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The use of ecological, fishing and environmental indicators in support of decision making in southern Benguela fisheries

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ABSTRACT

Indicators have been recognised as a useful tool aiding the implementation of an ecosystem approach to fisheries in marine ecosystems. Studies, such as the IndiSeas project (www.indiseas.org), use a suite of indicators as a method of assessing the state and trends of several of the world's marine ecosystems. While it is well known that both fishing and climatic variability influence marine fisheries in the southern Benguela ecosystem there are currently few studies in support of fisheries management that make use of environmental indicators in order to include climatic impacts on marine fish populations. Trends in ecological, fishing and environmental indicators can be utilised in a way that allows an overall ecosystem trend to be determined, and can therefore be used to aid decision support within southern Benguela fisheries. In this study trends in indicators were determined using linear regressions across three time periods, Period 1: 1978–1993, Period 2: 1994–2003 and Period 3: 2004–2010. These time periods were selected based on the timing of regime shifts within the southern Benguela, including changes in upwelling, wind stress and temperature. Each ecological indicator received a score based on the direction and significance of the observed trend with respect to fishing. To account for the impacts of fishing and environmental drivers on ecological indicators, scores were adjusted by predetermined factors, depending on the extent and direction of trends in these indicators. Weightings were applied to correlated ecological indicators to account for their redundancy, and lessen their impact on overall ecosystem score. Mean weighted scores were then used to establish an overall ecosystem score for each time period. Ecosystem classification was determined as follows: 1–1.49 = improving, 1.5–2.49 = possibly improving, 2.5–3.49 = no improvement or deterioration, 3.5–4.49 = possible deterioration, 4.5–5 = deteriorating. The ecosystem was observed to neither deteriorate nor improve across Period 1 or 2 (mean weighted scores: 2.75 and 2.56 respectively), however, during Period 3 a possible improvement was observed (mean weighted score: 1.99). This study shows that the sequential analysis of suites of ecological, fishing and environmental indicators can be used in order to determine ecosystem trends, accounting for both the impacts of fishing and the environment on ecosystem components.

1. Introduction

1.1. The IndiSeas project and an ecosystem approach to fisheries

Current methods of marine fisheries management are generally considered inadequate, which has resulted in a strong global move towards an ecosystem approach to fisheries (EAF). The concept of an EAF is not new and over the past two decades an interest in an ecological approach to fisheries management has emerged (Garcia and Cochrane, 2005), with the EAF being formalised in 2001 (FAO, 2003). In response to this the IndiSeas working group was established in 2005 under the auspices of the Eur-Ocean European Network of Excellence, to examine the use of "EAF Indicators: a comparative approach across ecosystems" (www.indiseas.org). IndiSeas implements comparative analyses of ecosystem indicators from several of the world's marine ecosystems in order to better understand the impacts of fishing pressure and provide decision support for fisheries management (Shin and Shannon, 2010; Shin et al., 2012). There are currently numerous indicators available for marine ecosystems, therefore rather than creating new indicators, the IndiSeas project makes use of strict selection criteria (see Rochet and Trenkel, 2003; Rice and Rochet, 2005) in order to select the most representative and meaningful indicators from those already proposed (Shin et al., 2010b; Coll et al., 2016).

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While fishing is generally considered one of the greatest threats to marine fish populations, in some ecosystems other factors such as climate and pollution may inflict even greater pressure (Derraik, 2002; Hoegh-Gulderberg and Bruno, 2010). Fishing and climate variability are known to interact in a number of ways, and therefore cannot be treated separately (e.g. Brander, 2007; Shannon et al., 2010; Jarre et al., 2015). However, despite this few EAF studies of the southern Benguela include the impacts of climatic variability on the ecosystem quantitatively. This study will therefore follow on from previous IndiSeas work on the southern Benguela (e.g. Bundy et al., 2010; Shannon et al., 2010), making use of a suite of previously determined ecological and fishing indicators with the addition of a suite of environmental indicators to better aid decision support within southern Benguela fisheries.

1.2. Southern Benguela ecosystem

The Benguela Current Large Marine Ecosystem (BCLME) is one of the world's four eastern boundary upwelling ecosystems. Situated off the south west coast of Africa it stretches from the northern border of Angola to East London on South Africa's south coast. The distinctive bathymetry, hydrography, chemistry and trophodynamics make the Benguela one of the most biologically productive areas in the world (Shannon, 2006). The BCLME can be divided into four subsystems; the Angola subtropical, northern Benguela upwelling, southern Benguela upwelling, and the Agulhas Bank systems (Jarre et al., 2015). The latter two sub systems, which adjoin the west and south coasts of South Africa respectively, hence forth referred to as the southern Benguela ecosystem, are the focus of this study (Fig. 1).

