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A frame-based modelling approach to understanding changes in the distribution and abundance of sardine and anchovy in the southern Benguela

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ABSTRACT

A number of ecologically and economically important species in the southern Benguela, including the forage fish sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*, have undergone southward/eastward shifts in their distribution in the 1990s/early 2000s. In addition to the effects of changes in prey availability to top predators, the spatially-distinct nature of the system means the location of a stock has implications for its productivity. The spatial dynamics of small pelagic fish are of particular importance because they are thought to exert wasp-waisted trophic control on the system. An objective-driven frame-based model was constructed to investigate the ability of the approach to represent spatial and population dynamics of sardine and anchovy, and to explore the implications of possible management strategies. Climate variability and fishing pressure were assumed as drivers. Sensitivity analyses were performed and a number of scenarios tested. A frame-based approach appears to be useful within this context. Results suggest that the productivity of the sardine resource within the model is highly dependent on the spatial characteristics of fishing pressure. The role of anchovy within the model system has not yet been fully developed. Increasing our understanding of the relative suitability of environmental conditions of different regions is also important if we are to increase our capacity to predict trends in abundance and distribution. This study shows support for continued careful consideration of spatialized management approaches to the South African sardine fishery.

1. Introduction

The southern Benguela (Fig. 1) comprises two of the four subsystems of the Benguela Current Large Marine Ecosystem (BCLME) (Hutchings et al., 2009): the west coast, characterised by seasonal, wind-driven upwelling; and the south coast with characteristics of both a shelf system and an upwelling system (Hutchings et al., 2009; Shannon 1985).

1.1. Biology

As in most eastern boundary current systems, small pelagic fish in the southern Benguela play an important role in ecosystem function, acting as a trophic stepping stone between plankton and higher trophic level species such as predatory fish and seabirds. A system operating under this model of trophic function is described as 'wasp-waisted', with small pelagic fish exerting both top-down control on zooplankton populations as well as bottom-up influence on predatory groups. The southern Benguela is thought to operate in this manner (Cury et al., 2000), and the structure was generally supported when modelled data were fitted to observed data time-series (Shannon et al., 2008).

Sardine and anchovy have also formed the bulk of South Africa's commercially valuable purse-seine fishery since the 1940s (Crawford et al., 1987; Fairweather et al., 2006). Their ecological and commercial importance make the dynamics of sardine and anchovy populations of particular interest from an ecosystem research and fisheries management perspective. Historically both research and management have focused on a target resource–oriented, two species approach, but more recently with the increasing emphasis on the application of an ecosystem approach to fisheries management, more importance is being placed on better understanding the role of sardine and anchovy within the system as a whole.

Sardine and anchovy populations around the world have been observed as highly variable on an interannual and decadal scale,

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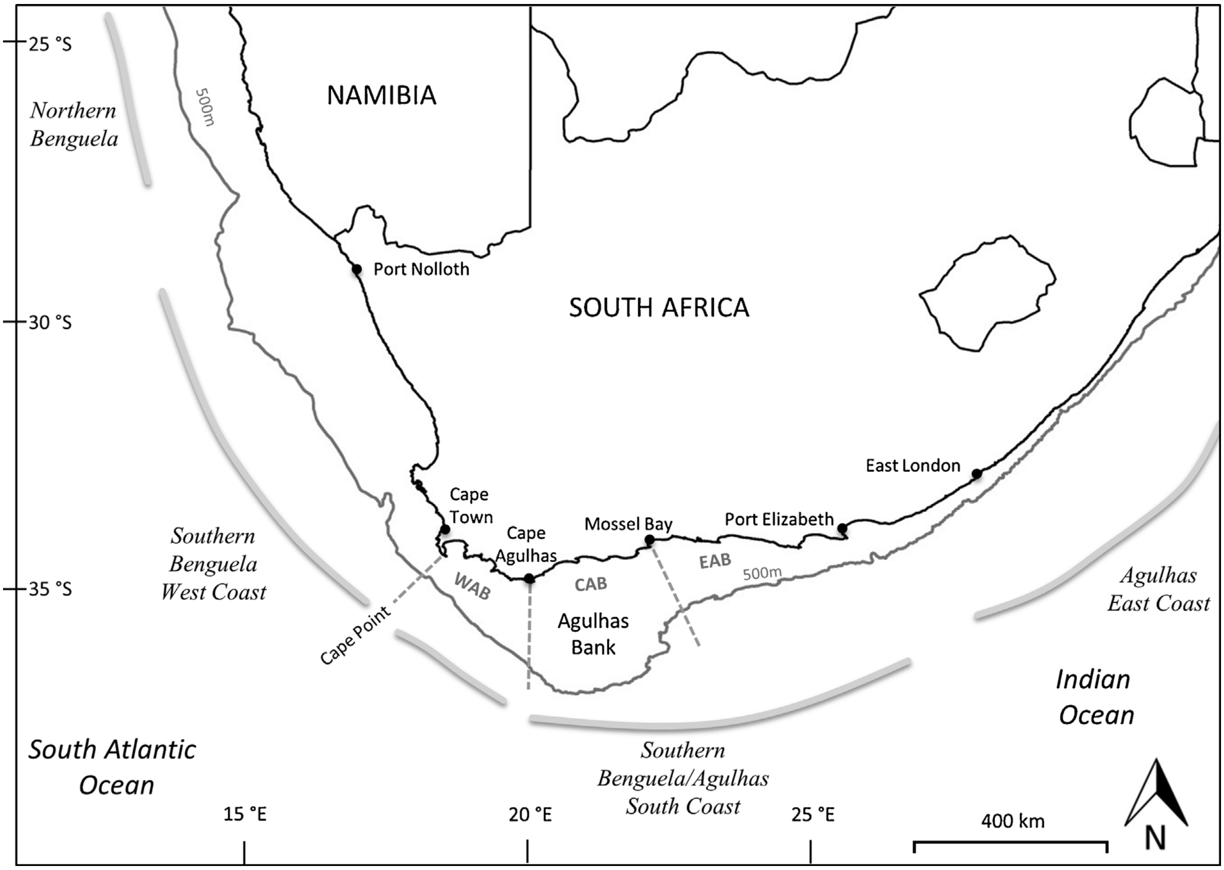

