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Using an Atlantis model of the southern Benguela to explore the response of ecosystem indicators for fisheries management

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ABSTRACT

Atlantis is a whole-of-system modelling framework developed for Management Strategy Evaluation. This paper describes an Atlantis model that was built to simulate the southern Benguela ecosystem and its major associated fisheries to assist fisheries management in the region. We divided the region into spatial zones based on hydrodynamics, current fishing management, and important ecosystem processes. We divided the biological components of the system into functional groups based on trophic interaction, life history traits and fisheries management objectives. We evaluated the model against historical data and known ecosystem interactions (such as competition and predation), and found that it simulates important ecological processes well at multiple trophic levels. We tested the model under fishing pressure scenarios and evaluated the performance of common ecosystem-level indicators. The response of the modelled system (as shown by indicators) was in line with expected behaviour of the indicators, reinforcing our confidence in the usefulness of the model.

1. Introduction

1.1. Modelling for ecosystem-based fisheries management

Ecosystem-based fisheries management (EBFM) is a holistic approach to the management of marine living resources (Larkin, 1996; Link, 2002). EBFM is centred on multi-species interactions in a variable environmental context, and includes social, economic and political elements as part of fisheries management (Larkin, 1996). Significant commitments have been made in recent years towards the implementation of Ecosystem-based Fisheries Management (EBFM) in several ecosystems around the world (Pitcher et al., 2009; Sherman et al., 2005; Keith et al., 2013). Fisheries legislation in many countries now includes ecosystem objectives, generally based on such agreements as the Law of the Seas Convention, which explicitly requires a precautionary approach in the management of marine living resources. Balanced against such ecological conservation requirements is the continuing need to engage in fishing activities for economic, nutritional and social needs (Hilborn et al., 2012; Hall et al., 2013). The development and implementation of such solutions requires a broad array of scientific support (Worm et al., 2009).

Marine fisheries management typically employs focussed mathematical models of single species which are rigorously fitted to data. In contrast, ecosystem models emphasise generality and realism over precision (*sensu* Levins, 1966). Ecosystem models are useful in comparing the relative performance of multiple candidate management strategies, or the performance of a single strategy under multiple alternative assumptions regarding environmental conditions or ecosystem dynamics. Although the complexity of ecosystem models may preclude rigorous validation (Oreskes et al., 1994), they nevertheless afford the only feasible means for conducting ecosystem-scale experiments (Scheffer and Carpenter, 2003), and allow for representation of multiple regimes in a single model. Fulton et al. (2011) note that the associated increases in model complexity in moving from single-species to ecosystem models will generally mean that the latter are not suitable for tactical management (such as quota setting). Rather, ecosystem models are better employed as strategic tools to support adaptive management (Fulton, 2010), and are proving particularly helpful in understanding overall ecosystem functioning, including trophic cascade mechanisms and complex non-linear system responses (Fulton et al., 2005; Plagányi and Butterworth, 2004; McDonald et al., 2008).

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Management strategy evaluation (MSE) is an iterative process used to design and evaluate operational management strategies (as described in de la Mare, 1996; Butterworth and Punt, 1999; Sainsbury et al., 2000). MSE seeks to guide the selection of a management strategy by analysing the performance and trade-offs of any candidate strategy in light of management objectives. MSE has been implemented as a fisheries management tool in South Africa (Cochrane et al., 1998), and offers a useful methodology to achieve EBFM objectives (Sainsbury et al., 2000). Traditionally MSE has been done with single species, or simple multi-species models. However, basing the work around an ecosystem model has proved an effective approach (McDonald et al., 2008; Fulton et al., 2011). Models such as the one described in this paper (ABACuS, Smith, 2013) allow candidate management strategies to be evaluated in terms of quantitative performance measures such as targets and limits (Sainsbury et al., 2000; Smith et al., 2011). Any system model will incorporate assumptions about system processes (which are generally uncertain), so the use of multiple models allows for such evaluation to be made under alternative hypotheses about system structure and function and alternative model formulations (Fulton, 2010; Sainsbury et al., 2000).

