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Making the best of change

FAO/Benguela Current Commission Workshop
1–3 November 2011
Windhoek, Namibia

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Climate change implications for fisheries of the Benguela Current region

Making the best of change?

FAO/Benguela Current Commission Workshop
1–3 November 2011
Windhoek, Namibia

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Preparation of this document

These Proceedings present the outcome of the Workshop on Climate Change Implications for Fisheries of the Benguela Current Region: Making the Best of Change. The Workshop was hosted by the Benguela Current Commission (BCC) in Windhoek, Namibia, from 1 to 3 November 2011. It was financed through a Japanese-funded, and FAO-implemented, project on Climate Change, Fisheries and Aquaculture: Understanding the Consequences as a Basis for Planning and Implementing Suitable Responses and Adaptation Strategies (GCP/INT/253/JPN), in collaboration with the BCC. Further support was provided by Nordenfjeldske Development Services (NFDS) and the United Nations Development Programme (UNDP). The contributed papers were drafted by Ian Hampton and are reproduced as submitted.

Abstract

These Proceedings include the Report of, and the background papers prepared for, the Workshop on Climate Change Implications for Fisheries of the Benguela Current Region: Making the Best of Change. Presentation topics included: the regional biophysical features and decadal trends in the Benguela Current Large Marine Ecosystem (BCLME); national contexts of climate variability and change and fisheries; and a vulnerability assessment of the region's fisheries. Discussions largely focused on: aspects of developing a methodology for vulnerability assessment; definition of vulnerability in a fisheries context; potential climate change impacts on, and vulnerability levels of, the different fisheries in the region; and potential short- and medium-term adaptation actions. The Workshop recommended that a regional programme be developed with the aim of reducing vulnerability and increasing adaptive capacity of the social-ecological fisheries systems of the BCLME, primarily focusing on: establishing/improving national and regional interagency collaboration and communication to facilitate responses and action in relation to climate change; developing a holistic and coherent methodology for vulnerability assessment of fisheries; developing and implementing pilot projects to develop and test anticipatory and responsive actions, providing for lesson learning/sharing and improvements.

De Young, C., Hjort, A., Sheridan, S. & Davies, S.
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Abbreviations and acronyms

ACCESS	Applied Centre for Climate and Earth Systems Science
AECDI	Agency of International Cooperation for Development
BCC	Benguela Current Commission
BCLME	Benguela Current Large Marine Ecosystem
COP	Conference of the Parties
EAF	ecosystem approach to fisheries
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
HIV/AIDS	human immunodeficiency virus/acquired immunodeficiency syndrome
IGO/CSO	intergovernmental organization/civil society organization
IPCC	Intergovernmental Panel on Climate Change
LDCF	Least Developed Countries Fund
LME	large marine ecosystem
MPA	marine protected area
NAPA	National Adaptation Programme of Action
NEPAD	New Partnership for Africa's Development
NFDS	Nordenfjeldske Development Services
NGO	non-governmental organization
PaCFA	Global Partnership on Climate, Fisheries and Aquaculture
PIF	Project Identification Form
REDD	Reducing Emissions from Deforestation and Forest Degradation
SCCF	Special Climate Change Fund
SLR	sea level rise
SSF	small-scale fisheries
SST	sea surface temperature
TAC	total allowable catch
TCP	FAO Technical Cooperation Programme
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Workshop summary

OPENING OF THE MEETING AND ARRANGEMENT FOR THE SESSIONS

On behalf of the Benguela Current Commission (BCC) and FAO, Dr Hashali Hamukuaya, the Executive Secretary of the BCC, opened the Workshop. He welcomed the participants thanking them for their attendance at the Workshop, expressing gratitude to the countries, institutions and persons who had contributed to its organization. He noted that the Workshop provided one of the first steps towards understanding climate change impacts on, and options for adaptation in, the fisheries of the Benguela Current Large Marine Ecosystem (BCLME). He also noted that climate change and adaptation to reduce its impacts related to the ecosystem approach to fisheries (EAF) and its human dimensions. Furthermore, he explained that dealing with the effects of climate change in the BCLME had now become even more relevant as the mandate of the BCC had expanded to include other sectors such as mining and oil exploration. Lastly, Dr Hamukuaya provided an update of the development of the BCC convention, noting that a draft was currently being reviewed by the three BCLME countries Angola, Namibia and South Africa, and that it was expected to be signed no later than December next year.

INTRODUCTION OF PARTICIPANTS

Following this introduction, the participants introduced themselves (see Annex 1). Dr Hashali Hamukuaya acted as chair of the Workshop; Cassandra De Young, FAO, and Sandy Davies, NFDS, acted as facilitators; and Antonia Hjort and Sinéad Sheridan, NFDS, acted as rapporteurs.

BACKGROUND AND OBJECTIVES OF THE WORKSHOP

In outlining the background to the Workshop, Cassandra De Young noted that, in the climate change arena, the fisheries and aquaculture sector was "the best known secret". She further noted that climate change was a pervasive issue, relating both to biophysical processes and human choices, but that it was only one of the issues facing the sector. With regard to what could be done to address the impacts of change, she stressed the fact that many of the things that should or could be being done were already known, giving the examples of implementation of the EAF and the Code of Conduct for Responsible Fisheries. However, flexible management systems, insurance schemes, technological innovation (particularly in aquaculture) were some of the types of approaches suggested by Ms De Young that could be particularly relevant in addressing climate variability and change in this sector. Furthermore, planning for adaptation rather than only taking reactive measures as well as policy coherence between different line ministries were two additional important aspects noted. She then went on to explain that although the fisheries and aquaculture sectors contributed relatively little to climate change, mitigation actions could, for example, consist of plantation or re-plantation of mangroves, exploring renewable energy potentials and improving food production systems such as aquaculture.

As steps towards improved understanding of climate change impacts and solutions, Ms De Young explained that the FAO Fisheries and Aquaculture Department currently focused on the following thematic areas:

- improving awareness of impact pathways and vulnerabilities as well as supporting adaptation potentials;

- understanding greenhouse gas (GHG) emissions from aquaculture and fisheries sectors as well as supporting mitigation efforts;
- communicating and advocating for the sectors in global, regional and national climate change discussions;
- making the bridge between science and policy;
- coordinating and collaborating (e.g. through the Global Partnership on Climate, Fisheries and Aquaculture [PaCFA] and the 17th Conference of the Parties [COP17] of the UN Framework Convention on Climate Change [UNFCCC] in Durban) in joint project development and information sharing.

With regard to the Workshop and its objectives, Ms De Young explained that it constituted a part of a project funded by Japan that aims to increase awareness of climate change impacts and adaptation potentials. Among the outputs of the project are six case studies currently being developed, which will feed into adaptation guidelines (to be developed through an FAO Expert Consultation). The objectives of this Workshop were to:

- bring fisheries and climate change partners together to share and plan;
- identify drivers and impacts of change, their effects on fisheries and the communities that depend on these resources;
- identify short- to mid-term actions to improve the resilience of the aquatic system and the adaptive capacity of the fishing communities;
- agree on scope for a follow-up funding proposal.

Lastly, Ms De Young noted that the expected outputs of the meeting were agreed recommendations and workshop proceedings, but also a complementary follow-up effort would be to develop a project proposal in the form of a Global Environment Facility (GEF) Project Identification Form (PIF).

OVERVIEW OF THE REGIONAL BIOPHYSICAL FEATURES AND DECADAL TRENDS IN THE BCLME

As background information for the Workshop, Dr Ian Hampton, Fisheries Resource Surveys, had been tasked to prepare an overview of the regional biophysical features and decadal trends in the BCLME as well as a vulnerability assessment of the fisheries in this region. This resulted in two reports included in these Proceedings as Contributed Papers. With regard to the overview of the regional biophysical features and decadal trends in the BCLME, Dr Hampton noted the following in his presentation:

- The Northern regime of the BCLME has tropical features while the Southern regime consists of a colder nutrient rich upwelling. Lüderitz, Namibia, has the strongest upwelling in the region.
- Changes that have occurred/are occurring on a decadal period are primarily:
  1. Change in wind speed and direction – intensified in offshore direction in the summer months.
  2. Sea surface temperature (SST) trends over the same period include:
     - a general warming of surface waters in both the northern and southern part of the system, but a cooling of the inshore waters off western and southern coasts of South Africa, leading to an intensification of cross-shelf SST gradients in this part;
     - recurring intrusion of warm, low salinity and low oxygen water down into more southern parts, around Walvis Bay, from the most northern parts (e.g. through Benguela Niños), leading to warming of waters and lowering of oxygen levels (the latter affecting the hake stocks). This is the most important perturbation in the northern Benguela.
  3. Chlorophyll concentration (relating to primary production: phytoplankton) – no long-term trend in phytoplankton concentrations has been detected.

4. Trends in oxygen level (primarily in the St Helena Bay area) – oxygen level below thermocline has been declining. This has been extending further offshore.
5. Zooplankton abundance – this has greatly increased in the southern part since the 1950s, but has declined from 2000. In the northern Benguela, the trend has been less clear since the 1970s but there has been a noticeable decline since 2000. A reduction in the larger animals may mean changes in overall size structure as well. The cause could be change in abundance of small pelagic stocks or environmental anomalies
6. Changes in catches of major resources – all countries have suffered some major declines in catch. Dramatic changes have occurred in the northern parts (essentially with no small pelagic fish left in this region; and some changes in catch of horse mackerel, hakes, snoek, and rock lobster) and in the southern parts, catch of small pelagic fish is not as high as in the 1950s, with some changes in catch of horse mackerel, hakes, snoek, and rock lobster. There are not many detailed data from Angola available, although there has been a known decline in sardinella catches.
7. Shift in distribution of sardine and anchovy biomass from west to east of Cape Agulhas between 1985 and 2005 – this was first believed to be the result of climate change but the trend has now been reversed. Hence, it does not look like regime shift, but is possibly caused by environmental changes or fishing pressure on the west coast. Rock lobster has made the same shift.
8. Changes in top predator abundance – in the northern parts, there has been a general increase in seals. Although the population dropped dramatically following a major low oxygen event in 1993/94 and the 1995 Benguela Niño, it recovered rapidly. Gannets have suffered a rapid and continual decline in the northern parts, generally associated with anchovy and sardine decline in Namibia. Penguin populations have declined but are now stable.

In summing up, Dr Hampton suggested that the most dramatic long-term change in the BCLME was the major decline in exploited resources, which was primarily due to overfishing, not to environmental changes. With regard to prediction of long-term changes, Dr Hampton explained that so far such predictions had not been very good, but noted that early warning had more chance of success in this system. The difficulty in long-term prediction relates to the wide-ranging natural variability of the system, which makes it very difficult to detect long-term trends related to global climate change. One exception with regard to prediction is the Benguela Niños, which can be predicted up to two months in advance. Furthermore, long-term warming of SST at both extremes of the system as well as cooling of inshore water on the west and south coasts of South Africa is a fact. Lastly, Dr Hampton noted that responses to future unprecedented environmental changes were currently purely conjectural, but could be profound. For example, increased leakage of the Aghulas Current water into the south Atlantic in response to global warming could change the entire upwelling regime.

Discussion

A substantial discussion followed the presentation with many questions raised, including:

- Who, institutionally, could be in charge of an early warning system in the region? Dr Hampton explained that it could build on the good history of collaboration between the marine research institutions in the countries and be coordinated through, for example, the BCC and its ongoing scientific research programmes.
- Is anyone trying to capture traditional/experience-based knowledge with regard to changes in the climate and its effects? It was explained that some research was being carried out by the Environmental Evaluation Unit of the University

of Cape Town to integrate indigenous knowledge into information systems. It involves case studies based on interviews with skippers to capture knowledge of ecosystems and resources (i.e. not only related to climate change effects).

- Is ocean acidification taking place in the region? There is relatively little carbonate chemistry data for the Benguela Upwelling System but recent research and global biogeochemical climate models suggest that certain shelf ecosystems of South Africa, for example, will be threatened by ocean acidification within this century.
- Has there been an increase in storm activity in the region? It was suggested that there had been an increase in storm activity at sea, but that many of the region's vessels were large industrial ones and, hence, tended to be less affected. However, the smaller boats are vulnerable. Traditional/experience-based knowledge suggests that more time is now spent in port because of increased storm activity. Safety at sea issues are an area of great concern although little research is focused on this in the region. So far, it appears not to have caused less catch but rather increased the need for catching in rougher weather. In Namibia, fishers report on "swirl impact" on the rock lobster fishery day by day and have noted an increase.
- It was noted that with regard to declining catch trends since the 1950s, these were not always due to actual declines in stock but rather to caps put in place through management systems, e.g. total allowable catch (TAC) put in place post-independence.
- It was also noted that effects of climate change and its impacts on resources were known but that what exactly the resources respond to (i.e. the linkages/causal relationships) was unknown.
- Other questions related to the importance of fog patterns (this could affect primary production) and solutions to overfishing (moratorium being noted as a less good option as catches are already low with regard to the threatened species, and the view was that a complete stop would not help the recovery much); stock enhancement could work as part of planned adaptation).

NATIONAL PERSPECTIVES ON FISHERIES AND CLIMATE CHANGE

Two presentations followed on national contexts with regard to fisheries and climate change. On behalf of Namibia, Mr Johnson Ndokosho provided an overview of Namibia's planned response to climate change, which focuses on adaptation. He explained that the response was further elaborated upon in the country's 2002 National Communication to the UNFCCC (of which an update was submitted in October 2011). In explaining why Namibia is vulnerable to climate change, Mr Ndokosho explained that it: has a naturally dry environment (droughts are endemic); has a high dependence on climate-sensitive sectors such as agriculture; and has limited adaptive capacity owing to lack of human resources, skills and technology, coupled with high levels of poverty. With regard to potential impacts, the following were noted of high importance: loss of productivity (e.g. in relation to crop yield and livestock) in the agriculture sector; extreme weather events such as floods and droughts; sea level rise and coastal erosion; health impacts such as shift in distribution of diseases; and effects on biodiversity (e.g. shift in distribution of dominant vegetation structure and local extinctions of vulnerable species). Steps taken by Namibia to address the issues include: ratification of the UNFCCC and the Kyoto Protocol as well as submission of a national communication to the UNFCCC. Furthermore, Namibia has established a national climate change committee and finalized a climate change policy. Currently, work is under way to build the foundation for a national approach to climate change adaptation in Namibia, which would include: agricultural adaptation (agricultural conservation methods, including drip irrigation systems); aquaculture; rainwater harvesting (collecting floodwater, and rain on rooftops); water demand management; protection of watershed areas; etc.

Following the presentation, a discussion took place focusing primarily on the content of Namibia's national communication. It was explained that both the first and second communication to the UNFCCC did include the marine sector; however, as funding was and still is limited, much focus has been on agriculture. One reason given for this was that there are not that many coastal communities in Namibia, e.g. compared with Angola and South Africa. It was suggested that an increased focus on the marine sector could be raised in the third communication, which is currently under development. One participant noted that one limitation of the Workshop was the focus on marine capture fisheries, excluding inland fisheries and aquaculture although these are also important. Another participant raised the issue of considering how non-aquatic changes would affect the coastal communities, e.g. through migration of people and health issues. It was also noted that with regard to responses (to climate change) many of those presented by Namibia were relevant even disregarding climate change effects – in relation to fisheries, as such an approach would include the implementation of the EAF, etc.

The South African perspective, presented by Ms Moenieba Isaacs, focused on the situation of small-scale fishers and the human dimensions of the EAF, including food security, vulnerability (in the wider sense) and other related issues. She noted the paradigm shift that had taken place, from a single-species focus to the concept of the EAF, which considers the social-ecological system as a whole – covering ecological as well as human well-being, and also the ability to achieve the EAF. Ms Isaacs further explained that change was nothing new to fishers but that, in order to deal with change, some enabling conditions included: secure access to resources; adequate livelihoods; sufficient nutritious food (food security); good social relations; and a supportive governance framework. Furthermore, she described some of the current research being undertaken in relation to SSF in South Africa, focusing on fisheries reform, poverty, HIV/AIDS, vulnerability, and the national small-scale policy process. With regard to the vulnerabilities of SSF communities in South Africa, these relate to: biophysical threats; health risks (e.g. HIV/AIDS, tuberculosis, Foetal Alcohol Disorder Syndrome); skills (low numeracy and literacy skills); alcohol and drug abuse; role of women; conflicts (small and large operators, small-scale and recreational fishers, small-scale and interim relief permits); uncertainty (slightest change to economically insecure persons can have a big impact on their vulnerability); and nature of employment (seasonal and contract employment). Lastly, Ms Isaacs described the "Too Big to Ignore project"[1] which, among other things, aims to: promote recognition and understanding of the importance of SSF to livelihoods, wellbeing, etc.; as well as to assess SSF's vulnerability to global change processes such as large-scale fishing operations, climate change, aquaculture, coastal tourism, urbanization and migration.

A discussion followed, involving the following:

- One participant noted that the fact should be recognized that in these communities there were many issues that might overshadow climate change; however, these would inevitably be compounded by climate change.
- Another participant asked about the magnitude of small-scale fishers dependent on fisheries in South Africa. Ms Isaacs explained that it was difficult to tell but about 1 500 SSFs on the west coast of South Africa were allocated interim rights as SSF (or artisanal/subsistence), noting that if it had not been for government grants, mining and fishing, these communities would not exist. However, she further explained that single-species allocations did not work for these communities as they needed a basket of species allocations to be able to sustain themselves. Seasonality of (single-species) fishing makes it very difficult to sustain these communities throughout the year.

[1] A global partnership for small-scale fisheries research. Web site: http://toobigtoignore.net

- Another issue raised was the definition of SSF versus artisanal versus subsistence. Ms Isaacs explained that in the South African context it was probably easier to use SSF as even for subsistence fishers there was a need to sell parts of the catch. It was further clarified that, from an FAO perspective, the definitions are very context-specific, although some of the standard separation criteria include labour input, technology, etc. An Angolan representative noted that in Angola there was no differentiation between SSF and subsistence as people do not sell their catch, but that there was a differentiation with regard to vessel length.
- One participant asked about potential conflicts between large-scale and small-scale fishing being exacerbated by climate change. It was suggested that these operations mainly linked spatially (e.g. in relation to snoek-fishing), although it was noted that such conflicts might occur between small-scale and large-scale aquaculture operations (e.g. in relation to diseases).

Ms De Young wrapped up the national presentations discussions by noting that a number of adaptive strategies were already in place and that sharing these would be a valuable strategy. She further proposed that the EAF could assist in understanding vulnerability actions. With regard to adaptive capacity, she highlighted that, in relation to moving towards rights-based management systems, it should be borne in mind that with climate change it was not simply a case of moving towards a new stable system but rather towards one of continuous change.

ADAPTATION INITIATIVES IN THE REGION

Ms Martha Mwandingi, from the United Nations Development Programme (UNDP) in Namibia, gave a presentation on “Climate change adaptation initiatives in the region: sharing adaptation lessons”. This was based on UNDP’s experience in working towards adaptation on the continent, which focuses on six cross-sectoral areas: livelihoods and food security; water resources; natural resources/biodiversity and forests; disaster risk management; extreme weather events; and human health. In her introduction, Ms Mwandingi noted that according to the Intergovernmental Panel on Climate Change (IPCC) it was necessary not only to adapt to climate change but also to climate variability. Furthermore, she mentioned a climate change vulnerability mapping process of Africa, carried out by the United Nations Environment Programme (UNEP), which showed a key general trend – vulnerability in terms of food security. She added that this type of mapping needed more information, highlighting that the Fifth Report of the IPCC would put greater emphasis on socio-economic aspects and implications of climate change, risk management as well as more detailed information on specific regions. Ms Mwandingi then gave an overview of some UNDP adaptation projects and lessons learned through these, giving the example of a project on reducing vulnerability to drought in Ethiopia and an early warning system in Rwanda with regard to floods. She noted that, as adaptation does not happen in isolation, the project preparation and design process could serve as a convening platform for stakeholders. Lastly, she proposed that dealing with uncertainty in adaptation projects should be done using both top-down and bottom-up approaches. While the former helps in understanding trends, the latter helps in understanding the vulnerability of people and specific contexts.

A second presentation was given by Mr Carl Palmer (on behalf of Mr Neville Sweijd), on the activities of the Applied Centre for Climate and Earth Systems Science (ACCESS). In the introduction, Mr Palmer explained that the natural variability of the BCLME system was already highly complex today, which made prediction of long-term change difficult. However, although this variability is not necessarily caused by climate change, climate change could exacerbate the natural variability. In order to understand more fully this complicated system and its possible responses, long (longer) data sets are needed as well as a broader perspective, and, most of all, trained people. ACCESS's role is to facilitate the achievement of this. He further noted that many of the problems being experienced were caused by poor management and overfishing, suggesting that climate change should not be used as an excuse not to address these issues. However, he added that there was also an issue of "looking for climate change" – proof of it is looked for although much longer datasets are needed in order to be able to say anything for certain. Overall, in addressing climate change, Mr Palmer suggested that there was a need for an earth systems science approach to climate change, including transdisciplinary and transinstitutional collaboration. ACCESS aims not only to support development of human capacity in relation to earth sciences and climate change through undergraduate and graduate programmes but it is also a one-stop shop for higher-level climate change research in Africa. Lastly, Mr Palmer noted that that Africa was a globally critical and poorly studied region in the global climate system, and that ACCESS thus aimed to provide an African perspective on climate change.

Following the presentation, one of the questions asked related to why Africa does not produce more climate change research. Mr Palmer proposed that it might be a lack of motivation in terms of Africa not being to blame for climate change but also perhaps the thinking that the effects will only take place far into the future.

REGIONAL VULNERABILITY ASSESSMENT

In introducing his presentation (see Contributed Papers) on a vulnerability assessment of the fisheries of the BCLME, Dr Hampton explained that the focus of the report had been on:

- how vulnerable the exploited fish resources of the BCLME are to climate change; and
- how vulnerable industries, communities and individuals dependent on these resources are to climatically induced changes in abundance and/or distribution of these resources.

Dr Hampton further explained that his assessment had followed IPCC guidelines and covered "sensitivity" (the degree to which the resource is likely to be affected by the indicated change), "impact" (the importance of the resource to humans in terms of, for example, commercial value, employment and food security) and "adaptability" (the degree to which industries and people dependent on the resource can adapt to changes in resource abundance and/or availability) – the three aspects of "vulnerability" according to the IPCC. The three aspects had been scored for each of the fisheries (see report for more detailed description) and multiplied, of which the product became the vulnerability index (vulnerability index = sensitivity index × impact index × adaptability index). He noted that the scoring system was subjective, particularly in relation to "sensitivity". Following this, Dr Hampton gave some examples of how and why he had given certain scores to certain fisheries and also pointed out some extremes, e.g. the low vulnerability of the foreign-operated Namibian mid-water trawl fishery and the high vulnerability of the artisanal fishery of Angola. Lastly, he proposed some ways of adapting to reduced abundance or availability of stocks: changing target species; improving catching, processing and distribution efficiency; improving product value; etc. Dr Hampton concluded that large, highly organized and capital-intensive fisheries were generally the most adaptable ones (one exception being the South African small pelagics fishery, which is sensitive to environmental changes, and also operates with a low profit margin). The most vulnerable fisheries were found to be those with a large number of people living in communities heavily dependent on fish for food and livelihoods, with almost no ability to adapt. More specifically, Dr Hampton explained that his assessment had found the most vulnerable fisheries of the BCLME to be the artisanal and semi-industrial fisheries in Angola, the rock lobster fishery in South Africa (and to a lesser extent in Namibia), and the small-scale line fishery in South Africa. He then suggested some measures that could contribute towards increasing adaptive capacity, including research aimed at better prediction of environmental changes and responses to them.

In the discussion that followed, issues raised included:

- Subjectivity in scoring is not the problem as long as this is not disguised; however, with regard to vulnerability, it is key to note whose vulnerability is being discussed. In terms of concluding that industrial fisheries are less vulnerable, e.g. because of greater mobility, this does not take into account the case of the crew or the processing staff, who may have to stay behind, losing their jobs as the vessels move to other regions and/or countries. It was suggested that there was a scale-mismatch in the assessment – industrial sector (vulnerability is assessed by company and/or vessel) and small-scale (vulnerability is assessed by individuals).
- It was also noted that it could be dangerous to "quantify" vulnerability and draw assumptions from this as such scores tend to stick in people's minds and be taken for facts. Another objection to the quantification was that it was unclear what the numbers actually meant, e.g. what is the quantitative difference between 5 and 6? It was concluded that what was key was to have a framework for discussion, not to set definite scores.
- Overall, there was a strong voice for having a defendable methodology for assessing vulnerability in the region. However, it was also suggested that, rather than waiting until all the data were available, starting to make qualitative assessments would be a way of trying to assess vulnerability, which could then allow for (anticipatory) actions. It was noted that although the assessment followed the methodology recommended by the IPCC, it should be recognized that the scale for the IPCC was different.
- Another point raised was at what point it could be concluded that certain changes were due to climate change or other environmental changes, e.g. lowering oxygen levels. Dr Hampton pointed out that such issues were discussed in the biophysical report (see Contributed Papers).

CLIMATE CHANGE – ISSUES AND IMPACTS: VULNERABILITY ASSESSMENT OF THE FISHERIES OF THE BCLME

The second day's plenary and group discussions were introduced by Ms De Young, consisting of: a plenary discussion on the vulnerability assessment report (to identify gaps and areas for improvement); group discussions by country to define vulnerability and discuss vulnerability levels of the different fisheries and why; and group discussions by country to brainstorm on short- and medium-term adaptation actions related to the context of the fisheries and those dependent on these.

In the plenary discussion on the vulnerability assessment report, the following was noted:

- Again, the subjectivity of assigning numbers in assessing vulnerability and adaptability was raised and it was agreed that, at this stage, perhaps only ranking the vulnerability of the fisheries was more suitable. Spending more time on developing a methodology that everyone could agree on would be a very useful outcome of the Workshop or in its follow-on period.
- It was further added that "top-down approaches" to vulnerability assessments (such as the IPCC guidelines) needed to be validated through bottom-up approaches and that the indices needed to be contextualized, with the example of Namibia with a small population and few coastal communities being less vulnerable than Angola with a larger population depending on coastal fisheries.
- One participant raised a question about the process of moving from the biophysical report to the vulnerability assessment, via sensitivity (the degree to which the resource is likely to be affected by the indicated change). The participant asked

whether anything might have been missed in this process, giving the example of the sensitivity of Walvis Bay to flooding: with a likelihood uncertain, but consequence huge. Dr Hampton explained that it had been concluded that such an event was unlikely (however, noting that it could be included in the vulnerability assessment as a local impact).

- Dr Hampton also noted that comparing the vulnerability of fisheries within a country was probably easier and more accurately done than comparing fisheries between countries.

Some further discussion included:

- The meanings of "adaptive capacity" (innate capacity of the "system") and "adaptation" (actions to increase resilience/adaptive capacity, reduce vulnerability) were clarified.
- The issue of differentiating between "business-as-usual" actions versus "climate change adaptation actions" was brought up by one participant, noting that the ongoing work on implementing EAF and the consideration of its human dimensions when planning adaptation strategies should not be forgotten. An example was given: the Namibian sardine fishery has, rather than a complete moratorium, a very low TAC for socio-economic reasons. It was added that a complete moratorium would probably not lead to stock recovery.
- One participant asked how the Workshop could focus specifically on climate change and not suggest things that were already being done in the region (with reference to the EAF and its human dimensions above). Ms De Young explained that although generally implementing fisheries management (e.g. the EAF) would reduce the system's vulnerability, there were specific management responses to deal with climate change and certain issues could be specifically climate change-induced (e.g. change in species distribution). She gave the example of a marine protected area (MPA) established to protect juveniles – if climate were added change, what would need to be changed? Perhaps making the MPA temporally and spatially more flexible?
- The importance of causality (causal relationships) was raised although it was suggested that it would be costly to achieve such precise understanding. It was agreed that it would be a matter of prioritization in terms of how far towards such understanding one could move.
- With regard to climate change effects on the BCLME, it was proposed that even if understanding of the effects and impacts was not perfect, this Workshop was a good start for using the current best understanding/knowledge to assess vulnerability and propose some actions.

With regard to the group discussions, some issues raised included:

- The Angolan group raised the issue of not all subsectors of the vulnerability assessment being represented in the Workshop, hence noted it would be difficult to rank and prioritize on the spot. They suggested that perhaps it would be better to focus on the methodology and then go home and consult with colleagues representing the other subsectors in order to avoid subjective ranking and/or prioritization. However, it was concluded that there was sufficient expertise among the participants to make at least some observations on the topic. Dr Hampton added that although climate change was a new area, this kind of discussion was normal for the BCC, suggesting that the focus should be on "best available knowledge".

