this preliminary experiment studies concentration processes, food availability and success in feeding through definition of the horizontal (SST gradient) and vertical (bottom of the thermocline) dimensions of fronts. The underlying hypothesis is that fronts are concentration areas where larvae can feed successfully.

Food **–** the aim of this preliminary experiment is to reproduce the highly variable distribution in space and time of food in the Benguela ecosystem. It represents the dynamics of nutrients, phytoplankton and zooplankton. Nutrients, i.e. masses of enriched water, are continuously released at 200-300m depth, and carried to the surface during upwelling events. Phytoplankton patches are advected by currents, and consume nutrients and reproduce according to satiation. Zooplankton colonies are also advected by currents and consume phytoplankton patches and reproduce according to satiation.

Evolutionary model of spawning - this evolutionary approach tries to express how patterns at the population level emerge from constraints at the individual level through a Darwinian selection process (Mullon *et al.* submitted). According to an initial set of selective constraints (concerning advection, temperature, and recruitment areas), a population of 10,000 individuals with random spawning behaviour is created. Over a simulation of 60 generations, individuals that have fulfilled these constraints are allowed to reproduce, creating new individuals with the same spawning behaviour as their parents. Examples of selective constraints are (1) to avoid offshore advection, (2) to avoid offshore advection and reach the nursery area, and (3) to avoid offshore advection and cool waters (14 °C).

This model may be considered as a genetic solver, which establishes a relationship between a set of constraints and population dynamics (including variability in spawning area and recruitment). Going further, one may consider that it represents some evolutionary features of the species, that the reproductive spawning strategy reflects the past environment. *"By its behaviour - its genetically determined use of habitats and resources - an animal largely defines the selective pressures to which it is subject"* (Lewontin 1983). It appears that studying spawning patterns is a relevant way to identify environmental factors important for recruitment studies. An important issue could be relating changing spawning patterns (see van der Lingen *et al.* this volume) and recruitment strength.

Next steps

New IBM experiments examining transport, buoyancy, growth and feeding and using the output of a more realistic PLUME model and a dynamic map of favourable spawning areas are planned for 2002, as is a new experiment to test the "Parental Condition" hypothesis. We also wish to improve the genericity of the tools, approach and the concept by applying them to other pelagic systems.

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Figure Legends

Figure 1. Flow-chart of an IBM model.

Table 1. Output of a sensitivity analysis examining the effect of various parameters (spawning area, model year, spawning date, and feeding probability) on anchovy recruitment success (significant parameters and interactions are shown in bold).

	DF	SS	MS	F	p	Explained variance
Intercept	1	3.78 E+08	3.78 E+08	7543.8	0	
AREA	**2**	**4.83 E+08**	**2.41 E+08**	**4816.6**	**0**	**65.8**
YEAR	4	17520065	4380016	87.4	0	2.4
DATE	6	41076224	6846037	136.6	0	5.6
FEED_PRO	4	718.2	179.6	0.0	1	0.0
AREA*YEAR	**8**	**39765476**	**4970685**	**99.2**	**0**	**5.4**
AREA*DATE	**12**	**42026995**	**3502250**	**69.9**	**0**	**5.7**
YEAR*DATE	**24**	**37520954**	**1563373**	**31.2**	**0**	**5.1**
AREA*FEED_PRO	8	7575.7	947.0	0.0	1	0.0
YEAR*FEED_PRO	16	6337.6	396.1	0.0	1	0.0
DATE*FEED_PRO	24	7630.3	317.9	0.0	1	0.0
Error	**1466**	**73466268**	**50113.4**			**10.0**
Total	1574	7.34 E+08				