I-1 Benguela Current: LME #29

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The boundaries of the Benguela Current LME extend from the Agulhas Current to 27^{o} E longitude, and to the northern boundary of Angola. It encompasses the Exclusive Economic Zones (EEZs) of Angola and Namibia, and part of the EEZ of South Africa, with an area of 1.5 million km^2 of which 0.59% is protected, and contains 0.06% of the world's sea mounts (Sea Around Us 2007). One of its unique features is that it is bounded in the north and south by two warm water systems, the Angola Current and Agulhas Current, respectively. These boundaries are highly dynamic and the neighbouring warmer waters directly influence the ecosystem as a whole as well as its living resources. A strong wind-driven coastal upwelling system, with the principal upwelling centre located off Lüderitz (27°S, southern Namibia), dominates this LME. The system is complex and highly variable, showing seasonal, interannual, and decadal variability as well as periodical regime shifts in local fish populations (Shannon & O'Toole 1998, 1999, 2003). The Benguela Current LME has a temperate climate, and plays an important role in global climate and ocean processes (GEF/UNDP/UNOPS/NOAA 1999). Its major estuaries and river systems include the Kwanza and Cunene Rivers. Books, book chapters, articles and reports on this LME include Crawford *et al*. (1989), Palomares and Pauly (2004), O'Toole et al. (2001), Shannon & O'Toole (2003), Shannon *et al*. (2006) and UNEP (2005).

I. Productivity

The Benguela Current LME is a Class I, highly productive ecosystem (>300 gCm^{-2}y^{-1}). The distinctive bathymetry, hydrography, chemistry and trophodynamics of the Benguela Current LME make it one of the most productive marine areas of the world. The plankton has been generally regarded as a diatom-dominated system, but this perception is to some extent an artefact of past sampling (Shannon & O'Toole 1998). Copepods, which are numerically the most abundant and diverse zooplankton group, play an important role in the trophodynamics of this LME since they are the principal food of sardines, anchovies, and other pelagic fish including the larval and juvenile stages of both fish and squid. The high level of primary productivity supports an important global reservoir of biodiversity and biomass of fish, seabirds, crustaceans, and marine mammals. Favourable conditions exist for a high production of small pelagic fishes such as sardines, anchovies, and round herrings. The LME's estuaries provide nursery areas for a number of fish stocks that are shared among the bordering countries, while both the estuaries and coastal lagoons provide critical feeding grounds for migratory birds.

The LME's considerable climatic and environmental variability is the primary driving force of biomass change in the Benguela Current LME (Sherman 2003, Shannon *et al*. 2006). Harmful Algal Blooms (HABs) regularly occur, and have been associated with fish mortalities as a result of oxygen depletion in the water during and after major blooms (Shannon & O'Toole 1998). Satellite images show frequent and widespread eruptions of toxic hydrogen sulphide off the coast of Namibia (Weeks *et al*. 2004). Eruptions often seem to be coincident with either increased intensity of wind-driven coastal upwelling or the passage of a low-pressure weather cell. In 2001, nine major hydrogen sulphide eruptions occurred, with the largest covering 22,000 km^2 of ocean. Their relevance to the fishery resources, including lobsters, is likely to be high. For example, a widespread depletion of oxygen is blamed for the deaths of two billion young hake in 1993 (Hamukuaya *et al.* 1998, Weeks *et al*. 2004).

Since 1995, efforts have been underway in the BENEFIT and Benguela Current LME project (see Governance) to better understand this highly variable and complex system of physical, chemical, and biological interactions and processes (Shannon *et al*. 2006). Systematic surveys have been conducted to assess oceanographic conditions using both shipboard sensors and satellite remote sensors for temperature, chlorophyll, nutrients, and primary productivity.

Oceanic fronts (after Belkin et al. 2009): The coastal upwelling zone off South Africa extends from Cape of Good Hope (34.5°S) north to 13°S and consists of the two major areas, the northern and southern Benguela upwelling frontal zones (UFZ) separated by the so-called Lüderitz line (LL) at 28°S, where the shelf's width is at a minimum (Shannon 1985, Shillington 1998) (Figure I-1.1). The northern UFZ is year-round, whereas the southern UFZ is seasonal). A peculiar double front is observed within the southern UFZ, between 28°S-32°S, with the inshore front close to the coast (a few tens of km) and the offshore front over the shelf break (150-200 km off the coast). This double-front pattern can be explained by the conceptual model put forth by Barange and Pillar (1992). A vast frontal zone develops seasonally off the Angolan coast. This zone consists of numerous fronts; most fronts extend ESE-WNW; the entire zone seems to protrude seaward from the Angolan coast north of 20°S (Belkin et al. 2009). This zone is likely related to the Angola-Benguela Front (ABF) (Shannon *et al*. 1987, Meeuwis & Lutjeharms 1990).