South Africa's presentation on its group discussion began by discussing the concept of vulnerability, noting that in the BCLME currently, vulnerability to natural variability rather than to climate change may be the most pressing issue. With regard to the definition of vulnerability, it was found to be defined relative to people, not the environment. Turning the discussion to which fisheries are actually the most vulnerable in South Africa, it was suggested that such conclusions could not be reached in a brief discussion. Furthermore, before deciding on which fisheries were most vulnerable, it would be necessary to discuss whose perspective one was considering when doing the ranking. With regard to the ranking, it was agreed that it was important to "unpack" the factors involved in the assessment (i.e. sensitivity, impact, adaptability, etc.). The following was proposed:

- Sensitivity index: magnitude of effect and likelihood of it occurring – magnitude stems from marine research studies and likelihood stems from models.
- Value index: monetary value of the resource – but how is this defined? Could be, for example, raw value, value after processing, contribution to gross domestic product (GDP).
- Employment index: how many people work in catching, processing, marketing, retailing, etc. (direct versus indirect involvement – such estimates will be complex)? To take into account temporary versus permanent employment, counting the number of days per year could be useful. Another way to count employment levels could be through tax records of amount paid, although it was uncertain how reliable such figures would be.
- Poverty index (rather than food security): it was concluded that using a poverty index (although there are many different ones) instead of "only" food security as an index would broaden the scope appropriately as, first, it was suggested that catch not only provides for direct consumption but also for income to purchase other food, etc. Second, a reduction or collapse in catch could result in unemployment, causing other vulnerabilities than in relation to just food.
- Community well-being and cohesion (formerly, societal importance) index: this may be more specific to small-scale fisheries (considering reliance of specific community on a fishery, as well as cultural importance and heritage). This index could also consider health as this affects ability to fish or work in industry.
- Adaptability index: while the industry could be highly adaptable, the labour force might not be, suggesting that separate assessments would be required for "industry" and "labour force".

Some comments in relation to the presentation related to the definition of a fishing community, noting that the scale issue is important in analysing vulnerability and therefore downscaling issues to lower levels (e.g. from industry to individuals of a labour force) is helpful. Another comment related to the fact that this type of analysis has much in common with the risk assessment in the EAF process – the ecological and human well-being as well as the ability to achieve, proposing that the assessment methodology could be used to assess vulnerability to climate change as well.

Angola's presentation on its group discussion began with an overview of the country's artisanal fishery and its importance, noting that although the country does have three sub-sectors, only the artisanal subsector was represented at this Workshop. The presenter explained that the vessels used in this subsector ranged from 5 to 14 m; fishing takes place in the area within 4 nautical miles (nm); about 7 000 vessels were registered in 2010; and about 96 000 tonnes were caught, accounting for 30 percent of total the catch in Angola. Thereafter, the main challenges related to climate change and variability were described, primarily the floods in recent years, which have lead to erosions, difficulties to access local communities as well as loss of infrastructure, housing, and fishing equipment. Furthermore, it was noted that artisanal fishers spend more time now looking for resources compared with previous years and there have also been changes in target species (from demersal to small pelagic, e.g. mackerel and sardinella). However, some positive developments that followed from the flood impacts were: establishment of support centres for artisanal fishing in seven coastal provinces; granting of credits; replacement of destroyed vessels; relocation of the population from affected areas to those offering better security; fishers in some coastal provinces have been showing interest in the practice of fish farming as an alternative livelihood; and training and capacity building initiatives. With regard to aquaculture, it is included in the national fisheries master plan, however, only as regards land-based aquaculture. Land-based aquaculture is currently being implemented in 13 provinces, through the Spanish Agency of International Cooperation for Development (AECDI).

Namibia's presentation began by providing an overview of the major issues in the Namibian context, including: the need to integrate human and ecological dimensions in the vulnerability assessment; the need to assess climate change impacts at a wider scale than just the fisheries (rather consider it from for example a Namibian national perspective); the impact on the fishing processing industry (e.g. considering water availability); impacts on coastal development; and lastly, not forgetting the mariculture and inland fisheries subsectors. Thereafter, the different stakeholder groups were identified as well as how they may be affected:

- industrial fishing subsector (including industrial mariculture, companies, workforce) (e.g. through effects on resources);
- government overall (e.g. through changes in the revenue to GDP);
- recreational fishing subsector (e.g. through changes in stocks and tourism levels);
- small-scale fisheries (e.g. through effects on resources);
- Ministry of Fisheries and scientists (e.g. through effects on resources);
- global markets (e.g. through effects on resources);
- infrastructure and overall coastal development (e.g. through migration of people).

Following this, the key environmental changes expected were identified:

- Benguela Niños;
- intrusion of Angolan warm water;
- low oxygen levels;
- climate change effect on freshwater availability;
- sea level rise (SLR);
- extreme weather events;
- sea surface temperature (SST) rise;
- change in wind speed;
- health issues (related to expected increased rainfalls).

Lastly, the effects of the changes were listed:

- Benguela Niños: impacts on industrial subsector through reduced catch and loss of government revenue but could have positive effects on tourism due to warmer waters.
- Warm-water intrusions: reduced recreational activities owing to reduced stock levels.
- Low oxygen: reduced stock levels.
- Reduced freshwater availability: competition for ice and freshwater could increase the cost of ice, lowering quality of products, reduced government revenue from reduced exports. However, it may spur more investment in desalination.
- Sea level rise: reduced processing capacity, displacement of people and processing plants, safety at sea issues, habitat destruction, other impacts on infrastructure.
- Wind speed changes: if reduced wind speed – reduced production owing to reduced upwelling but safer to go to sea for small-scale fishers.
- Health: to be further investigated.
- Impacts on biodiversity: less biodiversity gives less resilience (although this depends on whether on is referring to actual reduction of biodiversity or rather a substitution of species).
- Extreme weather events: affect operations of all fisheries (safety at sea issue) as well as mariculture.

Following the presentation, one participant asked about the importance of extreme weather events in the BCLME. It was noted that in Namibia, the rock lobster fishers have experienced impacts of more severe weather events – they have been able to go to sea fewer days than in the past, but effects have also been noticed in other fisheries. Sea level rise and coastal erosion are additional issues in Namibia.

POTENTIAL SOLUTIONS/ACTIONS – DISCUSSION AND EXAMPLES

The second group discussion was introduced by Ms De Young, asking participants to consider examples of adaptation actions and which could be relevant in the BCLME context, using Table 6 of FAO Technical Paper No. 530[2] as inspiration. It was suggested that the outcome of this exercise could inspire the development of a project, e.g. by the BCC or be taken into consideration by the national ministries.

Namibia presented its conclusions from the group discussion, listing proposed adaptation measures for different potential climate change impacts:

- Reduced productivity: further development of aquaculture/mariculture; increased effort if profitable or shifting target species; increased efficiency in fishing operations; increased value-addition in fisheries with further potential (e.g. horse mackerel); stock enhancement; and habitat rehabilitation.
- Changes in stock and/or species distribution: could cause (further) conflict with mining sector, requiring improved coordination and collaboration between the ministries responsible (Ministry of Mines and Energy and Ministry of Fisheries and Marine Resources); and shared fishing rights between countries for transboundary stocks (including strengthening institutional arrangements to facilitate such a management approach).
- Reduced profitability: alternative livelihoods (however, a comprehensive analysis would be needed, one looking beyond the fisheries sector, as the changes in other sectors, caused by climate change or other factors, are unknown) and shared/flexible TACs within the BCLME.
- Increased vulnerability of coastal communities and infrastructure due to floodings and surges: enforce laws that ban building too close to the shore; improve and/or build hard defences; insurance schemes; monitoring, early warning and improved interagency collaboration and communication; and emergency planning and awareness-raising in relation to this.
- Increased risks: safety at sea training; early warning systems; lessons learning and statistics from previous incidents; and improved interagency collaboration.
- Trade and market shocks: diversification of markets.
- Displacement of population: nationwide analysis of migration flows (research by statistics bureau and sharing of data).
- Various: alternative livelihoods (tourism, aquaculture, mining); better representation of fisheries sector in the national committee on climate change (including through tracking of investment needs of fishing sector in relation to adaptation, risk analysis of the sector and awareness-raising); and establishment of Blue-Reducing Emissions from Deforestation and Forest Degradation (REDD) funds (compensation for offsets/conservation).

Following this presentation, the Executive Secretary of the BCC noted that it would revise its science programme, towards a likely focus on climate change. However, such activities will require funding.

In Angola's presentation, the focus was more on what needs to change in order to reduce vulnerability and improve adaptive capacity. Change of gear types to legal

[2] Cochrane, K., De Young, C., Soto, D. and Bahri, T., eds. 2009. *Climate change implications for fisheries and aquaculture: overview of current scientific knowledge*. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, FAO. 212 pp.

gear was highlighted as well as improved communication and collaboration between research services and fishers in order to supply data and information on a regular basis (e.g. to raise awareness but also with regard to weather forecasting and other early warning pertaining to environmental changes). In terms of what needs to be done to start taking action, advocating the interests of fishers in government poverty reduction programmes is one important step, but so is analysing maladaptation situations such as increased effort in a state of overfishing (reducing the number of vessels would be a low-cost/high-impact action but it could have other negative impacts on the communities, such as loss of livelihood in an environment with few alternatives). Following the presentation, one workshop participant asked whether Angola had finalized its National Adaptation Programme of Action (NAPA). It was noted that this was in the progress of being drafted. Another question raised was when action should be taken, considering that risks and opportunities were uncertain at this stage in time, which would make action and prioritization difficult. In response, it was suggested that rather than focusing on where funding would come from for, for example, building walls, at this stage the focus should be on analysing risks and likelihood of change and impacts, etc., stressing the need to take a closer look at vulnerabilities.

South Africa's presentation focused on potential impacts and adaptation actions in two important fisheries in South Africa: one industrial, hake, and one small-scale, snoek. With regard to the hake fishery, reduced catches and change in distribution were noted as potential impacts of climate change. To respond to reduced catches, adaptation actions identified included: increase price of catch, reduce labour costs, increase catching efficiency (through improving fishing gear, etc.), and change target species. To respond to change in distribution, adaptation actions identified included: relocate fishing grounds (e.g. further offshore to deeper waters), and more flexible use of wet and freezer vessels according to conditions. With regard to the snoek fishery, reduced abundance and more variable distribution were noted as potential impacts of climate change. To respond to reduced abundance, adaptation actions identified included: increase price of catch, change livelihood and/or fishery, change target species, lease vessels for tourism and recreational fishing. To respond to more variable distribution, relocation to follow the fish was suggested as an adaptation action. For each of the responses, cost (and to whom) and impact were estimated as low, medium or high, suggesting that not all responses are recommendable. Furthermore, in relation to this, it was noted that a more thorough analysis and quantification of impacts would be needed as an adaptation action in one area of the sector, or in one subsector, might affect other areas or subsectors. Last, the particular situation of small-scale fishers in South Africa was highlighted, noting that some responses were not straightforward options for these fishers. For example, changing livelihood may be a limited option owing to lack of education and availability of alternative livelihoods and changing species is not allowed in the current regulatory framework. Following the presentation, one participant proposed that as well as considering costs of adaptation to society and/or industry, costs to the ecological system should also be taken into account: for example, increasing efficiency in fishing operations could negatively affect the ecosystem – a potential maladaptation. However, it was noted that if the fleet size were also reduced, the remaining fleet might then become more economically efficient. With regard to the hake fishery, one participant asked what possible climate change effects could affect one species and not the other – shelf oxygen levels was suggested in response to this. Last, the discussion focused on what the entry points should be for this type of analysis (species/gear type/fishery, etc.). It was suggested that the more detailed the analysis became, the more helpful it would probably be. One participant stressed the importance of having the social-ecological system as the unit of analysis.

RECOMMENDATIONS OF WORKSHOP AND OPTIONS FOR MOVING FORWARD

Following the substantial discussions on vulnerability, potential impacts and adaptation actions, summarizing the discussions, the Workshop recognized that:

- the BCLME, and the fisheries and coastal systems, communities and economies supported within, are complex and facing multiple drivers of change (overfishing, land and aquatic resource management, water management, markets, natural variability, climate change, etc);
- vulnerability to climatic variability and change may stem from factors independent of environmental factors;
- adaptation must take place in a multisectoral and multidisciplinary ("big picture") context and programme but that individual adaptation actions may be led by sector-specific groups;
- although the evidence basis for understanding climate variability and change and its impact pathways is incomplete, immediate and informed action is necessary to support the resilience of the human and aquatic systems to change coming about because of climate change – including robust management and "no regrets" actions (i.e. if climate change is not the driver as forecast);
- although this Workshop was convened to discuss issues of marine capture fisheries within the BCLME, the issues and process raised are relevant for other large marine ecosystems (LMEs) in the countries as well as for marine aquaculture, recreational fisheries and inland fisheries and aquaculture sectors;
- the BCLME region benefits from the multisectoral approach to aquatic resources management through the BCC.

With this in mind, the Workshop recommended to the BCC, national governments and relevant partners that they:

- support actions toward better understanding of the vulnerability of the (BCLME) human and aquatic systems to climate change and variability – of different systems, at different scales, comprehensive (e.g. throughout the value chain, through to communities and nations);
- identify and support actions to decrease the vulnerability of the (BCLME) human and aquatic systems and support broader moves toward sustainable development;
- organize national and regional processes (e.g. workshops, pilot and case studies) to support the fisheries and aquaculture sector in reaching consensus on vulnerabilities and appropriate adaptation actions within national and regional climate change and development priorities and strategies;
- identify and implement pilot projects to explore options and demonstrations for best practice and tools that can be used for implementing practical actions for adaptation to climate-induced change;
- pulling together broad stakeholders from climate change, fisheries, land and aquatic management, water, agriculture, development to ensure participatory and integrated approaches are supported;
- identify means of supporting and funding the implementation of recommended actions at all levels (e.g. industry, fisher, community, non-governmental organization [NGO], government, intergovernmental organization/civil society organization [IGO/CSO]);
- support the participation of the (BCLME) fisheries and aquaculture sectors within national, regional and global climate change discussions and actions (e.g. presenting issues specific to fisheries and aquaculture, understanding trade-offs and synergies of adaptation and mitigation actions within other sectors);
- utilize and build on the existing political commitment and integrated institutional arrangements of the BCC to facilitate and coordinate a regional programme on climate change adaptation in the BCLME region.

The Workshop also recommended that the BCC coordinate follow-up actions with FAO, UNDP and other relevant actors. On how the BCC could take this forward, the BCC Executive Secretary reiterated the opportunities involved in the revision of the BCC science programme, noting that climate change could be a focus area but also stressing that funding options would need to be considered, for example in collaboration with FAO and UNDP.

ROADMAP

In terms of options for moving forwards with regard to the agreed Workshop recommendations, Ms Antonia Hjort provided an overview of the purposes and criteria of three different climate change adaptation funds: the Least Developed Countries Fund[3] (LDCF); the Special Climate Change Fund[4] (SCCF); and the Adaptation Fund[5]. Ms Hjort explained that whereas the latter two were open to all three of the BCLME countries, the LDCF was only available to least-developed countries, i.e. Angola in the case of BCLME. Furthermore, she provided a brief outline of the application process for the LDCF and SCCF, including an overview of the Project Identification Form[6] (PIF) used by the Global Environment Facility[7] (GEF) as a first step in identifying projects for funding through the LDCF and SCCF.

In summing up areas for further investigation and action identified through the discussions and Workshop recommendations, Ms Sandy Davies proposed the following:

- that a programme be developed with the aim of "climate proofing" the social-ecological fisheries systems of the BCLME;
- that the three countries present a combined submission of a PIF to GEF to seek funding from the SCCF and, potentially the LDCF;
- that the BCC act as a key coordinator.

Ms Davies further proposed that the programme would contain the following components:

1. Development of local, national and regional multidisciplinary cooperation and institutional arrangements (human and institutional capacity/linkages/ communication, etc.) to facilitate responses and action in relation to climate change effects (the Workshop had identified lack of interagency collaboration, communication and information-sharing as a major obstacle to adaptation action).
2. Development and implementation of methodology (or methodologies) for assessing vulnerabilities in order to ensure a holistic and coherent approach to identifying issues and for prioritization of actions (the Workshop had warned against a narrow approach to assessing vulnerabilities).
3. Development and implementation of national pilot projects to develop and/or test anticipatory and responsive actions for a specific social-ecological fishery system in each of the countries, in line with an EAF, with the aim of providing for lesson learning/sharing/feedback for improvement in relation to policies/processes/ actions (the Workshop noted that, considering that little adaptation work had so far been done in fisheries globally, pilot actions would be key for learning processes and scaling up).

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[3] For information on the Least Developed Countries Fund: http://unfccc.int/cooperation_and_support/financial_mechanism/least_developed_country_fund/items/3660.php and www.thegef.org/gef/LDCF

[4] For information on the Special Climate Change Fund: http://unfccc.int/cooperation_and_support/financial_mechanism/special_climate_change_fund/items/3657.php and www.thegef.org/gef/SCCF

[5] For information on Adaptation Fund: http://unfccc.int/cooperation_and_support/financial_mechanism/adaptation_fund/items/3659.php and www.adaptation-fund.org/

[6] Project Identification Form template available at: www.thegef.org/gef/node/1708

[7] Global Environment Facility Web site: www.thegef.org/

In response to this presentation on programme development and next steps, Workshop participants welcomed what had been proposed and noted the following:

- Recent work on social-ecological systems in the region could feed into all three programme components. With regard to Component 2, it could be a matter of validating and/or improving existing methodologies. One participant with vast experience in PIF development suggested that one should disentangle what would be part of the preparatory phase and what would be part of the implementation phase. For example, considering that PIF development takes at least one year, Component 2 could be part of this preparatory phase as a strong vulnerability assessment methodology would assist in identifying hotspots and areas for pilot projects. Again, the importance of a holistic methodology was stressed, considering not only fisheries but also interlinkages between this social-ecological system and others.
- It was further clarified that the programme would contain both national and regional approaches and/or activities with the BCC as the executing and coordinating agency.
- Last, one participant asked which component would be used to explicitly include uncertainty into decision-making, a key aspect of climate change adaptation. Dr Hampton proposed that such consideration could be included in the work on Component 2, with the pilot projects in turn responding to the findings of the work on Component 2. A multidisciplinary specific task group could be formed to work on this, and Ms De Young explained that a regional FAO Technical Cooperation Programme[8] (TCP) could be used for fast-tracking Component 2.

With regard to related initiatives in the region, the following were noted:

- NansClim (lacks a social component);
- EcoFISH (has a social component);
- the NEPAD-FAO Fisheries Programme;
- the EAF-Nansen Programme.

Having outlined the proposed programme components, Ms Davies suggested the following next steps would include:

1. finalization of the vulnerability assessment report;
2. preparation of the Workshop report;
3. drafting of a joint PIF;
4. review of the PIF by Workshop participants;
5. finalization of the PIF and submission to GEF.

As an additional step, the Workshop proposed that the country representatives should assist in encouraging and ensuring the involvement of the GEF focal points in their respective countries.

CLOSING OF THE WORKSHOP

In closing, Ms De Young explained that Dr Hamukuaya, the Executive Secretary of BCC, would present the outcome of this workshop at COP17 in Durban at the end of the year, during the allocated fisheries and aquaculture session. On behalf of the BCC, Dr Hamukuaya thanked the participants for their valuable contribution and declared the Workshop closed.

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[8] More information of the FAO Technical Cooperation Programme is available at: www.fao.org/tc/tcp/

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Annex 2 – **Agenda**

Tuesday 1 November 2011	
08.00	Registration and tea/coffee
Session 1: Welcome and introduction (09.00–10.00) **Facilitators:** Sandy Davies and Cassandra De Young **Rapporteurs:** Antonia Hjort and Sinead Sheridan	
09.00	Welcome and opening remarks by Hashali Hamukuaya (BCC)
09.10	Introduction by participants
09.30	Background and objectives of the workshop by Cassandra De Young (FAO)
COFFEE & TEA: 10.00 – 10.30	
Session 2: Overview of the regional biophysical context, and national perspectives on fisheries and climate change (10.30–12.30)	
10.30	Biophysical features and decadal trends in the Benguela Current Large Marine Ecosystem by Ian Hampton
11.00	National presentation by Angola
11.30	National presentation by Namibia
12.00	National presentation by South Africa
12.30	Questions/discussion
LUNCH: 13.00 – 14.30	
Session 3: Adaptation initiatives in the region (14.30–15.30)	
14.30	Climate change adaptation initiatives in Southern Africa by Martha Mwandingi
15.00	Other climate-related projects
COFFEE & TEA: 15.30 – 16.00	
Session 4: Regional vulnerability assessment (16.00–17.00)	
16.00	Regional vulnerability assessment of the BCLME fisheries by Ian Hampton
16.45	Summary and wrap-up by the facilitator
Wednesday 2 November 2011	
Session 5: Climate change adaptation – issues and solutions (09.00–10.00)	
09.00	Introduction to Day 2 by facilitator
09.15	Introductory plenary discussion on perceived climatic issues and impacts (national and regional)
COFFEE & TEA: 10.00–10.30	
Session 6: Climate change adaptation – issues and solutions (cont.) (10.30–13.00)	
10.30	Group discussions on perceived climatic issues and impacts (Angola, Namibia, South Africa and regional)
11.30	Reporting back to plenary by each group
12.30	Introductory plenary discussion on potential solutions/actions

LUNCH: 13.00–14.30	
Session 7: Climate change adaptation – issues and solutions (cont.) (14.30–15.30)	
14.30	Group discussions on potential solutions/actions (Angola, Namibia, South Africa and regional)
15.15	Reporting back to plenary by each group
COFFEE & TEA: 15.30–16.00	
Session 8: Climate change adaptation – issues and solutions (cont.) (16.00–17.00)	
16.00	Reporting back to plenary by each group (cont.)
16.15	Introduction to gaps analysis by facilitator
16.20	Plenary discussion on gaps analysis – which issues/impacts are being addressed and which are not?
16.45	Wrap-up by the facilitator
Thursday 3 November 2011	
Session 9: Options for moving forward (09.00–10.00)	
09.00	Introduction to Day 3 and brief summary of issues/impacts, solutions/actions and gaps by facilitator
09.30	Introduction to prioritization of actions by facilitator
09.45	Plenary discussion on criteria for prioritization
COFFEE & TEA: 10.00–10.30	
Session 10: Options for moving forward (cont.) (10.30–13.00)	
10.30	Groups discussions on prioritization of actions (Angola, Namibia, South Africa and regional)
11.30	Reporting back to plenary by each group
12.30	Review of adaptation priority recommendations
LUNCH: 13.00–14.30	
Session 11: Options for moving forward (cont.) (14.30–15.30)	
14.30	Available funding options from international, regional and national sources to finance adaptation actions by Antonia Hjort (NFDS)
15.00	One step in implementation: Developing a climate fund project proposal: scope, content and criteria by Sandy Davies (NFDS)
15.10	Plenary discussion
COFFEE & TEA: 15.30–16.00	
Session 12: Options for moving forward (cont.) (16.00–17.00)	
16.00	Proposed roadmap by facilitator
16.30	Plenary discussion and end of workshop

CONTRIBUTED PAPERS

Vulnerability to climate change of the Benguela Current Large Marine Ecosystem and the human livelihoods dependent on it

by

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Contents

Executive summary

This report, which was commissioned by the FAO and supported by the Benguela Current Commission, is aimed at assessing the vulnerability of human beings who depend on the living resources of the Benguela Current Large Marine Ecosystem (BCLME) for their livelihoods, to changes in the marine ecosystem brought about by climate change. Following IPCC guidelines, this has been done by combining indices of a) the sensitivity of the major exploited resources to environmental influences, b) the socio-economic impact of environmentally-induced changes in resource availability and abundance, and c) the capacity of industries, individuals and communities dependent on these resources to adapt to such changes. Note that the vulnerability of fishing installations and infrastructure to climate change in general is outside the scope of the report and is not specifically considered in this assessment. For the same reason, the effect of changes in ocean climate on other marine activities such as shipping, oil exploration, marine mining and marine-related tourism activities, are also excluded.

The sensitivity assessment is founded on a companion commissioned review of the biophysical changes in the ecosystem in recent decades, including the changes which have occurred in the abundance and distribution of the region's major commercial resources (Hampton, 2011). This is followed by a summary of the fisheries in each of the three countries (Angola, Namibia and South Africa) which are most important in terms of revenue, employment, food security and societal values. Particular attention is given to the small-scale, subsistence and artisanal fisheries, which although they are much less important in terms of revenue than the larger, more industrialized fisheries, are of major importance in the other three respects. The assessment of adaptability is based on the nature and labour profiles of the various fisheries in the region, from which generic differences in the capacity of these fisheries to adapt to changes in their resource base, however caused, are extracted.

The three indices are combined to give semi-quantitative vulnerability indices for the various fishing sectors in each country, which although inevitably subjective in many respects, do enable the vulnerabilities of the individual fisheries within each country to be rated as High, Medium or Low. Comparison between the countries has been avoided because of major differences of scale in the nature, magnitude and importance of the fisheries sector in each of the countries. The report closes with a brief discussion of possible research and management strategies for reducing the adverse effects on humans of changes in the BCLME, however caused, and concludes with a number of recommendations for future research.

The major conclusions concerning the environment are that:

- The BCLME, being largely upwelling-driven, is naturally highly variable and complex, making it difficult to discern clear long-term trends which could be attributed to global climate change. Exceptions are the widespread warming of the surface water at both the northern and southern boundaries of the system over the past few decades, and the cooling of inshore waters off the west and south coasts of South Africa over the same period, the latter of which could be related to a general increase in upwelling – favourable winds in summer throughout the system.
- Because of the natural variability and complexity of the system and the poor understanding of the way in which resources are affected by the environment (despite many decades of research in some cases), it is not generally possible

at present to use environmental information to improve management of the resources or reduce the adverse effects of environmental perturbations. The situation is unlikely to change in the near future.

- The most obvious long-lasting documented changes in the BCLME in the past half-century have been the drastic declines in the abundance of many of the major resources, all of which have clearly been primarily due to over-fishing rather than environmental effects. It would therefore appear that provided the environmental changes remain within the bounds of those observed over this period, optimal management of the resources themselves would be the best way to counter further deterioration of the ecosystem.
- In the northern Benguela, the virtual removal of the "wasp waist" small pelagic fish species has resulted in what may be an irreversible shift to a less efficient regime. Even the long term, major changes in zooplankton abundance which have been observed in both the northern and southern Benguela since the 1950s could be as much due to changes in predation by the exploited small pelagic fish species as to large-scale environmental effects.
- Although none of the more obvious environmental effects during the past half-century have been as dramatic or as long-lasting as the collapses in the resources, this does not exclude the possibility of unprecedented much more harmful changes in the ecosystem in response to global climate change some time in the future. Of particular concern is the anthropogenically-generated increase in the leakage of Agulhas current water into the south-east Atlantic in the past decade, which could have profound effects on the entire upwelling region.
- It appears that because of its geographical location, more uniform nature and currently more stressed state, the northern Benguela may be less resilient to environmental perturbations than the southern Benguela, although the rapid recovery of the system from the major environmental anomaly in 1994 and 1995 suggests a degree of resilience in this system as well.

The primary conclusions from the vulnerability analysis were that:

- The most vulnerable fisheries are those in which a large number of people living in communities heavily dependent on fish for food and their very existence are engaged, with almost no ability to adapt to reduced catch rates. These include the artisanal and semi-industrial pelagic fisheries in Angola, the fishery for West Coast rock lobster in South Africa and (to a lesser extent) Namibia, and various line fisheries in South Africa. The South African small pelagic fishery is particularly vulnerable because of its economic and social value, inherent sensitivity to climatically-induced variability in the southern Benguela and the threat of major perturbations stemming from anthropogenically-induced changes in the Agulhas current. The vulnerability of the Namibian small pelagic fishery, although possibly equally threatened from the north, is rated lower because of its much lower value.
- South Africa's valuable demersal trawl fishery for hake and other demersal species appears not to be particularly vulnerable to climate change due to an apparently low sensitivity to environmental perturbations and the ability to adapt to them, should they occur. The equally valuable Namibian hake industry, although probably as adaptable, is rated more vulnerable due to a documented susceptibility to intrusions of low oxygen water, which do occur on occasion in the northern Benguela, and may be linked to climate change.
- South Africa's valuable demersal trawl fishery for hake and other demersal species appears not to be particularly vulnerable to climate change due to an apparently low sensitivity to environmental perturbations and the ability to adapt to them, should they occur. The equally valuable Namibian hake industry, although probably as adaptable, is rated more vulnerable due to a documented susceptibility

to intrusions of low oxygen water, which do occur on occasion in the northern Benguela, and may be linked to climate change.
- The fisheries rated least vulnerable are those of low economic value and societal importance in which companies and individuals are best able to adapt to changes in the environment (e.g. recreational fishing and midwater trawling in Namibia and South Africa and fishing for large pelagic fish in South Africa).

It is recommended that the adverse effects on humans of changes in resource abundance and availability, whatever their origin, should be reduced by research aimed at early detection, rather than prediction, of these effects (at least in the short-to medium term), allied to the development of new management strategies which take this information into account as early as possible. In small-scale fisheries, which tend to be affected more by local changes in environment, it may be more effective to spend less research effort on understanding and describing these variations, and more on finding socio-economic ways of adapting to them and combating their adverse consequences, in close consultation with the affected local communities.

