The ABACuS Model: Atlantis in the Benguela and Agulhas Current Systems

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Abstract

The management strategy evaluation (MSE) process seeks to guide the selection of a management strategy by quantitatively analysing the performance and trade-offs of any candidate strategy in light of management objectives. This requires simulation of both the ecosystem and the management process. The addition of an Atlantis model for the southern Benguela ecosystem would have several immediate benefits. These include increased understanding of the relative strengths of different ecosystem modelling techniques, the potential of Atlantis to model upwelling systems, and the usefulness of Atlantis in conjunction with stock assessment models for long-term fisheries management.

The approach taken over the course of the project will consist of two key parts. Firstly, the model will be designed, configured and parameterised. Secondly, the model will be used to explore alternative management strategies with regard to biological outcomes. Particular issues to be explored include the degree of compatibility between the ecosystem-level MSE approach and a suite of single-species management plans, and the bioeconomic implications of ecosystem states.

1. Background

1.1 Management Strategy Evaluation in marine systems

Management strategy evaluation (MSE) is an iterative process used to design and evaluate operational management strategies (as described in Cochrane et al 1998, Butterworth and Punt 1999, Sainsbury et al. 2000). An MSE process focuses on evaluating implementations of the adaptive management approach (Walters, 1986). In an Ecosystem-based Fisheries Management (EBFM) context, MSE requires simulation of the entire system, including both ecological components and the management process itself. For the simulated management system, all stages of the decision process should be included.

Because of the complex nature of marine ecosystems, useful assessment of ecosystem health may require that a suite of indicators be evaluated simultaneously (Link et al., 2002). Such a suite will typically require indicators from several functional groups, including a spectrum of fast- and slow-growing species, target species for the fisheries and habitat-defining groups (Fulton et al, 2005).

1.2 Ecosystem modelling in the southern Benguela

Substantial food-web modelling has been done in the region using Ecopath with Ecosim (EwE). Such models have been used to explore the effects of fishing on pelagic stock structure under various trophic control assumptions (Shannon et al., 2000). Later EwE models compared trophic flow in the southern Benguela food web between the 1980s and 1990s (Shannon et al., 2003), and investigated the drivers of regime shifts in small pelagic fish populations (Shannon et al., 2004a; Shannon et al., 2004b).

The individual-based model OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation) has assumptions of size-based predation and focuses on fish population dynamics. An OSMOSE model of 12 fish species in the southern Benguela was used to simulate the same fishing scenarios as the EwE model of Shannon et al. (2000), and the results compared (Shin et al., 2004). OSMOSE has also been used to explore the sensitivity of ecosystem-based indicators across a range of fishing scenarios (Travers et al., 2006).

A frame-based model was developed to investigate regime shifts in the sardine and anchovy stocks under various scenarios of climate and fishing (Smith and Jarre, 2011).

Atlantis (Fulton et al., 2004a) is a whole-of-system modelling framework designed for management strategy evaluation. Previous applications of the model have ranged in scale from small estuarine regions to several millions or square kilometres of ocean. The addition of an Atlantis model for the southern Benguela ecosystem would have several immediate benefits:

1. The different strengths of the various modelling techniques can be explored in a reasonably well-understood ecosystem. In particular, this would extend the previous work on EwE / OSMOSE comparisons of Shin et al. (2004) and Travers et al. (2010).
2. The wide range of existing stock-assessment models in the region will allow us to evaluate Atlantis alongside a suite of stock-assessment models in an EBFM context, and give insight into the usefulness of Atlantis in conjunction with stock assessment models for long-term fisheries management.
3. The links between social and ecological systems possible in Atlantis would greatly increase the ability to examine the economic and social impacts of various alternative fishing strategies.
4. The implementation of Atlantis in an upwelling system will improve understanding of the potential for usefully modelling this kind of marine systems with Atlantis.
5. Pelagic fish species occupy a vital niche in the functioning of upwelling ecosystems, and the pelagic fisheries are particularly prone to high catch variability and risk of collapse, due to high natural variability and instability of the fish populations (Fréon et al, 2005). Models such as the proposed Atlantis implementation are vital to evaluating both the economic implications and the ecosystem-scale impact of alternative strategies for pelagic fisheries.