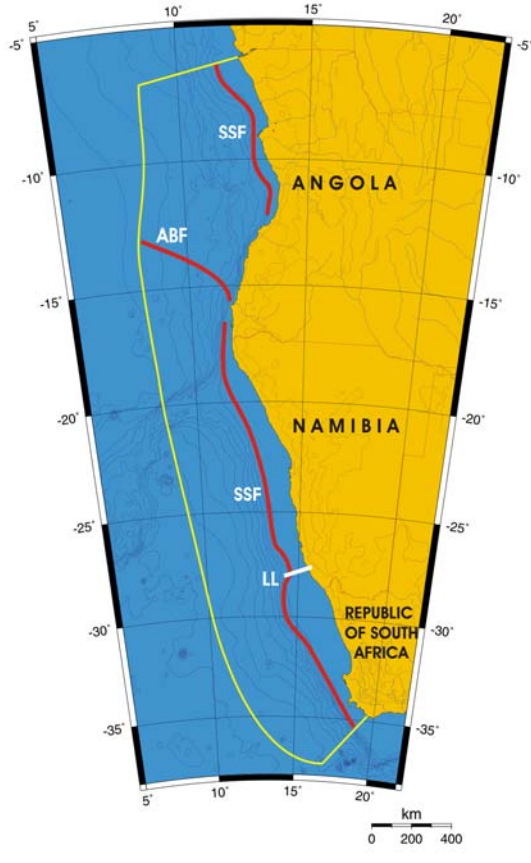

Figure I-1.1. Fronts of the Benguela Current. ABF, Angola-Benguela Front; LL, Lüderitz Line; SSF, Shelf-Slope Front. Yellow line, LME boundary. (Belkin et al. 2009)

Benguela Current SST (after Belkin 2009)
Linear SST trend since 1957: 0.26°C.
Linear SST trend since 1982: 0.24°C.

The Benguela Current's thermal history was punctuated by warm and cold events associated with Benguela El Niños and La Niñas, Atlantic counterparts of the Pacific El Niños and La Niñas. Fidel and O'Toole, in a presentation made at the 2nd Global Conference on Large marine Ecosystems in Qingdao, distinguished five major Benguela El Niños over the last 50 years. The most pronounced warming of >1.2°C occurred after the all-time minimum of 1958 and took 5 years to peak in 1963. Other warm events peaked in 1973 and 1984, alternated with cold events of 1982 and 1992. Clearly, decadal variability in the Benguela Current was strong through the last warm event of 1984. After that, the Benguela Current experienced a shift to a new, warm regime, in which decadal variability is subdued. Some researchers also note the 1995 warm event, although this maximum is not conspicuous from Hadley SST data. The post-1982 warming of the Benguela Current LME was spatially non-uniform: whereas SST in some areas of northern Benguela (between 12-26°S) increased by 0.6 to 0.8°C, the inshore shelf area of southern Benguela experienced a slight cooling (Fidel and O'Toole, 2007, after Pierre Florenchie, University of Cape Town, personal communication).

The thermal history of this LME bears limited commonality with either the Guinea Current LME (its northern neighbor) or to the Agulhas Current LME (its southern neighbor). This is not at all surprising since these three LMEs are oceanographically disconnected. Indeed, the Agulhas Current retroflects southwest of Cape Agulhas and therefore does not feed the Benguela Current, save possibly for small occasional alongshore leakages. In the north, the Angola-Benguela Front (ABF) blocks any direct along-shelf connection between two neighbors, the Benguela Current LME and Guinea Current LME.

Correlation analysis suggests different responses to environmental forcing in the northern, central, and southern parts of the Benguela Current region (Jury and Courtney, 1995). For example, the lower correlation in the southern Benguela between SST and local winds suggests that SST variability here is often driven by advection, likely by the Agulhas Current and its extension. The higher correlation in the central Benguela between SST and local winds indicates that SST variability here is largely driven by local upwelling.