Fig. 1. The southern Benguela extending from 29°S around the west and south coasts of South Africa, divided at Cape Agulhas, to 28°E at East London. Adapted from Blamey et al. (2015).

with decadal-scale dominance shifts between the two species (Schwartzlose et al., 1999; Cury and Shannon 2004). This holds true for populations of sardine and anchovy in the southern Benguela, where one species has been dominant for a period (on a decadal scale), followed by a change in the community structure and dominance of the other species. The southern Benguela has also seen a period of high abundance of both species during the early 2000s, as a consequence of an ecosystem regime shift (Blamey et al., 2012; Howard et al., 2007).

Recent decades have seen the concept of regime shifts in marine systems become a more common approach to describing long-term changes at an ecosystem level (de Young et al., 2004). Here we are defining a regime shift as a sudden change from one quantifiable state to another, occurring at a large spatial scale (de Young et al., 2004; Jarre et al., 2006). Shifts in a number of physical and biological time series for the southern Benguela, have been detected in the late 1990s–early 2000s (Roy et al., 2007; Howard et al., 2007; Blamey et al., 2012; Atkinson et al., 2012), including in the distribution of sardine and anchovy: since the late 1990s the majority of small pelagic fish spawner biomass has been found east of Cape Agulhas (south coast, Fig. 1), whereas historically biomass was located largely on the west coast, illustrated in Fig. 2 (van der Lingen et al., 2005, 2002). This has had serious implications for both the management of the fishery, and the structure and function of the ecosystem itself (e.g. Coetzee et al., 2008; Crawford et al., 2008a; Jarre et al., 2013; Sherley et al., 2013; Watermeyer et al., 2016).

The physical and biological differences between the west and south coasts mean that the location of a stock has implications for its productivity: the west coast is characterised by high but episodic wind- induced productivity; the south coast has lower concentrations, but more continuous availability of nutrients and a higher biomass of consumers/predators. As a result, the population dynamics of small pelagic fish have been shown to be quite different on each coast, with sardine recruitment poorer on the south coast (van der Lingen 2011; de Moor and Butterworth 2012).

The mechanisms behind the distributional shifts in sardine and anchovy are not well understood. Fishing pressure and environmental shifts, in combination with possible natal homing of those sardine spawned further east are thought to be the main drivers behind the changes in distribution (Coetzee et al., 2008; Cury, 1994). Coetzee et al. (2008) outline the role that maintaining high fishing pressure on the west coast, while the stock had shifted south and east, may have played: the sardine fishery is managed using an Operational Management Procedure (OMP) that until now has assumed a single stock and with no spatial structure. Consequently, during the late 1990s and 2000s when the majority of biomass has been on the south coast, fishing effort remained largely where it had been focused for the previous 50 years and where the majority of processing infrastructure had been developed–on the west coast. The resulting high fishing pressure exerted on the diminished biomass of sardine on the west coast may have contributed to the continued lower abundance. As a result, spatial management of the sardine fishery is now under consideration (de Moor et al., 2014, 2013). In the case of anchovy, Roy et al. (2007) suggest links between changes in anchovy distribution and shifts in SST on the Agulhas Bank.

1.2. Modelling sardine and anchovy in the southern Benguela

Given the levels of complexity and interdisciplinarity inherent in any attempt to apply an ecosystem approach to fisheries (EAF), the use of models and indicators as means of increasing both our