2. Parameterisation of the Atlantis model

An Atlantis model consists of a spatially explicit stock structure of higher trophic levels supported by a deterministic primary production model, driven by hydrodynamic forcing of nutrient and water flows. The region to be modelled is broken up horizontally into polygons (each of which can have several depth layers as desired), which allows the level of detail to be adjusted as appropriate for different parts of the geographic area, while still remaining computationally efficient (Fulton et al., 2004b). The hydrodynamic input is produced by eddy-resolving hydrodynamic models (e.g. a regional ocean modelling system (ROMS) model of current flows), which provide current flows for dispersion within Atlantis. Within Atlantis the flow of nutrients is tracked explicitly (including uptake, processing and remineralisation) through the major components of the local food web. Nutrient-, light-, space- and temperature-dependent primary production is represented using size-structured phytoplankton and macrophyte biomass pools. Lower trophic levels are modelled as biomass pools, but vertebrates (and potentially some of the larger-bodied invertebrates) are modelled with age and stock structure, with the model tracking population change and the condition of an “average” individual. Planktonic movement is determined by advective transfer between the polygons, and modelled nektonic organisms can exhibit directed movement between the polygons as well as in and out of the modelled region as a whole (to represent long-distance migration for species which may be present in the region only seasonally).

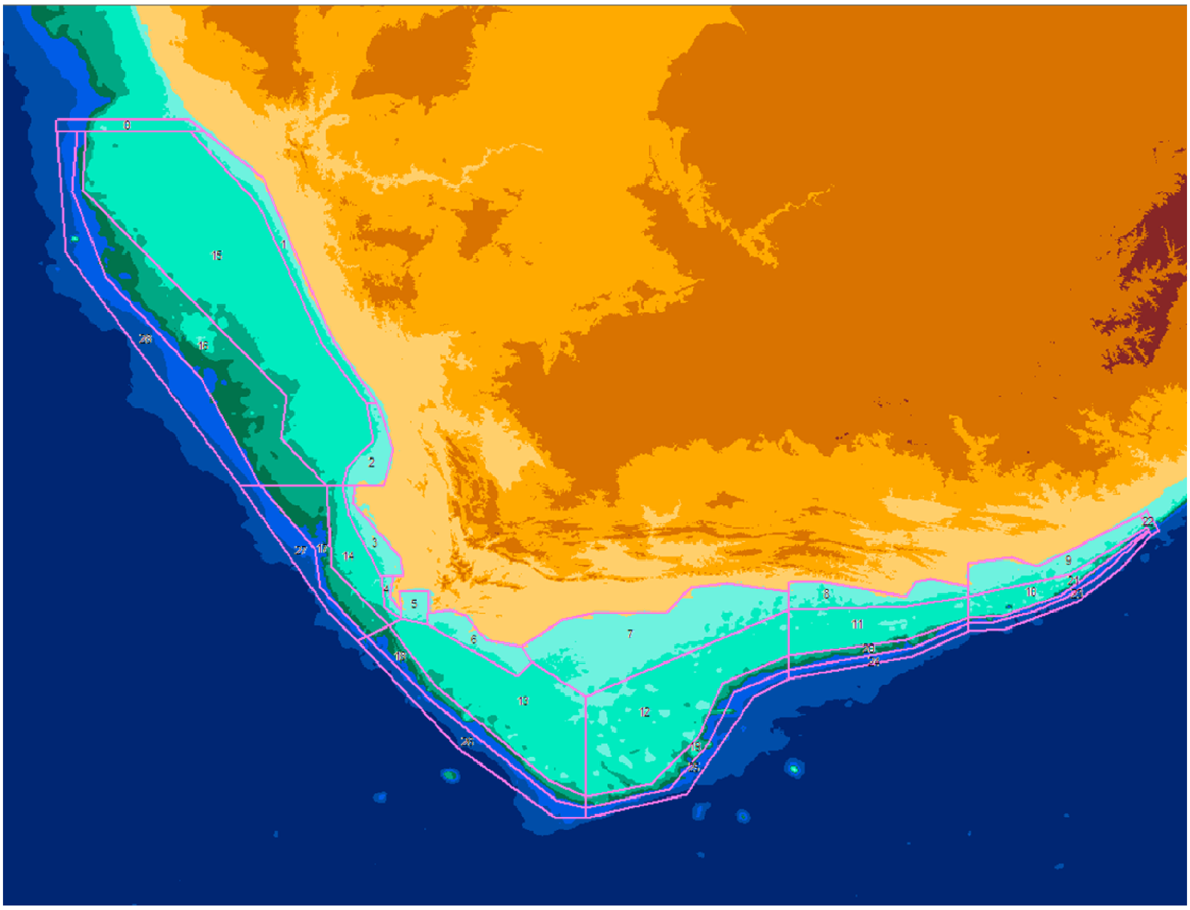
The regional breakdown of the system was performed to fit two primary criteria. Moving out from the coastline, regions are divided by increasing depth, as this corresponds to additional layers in consecutive model polygons and reflects the depth structuring of ecology and life history stages typical in marine ecosystems. Regions are also be divided according to significant ecosystem and/or hydrodynamic zones.