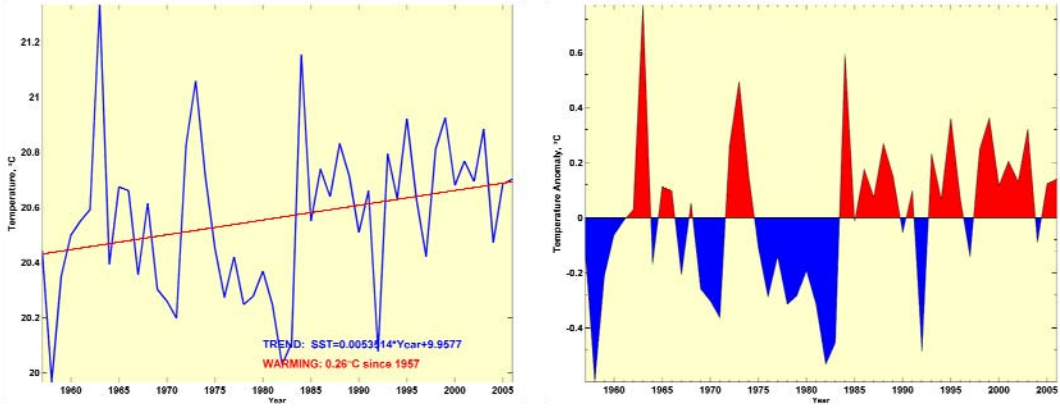

Figure I-1.2. Benguela Current LME mean annual SST (left) and annual SST anomalies (right), 1957 – 2006, based on Hadley climatology (after Belkin 2009).

Benguela Current Trends in Chlorophyll a and Primary Productivity: The Benguela Current LME is a Class I, highly productive ecosystem (>300 $gCm^{-2}y^{-1}$).

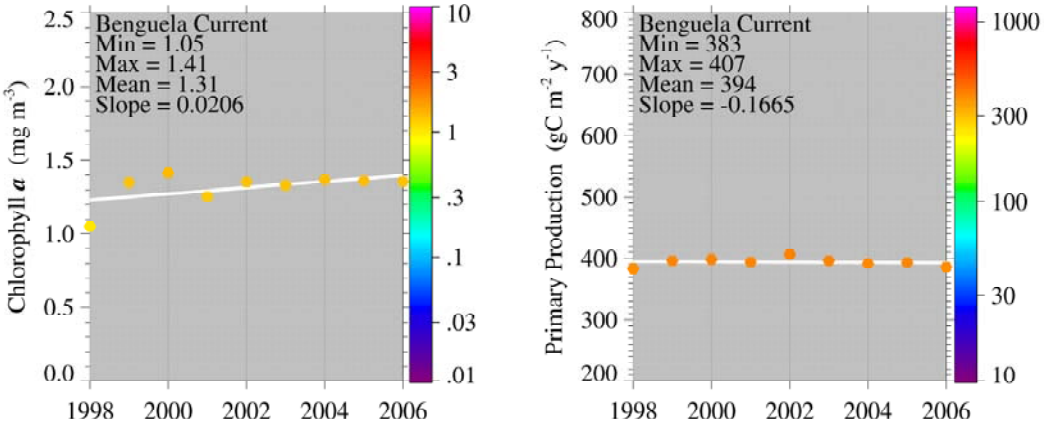

Figure I-1.3. Benguela Current LME trends in chlorophyll *a* (left) and primary productivity (right) 1998-2006; values are color coded to the right hand ordinate. Courtesy of J. O'Reilly and K. Hyde. Sources discussed p.15 this volume.

II. Fish and Fisheries

The Benguela Current LME is very rich in pelagic and demersal fish. Most of the LME's major fisheries resources are shared between the bordering countries or migrate across national jurisdictional zones, and include sardine (*Sardinops sagax*), anchovy (*Engraulis capensis*), hake (*Merluccius capensis* and *M. paradoxus*), horse mackerel (*Trachurus trachurus* and *T. trecae*), sardinella (*Sardinella* spp.), and rock lobster (*Jasus lalandii*). Artisanal, commercial (industrial) and recreational fisheries are all of significance in the LME, with artisanal fisheries being particularly important for Angola. Total reported landings of the LME increased steadily from 1950 to a peak of about 3 million tonnes in 1978 (Figure I-1.4). In the subsequent years, however, the landings show a general decline, down to about 1.1 million tonnes in 2004. The trend in the value of the reported landings closely resembles that of the reported landings, peaking at just under 3 billion US$ (in 2000 real US$) in 1978 (Figure I-1.5).