Acknowledgements

I gratefully acknowledge input from participants in the FAO/BCC Workshop on Climate change implications for fisheries of the Benguela Current region. Comments from Professor Geoff Brundrit, Department of Environment Affairs, Cape Town, South Africa, on the Biophysical Report, and guidance throughout the production of both reports by Cassandra DeYoung, FAO, Rome, are also much appreciated.

1. Introduction

This report was conducted under the Japanese-funded United Nations Food and Agriculture Organisation project and supported by the Benguela Current Commission (BCC). It presents the findings of a desktop study into the vulnerability to climatically-induced changes in the living resources of the Benguela Current Large Marine Ecosystem (BCLME) of humans who depend directly or indirectly on these resources for a living. The biophysical changes that have occurred to the system itself over the past 50 years or so, and the expectations for future such changes, have been reviewed in the 2nd Contributed Paper of these Proceedings, hereafter referred to as the Biophysical Report. The current report focuses on the human consequence of such changes, and the capacity of society at all levels to adapt to them and reduce their effects.

Note that although ecosystem considerations are given some attention, the report has for convenience been structured around the fisheries of the region, following for the most part the manner in which the fisheries have been grouped by the national institutes for the purposes of research and management. (It was necessary to keep within national boundaries here since regional fisheries management structures are still being developed through the Benguela Current Commission, and there are as yet no mechanisms in place for regional management of the BCLME's resources). It is however recognised that other forms of structuring (e.g. by ecosystem, fisher category or community type) would have been possible, and may prove to be more appropriate in future work, depending on the objectives. Note too that the effects of climate change in general on the installations and other infrastructure of the fishing industry, such as flooding of fishing ports due to increased rainfall, rising sea level and increased frequency of storms at sea, have not been specifically considered here, nor have the possible effects on other maritime activities such as shipping, oil exploration, marine mining and marine tourism.

1.1 OUTLINE OF REPORT

Boundaries of system

For the purposes of this report the Benguela Current system is defined as that part of the South-east Atlantic which lies between about 14° S and 37° S, east of the 0° meridian. It encompasses the coastal upwelling regime, frontal jets and the eastern part of the South Atlantic gyre. A schematic diagram of the salient features is shown in Figure 1. The northern boundary of the upwelling region coincides with the Angola/Benguela Frontal Zone (ABFZ) where the warm Angola Current meets the cool Benguela upwelling regime. The southern boundary is considered to be the Agulhas retroflection area, which typically lies between 36 and 37° S.

The Benguela system in the narrow sense extends from southern Angola, through Namibia, to the west and south-west coasts of South Africa. In the wider sense it includes Angolan waters to the north of the ABFZ which have a strong influence on the dynamics of the system, and the south coast of South Africa, particularly the Agulhas Bank, which is a major spawning area, feeding recruitment of many species to the South African West Coast. Offshore, the political boundary is the 200 nmile exclusive economic zone (EEZ) of each of the three countries.

Resources considered

In order to keep it within reasonable bounds, the fisheries considered in the Biophysical Report are those which are of major economic importance in the region and/or in their respective countries from the point of view of their contribution to revenue and/or employment in the formal fisheries sector. Small scale, artisanal and subsistence fisheries were excluded because of their very much lower commercial value and the paucity of information on the effects of the environment on them. The current report gives greater attention on these fisheries because of their importance in human terms and greater vulnerability to environmental change, despite the relatively little information on them compared to the industrial fisheries in the region.

Both the Biophysical Report and this report have been restricted to species which for a significant part of their life cycles occur largely within the boundaries of the Benguela Current system and therefore could be affected by changes in this system brought about by climate change. Species whose distribution only marginally overlaps that of the BCLME in the narrow sense, such as chokka squid and east coast sole on the south coast of South Africa, or whose distribution extends well beyond the system at all times of the year, such as commercially important demersal fish and shrimp resources in Angola, have been excluded because of the difficulty of determining how much (if at all) they would be affected by changes in the Benguela ecosystem as such. A number of currently unexploited species of ecological importance have been briefly mentioned in the Biophysical Report in the context of their role in ecosystem functioning and their possible implication in regime shifts. Mariculture has been excluded because of its current low importance in all respects in all three countries, and the fact that mariculture installations are relatively isolated from environmental effects in the open ocean, although they could be affected by changes in the atmosphere, such as increases in air temperature or CO_2 levels.

Vulnerability analysis

This report is the first attempt at an analysis of the BCLME's vulnerability to climate change, following the IPCC's vulnerability framework (see for example, Daw *et al*., 2009). A Vulnerability Index is produced for each of the major fisheries in Angola, Namibia and South Africa, by combining indices of:

a) The **sensitivity** of the system and its commercially-exploited resources to environmental changes of the kind identified in the Biophysical Report;
b) The likely economic and social **impact** of such changes; and
c) The capacity of the fishery and the communities and individuals dependent on it to **adapt** to the socio-economic impacts

The sensitivity assessment is founded on observed changes in the past few decades which could be symptomatic of what is likely to happen in the future if present trends in global climate change continue. These changes and their impacts on the ecosystem (particularly the important commercial resources) are discussed in some detail in the accompanying Biophysical Report. The major, reasonably well-substantiated trends identified in that report and the primary conclusions derived from them are summarized in Section 2 as the foundation for the sensitivity assessment, which is contained in Section 3. The socio-economic importance of each fishery, which effectively determines the impact of changes in resource abundance and availability on human lives and well-being in the region, is discussed in Section 4, with emphasis on the labour-intensive small-scale, artisanal and subsistence fisheries because of their societal importance, particularly in Angola and South Africa. In Section 6 generic differences in the capacity of the various fishing sectors in the region to adapt to changes in the resource base (however caused) are briefly discussed, working from the large, industrial fisheries to the smallest-scale, least commercialized fisheries of the region. In Section 7 the three indices are combined into a Vulnerability Index for each fishery in each country. The report concludes with a brief discussion on possible ways of reducing the adverse effects on humans of climate change in the BCLME measures (Section 8), overall broad conclusions of the study (Section 9) and recommendations for further work (Section 10).

2. Biophysical changes in system

2.1 ENVIRONMENT

The major conclusions of the Biophysical Report on the broad-scale changes in the environment system's biotic and abiotic environment in recent decades in response to climate change are that:

- There has been widespread warming of surface water at both the northern and southern boundaries of the system and in the northern Benguela over the past few decades, but a general cooling of inshore waters of the west and south coasts of South Africa over the same period. The latter has led to an intensification of cross-shelf surface temperature gradients in the southern Benguela.
- There has been a general increase in upwelling-favourable winds in the northern and southern Benguela in the summer months. These trends have however been subject to decadal scale modulations, with the northern Benguela currently being in a low phase. Notably, there is little evidence to suggest that there have been large-scale inter-annual changes in primary production in response to changing wind fields, contrary to what is often assumed.
- All indicators suggest a general decline in oxygen concentration below the thermocline in the southern Benguela over the past two decades, at least in the St Helena Bay region, where most of the monitoring has been done.
- The mean sea level rise in the Benguela upwelling area is of the order of the global average, but is not considered to be a threat along the west coast of southern Africa, except perhaps in Walvis Bay, where it could lead to breaching of the sandspit and flooding of the lagoon, harbour and town. Increased storm activity arising from the increased amount of heat in the ocean does pose an increased threat to shipping and some coastal installations
- The abundance of copepods (the major zooplankton group) has increased by at least an order of magnitude in both the northern and southern Benguela over the past 40 years or so, accompanied by a substantial reduction in the proportion of larger copepods (the preferred prey of anchovy). However, because of the uncertainty regarding the relative importance of bottom up versus top-down control of zooplankton biomass, and the lack of clear evidence of a region-wide, long-term increase in primary production (despite such changes in the wind fields), it would be premature to attribute the apparent increase in copepod biomass in both the northern and southern Benguela primarily to a general increase in primary production in the region.
- The events with the most obvious consequences for marine life in the northern Benguela are the Benguela Niños and other such intrusions of warm, nutrient-poor water from southern Angola, which has in extreme cases severely affected a wide range of species from small pelagic fish to top predators. Over the past decade the frequency of these events, and consequently the extent of low oxygen water in Namibian shelf waters, appears to have increased, although the time series may still be too short to assess whether these are continuing, long term trends or not.
- Although much progress has been made in understanding the functioning of the Benguela ecosystem on many different levels in the past few decades, much has still to be learned before any predictions based on new understanding can be used in management of the region's marine resources. A possible exception is the far greater appreciation of the origin and significance to marine life of Benguela

Niños in the northern Benguela, which it seems can now be predicted to some extent, and be taken into account in management advice, at least in a qualitative sense. In contrast, the net effect on resources of changes in the retroflection of the Agulhas current (believed to be a major driving force in the southern Benguela) is still totally unpredictable at present despite the greatly increased understanding of its dynamics and the ease with which its surface expression can be monitored through satellite imagery. This is particularly important considering recent evidence of anthropogenically- generated increases in the leakage of Agulhas current water into the South-east Atlantic, and of the great importance of the Agulhas current in the global climate system.

2.2 RESOURCES

As described in Section 2.3 of the Biophysical Report, most of the important commercial resources of both the northern and southern Benguela have suffered heavy declines in the second half of the twentieth century due to over-exploitation. Some of the trends in the catches over this period are illustrated in Figure 2 for Angola and Figure 3 for Namibia and South Africa. Notable features in Angola are the sharp reduction in catches of horse mackerel (both species combined), sardinella (both species) and deep sea red crab towards the end of the 1990s. In Namibia and South Africa the most dramatic declines have been in the catches of sardine in the northern Benguela since the early 1970s and of anchovy since 1990, sardine in the southern Benguela in the mid 1960s, hakes in the northern Benguela since the early 1970s, and West Coast rock lobster in both regions following the initial large catches in the 1950s. The only resource to show a sustained increase in recent decades is the sardine resource in the southern Benguela, where catches have at times been comparable with those at the height of the fishery in the 1960s. These catch trends are generally consistent with the stock estimates from acoustic and trawl surveys and population modeling presented in Section 2.3 of the Biophysical Report, which should be consulted for further, more detailed information.

The virtual removal of sardine and anchovy from the northern Benguela ecosystem in the 1970s and 1980s due to over-fishing has resulted in a shift to a less efficient and less environmentally robust regime, believed now to be dominated by gobies, jelly fish and horse mackerel, with no sign of a recovery despite low fishing pressure on sardine and anchovy over the past two decades. In the southern Benguela the most obvious change in the ecosystem over the past few decades has been the shift in the distribution of sardine, anchovy and rock lobster to the Agulhas Bank in the late 1990s, the reasons for which are poorly understood but which are believed to be at least partly environmental. This shift is however not seen as being as far-reaching or as likely to be irreversible as that in the northern Benguela. Further details on these changes in the ecosystem, and discussion on the reasons for them and their consequences, may be found in Section 2.5 of the Biophysical Report.

3. Sensitivity of system to environmental influences

3.1 WHOLE SYSTEM

The question here is the extent to which the marine environment in the BCLME as a whole is likely to be significantly and permanently affected by anthropogenically-induced global climate change. Setting aside the question of the likelihood of such changes, the issues become a) whether there are compensating responses to them which will reduce their net effect on the ecosystem, and b) whether any ultimate effects due to climate change are likely to be irreversible.

Regarding the first question, it will be clear from the Biophysical Report that there are many competing processes in operation within the ecosystem, making it extremely difficult, if not impossible, to predict the system's overall response to any particular change. Some examples from many possible responses to the major environmental changes identified in the Biophysical Report are:

- An increase in upwelling-favourable winds in the southern Benguela may increase primary production, and therefore feeding conditions for sardine and anchovy, but increase offshore advective loss of their ichthyoplankton off the Cape Peninsula en route from the spawning grounds on the Western Agulhas Bank to the nursery grounds on the West Coast.
- Increased temperatures in the euphotic zone may enhance primary and secondary production rates and directly or indirectly accelerate the growth rates of pelagic fish, but cause a shift in spawning to less favourable areas and times and/or increase the incidence of deformities in egg and larvae development
- An increase in the extent of low oxygen water on the shelf in the northern Benguela may inhibit recruitment of both species of hake, but because of differences in their tolerance to hypoxia, reduce the degree of overlap between the distributions of the two species, and thereby the predation of M. capensis on M. paradoxus, which is a major source of mortality in the latter.
- A change in the size and species structure of zooplankton communities could benefit or inhibit pelagic fish production, depending on many factors such as the distribution of the predators and prey, turnover rates and inter-specific competition for food. The indirect effect of species-selective fishing pressure on zooplankton communities could also to some extent counteract the detrimental effects of climatically-induced changes in community structure, depending on its nature.
- Severe reduction in the biomass of one species of pelagic fish could result in its replacement by another. There are a number of examples of this in the BCLME in the second half of the twentieth century, with sardine replacing horse mackerel and then being replaced by anchovy in the southern Benguela in the 1950s and 1960s, and anchovy replacing sardine in the northern Benguela in the 1970s. An analysis of scale deposits on the shelf shows that shifts between sardine and anchovy dominance have occurred frequently in past centuries within the Benguela.

All of these scenarios, and many others which could have been constructed, are highly speculative, but they do serve to illustrate the complexity of the ecosystem and its dynamics. This complexity, combined with the high degree of natural variability on a wide range of temporal and spatial scales, suggests that the system as a whole is probably highly resilient to the kind of environmental changes which have been observed over the last century (including those in the past few decades), and by implication, long before that. It is not unlikely that the biota have in fact evolved specifically to cope with this variability. A further factor making for resilience in the southern Benguela is the wide variety of available habitats arising from large differences in environmental conditions on the west and south-west coasts, combined with the ease of moving between these regions due to the strong oceanographic linkages between them. This facilitates the movement of fish from one habitat to another (e.g. the migration of pelagic fish from the West Coast to the Agulhas Bank in the 2000s), reducing the effect of environmental conditions in a particular region turning unfavourable. It could be that this is less of an advantage in the northern Benguela, which in the broad sense is a more integral, less variable system, bounded more strongly at both the northern and southern extremities by the Angola/Benguela Front and the Lüderitz upwelling cell respectively. One might tentatively conclude that because of this the northern Benguela will generally be less resilient to climate change than the southern Benguela, although the rapidity with which the hake stock recovered from possibly the worst environmental perturbation on record (ie. the extensive and prolonged intrusion of warm, nutrient poor water from the north in 1994 and 1995), suggests a degree of resilience in this system as well.

The most obvious and long-lasting documented changes which have occurred in the BCLME in the past century have been the sharp declines in the abundance of certain resources, particularly small pelagic fish in Namibia, West Coast rock lobster in both the northern and southern Benguela, and many line fish species throughout the region. All of these declines have clearly been due to over-fishing rather than environmental effects, and all give the appearance of being irreversible, in that none of these stocks have recovered despite greatly reduced fishing pressure on them since their collapse. In the case of the northern Benguela, the collapse of the sardine and anchovy resources in the 1970s and 1980s appears to have led to a major regime shift from which there are no signs of recovery some 20 years later. In contrast, the pronounced eastwards shift in the distribution of sardine and anchovy in the southern Benguela in the early 2000s, which was seen at the time as heralding a regime shift, has to a large extent reversed recently, and now appears to have been merely a large-scale protracted perturbation within the existing regime, possibly aggravated by the fishing patterns at the time. The fact that the sardine and anchovy there continue to act as "wasp-waist" species in the ecosystem whereas they are too scarce to do so in the northern Benguela, suggests that the northern Benguela ecosystem is currently less efficient than the southern Benguela ecosystem, and therefore, according to Odum's (1985) hypothesis, is more sensitive to environmental change, as was tentatively concluded on the basis of physical differences between the two systems.

The major point to emerge is that it is fishing pressure rather than environmental effects which have caused the greatest damage to the BCLME over the last 50 years or so, from which it would appear that provided environmental perturbations remain within the bounds of those which have been observed over this period, optimal management of the resources themselves would be the best way to prevent further deterioration of the ecosystem. However, this is not to deny the importance of the environment in the face of global climate change, since there must be a possibility of unprecedented changes to the ecosystem sometime in the future having more profound effects on the system's resources than have occurred within the observational period. For example, a major shift in the position or extent of the upwelling region (including the Lüderitz upwelling cell) could severely disrupt the functioning of the system and the life cycles of the species dependent on it, as could a major change in the amount of warm, nutrient poor water from the Agulhas current which penetrates the system. (There is already evidence that the amount of Agulhas Current water which enters the South Atlantic has increased due to climate change, and that its influence can now be felt well into the North Atlantic. The possibility of the West Coast of southern Africa being severely affected should this trend continue does not appear to be too remote).

Other climatically-induced changes in the ecosystem which are irreversible and therefore need to be considered, are an increase in the frequency and intensity of storms at sea due to the rise in sea level and the general increase in ocean temperature (G. Brundrit, *pers. comm.*) and the destruction of calciferous life forms due to acidification of the ocean (e.g. Meyer, 2011). Neither is threatening at present, the former because of the relatively few vulnerable installations along the coast, and the latter since corals are scarce in the region and few of the zooplankton species on which fish prey have calciferous exoskeletons. The system is therefore resilient to these changes at present, but may not always be so.

In the sub-sections which follow, the possible effects of environmental change on the major resources in each of the three countries of the region are considered. In each case the discussion starts with a summary of the major national fisheries, and continues with a (largely speculative) assessment of the effects which the kind of environmental change summarised in Section 3.1 could have on these fisheries.

3.2 ANGOLA

Fisheries

Within the BCLME as defined here, the most important industrial fishery is the small pelagic fishery, which in terms of volume is the largest in Angola. The fishery primarily exploits two species of horse mackerel (Cunene horse mackerel *Trachurus trecae* and Cape horse mackerel *Trachurus trachurus capensis*), the round and flat sardinellas (*Sardinella aurita* and *S. maderensis* respectively) and, to a lesser extent, sardine (*Sardinops sagax*) in the extreme south, where it forms a transboundary stock with Namibia. The two horse mackerel species are mixed in southern Angola and are not easily separated in the landings. In this region the stocks (particularly of Cape horse mackerel) overlap with those in northern Namibia, forming a transboundary stock. In the past the fish have been caught by large midwater trawlers, purse seiners of various size and as a bycatch in demersal trawls, but midwater trawling for pelagic species (including horse mackerel) is now prohibited to reduce pressure on the stocks. Horse mackerel are also important in the artisanal fishery. *S. aurita* and *S. maderensis* (which are less common than *S. aurita* within the BCLME region) are caught by purse-seine, partly as a by-catch in the horse mackerel fishery. They are also taken by artisanal fishermen close to the coast using a variety of netting techniques. The pelagic fish production is almost exclusively consumed by the local population, to whom it is an important source of protein.

Along the edge of the shelf there is a commercial fishery for the deep-sea red crab *Chaceon maritae,* which are mainly caught by directed fishing with traps within the BCLME area, and as a bycatch in the demersal trawl fishery for deep-water shrimps further north. In the south the distribution extends into northern Namibia, forming a transboundary stock. The production is almost totally exported. On the shelf there are also important demersal trawl fisheries for species such as large-eye dentex (*Dentex macrophthalmus)*, other sea breams, croakers, groupers, porgies and the Benguela hake *Merluccius polli*), and for the deep-water shrimps *Parapenaeus longirostris* and *Aristeus varidens*. However, since most of the catches are taken from north of the Angola/ Benguela Front, beyond the BCLME region as defined, they are not considered in any detail here.

The industrial sector accounts for around 170 000 tonnes of the total annual fish production in Angola, and is prosecuted by some 200 vessels. Many of the larger vessels are foreign-owned, leased to Angolan enterprises, or operate in joint ventures with them. Wholly-owned foreign vessels are not allowed to fish in Angolan waters. The number of vessels in the artisanal fishery, from which foreigners are totally excluded, is an order of magnitude higher (see Section 5.1).

The artisanal fishery, which extends along the entire coastline beyond the arid, largely unpopulated areas in the extreme south and exploits a wide range of species, ranging from small shoaling pelagic fish to demersal fish, sharks, invertebrates and large pelagic predators, is an extremely important source of employment and food for coastal communities in Angola. The fishery operates within an exclusive artisanal fishing zone which extends to 4 nmiles from the coast in the south and 8 nmiles in the north. The fish are caught by handline and a variety of nets (beach seine, gillnet, purse-seine, lift net) either from the beach or from small (< 14 m long) vessels ranging in size and complexity from canoes to so-called "chatas" (5-7 m long vessels with or without a motor) and "catrongas", which are somewhat larger vessels having an inboard or outboard motor. Although much of the fishing takes place north of BCLME region, special attention is given to this fishery in Section 5.1 because of its socio-economic importance, and the relatively large amount of information on this sector which has recently become available in a report prepared for the BCC and the FAO by Sowman *et al*. (2011).

In addition to the industrial and artisanal fisheries, there is a small recreational fishery, primarily for leervis (*Lichia amia*), West Coast dusky kob (*Argyrosomus coronus*) and shad/elf (*Pomatomus saltatrix*). (Potts *et al.*, 2008), which can be expected to expand as infrastructure for reaching and accommodation at the coast improves.

Environmental influences

It appears that there have been no specific studies on the possible effect of environmental changes on any of the Angolan resources and/or the communities which depend on them, but the following generic observations can be made.

1. Although there is no evidence that the warming that has been observed in the surface water north of the Angola/Benguela Front in recent decades has resulted in a shift in the average position of the front or in its variability, this does not exclude the possibility of such shifts in future if the physical processes which have caused the warming trend continue to change in the same direction. A significant and protracted change in the position and/or characteristics of the front could have a major effect on the ecology of the northernmost reaches of the BCLME and on the distribution and abundance the species which inhabit this region, including all of the exploited species. Disruption of the spawning migrations of the two sardinella species, which undertake extensive seasonal spawning migrations up and down the coast, would appear to be one of the more obvious effects. Other major perturbations can be imagined, all of which could affect both the industrial/semi-industrial sector and (particularly) the artisanal fishing communities along the entire coast.
2. An increase in the frequency of *Benguela Niño* events, for which there is some evidence, could have a strong effect on the distribution, and perhaps the abundance, of pelagic fish and crab resources, if sufficiently intense and protracted, with similar socio-economic consequences to the above.

3.3 NAMIBIA

Fisheries

The most important industrial fisheries in Namibia are:

- The bottom trawl fishery for hake (*Merluccius capensis and M. paradoxus*), monkfish (*Lophius* spp.) and various by-catch species such as Cape horse mackerel (*Trachurus trachurus capensis*), snoek (*Thyrsites atun*), kingklip (*Genypterus capensis*) and West Coast sole (*Austroglossus microlepis*). The fishery is prosecuted throughout the year by a fleet of over 100 Namibian-registered freezer and wet-fish trawlers based in Walvis Bay or Lüderitz. Almost the entire hake and monkfish catch is exported to European markets, mostly in the form of frozen fillets and other frozen products. More than half of the processing is carried out ashore. On the outer shelf there was once a lucrative bottom trawl fishery for orange roughy (*Hoplostethus atlanticus*) and other deep-water species, but this fishery has declined in importance because of declining catches, and is now only prosecuted by a single vessel for a short season against a very low TAC. The hake resource (both species) extends well into South African waters, making it the most important transboundary resource in the region. Recognition of this fact, and the need for a regional approach to research and management of the stock, was a primary motivation for the instigation of the BCLME Programme and the subsequent setting up of the Benguela Current Commission, under which a formal Regional Fisheries Management Organisation is expected to be established in due course.

- The pelagic fishery, predominantly for sardine (Sardinops sagax), whose distribution extends into southern Angola at times, making this an occasional transboundary stock. The Namibian fishery is currently carried out by a fleet of some 10 locally-registered purse-seiners (versus more than 100 at the height of the fishery in the early 1970s) operating from Walvis Bay within a roughly 6 month long fishing season. The fishery targets sardine for canning (the preferred product), meal and oil. Processing is done in Walvis Bay at a single cannery and reduction plant (versus nine at the height of the fishery).
- The midwater trawl fishery for Cape horse mackerel, which is conducted year-round by a fleet of some 25 large trawlers which target the adult fish and process their catches at sea. The vessels are largely ageing ex-Soviet bloc vessels, operated mostly by foreign crew. Most of the catch is frozen and trans-shipped to reefer vessels for export as a relatively low-value product to West African and other African markets.
- Line fisheries for hake, snoek and large pelagic species such as tuna, swordfish and large pelagic sharks. Hake are caught throughout the year by a fleet of some 25 local long-liners operating throughout the year from Walvis Bay and Lüderitz where the catches are processed for export, mostly to Europe. The large pelagic species are caught by Namibian and foreign bait-and-pole vessels, and by foreign vessels using surface-buoyed long-lines. All foreign vessels operate under license. Most of the catch is exported as frozen or canned fish. Snoek are mostly sold locally as fresh fish.
- Trap fisheries for West Coast rock lobster (*Jasus lalandii*), which are caught inshore off southern Namibia in summer in hoop nets and lobster traps from some 20 locally-registered vessels, and red crab (*Chaceon maritae),* which are caught in traps on the outer shelf in the north from a few Namibian-registered Japanese vessels, and whose distribution extends well into Angola. The rock lobster catch, which is processed in Lüderitz, is almost entirely exported to Japan in the form of cooked whole lobster. The entire crab catch is processed at sea and exported to Japan.

In addition to these industrial fisheries, an annual harvest of around 50 000 seals for pelts, and the harvesting of guano from offshore islands in southern Namibia and seaweed from the Lüderitz lagoon, there is a lucrative year-round recreational fishery from the shore and ski-boats, aimed at species such as the silver kob (*Agyrosomus inodorus*), West Coast steenbras (*Lithognathus aureti*) and galjoen (*Coracinus capensis*). Because of the inhospitable, largely uninhabited coastline, there are few individuals making their living as artisanal or subsistence fishermen along the Namibian coast.

Environmental influences

The potentially most damaging environmental perturbation, viz. an increase in the intensity and/or frequency of *Benguela Niños* and other intrusions of warm, nutrient poor water from southern Angola, (for which there is some evidence, discussed in the Biophysical Report), could have the following detrimental effects on these fisheries:

1. The distribution of hake, and possibly other demersal species, could be substantially altered *inter alia*, by changing the distribution and increasing the extent of low oxygen water on the shelf. This could make the fish less available to the trawl and long-line fleets, and could possibly reduce their catchability by trawl by altering their vertical distribution. In extreme cases, such as the prolonged and intense warm event in 1994/95, hake recruitment could be severely affected, reducing the biomass significantly, although because of the relatively large number of year classes in the population, this would have to happen for a number of years in succession to have a major long-lasting effect on the fishable biomass. Any significant reduction in availability, catchability or biomass would have an adverse effect on the industry and the people employed directly or indirectly in it (see Section 5.2).
2. The distribution, and possibly the biomass, of the sardine resource could also be changed significantly by intrusions of warm water from the north. While not necessarily detrimental, in that displacement of the distribution to the south would make the fish more available to the Walvis Bat fleet, such intrusions could severely reduce egg production and spawning success by shifting the spawning area and the dispersal of the eggs and larvae to less favourable environments. Since the fish are relatively short-lived, a single year of very poor recruitment can have a major effect on the biomass of the adult stock a few years later, as seems to have happened after the 1994/1995 warm event, which was followed in 1996 by the lowest acoustic estimate of sardine biomass on record. As in the hake fisheries, any major reduction in biomass or availability of sardine would have a major effect on the profitability of the fishery, which is already operating at a level that is barely sufficient to keep the fishery open. Further reductions in catch could well necessitate closure of the fishery (at least temporarily) with extremely serious consequences for the industry and the communities in Walvis Bay dependent on it.
3. While major changes in the extent and distribution of low oxygen water could conceivably effect catches of horse mackerel by the midwater fleet, the fact that adult horse mackerel are widely distributed over the shelf over most of the coast and unlike hake, inhabit well-oxygenated water above the oxycline should make them more resilient to such perturbations. Furthermore, the fact that the midwater trawlers, being large, can stay at sea for long periods and are not bound to Walvis Bay for off-loading makes it easier for the fleet to adapt to changes in distribution. Overall, it seems that this fishery, and the (largely foreign) fishing community which depends on it, should be less sensitive to major environmental perturbations than the demersal and pelagic fisheries in Namibia.
4. It seems reasonable to conclude that of the other fishing communities in Namibia, the (largely foreign) crab fishing community would be that most likely to be affected by intrusions of warm, hypoxic water from the north since the fishery is concentrated close to the Angola/Benguela frontal boundary, and the animals, being bottom dwellers are likely to be sensitive to reductions in oxygen concentration on the bottom. In contrast, the rock lobster fishing community in the south around Lüderitz is unlikely to be as affected since, although the animals actively avoid low oxygen water to the extent of walking out in extremely low levels, the region is too far south to be influenced directly by the Angola current and its intrusions.

The impact on fishing communities of other possible changes in the environment brought about by climate change, such as large-scale changes in primary and secondary production are difficult to assess since the processes involved and the connections between them are complex, and their effects on fish production are difficult to separate from the effects of fishing and other forms of predation. All that can be said at present is that a) there is no evidence of a major change in phytoplankton distribution or abundance in the northern Benguela in recent decades despite some long-term changes in the wind field, and b) the long-term changes in zooplankton abundance and community structure which have been recorded since the start of data collection in the 1950s are as likely to have been caused by changes in predation by pelagic fish as by changes in the environment over this period. This is not to exclude the possibility of large-scale environmentally-driven changes in primary and secondary production in the long term, which could have profound effects on the resources and the fisheries and communities dependent on them.