The area covered by the model includes the southern Benguela ecosystem and the southern Agulhas Current system, and extends along the coast approximately from the Orange River mouth to East London. The modelled system starts at the coastline and extend out to the 500m depth contour, which covers the vast majority of fishing activity in the ecosystem. The region is similar to the EwE model of Shannon et al. (2003).

Hydrodynamic flows have been reconstructed from existing ROMS data sets (as described in Penven et al., 2001), and basic biological parameterisation work has been done.

3. Current model configuration and data requirements

- The model includes 33 functional groups, covering the full range of scale from bacteria to cetaceans.
- Biomass levels of the functional groups are mostly drawn from the levels indicated in Shannon et al. (2003) for the period 1990-2000
- Primary production distribution estimates from Weeks et al. (2006).
- Zooplankton distributions based primarily on Hugget et al. (2009).
- Spatial distribution of vertebrates and cephalopods in the region comes primarily from data aggregated by Laurent Drapeau and described in Pecquerie et al. (2004).
- Bathymetric map of the model region with box geometry:



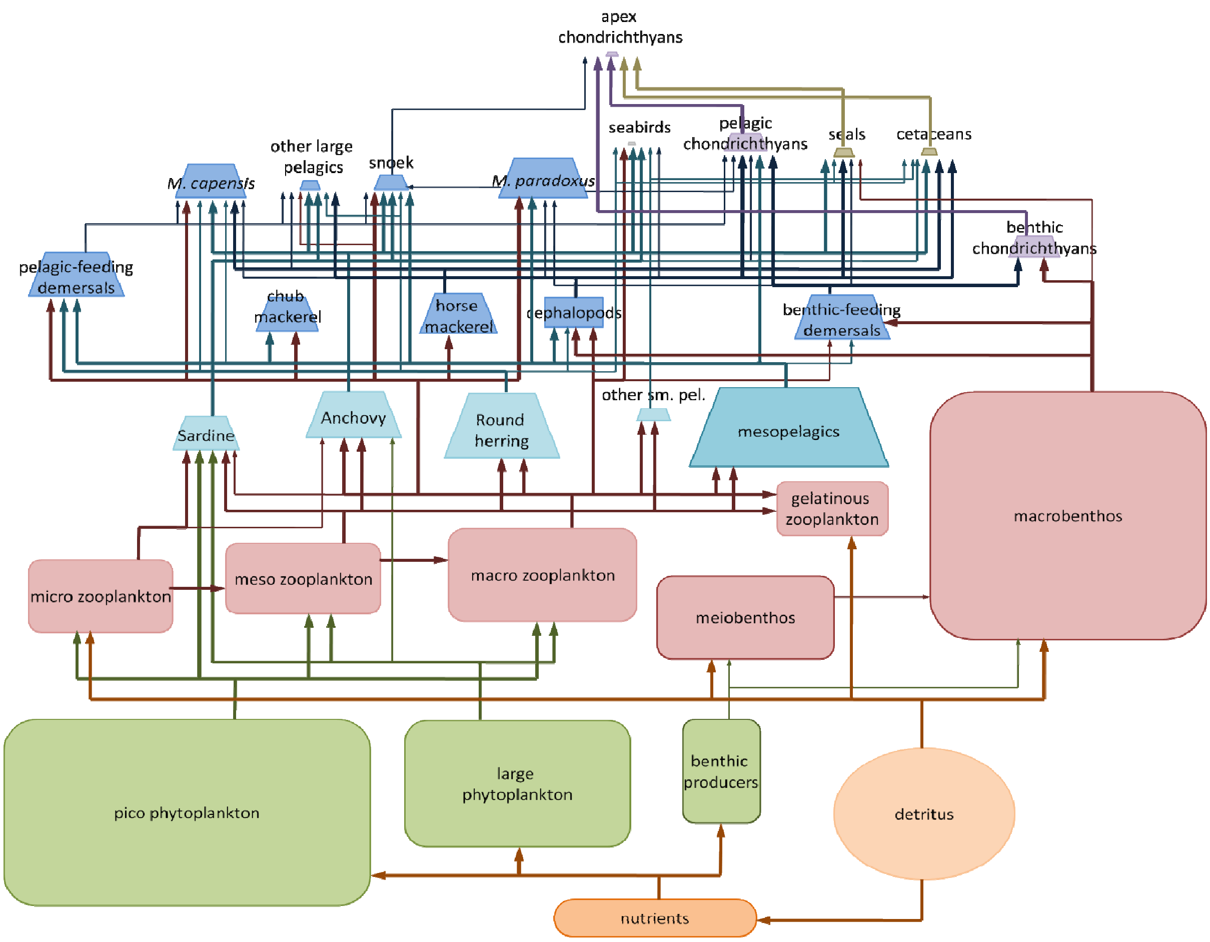
Current hydrodynamic flows involve a repeated single year of data. The exchanges for each time step are based on monthly means from a ROMS data set. Improving the hydrodynamic resolution to capture both long-term (decadal scale) variation and short upwelling events is a priority. Survey data from cruises or static observing stations could be used to “truth” the ROMS model, as simulations near the coast are difficult to resolve accurately.