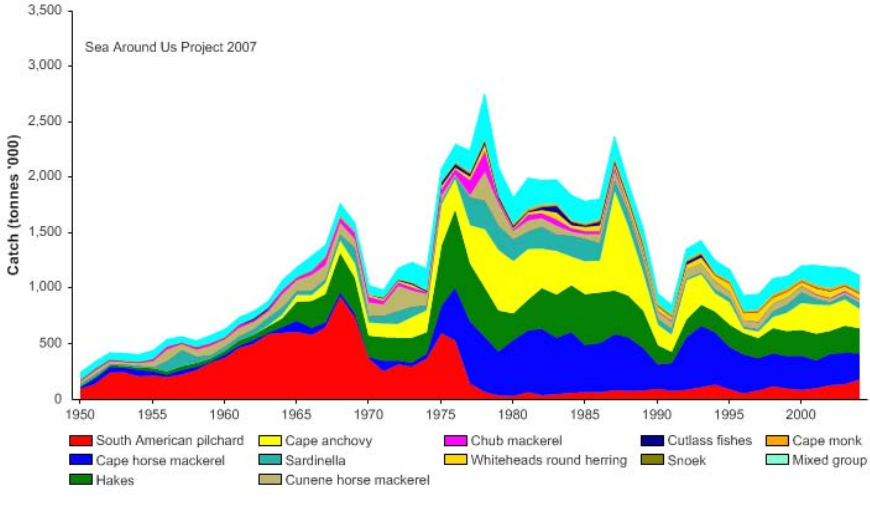

Figure I-1.4. Total reported landings in the Benguela Current LME by species (Sea Around Us 2007).

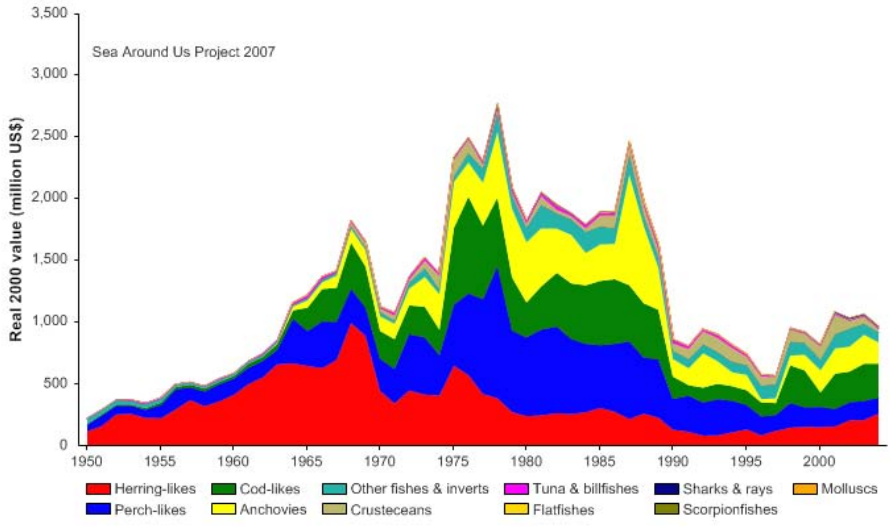

Figure I-1.5. Value of reported landings in the Benguela Current LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in the LME reached one third of the observed primary production by the mid 1970s, but has since declined to half that level (Figure I-1.6). Although there were large numbers of foreign fleets operating in the LME in the 1970s and 1980s, since the early 1990s, Namibia and South Africa have the largest ecological footprints in the region.

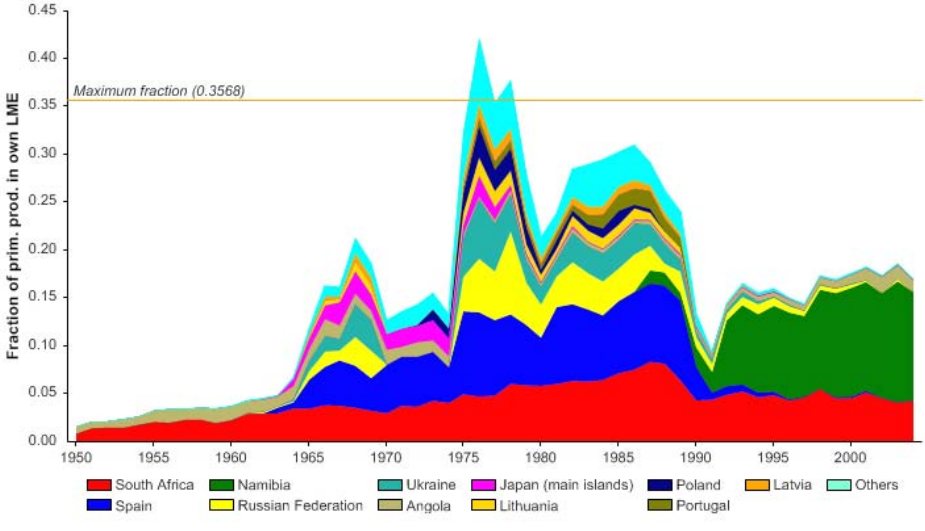

Figure I-1.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Benguela Current LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Since the mid 1970s, the mean trophic level of the reported landings (i.e, the MTI, Pauly & Watson 2005) has been relatively stable in this LME, (Figure I-1.7 top), but as the amount of catch (tonnage) has declined over the same period, the FiB index shows a rapid decline (Figure I-1.7 bottom).