3.4 SOUTH AFRICA

Fisheries

The most valuable industrial fisheries in terms of food production, revenue and employment within the South African sector of the BCLME are:

- The demersal trawl fishery for both hake species, which extends across the entire shelf from the Namibian border to the Agulhas Bank. Catches from the inner shelf are dominated by *M. capensis*, and from the outer shelf by *M. paradoxus*, with a region of overlap in between. The resource is exploited by fleets of offshore trawlers, inshore trawlers, long-liners and (close inshore) hand-liners. Hake are also taken as a by-catch in the horse mackerel trawl fishery and demersal shark longline fisheries, and to a small extent by the recreational sector. By far the most important sector from the point of view of revenue is the offshore trawl fishery, which in 2000 was prosecuted year-round by some 60 vessels operating from ports between Saldanha Bay on the West Coast to Mossel Bay on the South Coast. About 90 percent of their catch on the West Coast consists of *M. paradoxus*, in contract to the South Coast, where about 70 percent of their catch is *M. capensis*. A large proportion of the catch is exported as fresh fish or frozen products to Europe (particularly Spain). The fish are processed at sea or ashore in some 50 large and small land-based processing facilities between Port Nolloth and Port Elizabeth. It should be noted that the income from hake in South Africa is roughly equal to the total gross income from all other fishery sectors in South Africa (Section 5.3).
- The purse-seine fishery for small pelagic fish, particularly sardine (*Sardinops sagax*) and anchovy, (*Engraulis encrasicolus*) and to a lesser extent, round herring *Etrumeus whiteheadi*. Catches by this fishery are far larger than from any other South African fishing sector, and are second only to the demersal trawl fishery in commercial value. The fish are caught mainly in the first half of the year from some 65 steel and wooden-hulled purse-seiners vessels operating from ports between Lamberts Bay on the West Coast to (in the past decade) as far east as Mossel Bay on the South Coast. The fish are processed at 6 canneries, 8 fishmeal plants and some 40 small-scale packing plants on the West and South-west Coasts (2000 figures). Since the eastward shift in the distribution in the early 2000s, sardine landed at Mossel Bay have been trucked to canneries on the West Coast for processing. Most of the canned fish is sold on the local market where it is an important source of low-cost protein. Almost the entire fish meal and oil production is used locally in the food production industry.
- The West Coast rock lobster (*Jasus lalandii*) fishery, which is the most important rock lobster fishery in South Africa because of its high market value and the relatively large number of persons from fishing communities on the West Coast who are employed in the fishery (see Section 5.3). The commercial fishery operates within a fixed season between the Orange River and Danger Point on the South Coast in waters up to 100m deep. Currently about 20 percent of the resource is

harvested by hoop nets in the nearshore region, and the remainder by offshore trap vessels operating in deeper water. In the nearshore region the resource is also harvested by recreational fishers and informal subsistence fishers in the summer months. Most of the commercial catch, which is processed in some 20 factories and processing plants concentrated around the landing sites, is exported in the form of frozen whole lobsters. In recent years an eastward shift in the distribution resulted in the opening of three new lobster fishing zones to the east and a reduction in the proportion of lobsters taken in the West Coast commercial fishery from around 60 percent to approximately 40 percent. This decline has resulted in economic hardship for most of the rock lobster fishers along the West Coast, but has opened some new employment opportunities in the Walker Bay area.

- The line fishery (excluding the longline fishery for hake) is made up of commercial, recreational and subsistence sectors. Together these three sectors target between 95 and 200 of South Africa's marine species. Particularly important species taken from the BCLME region as here defined are snoek (*Thyrsites atun*), kob (*Argyrosomus spp.*), yellowtail (*Seriola lalandi*) and geelbek (*Atractoscion aequidens*). The commercial sector is almost entirely boat based, with some 455 boats currently in operation country-wide. Many of these operate on the West Coast and the South Coast west of Cape Agulhas. Commercial linefishing is a low-earning, labour intensive industry, which although contributing relatively little in terms of revenue is an important industry from a human livelihood point of view (see Section 5.3). Recreational line fishermen operate mainly from trailerable skiboats which can be launched from many small harbours and even beaches along the coast. It is estimated that there are at least 4 000 such boats along the South African coastline, of which a sizeable number operate on the West Coast and the western part of the South Coast. The value of this fishery to the tourist and allied industries far exceeds that of the catch. The subsistence sector, which was formally recognised in 2000, operates along the entire South African coastline. About 85 percent of the estimated 30 000 subsistence fishers in South African waters harvest linefish, a sizeable proportion of which is taken from the BCLME region as here defined.
- A trawl fishery for adult horse mackerel *Trachurus trachurus capensis* on the West and South Coasts, and a purse seine fishery on the West Coast for the juveniles. The adults are taken as a bycatch by the demersal fleet and as a targeted species by a number of midwater trawlers, mainly on the South Coast. The juveniles are taken as a by-catch in the sardine and anchovy pelagic fishery, particularly in the first few months of the year, and are reduced to meal and oil. The adult catch yields low value whole fish products which are largely exported to neighbouring countries as a source of cheap protein for human consumption.

In addition to the above fisheries, there is a wide-ranging (partly foreign) offshore fishery for large, highly migratory pelagic fish such as tunas and swordfish, small-scale beach seine and gillnet fisheries on the West Coast, predominantly for mullet (*Liza richardsonii*), and small local harvests of white mussel (*Donax serra*) and other invertebrates along the West Coast. There is also a seaweed industry based primarily on the harvesting of beach-cast and fresh kelps and the red seaweeds *Gelidium* and *Gracilaria*. None of these fisheries contribute significantly to the national marine production, but the small-scale fisheries in particular, are important locally as a source of food for subsistence fishers and in providing supplementary income for retired or out of work crew and factory workers during closed fishing seasons.

Environmental influences

Of the environmental perturbations summarized in Section 3.1, those which appear to be potentially the most damaging for these resources and the communities which depend on them are a) the general increase in upwelling-favourable winds in summer, b) increases in the amount of low oxygen water (which has been documented in the St Helena Bay region, at least) and c) whatever environmental changes may have been responsible for the eastwards shift in the distribution of pelagic fish and rock lobster away from the traditional West Coast fishing grounds in the past decade. These could have the following consequences.

1. A major change in the extent or distribution of low oxygen water across the shelf could affect the hake industry by making the fish less available to the deep sea trawl fleet and reducing catchability by forcing the fish further off the bottom. It could also alter the proportion of *M capensis* versus *M. paradoxus* in the catch, since there is some evidence that the two species have different levels of tolerance to hypoxia. Note though that since oxygen levels in bottom water on the West Coast seldom reach the low levels experienced on the Namibian shelf, and there is no convincing evidence to suggest that on the South African shelf oxygen levels have a strong influence on hake catch rates, these may be a relatively benign effects. In contrast, there is some (mostly anecdotal) evidence to suggest that catch rates are markedly affected by changes in wind direction. If so, continuation of the changes in the wind field which have been observed over the past decade or so could significantly decrease (or increase) catchability, at least in the summer months. As in Namibia, a significant reduction in availability and/or catchability would have a marked effect on the profitability of the industry, and on the fishing and processing communities in South Africa which are employed in it.
2. Significant environmentally-induced changes in the distribution of sardine and anchovy, and specifically in the proportion of their populations west and east of Cape Agulhas, are likely to affect their availability to the primarily West Coast-based purse seine fleet. Such changes are also likely to affect the locality, extent and intensity of spawning, the survival and dispersal of the ichthyoplankton, and movement of the pre-recruits into the inshore nursery areas, all of which have a bearing on annual recruitment strength, on which these short-lived species rely heavily. Of particular importance would be any significant effect on the shelf-edge jet current off the Cape Peninsula which connects spawning on the Western Agulhas Bank to recruitment on the West Coast. Although there is still insufficient understanding of all these processes, despite decades of intensive studies, and no strong evidence of a link between the environment and recruitment strength except over short time periods, there can be little doubt that changes in the environment, if large and persistent enough, could result in recruitment failures by disrupting one or more critical steps in the recruitment process. Such failures are likely to result in severely reduced catches, which would have serious consequences for the industry, the workers who are employed in it both at sea and the factories ashore (particularly on the West Coast), and in the supply of cheap protein in the form of canned fish to the local market. An ameliorating factor for anchovy, and to a lesser extent sardine, is that recruitment failures are likely to be detected within the first year of life by acoustic surveys which are carried out in May/June each year (e.g. Coetzee *et al*., 2008). These enable rapid adjustment of TACs according to a well established and accepted Operational Management Procedure (e.g. De Oliveira *et al*., 1998) which is aimed at maintaining a viable spawning stock even in years of poor recruitment.

   While it is clear that major changes in the upwelling regime in the southern Benguela, resulting in large-scale changes in the production, distribution and species composition of the phyto- and zooplankton communities on which pelagic fish feed, could have profound effects on these resources, it is not at all clear whether the outcome would be positive or negative because of competing effects. For example, as previously mentioned, an increase in upwelling-favourable winds off the Cape Peninsula would probably increase plankton production, but would also probably increase offshore advective loss of eggs and larvae in transit from the Western Agulhas Bank to the West Coast recruitment grounds, reducing the number of incoming recruits. The net effect of these two processes is unpredictable, and likely to be highly variable.

3. The West Coast rock lobster resource could well be adversely affected by an increase in natural mortality due to an increase in the frequency and/or extent of anoxic water close to the coast. The worst effects would probably be experienced in the St Helena Bay area, where the highest mortalities and most walk-outs have occurred in the past. If the shift to the east in the distribution over the past decade has indeed been caused primarily by changing environmental conditions, and should these conditions persist or even intensify, there could be further displacement to the east, exacerbating the hardship to the rock lobster fishing community which has already been caused by the shift away from the traditional West Coast fishing grounds. This would add to any increased hardship resulting from higher natural mortality of lobsters on the West Coast.

Partly because of the fewer studies on them, there are no clear pointers to the way in which the other resources within the southern Benguela region would react to changing environmental conditions in the southern Benguela. This is not to say that they and the communities which earn a living from them would not be affected by environmental changes, particularly if severe and long-lasting.

Arguably, the greatest long-term environmental threat to the resources of the southern Benguela is posed by changes in the Agulhas current and in its influence on the upwelling region. This is because:

- There is convincing evidence that the core temperature of the current has already increased by an average of more than 0.5 °C over the past decade, which combined with a cooling of the inshore region over this period has resulted in intensification of the thermal gradient across the Agulhas Bank (Roauolt, 2010).
- It appears that large-scale variability in phytoplankton biomass in the southern Benguela is more likely to be driven by the anomalous advection of warm surface water from the Agulhas retroflection in the south rather than by localized upwelling events (de Villiers, 1998).
- Recent studies have shown that the leakage of warm, saline Agulhas current water into the South Atlantic is a crucial component of the global climate system (even reaching the North Atlantic and possibly counteracting the cooling of the Gulf Stream, *inter alia*), and that the leakage has increased in the past decades in response to a progressive poleward migration of westerlies south of the African continent, which has been linked to anthropogenic warming (Biastoch *et al.*, 2009; Beal *et al.*, 2011). It seems reasonable to suppose that because the leakage occurs immediately offshore of the southern Benguela upwelling region, further increases in its extent as a result of continuing anthropogenic warming may have a great effect on the upwelling region, with dramatic consequences for the southern Benguela ecosystem as a whole.

4. Socio-economic impact of changes in resource abundance and availability

In this section the importance of each fishing sector in each country in terms of income and employment, food security and human society is examined to assess the possible impact of environmentally-induced changes in resource abundance and availability on human lives in the BCLME.

4.1 ANGOLA

Income and employment

The industrial and semi-industrial fishing sector in Angola is the third most important formal economic sector in the country after oil production and diamond mining, contributing about 3.5 percent to the GDP, and is a sector particularly marked for expansion (Fishing Industry Handbook for South Africa, Namibia, Mozambique and Angola, 2009). According to FAO statistics, around 95 percent of the fish captured within the EEZ is landed in the country, and only about 5 percent is exported. Approximately 90 percent of the marine landings are consumed locally as unprocessed, dried or salted fish.

In the new Master Plan for the development of the commercial fishing sector, produced by the Ministry of Fisheries in 2005, production goals for this sector for the period 2006 to 2010 were set at a little under 300 000 metric tonnes, with 69 percent allocated to the pelagic sector and almost all of the remainder to the demersal sector. It is likely that over this period a significant proportion of the pelagic catch, and a somewhat smaller proportion of the demersal catch, will have been taken from the more productive BCLME region in the south. The total employment at sea and ashore in these fisheries has been estimated at around 12 000 people (INFOSA, Angola fisheries country profile, 2011). A disproportionately large number in relation to the demography of the coastal population most probably operate in the south because of the comparatively large pelagic fishery there.

The artisanal fishery is also very important in Angola. Over the years the proportion of the total catch taken by the artisanal fisheries has increased to the extent that in the Master Plan for the 2006-2010 period, 35 percent of the TAC was allocated to artisanal fisheries, of which 73.5 percent was given to demersal fish and 19.3 percent to pelagic fish (Sowman *et al.*, 2011). Catches by this sector now exceed 100 000 tonnes per year, making this an important fishing sector in Angola, even in terms of volume. The sector is even more important in terms of employment. It has been estimated by Sowman *et al.* (2011) that the total number of people engaged in artisanal fishing activities in 2005, including beach-seine and shore-based subsistence fishers, was between 130 000 to 140 000, while a report by the European Union in 2006 (União Europeia, 2006) put the total number of people in Angola making a living from artisanal fishing and related activities such as buying, processing, distributing and marketing, at about 700 000; a number which could well have increased since then under the Master Plan for developing the fisheries sector between 2006 and 2010.

Within the BCLME region artisanal fishing is largely conducted from beaches and small harbours within the Namibe Province, whose northern boundary at about 14 °S more or less co-incides with the northernmost retreat of the Angola/Benguela Front.

Duarte *et al.* (2005) have identified 12 coastal fishing communities in this province, out of a total of 102 along the entire 1 650 km of Angola's coastline. Fielding *et al.* (*in prep*.) estimate that in 2005 there were about 4 000 artisanal fishers operating from boats in Namibe province, out of a total of nearly 20 000 in the country as a whole. Sowman *et al*. put the number of artisanal vessels in Namibe at this time at 769 out of a national total of 6 775. Most of these were chatas without motors. These numbers have probably increased under the 2006-2010 Master Plan. The fact that the number of artisanal fishers fishing from boats in Namibe province make up about 20 percent of the national total despite the fact that only some 3 percent of the population of the coastal provinces live there (Europa World Year Book, 2005) illustrates that a disproportionately high percentage of the artisanal fishers fishing from boats in Angola operate from the southern region. This imbalance is also evident from catch data in Duarte *et al.* (2005) which show that some 30 percent of the total estimated artisanal catch in 2003 (ca. 90 000 tonnes) was caught in the Namibe province.

Food security

Fish is part of the traditional diet of Angolans, about 70 percent of whom live below the poverty line, and about 85 percent of whom depend on subsistence agriculture for a living (INFOSA, Angola fisheries country profile, 2011). Angolans now consume an average of between 15.7 and 17.3 kg of fish per capita per year, up from 13 kg per year in 1995 (in Sowman *et al*., 2011) and well above the fish consumption in other Sub-Saharan countries.

No figures were sourced on the consumption of fish within the marine fishing sector as such, but it can be assumed that along the entire coast the artisanal catch (in particular) which is not sold or traded is very important as food for many impoverished households, and that fish consumption rates on the coast are probably considerably higher than the national average. The people living there are heavily dependent on fish for their nutrition, since few own land and most have little money to buy other forms of food. It is not possible to say from available information whether artisanal fishing communities in the south are more or less dependent on fish for food than they are elsewhere along the coast.

Human society

There is little information available on the social structure of the fishing communities which are directly involved in or affected by the industrial and semi-industrial fisheries in Angola. However it seems reasonable to assume that apart from the fishers themselves, many of the some 12 000 people reported to be employed in this sector are engaged in the services needed to keep the boats at sea and in the processing, distribution and marketing of the catches within the country. Most are likely to be concentrated in the more populated areas, with Namibe being the major centre within the BCLME region.

Sowman *et al*. (2011) report that people engaged in the artisanal fishery predominantly earn a living through fishing itself, boat building and repair, renting out of vessels, mending machinery and nets, off-loading fish, transporting, cleaning, drying, salting, selling and/or trading fish. Statistics on the proportions of the populace engaged in these particular activities are not available, but because of the relatively large amount of boat-based artisanal fishing in the south, it seems reasonable to assume that the number of people involved in servicing boats and gear there will be relatively large compared to the northern regions where the boats are smaller and there is relatively more fishing from the beach.

Angolans are among the poorest people in the world, indicated by the fact that in 2010 the UNDP's Human Development Index (HDI) for Angola was 0.403, according to which the country ranks 146 out of 169 countries world-wide. The artisanal fishing communities are among the poorest in Angola, particularly in remote areas along the coast where there are few alternative sources of income and employment and little infrastructure. Because of poor roads and lack of transport, most can only follow the fish over short distances so face further hardship when the fish are scarce locally due to depletion, environmental conditions or seasonal migrations. They generally have inadequate access to basic services such as clean water and sources of energy, and few ways of preserving and transporting fish to improve the market value of the catch. Health and educational facilities are poor in many fishing communities, resulting in a generally low standard of health and little ability to escape the poverty trap through better education.

Contributing to the static nature of the communities is the fact that fishing is a traditional way of life for many of these people, who for generations have known no other way of making a living, and who have no desire to do so in any other way. A positive aspect of this way of life is that it has engendered a harmonious spirit of co-operation within and between communities, in which knowledge is shared and mutual assistance readily given. Sowman *et al*. (2011) report that the only major source of conflict in the artisanal fishery is the intrusion of industrial and, to a lesser extent, semi-industrial vessels into the inshore exclusive fishing zone, where they do at times interfere directly or indirectly with artisanal fishing. They report that this problem, which is seen to be the result of weak law enforcement, has lessened in recent years.

Unemployment is seen as the major social problem in all areas where artisanal fishing takes place, and is likely to be in the industrial and semi-industrial fisheries too. Other social problems such as alcoholism, crime and drug abuse, and the destitution of war orphans and amputees, are aggravated by the high levels of unemployment.

4.2 NAMIBIA

Income and employment

Namibia's fishing industry is the second largest national industrial sector after mining, contributing around 8 percent to the country's GDP. The industry is almost totally industrialized, highly capitalized and very heavily directed at the export market, with more than 95 percent of marine catches being exported. In most years it accounts for some 25 percent of Namibia's foreign exchange earnings. In 2008 the total catch amounted to a little over 300 000 metric tonnes, which was valued at the time at around 4.6 billion N$/ZAR (575 million US$)[1] (Fishing Industry Handbook for South Africa, Namibia, Mozambique and Angola, 2009).

The demersal trawl fishery for hake and (to a far lesser extent) monkfish, and the midwater trawl fishery for adult horse mackerel are the most important monetary contributors, with the hake fishery contributing more the 50 percent of the total value. The once highly lucrative fisheries for sardine and anchovy and the deep water trawl fishery for orange roughy are now both minor contributors in monetary terms to the economy, as are the trap fisheries for rock lobster and deep sea crab and the long line fisheries for tunas and sharks. The total annual expenditure of shore-based recreational fishers, who take about 500 metric tonnes of fish per annum, has been estimated at about 1 percent of the turnover from the industrial sector (in Sowman *et al*., 2011). The contribution in terms of sales of the artisanal sector, made up of all forms of small-scale fishing, is negligible, being many orders of magnitude lower than the income generated by the industrial and recreational fishing sectors (in Sowman *et al.*, 2011).

The industrial fishery employs some 14 000 people on the vessels and ashore in the processing factories, and runs a fleet of around 300 vessels ranging in size from small wooden lobster-fishing boats less than 25 m in length to deep sea hake freezer trawlers typically 50 to 60 m long, to large horse mackerel midwater trawlers over 100 m in

[1] 1 ZAR = 1 N$ = 0.125 US$ (November, 2011)

length which carry (mostly foreign) crews of up to 100 and process their catches at sea and transfer the product to reefers. Around 57 percent of the workers in the industrial sector are employed onshore in Walvis Bay and (to a lesser extent) Lüderitz, and the remaining 43 percent on vessels. According to statistics from the Ministry of Fisheries and Marine Resources, in the late 1990s the demersal sector employed the largest number of fishers, followed by the midwater trawl fishery and the rock lobster fishery, which employs a relatively large number of fishers in relation to the size of the catch. More recent figures have not been sourced, but since none of these fisheries has changed radically in nature since the 1990s, the proportions today are likely to be broadly similar. As a result of the Government's so-called Namibianisation policy the proportion of the workforce at sea who are Namibian citizens has increased since Independence in 1990, and now stands at around 70 percent. The workforce ashore, which is almost totally Namibian, is engaged in canning, fish meal and fish oil production, as well as skinning, trimming, cutting and packaging, which is mainly carried out by women. Employment in the hake and horse mackerel fisheries is year-round, but in almost all the others it is seasonal, determined by the legislation pertaining to each particular fishery.

There is no direct employment profile for the recreational sector as yet, but based on data from the late 1990s, Fielding *et al.* (2006) have put the number of recreational anglers in Namibia at 8 800. They estimated the number of participants in the artisanal fishery in 2003 at less than 200.

Food security

In terms of food security, the marine fishing industry is very much less important in Namibia than it is in Angola and South Africa due to the fact that most of the catch is exported, the production of canned fish (a low-cost source of protein) is now orders of magnitude lower than it was at the height of the sardine fishery, and there is almost no artisanal fishing along the coast. (Although the national fish consumption rate of around 14 kg per capita per annum is not much lower than Angola's, this Figure is probably inflated by the relatively large amount of fresh water fish which is consumed in the interior of the country).

Human society

In 2010 Namibia's HDI was placed at 0.606, according to which the country ranks 105 out of 169 countries, similar to South Africa (110), but much higher than Angola (146). There are no indicators for the fishing sector as such, but it is probably safe to conclude that on the whole the standard of living of Namibians who depend directly or indirectly on marine fishing for a living is higher than in Angola, and possibly in South Africa too because of the relatively low importance of the small-scale line fishery and the lack of a significant artisanal fishery.

There have been no in-depth studies on the human dimensions of the Namibian fisheries apart from the study by Sowman *et al*. (2011) on the plight of the very few artisanal fishers in Namibia, which highlighted their poverty and marginalized position in society. However, from the following observations on the labour profiles in the various industries, some inferences concerning the lives of individuals and communities dependent on these industries for a living can be drawn.

The fact that Namibia's marine fishing sector is almost totally industrialized and centred on the two ports of Walvis Bay and Lüderitz means that the vast majority of workers in this industry are employed there either year-round or seasonally, depending on the nature of the fishery. In the closed seasons fishers and factory workers either seek casual work in the coastal towns of Walvis Bay, Swakopmund and Lüderitz, or migrate to the interior to return to their families and/or seek work there. Because of the desert environment agriculture is not a viable source of supplementary income anywhere along the coast. Their almost total dependence on the success of the highly capitalized industries which support them makes the fishing communities vulnerable to factors beyond their control such as downturns in catches or increases in fuel price and, because the production is almost entirely exported, adverse exchange rates or downturns in the global economy.

There have been few studies on the social structure of the various fishing communities in Namibia, but it can be expected that due to the itinerant, temporary nature of some of the labour force and the lack of substantial community-based small-scale fisheries, the fishing communities at the coast will be less socially cohesive than the artisanal fishing communities along the Angolan coast, for example. Their greater mobility, wider range of options for temporary or permanent alternative employment and generally weaker traditional ties to the fishing industry are all likely to be destabilizing factors. As in Angola and South Africa, unemployment is likely to be a root cause of most social problems in these communities. The closing of factories and the lay-off of workers at sea and ashore at relatively short notice due to rapidly deteriorating market conditions appears to be a particular source of hardship and strife between employers and employees at times (e.g. Mail & Guardian article, 1 February, 2005).

4.3 SOUTH AFRICA

The information in this section is largely drawn from the economic and sectoral study of the South African fishing industry prepared for the Department of Environment Affairs and Tourism by Rhodes University in 2003 (Sauer *et al.*, 2003a, 2003b), a Working Paper on the socio-economic contribution of South African fisheries by the Institute for Poverty, Land and Agrarian Studies (PLAAS), University of the Western Cape (Hara *et al*., 2009), and information on the small-scale South African fisheries in Sowman *et al.* (2011).

Income and employment

The contribution of the fishing industry to the total national GDP in South Africa is low at around 0.1 percent. However, this Figure rises to around 3 percent if the mining sector is excluded, and to around 5 percent if only the coastal economies are considered. The total catch from the BCLME region in 2008 was some 615 000 metric tonnes, of which about 69 percent was caught by the pelagic sector (mainly anchovy and sardine) and about 28.5 percent by the demersal trawl fleet, 68 percent of whose catch consisted of deep and shallow-water hakes. In recent years the wholesale value of the landed catch from South Africa's commercial fisheries has amounted to approximately 2 billion ZAR (250 million US$) per year, generating a further 2 billion ZAR in foreign currency. Most of this income has been generated from fishing within the BCLME region; ie. from the West and South-west Coasts. The larger sectors are heavily industrialized and capital intensive. For example, the market value of the deep-sea and inshore trawl fleet has been estimated at 800 million ZAR (100 million US$), and the replacement value much higher (Hara *et al.*, 2009). The replacement cost of the purse seine fleet of around 65 vessels would probably be of the same order.

In addition to the industrial fishery there is a large recreational line fishery whose total contribution nationwide to the economy in the mid 1990s was estimated by Griffiths and Lamberth (2002) at about 1.8 billion ZAR (225 million US$). There are no updated estimates, and none of the contribution from the BCLME region itself, but these figures are sufficient to illustrate the importance of the recreational sector in monetary terms. The income generated from small-scale fisheries, which although important in terms of the number of people dependent on them (particularly on the East Coast), is negligible because of the low volume and value of the catch, and the fact that much of the catch is consumed rather than sold or traded.

From a survey conducted in 2000, Sauer *et al.* (2003a, 2003b) estimated that at that time around 28 000 people were directly employed by the South African commercial fishing industry, with about 17 000 employed in the primary sector and the remainder engaged in secondary and tertiary activities such as processing, distribution and marketing. They estimated that a further 60 000 were employed at that time in related sectors such as the manufacture and maintenance of boats and equipment. Since there have been no major changes in the structure of the fishery since that time, it is probably reasonable to assume similar levels of employment and a similar breakdown at present. It can also be assumed that because of the concentration of the commercial fisheries on the West and South-west Coasts, most of the people directly or indirectly employed in the commercial fishing sector today derive their income directly or indirectly from the BCLME region, as they would have done when the survey was conducted. An exception is the jig fishery for chokka squid *Loligo reynaudii* in the Eastern Cape which employs a total labour force of nearly 2 000 persons (Sauer *et al.*, 2003b).

The fishing industry is an important employer in that the average salary paid to workers in the industry (36 000 ZAR or 4 500 US$ per annum in 2000, according to Sauer *et al.*) is relatively high by South African standards, and that the majority of employees are "semi-skilled" who have limited opportunities for alternative employment. The fisheries on the West and South-west Coasts which employ the greatest number of people are (in order) the traditional line fishery, the deep-sea trawl fishery for hake, the West Coast rock lobster fishery and the tuna bait boat fishery. However, the deep-sea hake industry has the largest wage bill, followed by the linefish and pelagic fisheries. In general the small-boat fisheries pay lower wages than the fisheries that use larger, more sophisticated vessels, which require a higher level of skill to operate. Further information on the numbers and earnings of the labour force in each of these and other smaller South African fisheries in 2000 is contained in detailed profiles complied for each fishery by Sauer *et al.*(2003b).

The commercial fisheries sector in South Africa includes both a large-scale offshore fishery and a smaller nearshore fishery, which could also be termed small-scale as defined in a new national policy for the management and development of small-scale fisheries, now being drafted. The latter includes nearshore fishing for West Coast rock lobster and traditional linefish species, beach seining and gillnetting, and the harvesting of oysters, abalone, white mussels and seaweed. Under the commercial fisheries policy instituted in 2005 a relatively small number of rights were allocated to these fishers, resulting in the exclusion of many fishers who had traditionally exploited these resources. As a measure to provide some relief pending finalisation of the new policy for small-scale fisheries, about 1400 small-scale fishers in the Western and Northern Cape (identified by the fishing communities themselves) have subsequently received interim permits to fish certain line fish species, West Coast rock lobster and white mussel. In 2010 similar rights were extended to a small group of net fishers. Arrangements such as this are likely to remain in place until implementation of the new small-scale policy, which appears to be imminent (Sowman *et al*., 2011). In addition to the small-scale fisheries recognised within the commercial sector, there is within the BCLME region a wide range of other small-scale fisheries, characterised by the use of simple gear from the beach or in the littoral zone targeted at multiple species that support local economies and provide food security. Many of these fisheries are informal and are not fully recognised by the fishing authority, making them in the strictest sense illegal. Raemaekers (2010) has estimated that, all these activities considered, close to 100 000 people could be directly involved in small-scale fishing activities along the South African coastline (up from an earlier estimate of 30 000 by Clark *et al*., 2002). A breakdown into the number engaged within different regions is not possible, although from the fact that there are about 30 geographically distinct small-scale fishing communities within the BCLME region, and many more fisher groups operating from within the urban areas (particularly in and surrounding Cape Town), it can be concluded that a significant number make their living from within the BCLME region.

