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The Benguela Current: An ecosystem of four components

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ABSTRACT

The Benguela system is one of the four major eastern boundary upwelling systems of the world. It is unusual as there are two stratified subtropical or warm temperate boundary regions, on either side of the major wind-driven upwelling region(19–34°S), which itself is subdivided at 26°S by the powerful Luderitz upwelling cell. Important biological components cross the boundary areas at different stages to complete the life-history cycle. While the "Bakun triad" of factors responsible for the development of large pelagic fish populations (enrichment, concentration and retention) provide an important unifying principle for understanding the compromise implicit in adaptation to upwelling systems, the role of predation has been neglected, as has the fish yield relative to photosynthesis. The role global climate change will have in the Benguela in terms of shifting boundaries or weakening or intensifying gradients is being explored. The interannual and decadal signals are so strong in the region that long term trends are difficult to distinguish. Intensive resource utilisation and the collapse of several fish stocks occurred in the Benguela region during the 1960s and 1970s, with different recovery trajectories in the north and the south. The Angolan subsystem can be described as a subtropical transition zone between the wind-driven upwelling system and the Equatorial Atlantic, with gentle upwelling-favourable winds, well-defined seasons, intermediate productivity and moderate, declining fisheries. It is separated from the Namibian subsystem by the Angola-Benguela front.

The northern Benguela shelf is a typical coastal upwelling system with equatorward winds, cool water, high plankton biomass and moderate to high fish biomass, which is currently in a depleted state. A shift from sardines to horse mackerel occurred during the period 1970–1990, while hake have never fully recovered from intensive fishing pressure up to 1990. Widespread oxygen-depleted waters and sulphur eruptions result from local and remote forcing, restricting the habitat available for pelagic and demersal fish species.

The Luderitz–Orange River Cone is an intensive perennial upwelling cell where strong winds, high turbulence and strong offshore transport constitute a partial barrier to epipelagic fish species. Upwelling source water alters in salinity and oxygen, across this boundary zone. A decline in upwelling-favourable winds occurred between 1990 and 2005.

The southern Benguela region is characterised by a pulsed, seasonal, wind-driven upwelling at discrete centres and warm Agulhas water offshore. High primary productivity forms a belt of enrichment along the coast, constrained by a front. Low-oxygen water, which only occurs close inshore, may adversely affect some resources. The west coast is primarily a nursery ground for several fish species which spawn on the Agulhas Bank and are transported by alongshore jet currents to the west coast.

The Agulhas Bank forms the southern boundary of the Benguela system and it displays characteristics of both an upwelling and a temperate shallow shelf system, with seasonal stratification and mixing, coastal, shelf-edge and dynamic upwelling, moderate productivity and a well oxygenated shelf. A large

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biomass of fish occupies the Bank during the summer season, with some evidence for tight coupling between trophic levels. A cool ridge of upwelled water, with links to coastal upwelling and to the Agulhas Current, appears to play an important but poorly understood role affecting the distribution and productivity of pelagic fish. A boom in sardine and anchovy populations was accompanied by an eastward shift, followed by 5 years of poor recruitment by sardine but successful recruitment of anchovy, indicating changes in the early life-history patterns of these two species.

1. Introduction

The Benguela region has been subject to a number of disciplinary reviews (Andrews and Hutchings, 1980; Nelson and Hutchings, 1983; Shannon, 1985; Chapman and Shannon, 1985; Shannon and Pillar, 1986; Crawford et al., 1987; Shannon and Nelson, 1996; Hill et al., 1998; Field and Shillington, 2004; Mackas et al., 2006; Shannon et al., 2006; Shillington et al., 2006; van der Lingen et al., 2006) Two substantial multidisciplinary programs, the Benguela Fisheries and Environment Interactions and Training (BENEFIT) program, funded largely through the Norwegian Agency for Development and Co-operation (NORAD) and German Agency for Technical Cooperation (GTZ) and the Benguela Current Large Marine Ecosystems (BCLME) program, funded through the Global Environment Facility (GEF), recently terminated and provided a large stimulus for a coherent study of the entire Benguela region from 5°S, 12°E off Cabinda in Angola to the Nelson Mandela Metropole (Port Elizabeth) on the south coast of South Africa at 34°S, 26°E. While much focus has been on the continental shelf areas and the associated fishery and mineral resources, there has been a growing awareness of the large basin scale ocean and atmospheric forcing of the Benguela region, which comprises a number of fronts or boundary regions. This overview attempts to provide a concise multidisciplinary description of the major features of the Benguela system within the constraints of length. Interested readers are referred to Shannon et al. (2006) for more details.