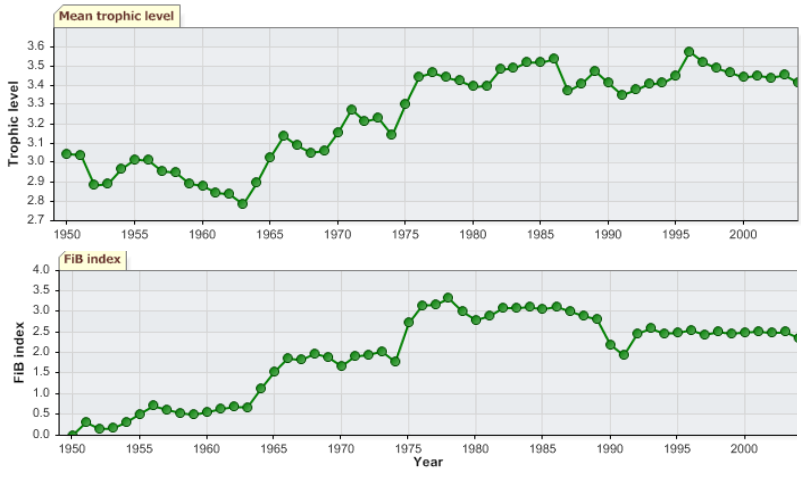

Figure I-1.7. Trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Benguela Current LME (Sea Around Us 2007).

This decline of the FiB index is particularly strong off Namibia (Willemse and Pauly 2004), where the ecosystem has been greatly modified, with jellyfish now dominating the food web (Lynam *et al.* 2006). This is a case of 'fishing down marine food webs' (Pauly *et al.* 1998), but one in which the species that replaced the exploited species are presently not targeted by fisheries.

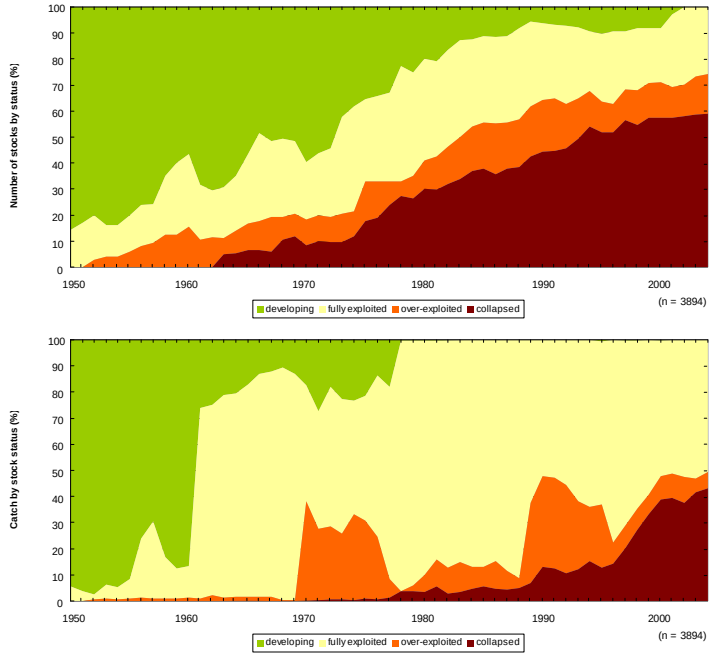

Figure I-1.8. Stock-Catch Status Plots for the Benguela Current LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al.* this vol. for definitions).

The Stock-Catch Status Plots indicate that about 60% of commercially exploited stocks in the LME has collapsed, with another 10% overexploited (Figure I-1.8 top), with fully-exploited stocks contributing 50% of the catch (Figure I-1.8, bottom). However, fully exploited stocks, while accounting for less than 30% of the stocks, provide over 50% of the reported landings (Figure I-1.8).