Food security

According to FAO statistics, between 1999 and 2001 South Africans consumed on average 6.9 kg of fish per person per year nationwide, less than half the national consumption rate in Angola and Namibia. There are no figures available on the consumption of fish by people living close to the coast within the BCLME region, but it would be reasonable to assume that is significantly higher, particularly for people engaged in the small-scale commercial, artisanal and subsistence fisheries, which often supply whole communities with their primary source of food.

Human society

In 2010 South Africa's HDI was placed at 0.606, earning the country a rank of 110 out of 169 countries, versus 105 for Namibia and 146 for Angola. There is no *a priori* reason to expect this index to be unrepresentative of the fishing communities, unlike in Namibia where an HDI index for the marine fishing communities would probably be higher than the national average because of the heavily industrialized nature of the fisheries there.

As in the South African economy at large, the fishing sector is extremely diverse in its social make up. Those involved range from wealthy industrialists and professionals to very much less wealthy small boat owners, to even less wealthy fishers and factory workers and artisanal/subsistence fishers who are among the poorest workers in the South African economy. The country is still emerging from the apartheid era when participation in the economy and access to education and many services and amenities was determined on racial grounds, resulting in inequitable involvement of different population groups in the fishing industry, as in other sectors of the South African economy. The situation is being actively redressed by the post-apartheid government through transformation legislation which encourages and promotes wider participation of so-called Previously (or Historically) Disadvantaged Individuals (PDIs or HDIs) in the fishing industry. This has led to a substantial increase in the number of P(H)DIs who have fishing rights, own their own boats and/or companies or have a share in previously exclusively white-owned fishing companies and related enterprises. Nonetheless, the earnings of PDIs in the industrial sector are still disproportionately low compared to their numbers, and the number of them who are poorly educated and classified as unskilled or semi-skilled is disproportionately high. Most of those engaged in or dependent on small-scale fisheries within the BCLME region, and practically all subsistence fishers there, were previously disadvantaged by law, and now, as then, many barely earn a living wage (Sowman *et al*., 2011).

The nature of the various fishing communities varies considerably from fishery to fishery. A summary of the situation in the most important industrial, recreational and small scale fisheries is attempted below.

The **deep-sea and inshore trawl fishery** for hake provides the most secure employment of all South African sectors, and is the only sector providing formal employment for workers both at sea and ashore. It has a permanent, non-seasonal labour force employed on fixed salaries with commission and incentive bonuses for some. The labour force is well organized and on the whole reasonably skilled, with only about a third classified as unskilled. There are union-regulated salaries and benefits for all workers, investments in training and development and support for community projects. The industry has been largely transformed at all skills levels, to the extent that by the early 2000s PDIs made up 92 percent of the total staff and 86 percent of the total payroll (Sauer *et al*., 2003b). In contrast to the trawl fishery, the **longline and handline fisheries** for hake and other species are seasonal, catches are erratic, employment is temporary and fishers are generally paid for what they catch. Labour is less organized than in the trawl fishery and training and community support structures far weaker.

Employment in the **pelagic fishery** is less stable than in the trawl fishery due to greater fluctuations in the annual TAC, and the fact that many operators work on a marginal profit basis against high fixed operating costs, making them highly susceptible to fluctuations in catch rates or TAC adjustments. The smaller companies and private boat owners are particularly at risk in this respect. About a third of the roughly 8 000 people directly employed in the industry are seasonal workers. The communities are centred on the fishing harbours, six canning factories and eight fishmeal plants (2000 figures) which stretch from Lamberts Bay on the West Coast to Gansbaai on the South-west Coast. The larger, traditional companies have established infrastructure to support their workers by way of training schemes, medical clinics, social services, housing subsidies and educational bursaries, all of which mitigate the societal effects of instability in production, although adding to the operating costs. In 2000 about 92 percent of people employed in the industry were PDIs, earning approximately 76 percent of the annual wages; a somewhat lower proportion than in the deep-sea trawl industry. In contrast to the trawl industry, a high proportion of full-time employees in the pelagic industry (around 85 percent) work in jobs which are classified as semi-skilled or unskilled. In 2000 PDIs were over-represented in the unskilled group and under-represented in the skilled group and, to a lesser extent, the professional and middle services groups. Since there have been no major changes in the structure of the industry over the past decade, the situation is probably broadly similar today.

Commercial line fishing is a very low-earning , labour-intensive occupation, but although it contributes comparatively little in terms of landed value, it is important from a human livelihood point of view along the entire South African coastline, often supplying whole communities with their primary source of food and income. Roughly half of those employed in this sector operate from small harbours and the larger centres within the BCLME region. Fishers fall within two categories; skippers, (classified as skilled) and crew (classified as semi-skilled). In the 2000 study it was found that a disproportionately low number of skippers and large number of crew were PDIs; an imbalance which was also evident in their relative incomes. Levels of formal education are generally very low, and few have other skills which would enable them to seek work or supplement their income from work outside the fishing sector. Because the availability of the many species which are targeted fluctuates widely and the boats are too small to venture far to search for the fish, income and employment in this fishery is erratic, characterized by long periods of unemployment during which fishers often have to rely on very poorly paid casual work, supplemented by social grants. The problem is particularly severe in the case of snoek, which contribute about 40 percent of the catch and are highly migratory. It has been compounded by the fact that many of the species which were historically exploited by line fishers since the nineteenth century have been severely depleted, almost to the point of extinction in some cases, narrowing the resource base dramatically and sometimes making quotas non-viable. The sector is essentially informal, characterised by poor support infrastructure, limited access to education and health facilities and no organized security network for workers other than social grants from the government. These factors, combined with the erratic nature of the fishery and the fact that many fishers have strong traditional ties to the fishery and the way of life it embodies, have few skills in other areas and little desire or ability to move away or seek work elsewhere, makes for severe hardship and economic deprivation at times on scales ranging from the local to the regional. Sowman *et al.* (2011) point out that a significant and defining trait of small-scale fishing in the BCLME region (including commercial fishing) is that it is essentially community-based, but they emphasise that the degree of cohesion within the communities in the various settlements differs substantially, particularly between the smaller rural areas and the larger more urbanized ones. They found for example that within the BCLME region there are very different attitudes towards the new policy of communities determining small-scale fishing rights, which tends to be supported by tightly-knit rural communities but strongly opposed by less cohesive communities in the larger, more urban areas. Another cause of conflict is racial tension arising from an influx of migrant workers who compete against the traditional fishers for jobs and fishing rights, to which they are equally entitled under the current legislation.

In contrast to the commercial line fishery, **recreational line fishing** is largely the pursuit of the relatively wealthy who are highly mobile and well equipped, and although some subsidise their sport by selling catches, earn their primary income from a wide range of other activities within the South African economy. The people engaged in this fishery are therefore far less affected materially by outside influences on the resources they exploit than those in the commercial line fishery.

In the commercial **West Coast rock lobster** fishery, roughly two thirds of the work force in 2000 were employed in processing the catch at some 19 factories between Port Nolloth in the Northern Cape and Gansbaai on the South-west Coast. Most of the rest are fishers who work on a permanent or seasonal basis, either close inshore using hoop nets from dinghies operated from harbours or from a motorized mother vessel, or (more commonly) further offshore (to about 100 m) using traps deployed from inboard motor vessels. Some of the vessel crew and most of the processing workers also work part-time in other fisheries such as the linefish, pelagic and (until recently) abalone fisheries. Sauer *et al.* (2003b) estimated that some 70 percent of the labour force employed in this industry in 2000 was made up of semi-skilled Previously Disadvantaged Individuals, a situation which is probably much the same today. Fishing is restricted to a limited range from the factories and processing plants, whose location therefore largely determines the distribution of the associated fishing communities. Since the factories and processing plants have in recent times become multi-facetted entities, processing various other marine products to take up spare capacity resulting from the reduction in rock lobster catches, they provide employment to a wider spectrum of coastal fishing communities, all of whom are heavily dependent on them, particularly since they often offer the only viable employment in the area. Closure of a factory due to uneconomical lobster catch rates is therefore highly detrimental to the whole local fishing community. Cases in point are the closure of a processing and packaging factory in Port Nolloth in 2001, which resulted in some 110 workers (mostly women) losing their jobs, and the loss of jobs resulting from the shift in distribution of rock lobster from the West to the South-west Coast (beyond the traditional fishing grounds) which has been occurring steadily since the mid 1990s. Communities in the Northern Cape are particularly vulnerable in this respect because of the relative lack of alternative employment there arising from the arid climate, low population density and recently, the decline in the marine mining industry, which is the major source of alternative employment on the coast.

The nature in human terms of **other commercial fisheries** within the BCLME such as the tuna, shark and swordfish fisheries are not considered here because of their relatively low value in terms of both revenue and employment. Also not considered is the dive fishery for abalone *Haliotis midae* between Cape Columbine and Quion Pt on the South West Coast which supported a lucrative commercial fishery for 60 years before being totally closed in 2008 as a result of declining abundance, illegal harvesting and finally, an ecological shift caused by the eastward migration of rock lobster into two of the most productive fishing areas on the South West coast. Hardship due to the loss of employment, particularly in the Walker Bay area, aggravated by continued poaching by, *inter alia*, international syndicates, has led to many conflict situations in the community, which have at times escalated into violence.

The human dimensions of the **artisanal and subsistence fisheries** within the BCLME are similar in nature to those of the small scale commercial fishery there. Although this fishery as such was not dealt with separately by Sowman *et al.* (2011), it is clear from their study that subsistence and artisanal fishers and their families within the BCLME region are even more socially marginalized and deprived than those in the region's commercial small scale fisheries. They earn even less (often below a living wage), are almost totally dependent on fishing for food, and generally have very little formal education and few other skills, making them even less able to escape the poverty trap in which they find themselves by bettering their education or switching to more lucrative pursuits. Furthermore, under the current legislation they have no recognised fishing rights or any other safeguard of their livelihood.

5. Adaptability

In Section 4 the resilience of the ecosystem to environmental perturbations of the type identified in the Biophysical Report was discussed. Here a brief overview is given of the capacity of the fishing industries, communities and individuals who depend on the resources of the BCLME for their living to adapt to changes in the distribution and/or abundance of these resources brought about by such changes. The overview moves from the large, highly-organised and capital-intensive industries in all three countries through to the totally informal artisanal and subsistence fisheries of Angola and South Africa.

5.1 LARGE-SCALE INDUSTRIAL FISHERIES

These industries, such as the demersal trawl fishery for hake in Namibia and South Africa, the pelagic industry in South Africa and, to a lesser extent, the fisheries for small pelagic fish and horse mackerel off Namibia and Angola, employ a relatively large number of individuals at sea and ashore whose ability to adapt to changes in the resource base of the industry is determined largely by the industry's ability to adapt to such changes. These industries have many options, including:

- Changing the target species according to changes in abundance and distribution. Examples would be changing from shallow to deep water hake in both the northern and the southern Benguela, from sardine to anchovy in the southern Benguela, and from juvenile horse mackerel to sardinella in the Angolan purse seine fishery. These changes can generally be made without changing the vessel or the gear substantially.
- Following the fish over large distances to maximize catch rates, made possible by the size, range and endurance of the vessels. For example, the larger purse-seiners in Namibia with chilled sea water on board for preserving the catch can stay at sea for up to a week, while most of the large deep sea freezer trawlers operating in the region can do so for a month or more. The very large midwater trawlers which fish for adult horse mackerel off Namibia can stay at sea even longer since they offload to reefer vessels and do not have to return to port.
- Improving catching, processing and distribution efficiency through the introduction of new technologies, and the rationalisation of existing facilities within and between the companies. An example of the latter is the consolidation of all sardine canning in Walvis Bay in one cannery, versus the nine company canneries that were in operation there at the height of the fishery in the late 1960s. Another rationalization option is to enter into joint enterprises and agreements with other companies to derive maximum benefit from their respective quota allocations.
- Countering lower production by reducing wastage, improving the value of existing products and introducing new and improved marketing strategies.
- Stabilising and improving the skills of the labour force through the provision of support infrastructure and education and health facilities for workers in the industry and their families.
- Sale of less economic vessels and the sale or moving of surplus plant to another area or fishery. An example of the latter is the moving of sardine canning machinery from Walvis Bay to Chile in the 1970s when the Namibian sardine fishery went into sharp decline.
- Importing of fish to preserve local markets when production is unable to meet the local demand.

- Coping with the problems of increased bad weather (a consequence of rising sea temperatures) within the companies' existing risk management strategies.

A further positive factor in these industries is the relatively good information available on the state of the resources in most cases because of the concentration of research effort on them due to their being the most valuable commercially. In consequence, population and harvesting models are more advanced here than in the other sectors, enabling TACs to be more finely tuned to fluctuations in stock size, assisting in the adaptation to them.

Factors limiting adaptation in these fisheries include:

- The lack of unexploited or under-exploited resources to which they can turn, with the possible exception of round herring in South Africa, which could sustain higher catches than at present, although they may not be economically viable.
- The fact that most fishing rights and investments in this sector are long-term, reducing the ability to adapt to rapidly-changing situations. This is a particular problem in the South African pelagic fishery; a high-risk industry which has to cope with large variations in TAC due to the variability and unpredictability of the annual recruitment. This industry has high fixed costs in vessels, gear and processing plants, making it difficult to adapt to these fluctuations and to return a profit when catches are poor.
- Limited ability to allow for possible detrimental effects of climate change by adopting a more conservative approach, due to the low profit margins against which many of the companies already operate.

5.2 RECREATIONAL FISHING SECTOR

Recreational fishers in the region (particularly in Namibia and South Africa) are generally highly mobile, enabling them to adapt to diminishing catches to some extent by moving to better fishing spots, targeting alternative species and improving catching efficiency through new technology, all within the constraints of the state of the stocks at large, which is the limiting factor. Also, most recreational fishers in the region are relatively wealthy and by definition do not depend on fishing for their livelihood. Adapting to a decline in catch rates, even to the point of stopping fishing altogether, is therefore less of a problem for them than it is for those in the other sectors. This is largely also true of the businesses which support recreational fishing, since they are generally well organized, with access to the capital needed to shift to other related activities within the tourism sector such as eco-tourism, or to other commercial enterprises in general.

5.3 SMALL-SCALE COMMERCIAL FISHERIES

The fisheries here, such as the so-called semi-industrial fisheries in Angola for horse mackerel and sardinella and the commercial line fisheries in South Africa, have far less capacity to adapt to changes in the abundance or availability of the resources which they exploit. The vessels are small and can only operate locally, there is very limited capital available for changing fishing or processing techniques, little scope, because of inadequate organization structures, for the rationalization of catch and processing strategies to mitigate the effects of reduced catches, and few organized social support structures to carry fishers and their families through difficult times. The problems are aggravated by the fact that people involved in these fisheries are generally poorly educated with few opportunities for developing new skills or bettering their positions through formal or informal education. This, combined with the fact that many live in isolated rural areas where there is little alternative employment, makes it difficult for workers in these fisheries to switch to alternative livelihoods, even should they wish to do so, which many do not for traditional and cultural reasons. In some of the fisheries (e.g. the inshore rock lobster and line fisheries in South Africa), unemployed fishers do manage to find occasional work in other fishing sectors, or change their roles in the fishery (e.g. a skipper may serve as a crewman on another vessel or hire out his boat to another individual or company, or a crewman may switch to net-mending or boat repair), but such employment is usually sporadic and unreliable. The result of all these factors is that most small scale fishing communities in the BCLME are tightly locked into the resources they have traditionally exploited in terms of species, location and capture methods, with very limited ability to adapt to changes in the abundance or availability of these species. Furthermore, they have few ways of countering the effects of low income and long periods of unemployment which may result from such changes other than through mutual help within their communities. It is fortunate that within these fisheries there is a culture of community support, which appears to be particularly strong in Angola.

5.4 ARTISANAL AND SUBSISTENCE FISHERS

Throughout the region, artisanal and subsistence fishers and their families are in all respects the least able to adapt to declining catches of the species on which they depend. Their communities are generally the poorest, least mobile and least organised in terms of social support, and their opportunities for alternative employment the most limited, if not non-existent in some areas. Furthermore they are very heavily dependent on the fish which they catch for food, and have little money to buy alternative foodstuffs when fish are in short supply. The situation is severe in Angola and South Africa because of the large number of artisanal and subsistence fishers there, but not so in Namibia, where there are very few such fishers because of the hostile environment along the entire coastline.

6. Vulnerability analysis

Following Daw *et al*., 2009 (in Cochrane *et al*., 2009), vulnerability in the context of climate change is defined as *the susceptibility of groups of individuals to harm as a result of climate change*. Here an attempt is made to assess the vulnerability of the people that depend on the various fisheries to the environmental changes in the BCLME which, according to evidence presented in the Biophysical Report, are occurring or could occur in the foreseeable future. This is done through the construction of a Vulnerability Index (VI) for each fishery, which is the product of three indices:

- A Sensitivity Index (SI), rating the degree to which the targeted resource is likely to be affected by the changes identified in the Biophysical Report on a scale of 1 (mild) to 3 (severe), taking into account the magnitude of the environmental effects and, where possible, the likelihood of their occurring. The concept of Sensitivity as defined here is equivalent to that of *Exposure* defined by Daw *et al*. (2009) in their Figure 1; viz. *The nature and degree to which fisheries production systems are exposed to climate change*. The scoring was based on the discussion of environmental influences on the fisheries of each country in Sections 4.2 to 4.4. A few examples are given below.
  - All the Angolan fisheries south of the Angola Benguela Front have been rated as very sensitive (3) to possible movement of the front, *Benguela Niños* and similar perturbations arising from ENSO events. The demersal trawl and shrimp fisheries, which extend along the entire coast, have been rated somewhat less sensitive (2) because of their wider distribution and less obvious sensitivity to events occurring in the euphotic zone.
  - The sensitivities of the Namibian hake, pelagic and midwater trawl fisheries to intrusions of warm, low oxygen water from the north have been rated 3, 2 and 1 respectively for the reasons given under *Environmental influences* in Section 4.3.
  - In South Africa, the fishery rated most sensitive (3) to environmental change is the rock lobster fishery due to the fact that high mortality due to low oxygen events has been frequently observed in the past and is likely to recur (possibly more frequently) in the future. The sensitivity of the pelagic fishery, although affected by the many environmental processes which affect recruitment, is rated lower (2) due to the lack of strong evidence of a general link between environmental influences and recruitment strength. The sensitivity of the hake fishery is rated low (1) because in this case there is even less evidence of environmental influences on abundance, distribution or catchability. More details pertaining to these ratings may be found in Section 4.4 under *Environmental influences.*
- An Impact Index (II), rating the importance of the fishery to the country concerned in terms of a) economic value, b) employment, c) food security and d) societal importance, each of which is rated as low (0), medium (0.5) or high (1)[2]. The Index, which when combined with the Sensitivity Index is a measure of all impacts that may occur without taking into account planned adaptations (ie. the *Potential Impact* as defined by Daw *et al*., 2009) is the sum of these ratings. For example, a fishery which is of low economic value but employs a large number of people who depend to a reasonable (but not- critical) extent on the catch for

[2] Note that it does not consider the socio-economic importance to other countries in the region, or even to the global economy, which would require a much broader study.

food and live mainly in communities which depend critically on fishing for their existence (such as the small-scale line fishery in South Africa) would be scored:

$$0 + 1 + 0.5 + 1 = 2.5.$$

- An Adaptability Index (AI), which rates the degree to which each fishery and the individuals dependent on it are able to adapt to environmentally-induced changes in the abundance and/or availability of their target species. The Index is essentially the *Adaptive Capacity* (AC) of a system to modify or change to cope with changes in actual or expected climate stress, as defined in Figure 1 in Daw *et al*. (2009). It is scored on a scale of 1 (highly adaptable) to 4 (almost totally unable to adapt), based on the material presented in Section 6.

The construction of the vulnerability indices for the Angolan, Namibian and South African fisheries is detailed in the Appendix. In Table 1 below the vulnerabilities of the various fisheries in each country have been summarized and ranked High (H), Medium (M) or Low (L) on the basis of the scores in the Appendix.

Although the scores in the Appendix (and therefore the ratings in Table 1) are inevitably subjective (different analysts would almost certainly come up with somewhat different scores, and possibly different ratings), it is believed that they do give a broad overview of vulnerability profiles within each of the countries. They should not however be used to compare vulnerabilities between countries because of great differences of scale in the nature, magnitude and national importance of the fisheries sector in each country. A possible exception would be the fisheries based on transboundary stocks (viz. hake in South Africa and Namibia and sardine, horse mackerel and deep sea red crab in Angola and Namibia), where the fact that the fishery is important to more than one country could warrant a higher rating as a regional resource than as a purely national one.

The most contestable indices are the sensitivity indices because of the large number and complexity of the environmental factors involved, and the great difficulty in predicting what their net effect on each fishery will be, as emphasised in the concluding comments in the Biophysical Report. In many cases (particularly in Angola where there have been very few studies on the response of the ecosystem to environmental changes), the net effect of a particular environmental perturbation is largely conjectural. Added to this is the almost total uncertainty regarding the potentially profound effects of a major anthropogenically-induced change in the Agulhas current and its retroflection on the southern Benguela, and perhaps on the northern Benguela as well.

TABLE 1
Vulnerability ratings for fisheries in Angola, Namibia and South Africa, derived from the analysis detailed in the Appendix

ANGOLA		NAMIBIA		SOUTH AFRICA	
Fishery	**Vulnerability Index**	**Fishery**	**Vulnerability Index**	**Fishery**	**Vulnerability Index**
Demersal trawl	M	Demersal trawl	H	Hake (including long-line) and other trawled species	L
Industrial pelagic	M	Small pelagic	H	Small pelagic	H
Semi-industrial pelagic	H	Midwater trawl	L	Midwater trawl	L
Crustaceans	L	Line fishery	M	Line fish (excluding hake long-line)	M
Artisanal	H	Rock lobster	H	Rock lobster	H
		Crab	L	Large pelagic	L
		Recreational	L	Recreational	L
		Artisanal/subsistence	M	Artisanal/subsistence	M

Although the Impact Indices are somewhat better founded in that there is a numerical basis for the economic and employment scores at least, they do not necessarily capture all aspects of the socio-economic impact of changes in the resource base of the fisheries, and could be developed further in future, more extensive assessments. For example, the value of the fisheries in terms of food security could be assessed through existing poverty indices, or if these are not available by fishing sector, standard methods used to quantify poverty could be used to construct sector-specific indices. Likewise, the adaptability indices could be refined to separate the adaptability of the fishers from that of the industry which employs them, which might be necessary if an industry's primary way of adapting to reduced catches is to lay off significant numbers of employees. Despite their shortcomings, the vulnerability indices do reveal a number of features, viz:

- The most vulnerable fisheries in general are those in which a large number of people living in communities which are heavily dependent on fish for food and their very existence are engaged, with almost no ability to adapt to reduced catches (artisanal and semi-industrial pelagic fisheries in Angola, the rock lobster fishery in South Africa and, to a lesser extent, Namibia, and the line fishery in South Africa).
- The South African small pelagic industry is rated as particularly vulnerable to climate change because of its socio-economic value and its sensitivity to climatically induced variability in the southern Benguela, added to which is the threat of major perturbations stemming from changes in the Agulhas current. The vulnerability of the Namibian small pelagic fishery, which may be equally threatened by environmental perturbations from the north, is rated lower because of the relatively small size of the fishery compared to the South African pelagic fishery.
- South Africa's most valuable fishery in terms of earnings and foreign exchange (viz. the demersal trawl fishery for hake and other demersal species) appears not to be particularly vulnerable to climate change due to an apparently low sensitivity to environmental perturbations and the ability to adapt to them, should they occur. The Namibian hake industry, although probably equally adaptable, is rated more vulnerable due to a documented susceptibility to intrusions of low oxygen water, which do occur on occasion in the northern Benguela, and may be linked to climate change. An important question would be whether the transboundary nature of the stock off Namibia and the West Coast of South Africa would make the resource as a whole more or less vulnerable to environmental perturbations. This would depend on the nature of the perturbation, which component(s) of the stock are affected, and in what way, and on the interactions between them. For example, since the *M. paradoxus* stock in Namibia appears to originate from spawning in South Africa (e.g. Burmeister, 2005), reduction in the spawning stock in South Africa is likely to affect catch rates in Namibia. Alternatively, favourable environmental conditions in one country could well help to offset losses due to unfavourable conditions in the other, adding a measure of resilience to the resource. Answering these kind of complex questions will clearly require considerable understanding of the dynamics of the different components of the stock, and of the interactions between them.
- The fisheries rated least vulnerable are those of low economic value and societal importance in which companies and individuals are best able to adapt to changes in the environment (e.g. recreational fishing and midwater trawling in Namibia and South Africa and fishing for large pelagic fish in South Africa).

7. Reduction of adverse impacts

Strategies which could be employed to reduce the effects on humans of environmental change in the BCLME, from whatever cause, fall into a number of categories, viz:

- Expanding **research** aimed at understanding the functioning of the ecosystem better, and thereby improving predictions of the way in which the resources are likely to respond to environmental changes.
- Developing new fisheries **management measures** which take environmental factors and the uncertainty surrounding them more into account than current management measures do.
- Initiating further **socio-economic investigations** to improve understanding of the circumstances of the individuals and communities who depend directly or indirectly on fishing for a living, and of the way in which they are likely to be affected by changes in the marine environment.
- Introducing **economic measures** to reduce the effects of lower catches and other undesirable consequences of climate change.
- Developing **legislative and compliance measures** to ensure that management measures aimed at mitigating the effects of climate change are effectively implemented in a just and equitable manner.

It is beyond the scope of this report to examine these options, but the following generic observations concerning the research and management strategies are offered as a point of departure for future planning.

While the prediction of responses to environmental change is a worthy long-term research goal, it is unrealistic to expect predictions of use in management and harvesting strategies to emanate from this research for many years, except perhaps in the case of extreme perturbations. This is emphasised in the Biophysical Report, where it is pointed out, for example, that despite decades of intensive study in the southern Benguela on the effects of the environment on sardine and anchovy recruitment, these effects are not yet known well enough to include them in management and harvesting models. In this case, adopting a more conservative management strategy to allow for greater uncertainty in environmental effects would probably be strongly resisted by the industry due to the already low profit margin in the fishery and the lack of convincing evidence of significant environmental effects on stock size. persuading the industry to accept lower catches as a safety measure against the effects of climate change would probably be even more difficult in almost all other fisheries in the BCLME, in none of which have the effects of the environment on stock dynamics been as intensively studied as in the South African fishery for small pelagic fish.

An alternative broad approach, which might be more effective in the short to medium term at least, would be to improve existing methods and develop new ones for measuring changes in the distribution and abundance of resources as frequently and accurately as possible, together with more flexible management strategies for utilizing this information as soon as it becomes available. This approach should enable the negative effects of environmental perturbations, whatever their cause and spatial or temporal scale, to be reduced by timely adjustment of fishing strategies and management actions. If combined with regular ship-board oceanographic monitoring and quasi-continuous monitoring of environmental parameters (e.g. through satellite observations, transmitting buoys and appropriately instrumented marine gliders), it should also ultimately lead to a better understanding of the effect of the environment on abundance and distribution, contributing to the long-term goal of reliable prediction.

In those small scale fisheries which exploit a wide range of species from many different locations, each affected in their own way by changes in the local environment (e.g. the artisanal fishery in Angola and the small-scale line fishery in South Africa), it may be more effective to concentrate less on understanding the causes of the variability and more on finding socio-economic ways of reducing its negative consequences. This is particularly so since the affected communities generally have very limited ways of adapting socially or economically to reduced catches, unlike the larger industries which have many options (see Section 8), and can largely be left to find their own solutions.

8. Conclusions

The major conclusion from this investigation is that, with a few possible exceptions, the biophysical changes that have been observed in the BCLME in recent times cannot be linked to global climate change with sufficient certainty to include climate change as a factor in management and harvesting strategies at present. This is largely because the ecosystem, being primarily upwelling driven, is naturally highly variable on a wide variety of scales, masking trends emanating from climate change, and the fact that the most obvious changes in the resources and food web which have been observed are clearly primarily due to over-fishing in the second half of the previous century and not the environment. This is particularly true of the northern Benguela where no changes of comparable magnitude to those resulting from the virtual removal of sardine and anchovy from the ecosystem in the 1970s and 1980s can be attributed to changes in the environment.

The inevitable consequence of the above is that it is at present not possible to predict the response of the BCLME's resources to any but the most extreme environmental changes which could result from global climate change, even if the effects of such changes on the BCLME were well understood, which they are not. A possible exception is the effect on the biota of the northern Benguela of *Benguela Niños* and other such intrusions of warm, nutrient-poor water from southern Angola, which appear to be predictable to some extent. Also, the increasing understanding of the teleconnection between *Benguela Niños* (which effect both the northern and the southern Benguela) and ENSO events in the south-east Pacific promises greater ability to predict changes in the BCLME in response to changes in southern hemisphere climate in the foreseeable future.