There is a long history of fishing in the southern Benguela, with fisheries being established for over 100 years. Bottom trawling was initiated in the early 1900s (e.g. Atkinson et al., 2011) and the demand for canned fish resulting from World War II initiated the development of purse seine fisheries (e.g. Griffiths et al., 2004). Like other upwelling systems the Benguela is characterised by a large and important small pelagic fish component, and is dominated by sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*). Due to their high abundance, the fishery for small pelagics is one of the largest and most productive in the southern Benguela, accounting for over 75% of total pelagic catches since the 1950s (van der Lingen et al., 2006) as well as over half the marine catch within South Africa's exclusive economic zone (Baust et al., 2015). These small pelagics exert a wasp-waist control on the ecosystem, influencing the abundance of both lower and higher trophic levels (Cury et al., 2000).

In the southern Benguela upwelling ecosystem environmental variability is known to strongly impact many ecosystem components (Shannon et al., 2010). The upwelling nature of the southern Benguela ecosystem, along with the dominance of small pelagic fish species, makes the region particularly susceptible to climatic variability. As a consequence of the dominance of short-lived species, fish production is largely dependent on recruitment, which is controlled by enrichment, concentration and retention processes (Bakun, 1998). These are in turn controlled by environmental factors. It is therefore essential to consider the impacts of environmental drivers within the ecosystem in order to aid fisheries management (Shannon et al., 2010).

1.3. The impacts of climate on the southern Benguela

Marine ecosystems change on a variety of timescales, from seasonal up to centennial and even longer, with much variation caused by atmospheric and climatic forcing and related processes (Lehodey et al., 2006). Climatic variability may give rise to important changes in marine fish populations and, consequently, changes within fisheries, as has been documented for the Benguela ecosystems (Hutchings et al., 2012). Given that environmental variability has been shown to change over time in the southern Benguela (see Blamey et al., 2012), for the purpose of this study climate variability rather than directional climate change will be used to identify the impacts of the environment on fisheries and ecosystem components. After careful consideration of how climatic variability impacts the southern Benguela, four important environmental drivers were identified; the position of the South Atlantic High Pressure System, upwelling, sea surface temperature (SST) and chlorophyll concentration.

The South Atlantic High Pressure System, also known as the South Atlantic Anticyclone, defines the dominant wind system over the southern Atlantic. This system consists of mid-latitude westerlies, equatorward winds along the west coast of southern Africa and south-easterly trade winds (Lübbecke et al., 2010). These wind patterns give rise to southerly wind stress near the west coast of Africa whilst to the south of Africa there is a general westerly flow with changes in wind direction associated with mid-latitude cyclones which travel in an east to west direction (Shillington et al., 2006). This high pressure cell shifts seasonally and its interaction with continental lows and the associated cloud band convergence zone results in upwelling-favourable winds on the west coast of South Africa (Hutchings et al., 2009), with consequences for nutrients and primary production.

It is essential that the variability of upwelling is considered when attempting to understand the impacts of environmental drivers in the southern Benguela. The high levels of nutrients transported into the surface layer during upwelling events, which are then available for use by phytoplankton, result in the high levels of productivity observed in upwelling systems. Coastal upwelling off the west coast of South Africa is seasonal, occurring mostly in the summer months (October–March). The pulsing pressure field and consequent south-easterly winds off South Africa's west coast, which are characterised by five to ten day variabilities, result in variations in upwelling, with a range of two to twelve days and a typical upwelling period of approximately six days (Roy et al., 2001; Crichton et al., 2013).

Temperature plays a central role within biological processes in the oceans due to its impacts on fundamental physiological processes as well as on distribution of marine species. Although it remains unknown how long-term natural variability in temperature will continue to change with fluctuating climatic conditions, it is clear that with increasing heat content of the oceans there will be a strong impact on strength and behaviour of the world's major ocean current systems (Bindoff et al., 2007), resulting in global ecosystem-wide changes.

Chlorophyll concentration can be used as a proxy for primary production, and therefore through the use of ocean colour satellite data it is possible to get an indication of surface phytoplankton levels in the southern Benguela. However, surface chlorophyll concentrations have been found to be a better indicator of phytoplankton biomass on the west coast than on the south coast of South Africa. The availability of phytoplankton can limit the productivity of fish populations and alter their distribution. For example, in the southern Benguela, the main limitation on copepod growth is localised food availability, i.e. phytoplankton variability (Richardson and Verheye, 1999). Many of the highly abundant small pelagic fishes in the southern Benguela rely on copepods as their principal food supply (Cury et al., 2000; van der Lingen et al., 2006) and therefore these populations would also be influenced by the levels of phytoplankton in the water column.

1.4. Decision support

Indicators support the decision making process involved in fisheries management in a number of ways, including their description