Major changes in the key harvested species have occurred in the last century (Hampton *et al*. 1999, Shannon & O'Toole 2003). While environmental variability has been a contributing factor, some of these changes were undoubtedly the consequence of overexploitation (FAO 2003, Sherman 2003). The decline in these fisheries is caused, in part, by excessive fishing effort and overcapacity of fleets, excess processing capacity, catching of under-sized fish, and inadequate fisheries management (GEF/UNDP/UNOPS/NOAA 1999). As a result, the fisheries in the LME have experienced years of catches well below the maximum or optimal sustainable yields, with dramatic declines in stock sizes and catch per unit effort.

Decline in commercial fish stocks and non-optimal fishing of living resources is now a major transboundary problem in the LME (GEF/UNDP/UNOPS/NOAA 1999). In all three countries bordering the LME, major fisheries resources have undergone significant changes in annual catch (Hampton *et al*. 1999, Tapscott 1999) and this is also true for exploitation of invertebrate resources. For example, rock lobster catches have declined dramatically since the early 1960s, particularly off Namibia, where catches are now well below their 1960s peak. Assessments of the South African rock lobster resource have shown it to be seriously depleted, and estimates of recruitment in recent decades are only about 35% of its pre-exploitation condition (Hampton *et al*. 1999). The abalone stock has also been declining since 1996 (Tarr *et al*. 2000) and the stock is considered to be on the brink of collapse as a result of illegal fishing (Tarr 2000) and an ecological shift in abundance (Tarr *et al*. 1996).

Some of the major stock fluctuations have undoubtedly been influenced by the large-scale environmental perturbations that occur periodically in the system (Shannon & O'Toole 1998, Shannon *et al*. 2006). System-wide changes in abundance of species and species shifts (e.g., sardine and anchovy) are well-documented in this LME (e.g., Hampton *et al*. 1999, Shannon & O'Toole 2003). Fluctuations in abundance of the LME's fish stocks have also been detected through acoustic surveys for pelagic species such as sardines and anchovies (Barange *et al*. 1999, Hampton *et al*. 1999), and trawl surveys for demersal species (Hampton *et al*. 1999). The geographic displacement of stocks (e.g., *Sardinella aurita* and *S. maderensis* in Angola into Gabon) is also a common phenomenon with alongshore migration of fish populations across national boundaries in the Benguela Current LME having important implications for resource management. Global warming and associated phenomena are also expected to influence the LME's upwelling system, with potentially significant impact on the local food webs and the entire ecosystem, including fish recruitment and fisheries production.

Fluctuations in fish stocks can also have effects on top predators such as seabirds and seals (Crawford 1999, Crawford *et al*. 1992). For example, the distribution of Cape gannets, Cape cormorants, and African penguins has changed over the past three decades in response to changes in the distribution and relative abundance of sardine and anchovy (Crawford 1998). The high mortality and breeding failure of Cape fur seal colonies in Namibia in 1994 and 1995 can be attributed to low food availability resulting from low sardine abundance, a consequence of the catastrophic environmental variability and anomalous low oxygen events (O'Toole 1996).

Despite the vast scale of the fisheries in the LME, bycatch is not a major problem, and is taken mostly in the large pelagic and demersal fisheries. Discarding is controlled by strict regulations as well as by observers in some fisheries (e.g., Patagonian toothfish) but by self-policing where the bycatch is used as a luxury product. In the demersal trawl fishery of South Africa, 10% of the total catch is discarded (Walmsley-Hart *et al*. 2000). Both South African and Angolan purse seine fisheries yield bycatch rates between 10-20% of the total catch (Crawford *et al*. 1987).

The status of the fisheries is problematic, as the countries develop and implement national and regional fisheries policies and management programmes (GEF/ UNDP/ UNOPS/ NOAA 2002). Furthermore, some stocks show signs of response to environmental variability, e.g., recently correlated with a movement of sardines from Namibian waters to the south and southwest coasts toward the Agulhas Bank (van der Lingen *et al*. 2006). Sardine stocks in South Africa showed signs of recovery from the mid-1990s as a result of careful control of bycatch of juveniles, and the introduction of an operational management procedure which focused on rebuilding sardine stocks while optimally utilising the anchovy. However, recent stock assessment surveys of sardines around the Cape indicate a decline to very low levels compared with the mid 1990s.