The vulnerability analysis, despite its limitations and somewhat subjective nature, indicates that the human beings most vulnerable to environmental perturbations in the BCLME, from whatever cause, are those engaged in the low-economic value, labour-intensive, small-scale fisheries in which fishers and fishing communities have very limited ability to adapt to changes in the distribution and abundance of the species they exploit. Striking examples are the artisanal and semi-industrial pelagic fisheries in Angola and the rock lobster and small-scale line fisheries in South Africa. Of the large-scale industrial fisheries, it would appear that the South African purse-seine fishery for small pelagic fish is particularly vulnerable because of its size, the high degree of capitalization, low profit margins, and susceptibility to environmentally-driven fluctuations in recruitment strength. In contrast, the highly-industrialised demersal trawl fisheries for hake and other species in Namibia and South Africa, which generate the greatest income and foreign exchange in both countries, appear on current evidence to be much less vulnerable, particularly in South Africa, although an important unknown is the extent to which the stock's transboundary nature affects its vulnerability as a regional resource.

9. Recommendations

Regarding future action, it is recommended that:

1. This report, and the Biophysical Report which forms the scientific basis for it, be refined and if necessary upgraded with more input from stake-holders in Angola and Namibia to redress the imbalance of information from these two countries in the two reports.
2. The methods used in assessing vulnerability in this report be evaluated by a regional multi-disciplinary task team consisting of marine and social scientists, economists and climate change specialists, and revised if considered necessary to capture more aspects of the problem and improve the quantification and prioritization of them. This should be done as the first step in re-assessing the vulnerability indices in this report and developing new ones where necessary.
3. The analysis in Section 7 of this report should be expanded to include:
   - The sensitivity of fisheries infrastructure to both the direct and indirect effects of climate change (for example the effects of increased flooding of fishing villages in Angola, and pressure on coastal infrastructure and services brought about by movement of people to the coast in response to deteriorating climatic conditions inland).
   - The socio-economic consequences of, and adaptability to, the above.
   - Construction of vulnerability indices for individual fisheries, and different fisher types and stakeholders.
4. Socio-economic studies on the various sectors in the Angolan and Namibian fishing industries be instigated to establish a firmer basis for assessing the vulnerability of these fisheries to climate change than was possible in this report because of the lack of studies akin to that undertaken in South Africa by Sauer *et al*. (2003a,b) some 10 years ago. It may also be worthwhile to repeat aspects of that study in South Africa, at least for fisheries which have undergone major changes since the study was undertaken.
5. A regional task team should be set up to investigate what research could be effective in elucidating the effects of climate change on the resources of the Benguela, even if only in the long term, and also ways of improving and utilising information on resource dynamics as a shorter-term goal, as suggested in Section 8. (An important question regarding the valuable hake resource in Namibia and South Africa is the effect which the transboundary nature of the stock has on its vulnerability in the region as a whole). The group would need to take into account work already being undertaken on the effects of climate change on the BCLME by national institutions in Angola, Namibia and South Africa, regional bodies (particularly the BCC) and through international collaborative efforts such as the NANSCLIM and GENUS programmes, and to include fishing industry representatives in the discussions. The focus of the discussions should be on identifying activities with the potential of materially reducing the effects of adverse environmental conditions within a reasonable period of time.
6. A similar socio-economic task team should be set up to investigate ways of alleviating social and economic hardship in those small-scale fisheries in which fishers and their communities are least able to adapt to reduced catches, from whatever cause. Strong input from the communities themselves would be vital in such an investigation.

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Appendix 1 – Vulnerability indices

TABLE A-1
Calculation of Vulnerability Indices for Angolan fisheries within the BCLME region

Fishery	Sensitivity		Impact					Adaptability	Vulnerability
	Environmental factors	SI	Value	Employment	Food security	Societal importance	II	AI	VI
Industrial pelagic	Movement of ABF *Benguela Niños* ENSO events Other factors?	3	1	0.5	0.5	0	2	2	12
Semi-industrial pelagic	Movement of ABF *Benguela Niños* ENSO events Other factors?	3	0.5	1	1	(0.5)	3	3	27
Demersal trawl	?	(2)	1	0.5	0.5	(0.5)	3	2	12
Crustaceans	?	(2)	1	0.5	0	0	1.5	2	6
Artisanal	Movement of ABF *Benguela Niños* ENSO events Other factors?	3	0	1	1	1	3	4	36

Note:
1. Entries in parenthesis are regarded as particularly uncertain
2. Mid-range SI values have been assumed for the demersal and crustacean fisheries in the absence of any information on the sensitivity of these fisheries to the envisaged environmental changes in the part of the BCLME affecting them

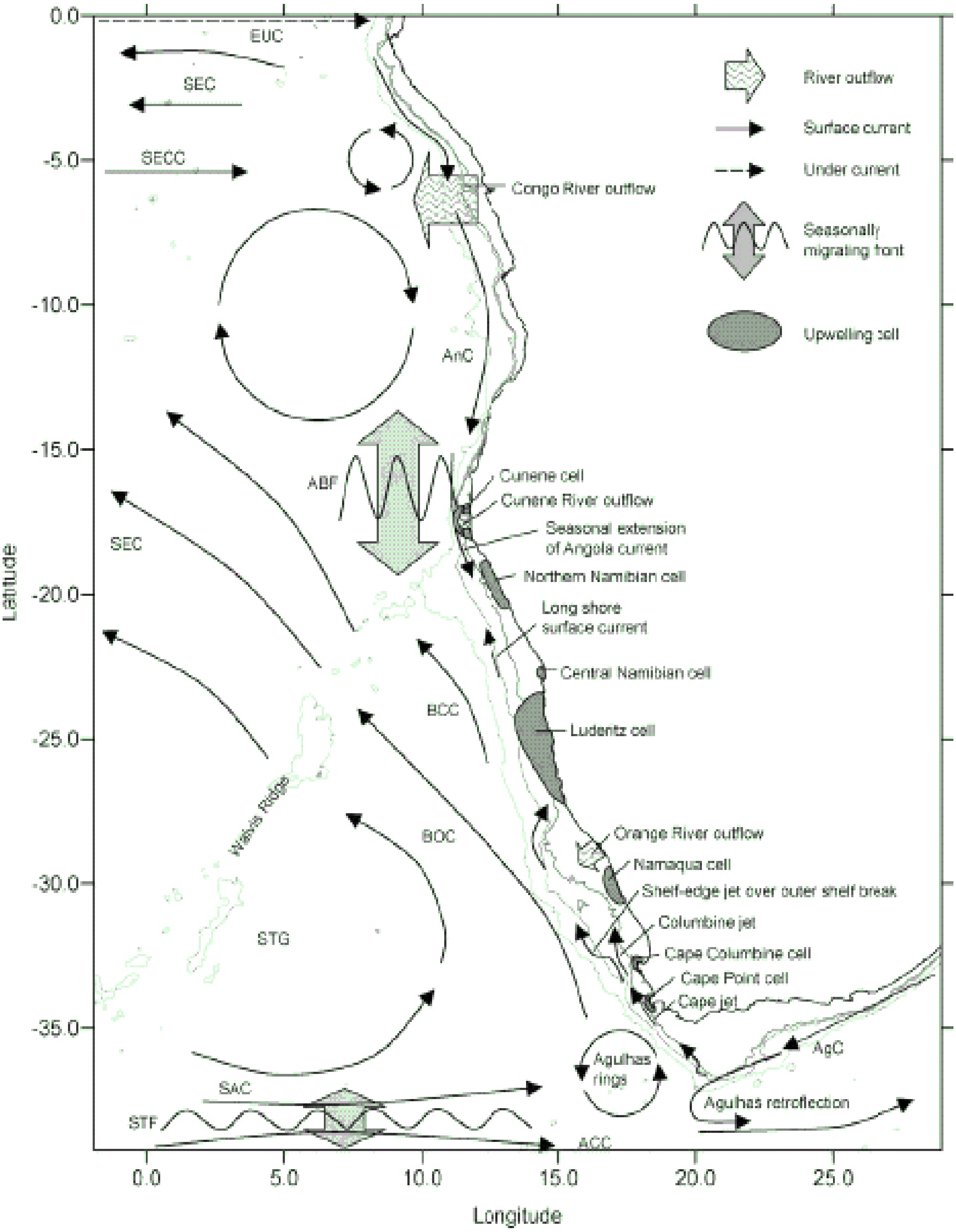
TABLE A-2
Calculation of Vulnerability Indices for Namibian fisheries within the BCLME region

Fishery	Sensitivity		Impact					Adaptability	Vulnerability
	Environmental factors	SI	Value	Employment	Food security	Societal importance	II	AI	VI
Demersal trawl	Warm water intrusions from north Increase in low oxygen water on shelf	2	1	1	0	0.5	2.5	2	10
Small pelagic	*Benguela Niños* ENSO events	3	0.5	0.5	0	0.5	1.5	2	9
Midwater trawl	Warm water intrusions from north Increase in low oxygen water on shelf	1	0.5	0	0	0	0.5	1	0.5
Line fishery	Increase in low oxygen water inshore	1	0.5	0.5	0.5	0.5	1.5	3	4.5
Rock lobster	Increase in low oxygen water inshore	1	0.5	1	0	1	2.5	4	10
Crab	Increase in low oxygen water on shelf	2	0	0	0	0	0	3	0
Recreational	Increase in low oxygen water inshore	1	0.5	0.5	0	0	1	1	1
Artisanal/ subsistence	Increase in low oxygen water inshore	1	0	0	1	0	1	4	4

TABLE A-3
Calculation of Vulnerability Indices for South African fisheries within BCLME region

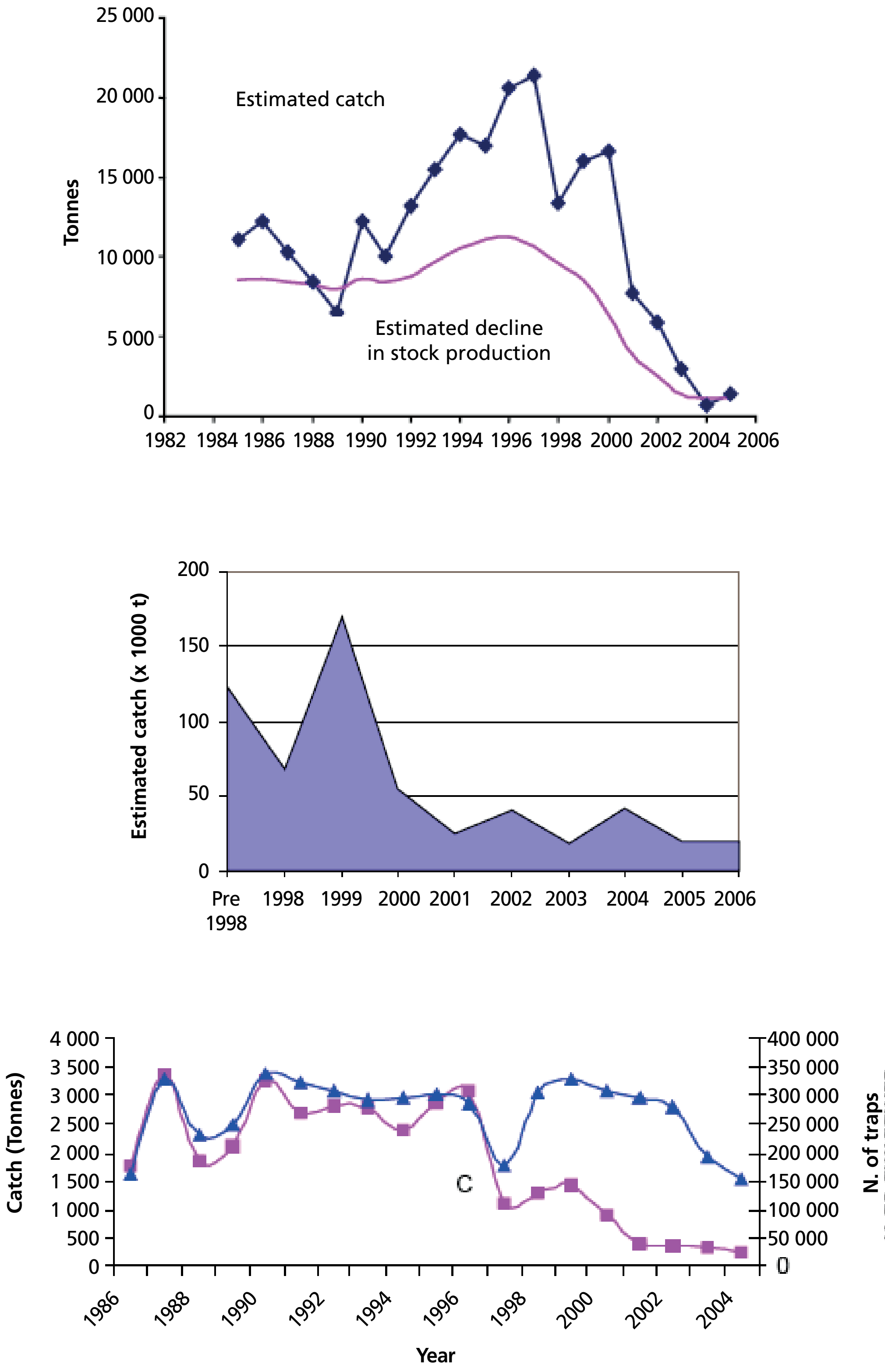
Fishery	Sensitivity		Impact					Adaptability	Vulnerability
	Environmental factors	SI	Value	Employment	Food security	Societal importance	II	AI	VI
Hake (including long-line) and other trawled species	Increase in low oxygen water on shelf	1	1	1	0	0	2	2	4
Small pelagic	Increase in upwelling-favourable winds Increase in cross-shelf temperature gradient Increased influence of Agulhas current?	2	1	1	0.5	0.5	3	3	18
Large pelagic	Increased influence of Agulhas current?	(2)	0.5	0	0	0	0.5	2	2
Midwater trawl	Increased influence of Agulhas current?	(1)	0.5	0	0	0	0.5	2	1
Linefish (excluding hake long-line)	Increased influence of Agulhas current?	(1)	0	1	0.5	1	2.5	3	7.5
Rock lobster	Increase in low oxygen water inshore Environmental factors causing shift to South Coast ?	3	0.5	1	0	1	2.5	3	22.5
Recreational	Increase in low oxygen water inshore Increased influence of Agulhas current?	(1)	0.5	0.5	0	0	1	1	1
Artisanal/ subsistence	Increase in low oxygen water inshore	(1)	0	1	1	1	3	4	12

FIGURE 1
Salient physical features of South East Atlantic and Benguela upwelling system



Source: from Hardman-Mountford *et al.*, 2003.

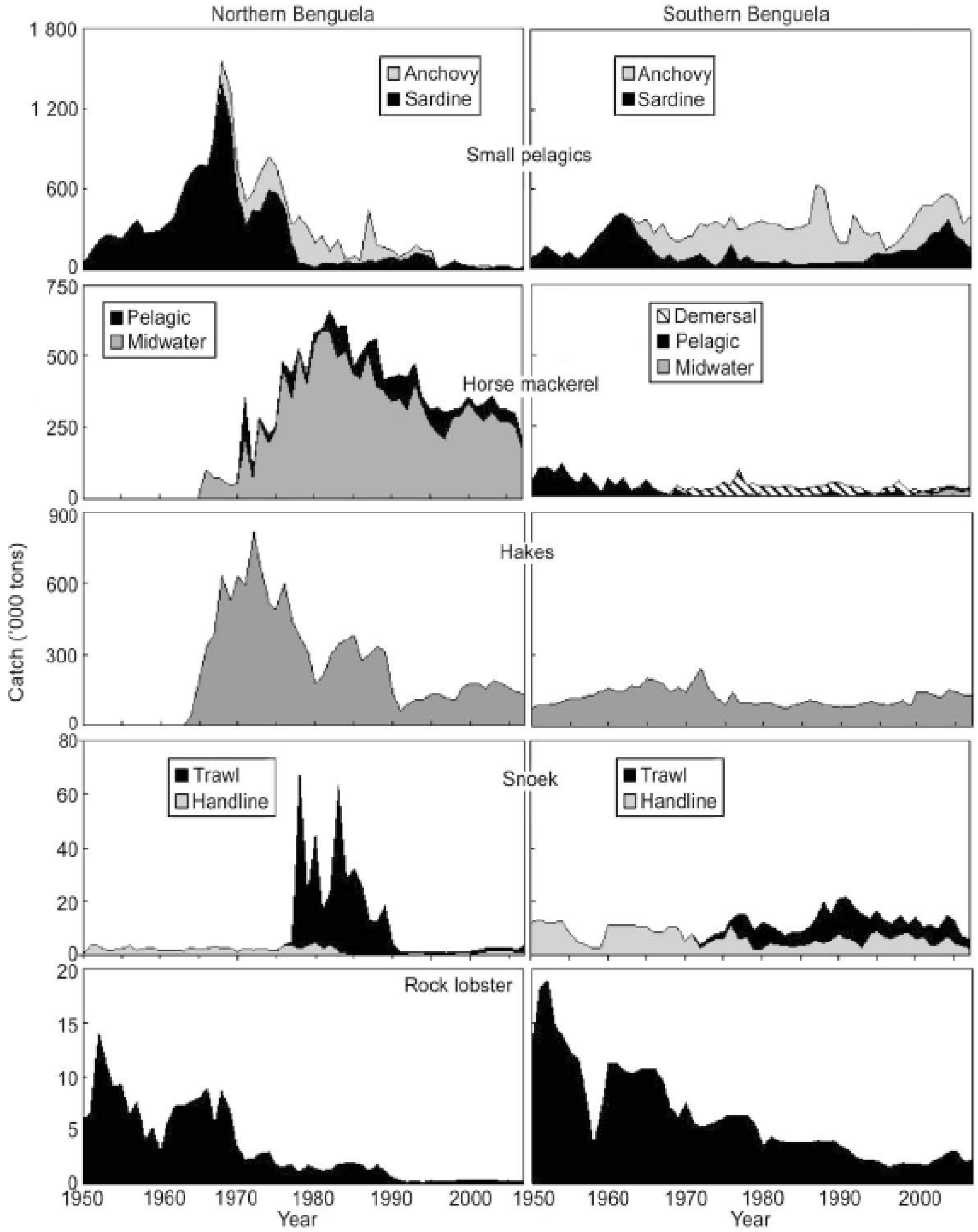
FIGURE 2
Commercial catches of Cape and Cunene horse mackerel (top), sardinella (predominantly *S. aurita*) (centre) and deep sea red crab (bottom) off Angola over past 2 decades



Source: From Japp *et al*., 2007.

FIGURE 3

Changes in catches of major fish resources in the northern and southern Benguela



Source: from Hutchings *et al*., 2009, updated from van der Lingen *et al*., 2006.

Biophysical features and trends in the Benguela Current Large Marine Ecosystem

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Contents

1. Overview

1.1 DEFINITION OF SYSTEM/SCOPE OF REPORT

For the purposes of this report the Benguela Current system is defined as that part of the south-east Atlantic which lies between about 14° S and 37° S, east of the 0° meridian. It encompasses the coastal upwelling regime, frontal jets and the eastern part of the South Atlantic gyre. A schematic diagram of the salient features is shown in Figure 1. The northern boundary of the upwelling region coincides with the Angola Benguela Frontal Zone (ABFZ) where the warm Angola Current meets the cool Benguela upwelling regime. The southern boundary is considered to be the Agulhas retroflection area, which typically lies between 36 and 37°S.

The Benguela system in the narrow sense extends from southern Angola, through Namibia, to the west and south-west coasts of South Africa. In the wider sense it includes Angolan waters to the north of the ABFZ which have a strong influence on the dynamics of the system, and the south coast of South Africa, particularly the Agulhas Bank, which is a major spawning area, feeding recruitment of many species to the South African West Coast. Offshore, the political boundary is the 200 nmile exclusive economic zone (EEZ) of each of the three countries.

Although all three countries at present manage the fisheries in their territorial waters independently, there has been strong collaboration in fisheries research between them since the inception of the BENEFIT (Benguela Environment, Fisheries, Interaction and Training) Programme in 1997 and the Benguela Current Large Marine Ecosystem (BCLME) Programme a few years later. This collaboration led to the institution of the Benguela Current Commission (BCC) in 2007, with headquarters in Windhoek, Namibia. The Commission is charged with formalizing scientific co-operation between the three countries, and developing an integrated management plan for the BCLME, including building the governance structures and mechanisms needed for joint management of the region's fisheries as a Regional Fisheries Management Organization (RFMO).

In order to keep this report within reasonable bounds, the fisheries considered here are those which are of major economic importance in their respective countries from the point of view of their contribution to revenue and/or employment in the fisheries sector. Small scale and subsistence fisheries, although important in human terms in parts of the system (particularly in Angola and some parts of South Africa), have been excluded because of their very much lower commercial value and the paucity of information on the effects of the environment on them.

The report is restricted to species which for a significant part of their life cycles occur largely within the boundaries of the Benguela Current system and therefore could be affected by changes in this system brought about by climate change. Species whose distribution only marginally overlaps that of the BCLME in the narrow sense, such as chokka squid and east coast sole on the south coast of South Africa, or whose distribution extends well beyond the system at all times of the year, such as commercially important demersal fish and shrimp resources in Angola, have been excluded because of the difficulty of determining how much (if at all) they would be affected by changes in the Benguela ecosystem as such. A number of currently unexploited species of ecological importance are briefly mentioned in the context of their role in ecosystem functioning and their possible implication in regime shifts.

In this report, the major biophysical features of the system are briefly reviewed, long-term trends in the biotic and abiotic environment in recent decades discussed, and prospects for predicting such trends and the ecosystem's response to them considered.

The report serves as an addendum to a report on the vulnerability of the BCLME to climate change, presented in these Proceedings.

1.2 INTRODUCTION

The Benguela Current is one of the four major eastern-boundary currents systems in the world. As in the Californian, Humboldt and Canary Current systems, the Benguela it is dominated by a coastal upwelling system, but unlike these systems, it is bounded on both the poleward and equatorward ends by tropical or sub-tropical regimes that have a significant impact on it. The system is highly productive but is complex, displaying substantial variability, which impacts on its living resources over a wide range of time and spatial scales. The effects of the ecosystem's natural variability have been, and continue to be, compounded by heavy exploitation of some of the region's major fish stocks.

It is believed that the living resources of the Benguela and adjacent areas may be particularly sensitive to long-term climate change as the region is situated at the choke point in the global ocean climate "conveyor belt", where, on time scales of decades to centuries, warm surface waters from the Indo-Pacific pass around Africa into the Atlantic. Consequently, the BCLME may well be a site for the early manifestation and detection of global climate change, brought about, for example, by an increase in global surface, trophospheric and sea surface temperatures (2007 IPCC Report).

Concerns about the effects of climate change (particularly global warming) on the Benguela ecosystem, and consequently its living marine resources, were first articulated through a number of papers at the Conference on Geosphere-Biosphere Change in Southern Africa in 1989 (Crawford *et al*., 1990, Shannon *et al*., 1990 Siegfried *et al*., 1990). Siegfried *et al*., (1990) speculated on the consequences for selected fisheries of the region of four possible scenarios of global warming- induced climate change, viz; increased intrusion of warm water from the Angolan region in the north and the Agulhas Current in the south, altered wind stress, and general warming of surface waters throughout the system. They argued that all four could potentially have dramatic, although largely unpredictable, effects on the fisheries considered, while stressing that all the scenarios were purely speculative due to great uncertainty about the nature, extent and likelihood of the postulated environmental changes (cf. Shannon *et al*., 1990), and the nature, and even the sense, of biological responses to such changes (cf. Crawford *et al*., 1990). For example, they pointed out that an increase in upwelling winds in the southern Benguela brought about by a southward shift in the zone of maximum wind stress could favour pelagic fish recruitment by increasing primary production, but could on the other hand be detrimental to it by increasing offshore advective loss of ichthyoplankton. (In this and a number of other such cases they were not prepared to speculate on the net outcome).

Shannon *et al*., (1990) noted the naturally high variability on intra- and inter-annual scales in the Benguela and Agulhas Current systems and the Subtropical Convergence area, and concluded that all these areas appear to be sensitive to the changes in wind fields. Among the large-scale changes which they hypothesized could be caused by a poleward shift in the hemispherical wind belts induced by global warming was a southward shift in both the northern and the southern boundary of the Benguela, the displacement of the upwelling centres, and an increase in the exchange of Atlantic and Indian Ocean water to the south of the continent, all of which would almost certainly have major effects on the marine environment of the region. They noted however that these scenarios were highly speculative, and should not be treated as predictions, *inter alia* because of inadequacies in the general circulation models (GCMs) in use at the time.

More recently, Clarke (2006) explored the implications of global climate change for fish stocks and their management off southern Africa, specifically in respect of projected changes in ocean temperature, pressure/wind fields, CO_2 levels, rainfall, mean sea level and UV radiation. He noted the common view that changes in pressure fields and hence wind stress over southern Africa are likely to have a greater effect on marine biota (and thereby fisheries) than the other effects, and paid particular attention to Bakun's (1990) global prediction that an increase in greenhouse gases in the lower atmosphere is likely to lead to intensification of onshore-offshore pressure gradients, and hence to stronger alongshore winds and increased upwelling. However, while not contesting this hypothesis, he noted that the link between increased upwelling and changes in fish production in the Benguela (whether positive or negative) is extremely tenuous, citing for example contradictory evidence from the region on the response of the ecosystem to apparent changes in upwelling intensity. Some other factors which he considered were the effect of changing wind fields on turbulence, hypoxia and harmful algal blooms, shifts in fish distribution due to changes in temperature, the detrimental effects of acidification on plankton with calcium carbonate skeletons and of increased UV-B radiation on primary production, and the effects of sea level rise and reduced fresh water discharge on coastal areas. He pointed out that these effects complicate an already unclear picture, making it very difficult to predict outcomes, but concluded nonetheless that there was no room for complacency regarding the possible effects of climate change on the region's fisheries, and outlined a number of steps for dealing with the effects if and when they become manifest.

Roux (2003), in speculating on the possible effects of global warming on Namibia's marine environment, singled out changes in the frequency and amplitude of tropical intrusions and modifications in upwelling resulting from changes in the wind field as the most important potential effects. He speculated on the effects on the ecosystem and the fisheries of four possible scenarios (viz: reduction in costal upwelling intensity, an increase in average summer wind stress, an increase in the frequency and severity of warm-water intrusions from the north, and gradual responses to climatic changes of low amplitude) and suggested possible mitigating action in each case. He too emphasised the uncertainties in the processes and magnitude of the physical and biological effects considered, and pointed out that because of these uncertainties timely management action to mitigate the effects had up to that time not been possible.

In this report the earlier studies are re-visited and updated, drawing particularly on the BCLME Workshop on Climate Change and Variability and Impacts Thereof, held in Cape Town on 15 and 16 May 2007 (Veitch (*Ed.*) 2007). Other sources consulted include articles in the primary scientific literature, Country Reports on Climate Change in Namibia and South Africa, articles in the book *Benguela: Predicting a Large Marine Ecosystem* (L.V. Shannon *et al.* (*Eds.*), 2006), published by Elsevier as Volume 14 in their Large Marine Ecosystem series, Volume 25 of the GLOBEC Scientific Report series, summarizing the chief scientific achievements of the BENEFIT Programme, and various editions of the Fishing Industry Handbook for South Africa, Namibia and Moçambique (and recently, Angola), published by George Warman, Cape Town. Information on the state of the resources in Angola, Namibia and South Africa was sourced directly from the relevant fisheries ministries in these countries.

1.3 ENVIRONMENT

Physical environment

Lying to the north of the BCLME, as here defined, is the Angolan subtropical zone, which is essentially a transition zone between the wind-driven upwelling system to the south and the Equatorial Atlantic, from where the seasonal cycle is remotely driven (e.g. Hutchings *et al.*, 2009). In the warm season (December – March) it is characterized by strongly stratified surface waters overlying cooler, productive waters below the thermocline, which becomes elevated in the cool season (July- September). Wind-driven upwelling is only important in the extreme south for a few months of the year (August and September).

The northern boundary of the BCLME upwelling region coincides with the Angola Benguela Frontal Zone (ABFZ) where the warm Angola Current meets the cool Benguela upwelling regime. The front is a permanent feature at the surface, moving seasonally over a narrow band of latitudes, characteristically between 14°S and 17°S. The southward movement of the front is most pronounced during summer, when longshore wind stress and upwelling in the northern Benguela is reduced.

The major wind-driven upwelling zone is situated between Cape Frio in the north and Cape Agulhas in the extreme south. Powerful perennial upwelling centred on Lüderitz in southern Namibia, which causes high offshore advection and strong turbulent mixing, partially separates the zone into northern and southern regions, hereafter referred to as the northern and southern Benguela.