The major functional groups are parameterised and the system is achieves dynamic stability in an unfished state. After a burn in period (during which some short-term instability is observed), the biomass levels remain will fairly constant for multiple decades. Most biomasses and fish sizes are similar to observed levels.

The fishing model is currently being configured. Data on total catch over multiple years needs to be used to simulate historic fishing patterns for all major target and by-catch groups. Groups which are affected by fishing (directly or indirectly) include:

Sardine	M. capensis	Benthic-feeding chondrichthyans
Round herring	M. paradoxus	Apex predatory chondrichthyans
Anchovy	Mesopelagic fish	Pelagic-feeding chondrichthyans
Benthic-feeding demersal fish	Other small pelagic fish	Seabirds
Horse mackerel	Pelagic-feeding demersal fish	Cetaceans
Chub mackerel	Snoek	Seals
Other large pelagic fish	Cephalopods	

The full list of functional groups in the model (and their associated biomasses) is given in the appendix. A basic overview of the nutrient flows between groups is shown below. Size of box indicates relative biomass.



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5. Appendix

Functional Group	**Group modelled as:**	**Biomass (tonnes)**
Sardine	Sardine *(Sardinops sagax)*	5.54E+05
Round herring	round herring *(Etrumeus whiteheadi)*	1.65E+06
Anchovy	Anchovy *(Engraulis encrasicolus)*	9.47E+05
Benthic-feeding demersal fish	Kingklip *(Genypterus capensis)*	9.86E+05
Horse mackerel	horse mackerel *(Trachurus trachurus capensis)*	6.42E+05
Chub mackerel	chub mackerel *(Scomber japonicus)*	1.21E+05
Other large pelagic fish	silver kob *(Argyrosomus inodorus)*	3.47E+04
M. capensis	Shallow-water hake *(Merluccius capensis)*	4.68E+05
M. paradoxus	Deep-water hake *(Merluccius paradoxus)*	7.80E+05
Mesopelagic fish	Lanternfish *(Lampanyctodes hectoris)*	2.71E+06
Other small pelagic fish	Saury *(Scomberesox saurus scombroides)*	9.65E+04
Pelagic-feeding demersal fish	Yellowtail *(Seriola lalandi)*	9.79E+05
Snoek	Snoek *(Thyrsites atun)*	8.93E+04
Benthic-feeding chondrichthyans	leopard skate *(Rajella leopardus)*	2.31E+05
Apex predatory chondrichthyans	great white (*Carcharodon carcharias)*	1.19E+04
Pelagic-feeding chondrichthyans	spiny dogfish *(Squalus acanthias)*	1.54E+05
Seabirds	Cape gannet *(Morus capensis)*	3.18E+03
Cetaceans	Bryde's whale *(Balaenoptera brydei)*	2.17E+04
Seals	Cape fur seal *(Arctocephalus pusillus pusillus)*	3.52E+04
Cephalopods	chokka squid *(Loligo vulgaris reynaudi)*	3.61E+05
Macrobenthos		1.54E+07
Macrozooplankton	euphausiids	3.86E+06
Benthic producers		1.74E+06
Gelatinous zooplankton		1.33E+06
Large phytoplankton	diatoms	6.12E+06
Small phytoplankton		1.43E+07
Mesozooplankton	copepods	2.32E+06
Microzooplankton		2.17E+06
Meiobenthos		3.23E+06
Detritus, ammonia, etc	Note: benthic and pelagic bacteria consumed with detritus	