III. Pollution and Ecosystem Health

Pollution: Virtually the entire coastline of the Benguela Current LME is exposed to the open ocean and experiences a relatively high degree of wave action. Strong wave action and currents tend to rapidly dissipate any pollution reaching the marine environment. Pollution is not a serious problem in the open marine areas of most of the LME, and is mostly evident in localised areas or hotspots such as ports and enclosed lagoons in all three countries. Poorly planned coastal developments, inadequate waste management, chronic oil pollution, inappropriate agricultural practices, contaminated stormwater run-off, as well as industrial and sewage wastewater discharges are among the factors that contribute to the deterioration of coastal and marine environments in the LME (UNEP 2005, Taljaard et al. 2006). Levels of pollution, with the exception of hotspots, are considered moderate (UNEP 2005). With poor urban infrastructure, there is a very real danger that a rapidly expanding urban population will pose a serious pollution threat, as untreated sewage is discharged into the sea in increasing volumes. HABs have been identified as a major transboundary problem, and their frequency of occurrence, spatial extent, and duration appear to be increasing (GEF/UNDP/UNOPS/NOAA 1999). Although HABs occur naturally in all three bordering countries (Tapscott 1999), several factors, including nutrient loading from anthropogenic activities (e.g., discharge of untreated sewage), can promote their incidence and spread. Toxins produced by HABs have led to mortalities of fish, shellfish, and humans, as well as anoxia in inshore waters that can cause mass mortality of marine organisms (GEF/UNDP/UNOPS/NOAA 1999).

Diamond mining operations impact negatively on the marine environment. Certain mining activities are conducted close to national boundaries (e.g., diamond mining near the Orange River mouth on both sides of the border between South Africa and Namibia), across which negative consequences may be transmitted. Diamond mining is also thought to affect marine living resources. For instance, although the dramatic decrease in Namibian rock lobster catches in the 1990s may be attributed to large scale environmental perturbations, it is evident that stock abundance might have also been influenced by marine diamond mining (Tapscott 1999). While mining is the primary cause of increased suspended solids in the marine areas, poor agricultural practices also contribute to this problem, particularly in estuaries, lagoons, and sheltered bays. Marine litter from land and shipping poses a serious growing problem throughout the LME, with significant transboundary consequences (GEF/UNDP/UNOPS/NOAA 1999). Oil and gas exploration and production are considered to pose a major threat, particularly off Angola,

with oil spills sometimes causing severe local pollution which impacts artisanal fisheries. A substantial volume of oil is transported through the region, and poses a significant risk of contamination to coastal environments, damage to shared and straddling fish stocks, and to coastal infrastructure (GEF/UNDP/UNOPS/NOAA 1999).

Habitat and community modification: Four estuaries and five coastal lagoons in the Benguela Current LME are considered to be of transboundary significance. Several lagoons have been designated as Ramsar sites. Species that are endemic to only one or two estuarine systems within the LME are also present. The rare estuaries represent the only sheltered marine habitat in the LME, and are important both for biodiversity and as a focus of coastal development.

Habitat and community modification was assessed as severe in the Benguela Current LME (UNEP 2005). The TDA produced by the GEF-supported Benguela Current Large Marine Ecosystem (BCLME) Project has identified habitat destruction and alteration, including modification of the seabed and coastal zone, and degradation of coastscapes, as a transboundary problem in this LME (GEF/UNDP/UNOPS/NOAA 1999). Nevertheless, compared to other parts of the world, these effects are minor in the Benguela Current LME.

Modification of the few estuarine systems was found to be severe in the Benguela Current LME (UNEP 2005). There is some loss of rocky and sandy foreshores in the region due to port construction, seawalls, resort development, and coastal diamond mining particularly in South Africa and Namibia, and some sand mining in Angola. The invasion of a significant stretch of coastline by the alien mussel (*Mytilus galloprovincialis*) has drastically altered community structure and functional group composition on the shore. Exploitation of some species in the kelp beds and mangroves has led to changes in community structure within these habitats.

The potential impacts of sea level rise on the coastal areas of the Benguela Current LME include increased coastal erosion and inundation of coastal areas. Available evidence suggests that variability and extremes in rainfall pattern are increasing in the south, particularly in the drier western parts (Tyson 1986, Mason *et al*. 1999). The resulting projected changes in stream flow are likely to have serious consequences for the estuaries.

Pollution, particularly microbiological, chemical and solid waste as well as eutrophication, is expected to become worse in the future, if poorly planned urbanization and economic development in the coastal areas of this LME continue (UNEP 2005). Habitat modification and loss are also expected to become worse if current practices continue, increasing the concern over the cumulative future effects on the health of this ecosystem.