The southern boundary is considered to be the Agulhas retroflection area. Like the northern boundary, this warm southern boundary moves during the year, as tropical Agulhas Current water leaks into the South Atlantic, mostly in the form of rings which are shed from the Agulhas current as it retroflects to the east, which in turn may be affected by atmospheric anomalies in the Indian and Pacific Oceans. The Agulhas Bank itself displays the characteristics of both an upwelling and a temperate shallow shelf system, with seasonal stratification and mixing, shelf-edge and dynamic upwelling, moderate productivity and a well-oxygenated shelf (Hutchings et al., 2009).

The area experiences episodic warming events, known locally as *Benguela Niño*s (Shannon *et al*., 1986) similar to the seasonal *El Niño* Southern Oscillation (ENSO) in the eastern Pacific. These events, which are probably linked to, but are not necessarily in phase with, the ENSO, occur when extreme warming takes place in the tropical eastern Atlantic and warm water is advected southwards and east along the Namibian coast. Florenchie *et al*. (2003) concur with earlier suggestions by Horel (1986), that *Benguela Niño*s are generated by a sudden change in the zonal wind stress in the western tropical Atlantic and propose that this excites an eastward propagating Kelvin-wave-like disturbance that continues southward and northward as a coastally trapped wave upon reaching the coast. They provide evidence that the warm anomaly is a subsurface feature as it travels southwards along the African coast, outcropping at the surface off Angola when it reaches the Benguela upwelling regime. They note that the timing of warm anomalies appears to be a crucial factor in the development of *Benguela Niño* events, which tend to occur in February/March.

The extent and intensity of coastal upwelling throughout the Benguela is primarily determined by the wind/pressure field. The winds are controlled by anticyclonic motion around the perennial South Atlantic high-pressure system, the pressure field over the African subcontinent, and by cyclones moving eastwards over the subcontinent. The South Atlantic high-pressure cell, which shifts both zonally and meridionally during the year, is part of the discontinuous high-pressure belt which encircles the southern hemisphere. Atmospheric pressure over the continent changes markedly from a well-developed low in summer to a weak high in winter, with resultant seasonality in the longshore pressure gradient and hence upwelling intensity. In the southern Benguela, cyclones approaching from the west give rise to coastal lows which migrate in a clockwise direction around the subcontinent. Wind relaxation or reversals associated with the passage of these cyclones modulates the upwelling in the south over periods of three to ten days during the upwelling season.

The South Atlantic high pressure system and its seasonal shift facilitates the upwelling-favourable wind regime, which is dominant during the summer in the southern Benguela and throughout the year in the northern Benguela. The primary perennial centre of upwelling-favourable winds lies near Lüderitz (26° 30'S), with a secondary centre near Cape Frio (18° 30'S). The periods of maximum upwelling intensity in the northern and southern Benguela are out of phase, with the former peaking in late winter/early spring and the latter in summer. This is due to the seasonal shift in the pressure system, which results in a higher frequency of westerly (ie. non-upwelling) winds in the south, particularly in winter.

The Lüderitz upwelling cell, which is characterized by weak stratification and high turbulence, is the most concentrated and intense found in any upwelling system on earth. This cell, and its interaction with the local topography, effectively divides the Benguela into two semi-independent parts, and is believed to act as an environmental barrier separating a number of commercially-important species. The upwelling cells in the extreme south tend to be more ephemeral and seasonal, and tend to have less effect on the distribution of plankton and nekton in this region.

Between Cape Frio and Cape Point there is a well-developed longshore thermal front, or series of fronts, which in summer extend eastwards around Cape Point. The front, which is meandering in nature, co-incides approximately with the seaward boundary of the general upwelling area. South of Lüderitz it is single and usually well defined, but further north its surface manifestation is more diffuse, and multiple fronts are sometimes evident. Associated with the front in the south are upwelling filaments which have a lifespan of days to several weeks, These are generally oriented perpendicular to the coast, causing the front to become highly convoluted in places.

Important circulation features affecting the life cycles of commercially-important marine species within the upwelling region include offshore Ekman-transport at the surface driven by equatorward winds, a poleward undercurrent over the shelf and in deeper water adjacent to the shelf throughout the region, and the growth and decay of frontal jets into meanders, eddies and filaments. Of particular importance to the successful transport of pelagic fish eggs and larvae from spawning to nursery grounds is the strong northwards flowing shelf-edge jet that connects the Cape Peninsula to Cape Columbine (eg. Shelton and Hutchings, 1982, Fowler and Boyd, 1998).

Oxygen

Central water in the south-east Atlantic commonly contains between 4.8 and 5.2 ml l^{-1} of dissolved oxygen, and is about 80-85 percent saturated. In contrast, the shelf waters of the Benguela current frequently contain lower levels of oxygen, and at times are anoxic, with considerable impact on the living resources of the Southern African west coast.

The formation of low oxygen water (LOW) depends on physical as well as biogeographical processes. A primary source of LOW in the northern and central Benguela is the Angola Gyre area of the South-east Atlantic, where the primary production, stratification and retention processes facilitate the maintenance of LOW in the area. The Angola Gyre feeds the Angola Current which deepens as it moves southward to form the Benguela Poleward Undercurrent. This undercurrent extends to 27°S, where it forms the boundary of advected LOW for the northern and central Benguela systems.

While southward advection of oxygen-deficient (< 2 ml l^{-1}) and oxygen-depleted (< 5 ml l^{-1}) water from the north via the poleward undercurrent is important in controlling the spatial and temporal distribution of the water on and adjacent to the shelf, local processes over the Namibian shelf are probably more important determinants of oxygen dynamics in the Benguela region as a whole. In the southern Benguela the formation of LOW is largely driven by a combination of local physical (stratification, recirculation and advection) and biochemical (upwelling-driven new production) factors. Hypoxic water occurs sporadically in a narrow inshore strip, but seldom reaches the extreme levels of depletion experienced in the northern Benguela.

Monteiro and van der Plas (2006) have identified three different regimes of LOW in the Benguela system, viz.

1. the northern Benguela, in which the LOW is controlled entirely by the advection of LOW from the Angola Gyre, and is strongly linked to the upwelling which peaks between June and August,

2. the central Benguela (off Namibia) in which fluctuations in LOW are controlled by complex interactions between remotely forced shelf processes, seasonal thermocline variability and biogeochemical carbon fluxes, and
3. the southern Benguela (off South Africa) , where the generation of LOW is primarily driven by local seasonal winds, with little remote influence.

In a more detailed investigation into the sources and variability of hypoxia in the central Benguela, Monteiro *et al.* (2008) concluded that while seasonal variations in the hypoxia in this region can be explained by the interaction of seasonally- varying advective and biogeochemical processes, the latter do not seem to influence the variability on inter-annual/decade scales. From a study of temperature, salinity and oxygen data between 1981 and 1999 they proposed that long term variations in hypoxia on the Namibian shelf are driven by a combination of advection in the first half of the year of hypoxic equatorial water from the north, and ventilation in the second half of the year by the upwelling of aerated South Atlantic Central Water from the Lüderitz upwelling centre. They postulated that the degree and extent of the hypoxia depends on whether these forcing factors tend to re-inforce or counteract each other, and on differences in amplitude and phase between the upwelling at Lüderitz and Cape Frio.

Off Namibia, the break-down of organic matter under anoxic conditions by sulphate-reducing bacteria often leads to eruptions of hydrogen sulphide which can extend over large areas, not only the coastal zone, as once thought (Weeks *et al*., 2002). The full extent and toll on marine life of this phenomenon, which is unique to Namibia, has yet to be established (eg. Brüchert *et al*., 2009).

Phytoplankton and primary production

Brown *et al*. (1991) have estimated that the total primary production in the northern Benguela (15° – 28°S), southern Benguela (28° – 34°S) and the Cape South Coast (34° 30'S – 27°E) is similar at about 80 tonnes C yr^{-1}. This is similar to that in the Peruvian system, but substantially greater than off California.

The Benguela is generally regarded as a diatom dominated system, although small flagellates are also important, particularly in warmer, lower density water further offshore (eg. Barlow *et al*., 2005, 2006). Phytoplankton assemblages are similar in the northern and southern Benguela, with *Chaetoceros, Nitzchia, Thalassiosirs* and *Rhizoselenia* being common throughout the region. There are however essential differences between the north and the south, some of which are due to differences in the atmosphere and ocean dynamics (eg. nutrient supply, turbulence and stratification) in the two regions. The abundant diatom *Delphineis karstenii* is restricted to the north, while *Skeletonima costatum* is particularly abundant in the south. Large-cell *Coscinodiscus spp*. are common in areas of high turbulence. Over the Agulhas Bank the species assemblages are more cosmopolitan than on the West Coast.

Algal blooms occur throughout the region, especially during quiescent periods following upwelling as the water ages and stratification increases. These so-called red-tides can be harmful to marine life through depletion of oxygen as the organisms decay, and some are toxic to humans, fatalities having occurred. The most common red-tide dinoflagellates around Walvis Bay are species of *Heterocapsa, gymnodinium* and *Scrippsiella*, whereas in the southern Benguela the non-toxic *Noctiluca scintilans* predominates. *Alexandrium catanella* and *A. grindleyi* have been associated with large-scale mortalities of sand mussels and benthos in the southern Benguela, particularly in St Helena Bay.

Figure 2, which shows monthly averages of integrated chlorophyll *a* between 12 and 34 °S from 1997 to 2007 derived from satellite imagery, illustrates the broad spatial and temporal patterns in primary production in the region. Features to note are the broad areas of high production north (ie. downstream) of the Lüderitz upwelling cell around 26 °S (an area of low production), the smaller high production areas north of the low-production upwelling centre off Cape Columbine ((34°S), and the broad area of low production north of the Angola Benguela Frontal Zone between about 14 and 17°S. Figure 2 shows that the seasonality in primary production is different in the northern and southern Benguela, tending to peak in winter in the north and in late summer in the south, in accord with the broad differences in the seasonality of the upwelling in these two areas. Ocean colour satellite imagery also shows that the area of upwelling-driven production broadens steadily from south to north, the 1 mg m^{-3} limit increasing from about 40 km off Cape Point to about 80 km off the Cunene River (Barlow *et al.*, in Hampton and Sweijd, 2008).

Despite the obvious connection between primary production and the upwelling of nutrient-rich water over short time scales, de Villiers (1998) found from a study of ocean colour imagery from the South African West Coast and the Agulhas Bank between 1979 and 1986 that coherent interannual trends in the concentration of surface chlorophyll corresponded with sea surface temperature records rather than with upwelling-favourable winds, as reflected in local records. This finding implies that interannual variability in phytoplankton biomass (at least in the southern Benguela) is associated with large-scale oceanic circulation features and forcing mechanisms, rather than with localized upwelling events. She suggested that the most probable causative mechanism in this case is the anomalous advection of warm surface water from the Agulhas retroflection in the south, although she did not rule out a possible link to *Benguela Niños*.

Zooplankton

There are relatively good estimates of zooplankton distribution, abundance and production in the southern Benguela. Estimates of zooplankton standing stock in the upwelling area off the Cape Peninsula reveal a distinct seasonality, associated with the upwelling cycle, with values ranging from a winter minimum of about 1.5 g dry mass m^{-2} to a summer maximum of roughly twice this figure. Superimposed on the seasonal cycle is substantial short-term variability driven by pulses of upwelling, the dynamics of phytoplankton blooms and the life histories of the various zooplankton groups affected.

Less is known about patterns of zooplankton abundance and zooplankton dynamics in the northern Benguela. Peaks in abundance appear to coincide with periods of maximum phytoplankton abundance – ie. from November to December and between March and May. The former occurs in the main upwelling season and the latter during periods of moderate upwelling when summer stratification weakens. In both cases the zooplankton tends to be more abundant offshore of the band of phytoplankton close inshore following the coastline.

Studies on the copepod *Calanus agulhensis* in the southern Benguela suggest production rates of between 17 and 150 g C m^{-3} yr^{-1} and a daily mean production/biomass ratio of between 0.1 and 0.3. Variations in zooplankton production appear to be caused by shifts in distribution and demography rather than by variations in growth rates. There have been no comparable estimates for the northern Benguela.

The food web and carbon budget

Probyn (1992) has estimated from stable isotope analysis that in the southern Benguela, new production (which determines the productivity of high trophic levels) is relatively low, being only one half to one third of that in the Californian and Peruvian upwelling systems. This, plus the removal of an unusually large proportion of the production of small phytoplankton by microheterotrophs (estimated at 38 percent by Moloney, 1992) helps to explain why the Benguela as a whole yields considerably less fish annually than would be expected from a simple short food-chain system.

It is clear from mass-balance and other models of the ecosystem (eg. Heymens *et al.*, 2004, Watermeyer *et al.*, 2008b) that the northern Benguela ecosystem and its trophic functioning is now very different in character from that in the 1970s when sardines (the most important wasp-waist[1] species in the ecosystem) were abundant. Pelagic fish are scarce, horse mackerel (a mid-water species) are abundant, and recent acoustic surveys, using techniques developed by Brierley *et al. (*2005) suggest that the biomass of the jellyfish *Chrysoara hysoscella* and *Aequorea forskalea (aequorea)* is now of the order of 10 million tonnes (Gibbons *et al*., in Hampton *et al.,* 2009), far exceeding that of pelagic finfish in the region. It also appears that the biomass of pelagic goby *Sufflogobius bibabartus* has increased since the collapse of the sardine, and that it is now a uniquely important keystone species in the ecosystem (Utne-Palm *et al*., 2010). It is believed that a greater part of the production is now used by benthic organisms and enters the bacterial loop as detritus. Some species might have benefited from these changes (eg. goby and jellyfish), but they are not fulfilling the role of wasp-waist species, are of low energetic value to the rest of the food web and are of no economic value. Dependent species (e.g. penguins and gannets) are declining and are facing local extinction. Other predators (hakes, seals, snoek, etc.) have also been negatively affected by the change in ecosystem functioning. The lack of alternative suitable prey has affected hake recruitment (shown by increased cannibalism in the first two years of life), reducing the productivity and affecting the dynamics of the stock.

1.4 LIVING MARINE RESOURCES

As in the Californian, Humboldt and Canary Current systems, the high primary productivity of the Benguela Current system supports large commercial fisheries for a variety of epipelagic, demersal and midwater species. There are three major resource groups, viz. 1) pelagic fish such as sardine *Sardinops sagax*, anchovy *Engraulis encrasicolus,* round herring *Etrumeus whiteheadi* and the sardinellas *Sardinella aurita* and *S. madarensis*, all caught by purse-seine 2) the hakes *Merluccius capensis* and *M. paradoxus* caught by trawl and long line, and 3) the Cape and Cunene horse mackerels, *Trachurus trachurus capensis* and *T. Trecae,* caught by purse seine when juvenile and by midwater trawl and (less frequently) bottom trawl as adults. These groups are similar to those found in the other eastern boundary upwelling systems. Since 1960 they have together contributed close to 90 percent of the total catch of finfish and shellfish from the region as a whole. Other important commercial fisheries in the region are those for West Coast rock lobster *Jasus lalandii*, and hook and line fisheries for species such as snoek *Thyrsites atun* and tuna, particularly albacore *Thunnus alalunga*, yellowfin tuna *T. albacores* and skipjack tuna *Katsuwonus pelamis*. There are also important recreational fisheries for a variety of species, whose value in terms of the tourist revenue which they generate greatly exceeds that of the catch itself.

A very brief account of the distribution and life histories of the most important species or species groups, specifically in relation to the environment, is given below. Trends in catches and the most recent estimates of stock size are reported in Section 2.

Pelagic fish

The distributional range of sardine and anchovy extends from southern Angola to Kwazulu-Natal in South Africa, with both species coexisting as quasi-discrete stocks off northern/central Namibia and off the Western Cape, separated by the region of strong upwelling off Lüderitz. Both species spawn predominantly on the Agulhas Bank and, in the northern Benguela, mostly within about 50 to 100 km of the coast off northern Namibia (Boyer and Hampton, 2001). Spawning tends to peak in early summer in the south and in late summer/early autumn in the north.

[1] Wasp-waist species are those which play a critical role in the ecosystem both as predators (in this case on plankton) and as prey.

Eggs and larvae from spawning on the Agulhas Bank (particularly the western side of it) are transported to inshore nursery grounds north of Cape Columbine by a shelf-edge frontal jet between Cape Point and Cape Columbine, resulting in recruitment to the west coast fishing grounds in winter of the following year. The recruits of both species move south in the inshore counter current along the West Coast during winter and early spring, reaching the western Agulhas Bank in early summer, when the anchovy reach first maturity and begin to spawn, initiating the next spawning cycle. Both species tend to move eastwards over the Agulhas Bank as they grow, resulting in spawning of older fish of both species over the whole bank. Sardines on the Agulhas Bank undertake a well-documented, highly visible, winter migration into nearshore waters of the East Coast to as far north as Durban (known locally as the "Kwazulu-Natal sardine run"), returning to the Agulhas Bank via the strongly flowing Agulhas current further offshore later in the year (see suite of papers in African Journal of Marine Science, Vol 32(2), 2010).

Since 1996 there has been a shift to the east in the distribution of anchovy in the southern Benguela, with the bulk of the population now being found over the central and eastern Agulhas Bank rather than over the western Bank, where abundances were highest in the previous 15 years or so (van der Lingen *et al.*, 2006). In the past three decades the principal areas of sardine spawning have moved periodically between the west and south coasts, with a sustained shift to the central and eastern Agulhas Bank, similar to that of anchovy, between 2001 and 2008. The proportion of the spawning population which is west of Cape Agulhas is now increasing again (possibly as a result of increased fishing pressure on sardine on the central and eastern Agulhas Bank), and is now roughly equal to the proportion east of Cape Agulhas.

In the northern Benguela, the larvae of both species drift south close to the coast to the cool upwelling areas near Walvis Bay, which is followed by a return of juveniles and young adults to the northern area where they spawn for the first time (Boyer and Hampton, 2001). Prior to the collapse of the sardine stock in the mid-1970s, older sardine appeared to return south to spawn around Walvis Bay, creating a second spawning area, but since then, spawning in the south seems to have diminished in importance (eg. Crawford *et al*., 1987)[2], The behavior of both species in this area is analogous to that in other eastern-boundary upwelling systems (Bakun, 1996), where both the spawning and the recruitment of pelagic fish occurs downstream of the principal upwelling region (the Lüderitz upwelling cell in this case).

Laboratory and field-based studies have shown that juvenile anchovy and sardine, as well as adult anchovy, feed primarily on zooplankton, but suggest that adult sardine utilize phytoplankton as well in areas of high abundance. The extent to which the two species compete for habitat and food in the Benguela ecosystem is not known, but it seems likely that during periods of high abundance of one of the species, competition is important, possibly resulting in offshore displacement of the less abundant species.

There have been intensive efforts over the past two to three decades to explain, and thereby predict, the strength of anchovy recruitment in the southern Benguela on the basis of environmental and biological factors, primarily for management purposes. Factors which have been considered include the timing and duration of spawning, the condition of the spawners, physical factors affecting the transport of eggs and larvae from the western Agulhas Bank to the nursery areas on the West Coast, feeding conditions and competition for food on the nursery grounds, predation pressure and many others. Although some potentially useful relationships have been found (e.g. one between acoustic estimates of recruitment and two satellite-derived temperature indices

[2] Kreiner *et al*. (2011) (abstract only seen) contend that in more recent times there has been a shift back to spawning in the south, in accord with the general warming of the northern Benguela over the past decade.

of transport off the Cape Peninsula during December and upwelling intensity off the West Coast in January, for the period 1985 to 1999 – Roy *et al.*, 2001), no predictor robust enough to be used in management has yet been formulated. Recruitment predictors for species other than South African anchovy are less well developed. While no quantitative predictors have yet been developed for the northern Benguela, the knowledge that environmental perturbations such as *Benguela Niños* and unusually extensive and protracted intrusions of low oxygen water can have a marked effect on both the distribution and abundance of sardine and other pelagic species in this region (O'Toole and Shannon, 1997, Boyer and Hampton, 2001), is likely to be of some predictive value when these events are extreme.

The less commercially-important round herring, which is only caught in substantial quantities in the southern Benguela, has a similar distribution and spawning habitat to that of the sardine and anchovy, and has similar larval dispersal and recruitment patterns. The fish are entirely zooplanktivorous, and when adult undergo extensive diel vertical migrations, unlike the sardine and anchovy, which for the most part inhabit the euphotic zone at all times of the day. Factors controlling round herring distribution and abundance are less understood than they are for sardine and anchovy in the southern Benguela.

Sardinella aurita is the dominant sardinella off southern Angola. Off central Angola its distribution overlaps with that of *S. madarensis*, which primarily occurs north of 10ºS. The main spawning area of these species is thought to lie between 5º and 7ºS, with peak spawning occurring in March/April. Both species appear to migrate equatorwards along the coast to the spawning grounds in the first part of the year. Juveniles apparently remain in the north, but adults migrate south during the second half of the year, occurring off central Angola and, in the case of *S aurita*, southern Angola from November to February.

Hakes

The Cape hakes contribute the bulk of the groundfish catch from the south-east Atlantic, and are the principal target species for demersal trawlers in the Benguela region. The deep water hake *Merluccius paradoxus* occurs over the outer shelf, between depths of about 150 and 800 m, from northern Namibia to about Port Elizabeth on the south coast of South Africa. The shallow water hake *M. capensis* is found in shallower water, from the coast to about 380 m offshore, over approximately the same region, which means that the species co-occur at intermediate depths.

Cape hakes migrate diurnally through the water column, rising during the night to feed and returning to the bottom at dawn. Spawning takes place throughout the year in the southern Benguela, with peaks for both species in early summer. *M. paradoxus* has a secondary spawning peak in February/March. It is thought that most *M. paradoxus* spawning takes place along the edge of the Agulhas Bank, although it also occurs over the shelf break on the West Coast. Annual demersal trawl surveys from 2000 to the present covering the whole distribution range on the West Coast have led to the important conclusion from both the ecological and the management perspective that *M. paradoxus* do not spawn in Namibian waters (in Hampton and Sweijd, 2008). *M. capensis* spawn throughout their range. In Namibia they move inshore to spawn in early summer, and offshore in late summer.

Hake are opportunistic feeders, resulting in substantial seasonal and spatial variability in their diet. Young fish feed predominantly on planktonic crustaceans, particularly euphausiids. Squid, epipelagic fish and to a lesser extent mesopelagic fish are important in the diet of adult *M. capensis*, but in areas where their distribution overlaps, they feed predominantly on small *M. paradoxus*. Adult *M. paradoxus* feed predominantly on squid and mesopelagic fish and are cannibalistic to a limited extent. The two species therefore clearly occupy different ecological niches.

Relatively little is known about the effect of environmental factors and behavioural responses on resource dynamics, although it would seem from their longevity, wide geographical range, diurnal vertical migrations, very diverse diet and ability to tolerate oxygen levels as low as 0.25 ml l^{-1}, that Cape hakes are relatively resistant to all but extreme, prolonged environmental perturbations in the system. Such a perturbation occurred in Namibia in the early to mid 1990s when a prolonged low oxygen event in 1993/1994, followed by a major *Benguela Niño* in 1995 resulted in extremely poor recruitment, effectively halting or reversing attempts to rebuild the hake stock.

Horse mackerels

At least two stocks of Cape horse mackerel *Trachurus trachurus capensis* exist off southern Africa, viz. off northern Namibia, where the stock extends into southern Angola, particularly in the winter months, and off the West and South coasts of South Africa, to as far east as the eastern Agulhas Bank, where densities are particularly high and the major targeted fishery now occurs. These stocks spawn over broad areas, with the most intense spawning occurring in warmer waters over the shelf break; in South African waters, mainly over the Agulhas Bank. In the north spawning occurs between spring and autumn with a peak in summer. In the south spawning on the Agulhas Bank appears to peak in winter (June - August) and in summer (November – February), with differences in timing between the eastern and western bank (Hecht, 1990, Naish, 1990).

Off Namibia, juvenile Cape horse mackerel occur in inshore waters, with the smallest sizes being found furthest north. Slightly larger individuals appear to migrate south towards Walvis Bay, especially in winter. Maturing fish move offshore to spawn, the adults generally occurring north of 21°S. Off the Western Cape, most juveniles are found inshore between the Orange River and Cape Agulhas, with the bulk of the recruitment in this region arising from the summer spawning on the western and central Agulhas Bank and subsequent transport of eggs and larvae to the West Coast in the shelf-edge jet off the Cape Peninsula in a similar manner to that of sardine and anchovy (Barange *et al*., 1998). Juveniles on the West Coast recruit to the purse seine fishery there between January and March. The fish move offshore and become demersal as they mature, before recruiting to the demersal fishery on the West Coast as 1-2 year olds. It appears that a portion of that population subsequently moves south to the Agulhas Bank in a similar manner to sardine and anchovy. The fish move slowly eastwards across the Bank as they grow, ultimately joining a resident population of large adults on the eastern Bank. This part of the population displays complex alongshelf and cross-shelf movements, probably related to feeding and spawning, the latter resulting in some direct recruitment to the inshore waters of the South Coast, mainly west of about 24°E. It is believed that the interactions between the fish on the West and South Coasts link the two groups into a single population which is separated from the Namibian population by the Lüderitz upwelling cell.

Comparatively little is known about seasonal changes in the distribution of the different life history stages of Cunene horse mackerel *Trachurus trecae*, although it can be expected that in southern Angola, the distribution will be strongly affected by movements of the Angola/Benguela Frontal Zone. At the BCLME/BENEFIT workshop on transboundary stocks in the northern Benguela (Boyer and Hampton (*Eds*.), 2007) it was made clear that much has still to be learned about spawning and nursery areas, seasonal and ontogenetic migration patterns and the major impacts of environmental factors on distribution and abundance of this species.

Horse mackerel up to the age of 2 years feed near the surface and are planktivorous. The diet, consisting mainly of copepods, is similar to that of sardine and anchovy, with which they can co-exist in mixed schools. Adults in both the northern and southern Benguela undertake diurnal vertical migrations, with feeding in both regions occurring mostly in the afternoon before the onset of migration towards the surface. Their diet consists mainly of euphausiids (the major constituent in Namibia), copepods (important on the Agulhas Bank), squid, various crustaceans and a variety of mesopelagic fish species. A notable difference between Cape horse mackerel in Namibian and South African waters is that in Namibia the adults are largely confined to midwater by low oxygen water close to the bottom, in contrast to South Africa, where they commonly descend to the bottom during the day.

West Coast rock lobster

Jasus lalandii is a spiny lobster associated with the cool upwelled waters of the Benguela. It occurs in commercially exploitable densities from east of Cape Point to approximately 25°S, and at lower densities beyond its core distribution. The species has a well-defined moulting and spawning cycle. Adults moult once per year, the males in spring and the females in late autumn/winter, after which mating takes place. Egg hatching peaks in October and November, and the phyllosoma larvae remain planktonic for 9 months or longer, drifting in oceanic sub-gyres until they reach the peurulus stage and settle. Females reach sexual maturity about 5 years later. Males grow faster than the females, which results in the fishery being largely based on males. The adults are generally distributed offshore of the juveniles, except in the north, where the population is constrained close to the coast by low-oxygen water. *J. lalandii* feed largely on mussels, particularly the ribbed mussel *Aulacomya ater*. Their principal predators are octopus, dogsharks, and young seals.

Environmental conditions, particularly the degree and extent of low oxygen water in their immediate vicinity, have a strong effect on *J. lalandii* distribution and also affect their abundance through influences on growth and mortality rates. The mass walk- outs of rock lobster which occasionally occur on the west coast of South Africa in response to episodic low oxygen water events is a highly visible example of the latter. The sharp decline in rock lobster production which occurred simultaneously throughout the Benguela system towards the end of the 1980s appears to have been a response to a large scale environmental effect such as a change in primary production or in the benthic food web. From that time to the present, the population in the southern Benguela has been gradually but steadily moving from the West Coast to the South Coast, possibly due to the long-term decline in oxygen concentrations below the thermocline off the West Coast (Cockroft *et al*., 2008).

1.5 TOP PREDATORS

The Cape fur seal *Arctocephalus pusillus pusillus* and various seabirds such as the Cape gannet *Morus capensis*, Cape cormorant *Phalacrocorax capensis* and African penguin *Spheniscus demersus*, are the major apex predators on pelagic fish in the region.

Seals

The distribution of the seals, which are exploited commercially in Namibia, extends from southern Angola to the south coast of South Africa. Breeding occurs on islands close to the coast and a few mainland colonies between Cape Frio in northern Namibia and Mossel Bay on the Cape South Coast. It has been found from recent satellite tagging studies (summarized in Hampton and Sweijd, 2008) that seals in Namibia move frequently between the colonies there and foraging areas in north, south and central Namibia. In South Africa, their broad distribution at sea on both the West and South coasts was found to be strongly related to the distribution of their food (ie. pelagic fish and discards from hake trawlers), and was only weakly related to large scale oceanographic features. There appeared to be little interchange between the populations on the West and South coasts. It seems that because of their catholic diet and mobility, Cape fur seals are not greatly affected by environmental perturbations other than major shifts in the distribution and/or abundance of their prey such as occurred in northern and central Namibia following the major low oxygen event in 1993/1994. This event, which affected the distribution and possibly the abundance of a wide range of fish species, resulted in high mortalities of pups and adults from starvation and a consequent marked decline in the Namibian seal population.