1.2. Features of the southern Benguela current and Agulhas Bank

The southern Benguela ecosystem is generally considered to include both the southern portion of the Benguela current itself, and also the south coast of South Africa and the Agulhas Bank (see Fig. 1). The Benguela Current extends from Cape Point all the way up the West Coast to Angola, but there is a strong biogeographical division at the Luderitz upwelling cell on the Namibian coast, which is commonly taken as the division between the northern and southern parts of the current. In our model we have instead taken the political boundary between South Africa and Namibia at the mouth of the Orange River as our northern limit, reflecting the focus of the model on fisheries management. The west coast of South Africa is characterised by strong wind-driven upwelling in the Benguela Current, which gives rise to high primary productivity, and this in turn supports large biomasses of fish species.

The Agulhas Current is a warm, fast-flowing water mass that moves southwards down the Natal coast on the east of South Africa. Along this coastline, the continental shelf is narrow, but on the south coast the Agulhas Bank extends 250 km further south than the shoreline. The main core of the Agulhas current is diverted away from the coastline along the edge of the Agulhas Bank, and waters on the Bank are relatively warm and calm, making it an ideal spawning area for many pelagic fish species.

Connecting the Agulhas Bank to the productive waters of the west coast are “transport currents”, which include a narrow jet current off the Cape of Good Hope, and also a series of ring-shaped eddies that are shed from the Agulhas Current as it retroflects southwards. These rings, along with the Good Hope Jet, transport eggs and larvae spawned on the west Agulhas Bank to the strong upwelling zone near Cape Columbine. This region is an important nursery area for juveniles of sardine, anchovy, round herring and snoek.

1.3. Modelling in the southern Benguela

The fisheries management regime in the southern Benguela region has been a pioneer in both implementation of EBFM and in the ecosystem modelling to support it (Pitcher et al., 2009; Shannon et al., 2006, 2010). Some of the modelling approaches already applied are detailed below:

- Substantial food-web modelling has been performed in the region using Ecopath with Ecosim (EwE, Christensen et al., 2005). Initial trophic flow models were built using Ecopath (Jarre-Teichmann et al., 1998; Shannon and Jarre-Teichmann, 1999), and a subsequent model was used to explore the effects of fishing on pelagic stock structure under various trophic control

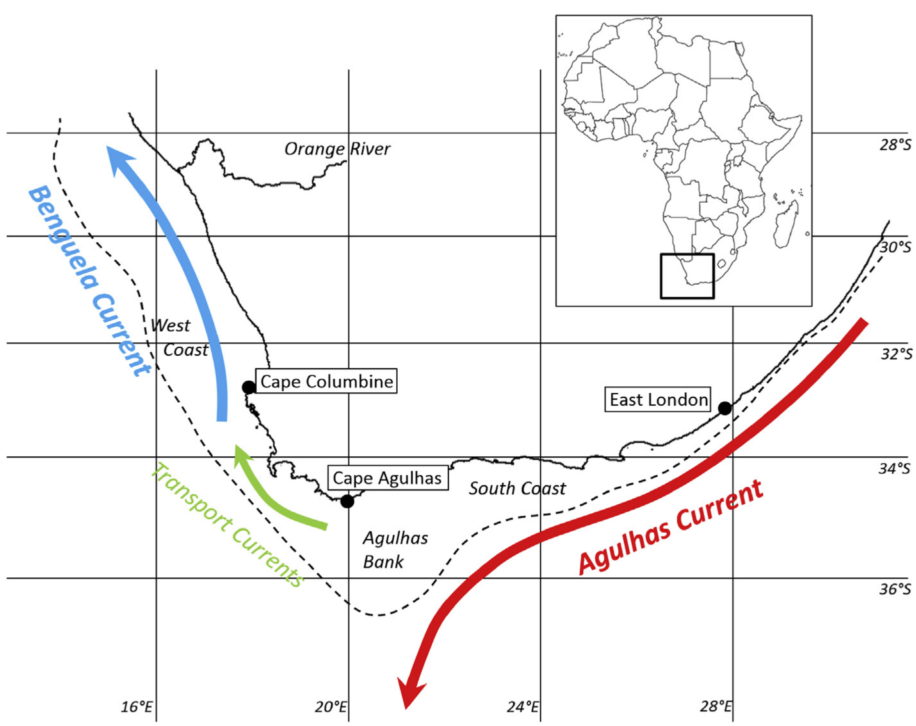

Fig. 1. Important physical features of the southern Benguela ecosystem. Dotted line indicates the 500 m isobath.