IV. Socioeconomic Conditions

A large part of the population of the countries bordering the Benguela Current LME lives in urban areas, many of which are situated near the coast. The LME and its resources are of considerable socioeconomic importance to the bordering countries. For example, the production of oil and gas off the coast is the most important economic activity in Angola, contributing 90% of the total Gross Domestic Product (GDP). The fisheries sector is an important source of revenue, food, and employment in the three countries. Traditionally, fisheries have contributed significantly to the livelihoods of coastal communities. In Angola, this sector currently rates third after oil and diamond mining, and is estimated to provide half of the animal protein consumed in the country. Fishing contributes 9% to Namibia's GDP (SADC 2003), with annual fisheries exports worth over 225 million US$. Although the fisheries sector plays a small part in South Africa's

economy, contributing about 1% to GDP (FAO 2006), it makes a significant contribution to the regional economy of the Western Cape, which is the centre for the industrial fisheries. In some coastal areas of South Africa, this sector is the dominant employer.

Fisheries constitute an important contribution to national revenue, employment, and food security in the bordering countries. These include a variable and uncertain job market, loss of national revenue, loss of food security, erosion of sustainable livelihoods, missed opportunities through underutilisation and wastage, and loss of competitive edge on global markets (GEF/UNDP/UNOPS/NOAA 1999). Unpredictable fisheries yields have sometimes resulted in closure of fish processing plants. Conflicts between subsistence, artisanal, commercial, and recreational fisheries also arise when resources become scarce. Subsistence fisheries depletion may adversely affect the diet and consequently the health of those dependent on fisheries. In many coastal settlements fishing is the only source of livelihood for the poorer segments of the population. Reduced fisheries resources also lead to migration of human populations from rural coastal areas to cities, resulting in expansion of urban poverty. Regime shifts as well as factors possibly related to climate change may displace fish stocks, contributing to socio-economic difficulties and threats to breeding populations of endemic species, e.g. African penguin.

V. Governance

The Benguela Current LME is located within the UNEP Regional Seas for the West and Central Africa Region, which was forged in the early 1980s. The West and Central African Action Plan for the Protection and Development of the Marine Environment and Coastal Areas of the West and Central African Region, the Abidjan Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region (Abidjan Convention) and associated Protocol Concerning Co-operation in Combating Pollution in Cases of Emergency were adopted by the Governments of the region in 1981. Projects on contingency planning, pollution, coastal erosion, environmental impact assessment, environmental legislation and marine mammals soon followed. A Conference of Plenipotentiaries, which met in Dakar, Senegal, in 1991, adopted the Regional Convention on Fisheries Cooperation among African States bordering the Atlantic Ocean (Dakar Convention), to which Angola has acceded.

There is a strong need for harmonising legal and policy objectives and for developing common strategies for resource surveys, as well as investment in sustainable ecosystem management in the Benguela Current LME. In 1997 a major regional cooperative initiative (BENEFIT: BENguela-Environment-Fisheries-Interaction and Training Programme) was launched jointly by Angola, Namibia, and South Africa, together with foreign partners (Norway and Germany) to enhance science capacity required for the optimal and sustainable utilization of living resources of the Benguela Current LME. This programme has been remarkably successful in developing cooperation among the three countries and in helping to strengthen marine scientific capacity in the region. A GEF grant and in-kind support of 38 million US$ to Angola, Namibia and South Africa, the three countries participating in the Benguela Current LME assessment and management project, will allow for significant additional support for initiating time-series measurement of selected indicators of the ecosystem's productivity, fish and fisheries, pollution and ecosystem health, and socioeconomics.

In March 2000, this regional cooperation was further enhanced with the initiation of the implementation phase of the Benguela Current LME Programme (www.bclme.org), to assist Angola, Namibia, and South Africa to assess and manage the marine resources of the LME in an integrated and sustainable manner. This programme, which is funded in part by the GEF and the 3 participating countries, chiefly addresses transboundary

problems in three key areas of activity: the sustainable management and utilisation of living resources; the assessment of environmental variability, ecosystem impacts and improvement of predictability; and maintenance of ecosystem health and management of pollution. Through this project, the Transboundary Diagnostic Analysis (TDA) and Strategic Action Plan (SAP) were used to review the existing knowledge on the status of, and to identify the threats to the Benguela Current LME. One of the main goals of the BCLME Programme was the creation of the Benguela Current Commission. This process was formalised through the signing of an Interim Agreement by the three countries on 29 August 2006 in Cape Town. This transitional management entity, which will last for four years, will be the precursor of the fully-fledged Benguela Current Commission whose function and responsibilities will be to implement an ecosystem approach to ocean governance in the Benguela region. This will include annual stock assessments of key economic species, annual ecosystem reports, the provision of advice on harvesting resource levels and other matters related to sustainable resource use, particularly fisheries and the management of the Benguela Current LME as a whole.

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