2. Large scale features

Fig. 1 (modified from Shannon (2006)), indicates the major features affecting the ocean and atmosphere in the Benguela, compared to the review of Eastern Boundary regions by Mackas et al. (2006), who of necessity had to treat the upwelling systems as single entities. The South Atlantic and South Indian Ocean anticyclones shift seasonally and interactions with the continental low and associated cloud band convergence and the complex intertropical convergence zone create upwelling-favourable winds along the west coast and a warm, poleward-flowing western boundary current on the east coast, which retroflects south of the continent. Warm water of the Atlantic and central Indian Oceans influences the boundary conditions and rainfall patterns and, uniquely, provides warm equatorial water to both the northern and southern boundaries of the Benguela. South of the continent, which ends at 35°S, the free passage of cyclones in the westerly wind belt and the close proximity of the Southern Ocean allow strong signals to propagate into the Benguela region.

Major modes of variance in the South Atlantic are described by Reason et al. (2006) and Colberg and Reason (2007), using rotated Empirical Orthogonal Functions (EOF's) of the upper mixed layer temperatures from the ORCA2 model. (Fig. 2). The first mode is in the equatorial Atlantic and links the strength of trade winds and the occurrence of Benguela Nino's (Shannon et al., 1986) at roughly decadal scales, the second is located approximately over the South

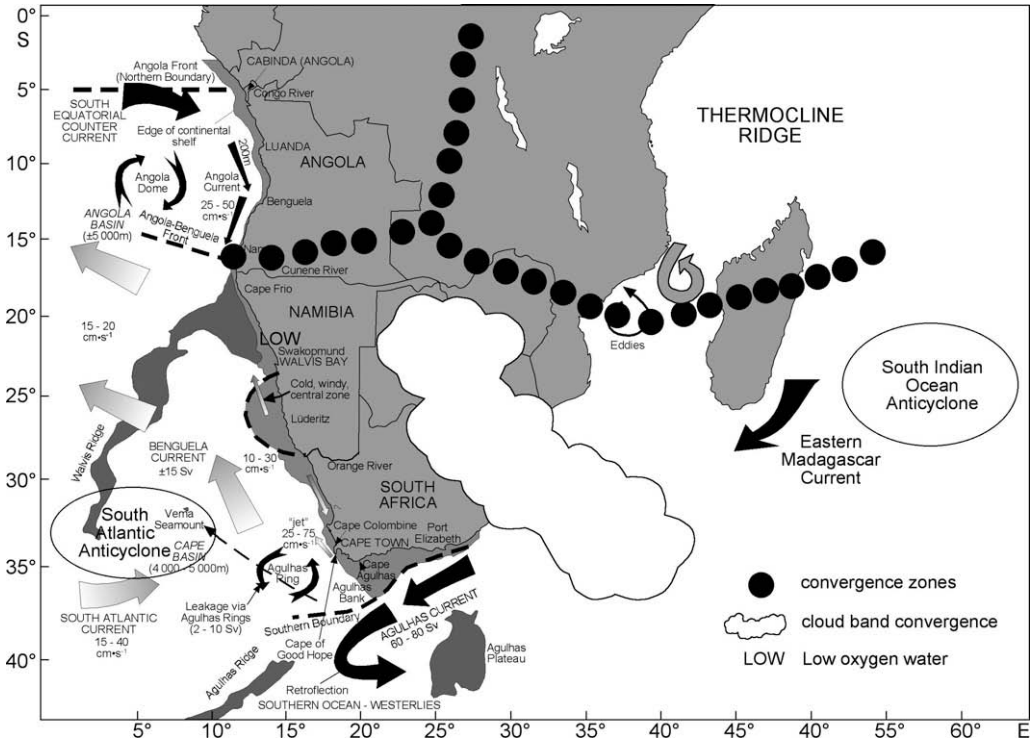

Fig. 1. Large scale oceanic and atmospheric features impacting on the Benguela ecosystem (modified from Shannon, 2006). The anticyclone high pressures systems, the intertropical convergent zones over land and the west wind belt in the form of eastward moving cyclones determine the dynamic boundaries of the Benguela upwelling region. Warm tropical water is advected southwards in the Angola and Agulhas Currents to form intense mixing areas on the northern and southern boundaries of the Benguela.