Sea birds

The Cape gannet breeds on a number of islands between Mercury Island in southern Namibia and Bird Island in Algoa Bay on the Cape South Coast. The birds feed by surface plunging and can follow their prey (predominantly sardine and anchovy) over large distances. For example, gannets resident in the Algoa Bay region follow the schools in the KwaZulu-Natal sardine run in winter to as far up the east coast as Durban, some 500 km away. Gannet distribution, abundance and breeding success is strongly related to the distribution and abundance of their major prey, evidenced, for example, by the disappearance of the Lamberts Bay breeding colony with the shift of sardine and anchovy from the West Coast to the South Coast in the late 1990s/early 2000s. Environmental factors appear to influence the birds through their effect on prey distribution and abundance rather than through any direct effect on their distribution or behaviour.

The breeding ranges of the Cape cormorant (the most abundant seabird in the region) and the African penguin are similar to that of the Cape gannet, although both these species have a larger number of (generally smaller) island and mainland breeding sites. Both species feed on pelagic fish (again predominantly anchovy and sardine) by pursuit diving, and forage over shorter distances than the Cape gannet. They are therefore more susceptible to local rather than regional changes in prey abundance and distribution. As with the Cape gannet, changes in abundance and shifts in distribution between the breeding colonies are driven largely by changes in the distribution and abundance of their prey.

2. Variability in the BCLME

2.1 INTRODUCTION

In common with other upwelling systems, the Benguela ecosystem exhibits a large degree of natural, environmentally-driven variability over spatial and temporal scales ranging from the decadal (driven by long term changes in global/regional weather patterns) to daily or even hourly variability resulting from small scale (of the order of kms) upwelling and associated events. Within the major upwelling region, event-scale variability is often dominant, particularly in the upwelling centres. There is further variability on larger spatial and temporal scales from seasonal modulation of upwelling winds in the northern and southern boundaries of the system, which are characterized by intense mixing and high variability (Hutchings *et al*., 2006).

Due to the variability in their environment, fish populations which inhabit the Benguela ecosystem are subject to a high degree of variability in enrichment, retention and concentration processes, which are believed to be dominating factors in determining recruitment, particularly during the early life-history stages (Bakun, 1996), thus exercising a "bottom – up" control over recruitment and ultimately distribution and abundance. These effects have been exacerbated by depletion of some of the system's major resources through commercial fishing, directly affecting their abundance and distribution (a form of "top- down" control), and more indirectly, the ecosystems of which they are an integral part, through changes in the structure and functioning of the food web.

Since this report is exclusively concerned with the effects of long-term climate change on the resources of the region in general, the discussion which follows has been restricted to long term (decadal or inter-decadal) events on large spatial scales (of the order 100 km or larger). The emphasis is on examining the variability in the biophysical environment on this scale over the past 50 years or so (the approximate extent of the reasonably well populated data record), and evidence for the effects of such variations on the major living resources of the system. Much of the material is drawn from Volume 14 of the Elsevier Science series on Large Marine Ecosystem, edited by Shannon *et al*., (2006), and the report on the BCLME Expert Workshop in 2007 on the Changing State of the Benguela Current Large Marine Ecosystem (Veitch (*Ed*.) 2007). The structure loosely follows that of the latter document.

2.2 THE ENVIRONMENT

Winds

From an analysis of wind data from the south east Atlantic between 1948 and 1989, extracted from the South African Data Centre for Oceanography, Shannon *et al.* (1992) concluded that during the 1950s, 1960s and 1970s there was a trend towards increased equatorward wind stress in both the southern and northern Benguela, and also further offshore, with a markedly strong increase in both Benguela regions from 1975. There was also an increase in easterly winds over the study period, consistent with a extended (decadal scale) southward shift in the mean position of the South Atlantic Anticyclone (SAA), which Taunton-Clark and Kamstra (1988) have proposed sets up strong equatorward winds and low coastal SSTs (typical summer conditions) when south and the opposite when further north (typical of winter conditions).

Subsequently, Hardman-Mountford *et al*., (2003) investigated the winds of the south east Atlantic from the equator to the Cape South Coast on the basis of model outputs for the period 1982 to 1999 obtained from the European Center for Medium-

Range Weather Forecasts. The models indicated a pronounced increase in westerly surface wind anomalies up until 1997 at the equator and off Angola, followed by a marked return to normal conditions towards the end of the time series in both areas. There was a general increase in equatorward anomalies at the equator for the whole time period, and off Angola up until 1992. After this there was a sudden increase in polewards winds, which continued until the end of the time series. No conspicuous inter-annual or longer term trends in either zonal or meridional wind stress in the northern or southern Benguela, or in the area south of the continent, were suggested.

From an analysis of NCEP reanalysis wind data for the period 1982 to 2005, Rouault extracted the maps in Figure 3 (from Veitch, (*Ed*.) 2007), showing the trends (assumed to be linear) in wind speed and direction per season over the southern African continent and adjacent ocean areas over this period. The strongest trends over the ocean occur in summer (January-March), particularly off the Namibian coast (which is dominated by an increase in equatorward winds), with a secondary maximum off the Cape Peninsula, where it appears that there has been an increase in south-easterly winds. The maps show little trend in the winds over the southern Benguela compared to the northern Benguela through the rest of the year, except in autumn (April- June) when there is a fairly strong tendency towards increasing easterlies south of the African continent and in the Agulhas retroflection area. Although the maps are based on low-resolution (1^{o} x 1^{o}) data, and the assumption of linearity in the trends is questionable (e.g. annual trends in Shannon *et al*., 1992 and in Hardman-Mountford *et al*., 2003), they are valuable in that they give a sense of the large scale fluctuations in the wind field that have occurred in the region over a long time period up until fairly recent times.

In a more recent analysis of similar data from around the South African coast between 1982 and 2009, Rouault *et al*. (2010) confirmed the increase in upwelling-favourable south-easterly and easterly winds in the southern Benguela in the first half of the year during this period, evident from their earlier analysis, while again noting the pitfalls in the use of low resolution reanalyzed global data for regional analysis. They found furthermore that the upwelling-favourable winds were on average weaker during *El Niño* ENSO events and *vice versa* for *La Niña* events, which supports earlier hypotheses of a teleconnection between climatic events in the south-eastern Pacific and the southern Benguela.

Wind monitoring stations at a number of locations between Lobito in Angola and Cape Point have provided relatively long time series of wind speed and direction, but because of the high degree of variability in the data at all scales, and the frequent lack of coherence between time series from stations a relatively short distance apart (eg. Cape Point and Cape Columbine), it is difficult to extract long time series from these data. Nonetheless, some coherent patterns are evident; for example a marked reduction in upwelling favourable winds at both Cape Point and Cape Columbine during the 1980s, following an *El Niño* event in 1982/83 (Hutchings, in Veitch (*Ed*.), 2007). This pattern was consistent with changes in 3 month averages of offshore Ekman volume transport (a proxy for upwelling-favourable windstress) at Cape Columbine over this period, which Johnson and Nelson (1999) extracted from the Cape Columbine wind record for the period 1957 to 1992. Their averages showed that upwelling at this site is perennial over this time scale with peaks and troughs occurring roughly every seven years, although there was a marked reduction in upwelling after the *El Niño* in 1983, which only increased again in 1990. Note that the decrease in upwelling-favourable winds in 1983 agrees with the finding of Rouault *et al.* (2010) of an apparent connection between *El Niño* events in the south east Pacific and reduced upwelling in the southern Benguela.

In the northern Benguela, plots of cumulative north-south wind anomalies based on data from the Lüderitz and Möwe Point (19^{o} 20’ S) weather stations from 1960 at Lüderitz and from 1979 at Möwe Point (Figure 4), show a broad increase in upwelling-favourable winds from around 1980 and a decline since the early 1990s in both areas, with a slight increase around 2000, particularly at Lüderitz. NCEP data on the zonal and meridional components of the wind off Lobito over the 32 year period between 1967 and 1999 (Figure 5) show low wind speeds throughout the period, with no obvious long-term trends in speed. There was however a switch from in-phase to out-of- phase fluctuations in the zonal and meridional components between 1982/83 and the early 1990s which implies a change in wind direction during this period.

Sea Surface Temperature

From an analysis of monthly mean SSTs between 1948 and 1989, Taunton-Clark and Shannon (1988) and Shannon *et al.,* (1992) found that there was a general increase of about 1°C in surface temperature over the areas offshore of the northern and southern Benguela. They noted no trend in the coastal areas other than a period of sustained cooling in the mid 1980s, particularly in the near-shore areas of the southern Benguela. The time series from the various areas studied, which extended from 10°S to 35°S and to about 1000 km offshore, show a reasonable degree of coherence, particularly in warm anomalies, which occurred in all areas every eight to 10 years on average.

Time series of high-resolution (4.5 km) satellite data for the period 1982 to 1999 compiled by Hardmann-Mountford *et al.* (2003) show that the warming trend noted by Shannon *et al.* continued into the next decade, being most pronounced near the equator and lessening progressively towards the south (Figure 6). Again, there is obvious coherence between the time series for all areas west of the continent, particularly between the 3 northern areas, with the warm anomalies in 1985 and 1995 (*Benguela Niño* years) being particularly noticeable there. Note the greater variability in the tropical regions compared to the areas further south. Of particular importance is the warming trend in the southern Benguela and Agulhas regions since 1995. The fact that it has been more consistent in the Agulhas region than in the southern Benguela implies that the cross-shelf SST gradient in that area has intensified, which could have implications for the transport of ichthyoplankton from the western Agulhas Bank to the West Coast nursery grounds by affecting the strength and position of the northward-flowing jet current along the shelf edge.

Veitch *et al.* (2006) showed from work on the same data set that the warming trend in the region of the Angola/Benguela Front was relatively uniform over the time period, suggesting that the position and intensity of the thermal front (which modeling studies by Colberg (2006) suggest is positively correlated with the intensity of the trade winds), remains relatively stable except during major warm and cool anomalies. Monteiro *et al*. (2008) provide further evidence of the general warming of the Angola Benguela Front over the last two decades from an analysis of optimally-integrated NCEP SST data from the frontal region between 1982 and 2005.

Figure 7, presented to the BCLME Climate Workshop by Rouault (in Veitch (*Ed*.) 2007), shows seasonal trends in SST for the oceans adjacent to the southern African continent over the past 25 years. It was compiled from 1 x 1° resolution, optimally interpolated NCEP Reynolds data for the period 1982 to 2007. The maps reveal that the most intense warming has occurred at the northern and southern boundaries of the Benguela upwelling system throughout the year, and that there has been cooling in a narrow strip along the south and south-western coasts. Warming has occurred offshore of this strip and throughout the rest of the Benguela upwelling region. This broad picture, and particularly the intensification of the SST gradients to the south of the continent, is in accordance with the findings of Hardman-Mountford *et al.,* (2003).

Rouault *et al*. (2010) have extended this analysis to include recent years, concentrating on South Africa and the region to the south of the continent. Their results clearly show the general warming of the Agulhas current and the cooling of the inshore area along the west and south coasts over the past two decades (Figure 8). They found a statistically significant cooling trend of up to 0.50 °C per decade along the West Coast from January to August and one of lesser magnitude along the South Coast between May and August. These trends were attributed to the increase in upwelling-favourable south-easterly and easterly winds, noted earlier. A warming trend of up to 0.55°C per decade throughout the year was detected in most parts of the Agulhas Current system. This was attributed to an intensification of the Agulhas Current in response to a poleward shift of westerly winds and an increase in trade winds in the South Indian Ocean at relevant latitudes. They also found a statistically significant positive correlation between warm events along the west and south coasts from February to May and *El Niño* events in the south east Pacific, in accordance with the apparent connection between the ENSO and upwelling-favourable winds in this region, previously noted. A further significant (negative) correlation was found between *El Niños* and warm events in the Agulhas Current south of 36°S.

Major anomalies

The major environmental anomalies which have been recorded in the Benguela since the start of the data collection are of particular interest, especially in respect of any long term changes which may have occurred in their frequency, intensity or nature which may be symptomatic of recent global or regional changes in climate.

By far the most prominent anomalies in the data record are the *Benguela Niño* events, whose generation and connection to ENSO events in the Pacific was briefly outlined in the previous Section. In their analysis of SST data extending from 1906 to 1985, Taunton- Clarke and Shannon (1988) concluded that these events, which result in a very conspicuous southward displacement of warm water in the northern Benguela in late summer and early autumn, have occurred throughout the environmental record about every 10 years on average since the start of the 20th century. Three such events (in 1963, 1984 and 1995) were clearly evident in temperature records from Walvis Bay between 1958 and 2004. A moderate, but very persistent warm episode between 1972 and 1974, evident in the same data set, is also generally considered to have been a *Benguela Niño*, and was categorised as such by Shannon *et al*. (1986). Other, less prominent, intrusions of warm water from the north, manifest as a southward shift in the Angola Benguela Frontal Zone have occurred more frequently. These can be seen in Figure 9, which shows satellite-derived SSTs along the entire Namibian coast between January 1982 and March 2004 (from Bartholomae and van der Plas, 2007). It appears from Figure 9, and other information in Bartholomae and van der Plas (2007) that these intrusions have increased in frequency since the early 1990s, although none have occurred in the past three years according to the most recent MFMR annual report. The general warming which this would imply is consistent with a time series of satellite-derived SST measurements for the region between 10 and 20°S, east of 8°E (Fig.18 in Reason and Rouault., 2006) which suggests a warming tendency in this region since the beginning of the 1980s. Figure 9 suggests that the extent of the warming in northern Namibia/southern Angola is to some degree inversely related to the extent and intensity of upwelling further south in summer. Note however that there is no obvious correlation between the SSTs around 26°S in Figure 9 and the cumulative north/south wind anomalies at Lüderitz since 1982 shown in Figure 4, suggesting a more complex relationship between wind strength and upwelling than is often assumed.

The southern Benguela is beyond the range of the southernmost movements of the Angola Benguela Frontal Zone, which can therefore be assumed to have little direct influence on this region. The major large-scale temperature and associated anomalies here appear to stem from anomalous injections of warm water from the Agulhas Current retroflection area into the south east Atlantic (eg. Mann, 1992, de Villiers, 1999), which there is evidence to suggest originate from processes in the northern Agulhas current on a mesoscale and forcing from the equatorial Indian Ocean on a larger scale (Reason and Rouault, 2006). Unlike the *Benguela Niño* events in the northern Benguela, and the long term records of ENSO events in the Pacific and of SST variability in the Tropical Atlantic, there are no long-term time series capturing these anomalies from which to discern any long term trends in their frequency, nature or intensity.

South of the African continent, pressure anomalies associated with the Antarctic Oscillation (see Section 1) produce wind anomalies over the south eastern Atlantic, particularly in spring, which Reason and Rouault (2006) postulate may well influence the Benguela system. However, as with the anomalies in the penetration of Agulhas current water into the south Atlantic, there are no long term data series from which to examine the importance of any such influences on the southern Benguela system, or to detect any long term trends in them.

Upwelling/Ekman transport

In most of the studies, anomalies in upwelling at various localities have been expressed in terms of variation in the speed of the north and south components of the coastal wind, averaged over time periods typically of the order of a month (eg. Shannon *et al.*, 1992, Hutchings *et al*., 2006, Bartholomae and van der Plas, 2006). An exception is the work of Johnson and Nelson (1999), who estimated the average rate of total Ekman transport at Cape Columbine for 3-monthly intervals between 1957 and 1990 from hourly records of wind strength there. Their time series shows a peak and a trough approximately once every 7 years up to 1983, followed by a sharp fall-off in volume continuing until the early 1990s. (Preliminary results reported in that paper suggest that the wind strength returned to its pre-1979 magnitude after 1995). As previously noted, the reduction in upwelling between 1983 and 1990 is consistent with a marked reduction in upwelling favourable winds at both Cape Point and Cape Columbine during the 1980s, following an *El Niño* event in 1982/83, reported by Hutchings (in Veitch (*Ed.*), 2007).

Since no estimates of long term changes in Ekman transport in the Benguela have been made since Johnson and Nelson's study, long term trends in the extent and intensity of upwelling in the Benguela over the past two decades can only be inferred indirectly from the changes in the wind field, as previously discussed.

Sea level

Brundrit (1984) and Brundrit *et al.* (1987) reported changes in sea level (often used as a proxy for global warming) from tide gauge measurements at a number of sites between Swakopmund and Mossel Bay on the Cape South Coast between 1959 and 1985. Anomalies in excess of 5 cm above or below the long term mean were recorded at times, being particularly strong at Lüderitz. They noted that the nature of the sea level variability was similar to that in the eastern Pacific Ocean, and that as in that region, sea level and SST were apparently correlated. While they did not extract an estimate of the long term increase in sea level over the study period, it is evident from the greater frequency of positive anomalies at all of the sites, that there was probably a general rise in sea level throughout the region over these years.

From satellite data for the period 1993 to 1999, Hardman-Mountford *et al.* (2003) showed that sea level anomalies between the equator and the southern Benguela during this period seemed to be in phase with one another, decreasing in amplitude from north to south. Their data shows an overall rise of about 40 mm over the 7 year period (ie. ca. 6 mm yr^{-1}) in the equatorial region, dropping to about half this in the northern Benguela, and showed no obvious rise in the southern Benguela.

In Veitch (*Ed*.), (2007) it is stated that the mean rate of sea level rise in the Benguela upwelling region (period unspecified) has been of the order of the global average (ca. 1.8 mm yr^{-1} according to the 2005 IPCC Report). It is noted there that this rate is not considered to be a threat to persons or infrastructure along the south west African coast because of the relatively few low-lying developments there.

Low Oxygen Water (LOW)

Long-term variations in the extent of low oxygen water have differed in the three oxygen regimes (northern, central and southern) defined by Monteiro and van der Plas (2006). This can be seen from Figure 10 (extracted from Monteiro and van der Plas, 2006), which displays oxygen profiles recorded at a position on a) the Angolan shelf between 1995 and 2004, b) the outer shelf of the central Benguela over the same period, and c) a mid-shelf position off Cape Columbine between 1984 and 2004.

Figure 10a suggests that there has been an increase in the frequency of LOW events on the Angolan shelf since 2000, with a particularly strong event in mid-2002. A similar but more obvious trend is evident in the Central Benguela (Figure 10b). Continuation of the time series from 2004 shows that the trend has continued since then (Hutchings *et al.*, 2009). Seasonal fluctuations in LOW in this region are not in phase with upwelling intensity (as expressed by variations in SST) since the LOW is formed by a number of physical and biogeochemical processes which are not directly linked. Monteiro *et al.* (2008) have confirmed the importance of advected rather than biogeochemically-generated oxygen fluxes in determining seasonal-decadal variability in LOW, and have hypothesised that it is the coupling of ocean-shelf boundary conditions and the advection of these conditions onto the shelf that are responsible for most of the interannual variability of hypoxia in the region. They identified two long-term influences on hypoxia variations in their data set: viz. changes in the lag between seasonal warming at Cape Frio and peak ventilation from Lüderitz (the timing of the former being the more important) and the long-term warming of the Angola Benguela Front. They detected a general increase in lag between 1981 and 1999 from 11 to 16 weeks with much shorter lags in the *Benguela Niño* years of 1984 and 1995. The fact that the increase in lag between 1995 and 1999 is consistent with the increase in oxygen concentration at a depth of 100 m off Walvis Bay over this period is support for their hypothesis, which should now be tested by an examination of the lags in subsequent years, when oxygen concentrations in this position appear to have returned to more normal (ie. lower) levels.

Figure 10c shows a strong contrast in oxygen regimes in the southern Benguela between an aerated period in the 1980s and an oxygen deficient/hypoxic period in the 1990s, which Monteiro *et al.* (2006) attributed to a change from relatively weak wind fields in the 1980s to strong upwelling conditions in the 1990s. Figure 11, from Hutchings *et al.* (2009), shows a significant declining trend in oxygen levels below the thermocline in St Helena Bay since the early 1980s, while Figure 12 (in Hampton *et al.* (*Eds.*), 2009) indicates a marked increase in the offshore extent of LOW off St Helena Bay since 2005. All indicators, including an increasing frequency of rock lobster walkouts in Elands Bay since the 1980s (caused by anoxic conditions on the bottom), suggest a general decline in oxygen concentration below the thermocline in the southern Benguela over the past two decades.

Primary production/phytoplankton

It is generally assumed that long term shifts in upwelling-favourable winds will lead to changes in upwelling, and consequently, to changes in primary production and phytoplankton biomass on similar scales. There is little evidence to suggest that this has happened in recent decades in the Benguela, but there is evidence of substantial inter-annual changes in phytoplankton production at a number of times and locations in both the northern and the southern Benguela, as detailed below.

From an analysis of chlorophyll data from the NASA Coastal Zone Colour Scanner (CZSC) between 1979 and 1986, de Villiers *et al.* (1998) found that there were marked inter-annual variations in phytoplankton biomass off Cape Columbine and the Cape Peninsula during this period. These however seemed to be more related to large-scale oceanic circulation features and forcing mechanisms (particularly the advection of warm Agulhas Current water into key regions of the south east Atlantic) than to seasonal variations in upwelling. Verheye (2000) found an increase in the mean concentration of chlorophyll α at the surface in the St Helena Bay region in the early to mid-1990s, which was accompanied by a pronounced increase in phosphate, nitrate and silicate concentrations in the same area over the same time period. An index of integrated chlorophyll for the same area between January 2000 and July 2003, derived by Barlow *et al.* from satellite imagery (in Hampton *et al.* (*Eds*.), 2009) suggests that although there were marked peaks in production in some months, there was no overall trend over this period akin to that in the first half of the 1990s. The same index for the northern Benguela suggested decreasing integrated chlorophyll levels off Walvis Bay between 2001 and 2007.

Figure 2 shows a time series of monthly averages of chlorophyll concentration integrated between the coast and the 1 mg m^{-3} limit between 1997 and 2007 for the whole west coast of Southern Africa, derived from SeaWIFS data. The Figure shows that there were substantial seasonal and inter-annual variations in concentration along the coastline during this period (some of which have been detailed above), but does not show any obvious, broad changes in chlorophyll distribution or biomass over the region which might be indicative of a regional response to large scale climate changes in the region during that period.

Zooplankton

From a very long (1950 to 2006) time series of zooplankton biomass in St Helena Bay, Verheye and colleagues have deduced that between the early 1950s and the mid-1990s there was a 100-fold increase in the biomass of crustacean zooplankton (primarily copepods) in this area, followed by an approximately 10-fold decline over the remainder of the time series. In earlier work on this data set, Verheye *et al.* (1998) observed that the larger copepods declined in abundance from the early 1990s to the end of their time series on size structure (1996), co-incident with the decline in total copepod biomass during this period. Fig.13 (in Hutchings *et al*., 2009, updated from Verheye *et al*., 1998), which extends the time series to 2009, does not indicate a further decline in recent years. An important question is whether these changes were primarily caused by changes in the upward-propagating effects of oceanographic and biological processes (ie. control from the “bottom-up”) or from the “top down” by the impact of predators, particularly sardine and anchovy, which are abundant in the St Helena Bay area, feed on different size fractions of the zooplankton, and have undergone major changes in abundance and relative abundance over the time period due to heavy fishing pressure. In support of the bottom-up hypothesis, Verheye (2000) presents evidence of parallel decadal-scale changes across consecutive lower trophic levels in the southern Benguela, which he attributes to a long-term increase in wind stress. However, he also notes that the long-term increase in zooplankton biomass following the onset of commercial fishing in the early 1950s, and differences in the size structure in the copepod community between periods when sardine dominated the catches (1951 to 1967) and the 1980s when catches were dominated by anchovy, are evidence for a measure of top-down control as well. Negative correlations between the abundance of large copepods (the preferred prey of anchovy) and acoustic estimates of anchovy recruits on the West Coast in autumn and spawners on the South Coast in early summer (in Hutchings *et al*., 2006) are further evidence of top down control of the zooplankton by anchovy, at least of the larger size fraction.

A comparison by Verheye (2007) between copepod abundances in the northern Benguela between 1972 and 1990 from ichthyoplankton sampling during the South West Africa Pelagic Egg and Larvae (SWAPELS) survey, and from more recent monitoring off Walvis Bay, shows a roughly 10 fold increase in copepod abundance over the past three to four decades, with a decline after 2007 (see Fig.13). He found that, as in the southern Benguela, these changes were also accompanied by long-term changes in zooplankton community structure. In this region there is a much less obvious relationship between copepod biomass and pelagic fish catches (note for example the lack of a clear response to the collapse of the sardine fishery in the mid-1970s), although the increase in 2000 could be at least partly related to the effective disappearance of anchovy from Namibian waters in the mid 1990s (Boyer and Hampton, 2001). In all, it seems reasonable to conclude that although top-down control of zooplankton biomass may well have occurred in the northern Benguela up until the collapse of pelagic fish stocks there in the 1970s, it is unlikely to have been a significant controlling factor there since then because of the persistently low abundances of the major zooplanktivorous pelagic fish species off Namibia in the past three decades. There is more convincing evidence for the effect of major environmental perturbations such as *Benguela Niños* on zooplankton communities in this region.

It is tempting to see the decadal-scale changes in zooplankton biomass and community structure over the whole Benguela region as a response to a common long term change in ocean climate over this period. However, because of the confounding effects of the different histories of pelagic fishing in the northern and southern Benguela, probable regional differences in the degree of top-down versus bottom-up control over zooplankton communities, and the lack of independent evidence of a common long-term environmental change over the time period of the zooplankton record, such a conclusion would not be justified on current evidence.

Summary

From the foregoing, the following conspicuous, well supported long term trends in the environment can be identified. They are in most respects in accord with those extracted from much the same information at the BCLME Workshop on the Changing State of the Benguela in 2007, listed in Veitch (*Ed.*), (2007), and the broad overview of trends in the marine environment off South Africa compiled by Brundrit (2010) for the South African Department of Environment Affairs.

- There has been widespread warming of surface water at both the northern and southern boundaries of the system and in the northern Benguela over the past few decades, but a general cooling of inshore waters of the west and south coasts of South Africa over the same period. The latter has led to an intensification of cross-shelf SST gradients in the southern Benguela.
- The events with the most obvious consequences for marine life in the northern Benguela are the *Benguela Niños* and other such intrusions of warm, nutrient-poor water from southern Angola. Over the past decade the frequency of these events, and consequently the extent of low oxygen water in Namibian shelf waters, appears to have increased, although the time series may still be too short to assess whether these are continuing, long term trends or not.
- Averaged over the past few decades there has been a general increase in upwelling-favourable winds in the northern and southern Benguela in the summer months. These trends have however been subject to decadal scale modulations, with the northern Benguela currently being in a low phase. Notably, there is little evidence to suggest that there have been large-scale inter-annual changes in primary production in response to changing wind fields, which calls into question the link between the wind field and primary production on a broad scale in this system.
- All indicators suggest a general decline in oxygen concentration below the thermocline in the southern Benguela over the past two decades, at least in the St Helena Bay region. This is consistent with the general increase in upwelling-favourable winds in the southern Benguela over this period (see above), but not with the apparent absence of any broad trend in primary production.

- The mean sea level rise in the Benguela upwelling area is of the order of the global average, but is not considered to be a threat along the west coast of southern Africa.
- The abundance of copepods (the major zooplankton group) has increased by at least an order of magnitude in both the northern and southern Benguela over the past 40 years or so, accompanied by a substantial reduction in the proportion of larger copepods (the preferred prey of anchovy). These changes have been attributed to a combination of increased primary production and the reduction of predation by small pelagic fish removed from the system through heavy fishing pressure. Since the late 1990s there has been a reduction in copepod biomass in the southern Benguela, co-incident with the substantial increase in the biomass of both the sardine and the anchovy in the southern Benguela at that time. Because of the uncertainty regarding the relative importance of bottom up versus top-down control of zooplankton biomass, and the lack of clear evidence of a region-wide, long-term increase in primary production (despite such changes in the wind fields), it would be premature to attribute the apparent increase in copepod biomass in both the northern and southern Benguela primarily to a general increase in primary production in the region.
- The virtual removal of the wasp-waist species sardine and anchovy from the northern Benguela ecosystem in the 1970s and 1980s has resulted in a shift to a less efficient and less environmentally robust regime, believed now to be dominated by gobies, jelly fish and horse mackerel, with no sign of a recovery despite low fishing pressure on sardine and anchovy over the past two decades. In the southern Benguela the most obvious change in the ecosystem over the past few decades has been the shift in the distribution of sardine, anchovy and rock lobster to the Agulhas Bank in the late 1990s, the reasons for which are poorly understood but which are believed to be at least partly environmental. This shift is however not seen as being as far-reaching or as likely to be irreversible as that in the northern Benguela.

2.3 COMMERCIAL RESOURCES

In this Section, long-term changes in the biomass and/or distribution of the region's major commercial resources is examined on the basis of catch records and, wherever possible, catch-independent evidence (surveys etc.) because of deficiencies in commercial catches and catch rates as indicators of biomass and distribution.

Pelagic resources

Figure 14 shows, *inter alia*, the annual purse seine catches of sardine, anchovy and juvenile horse mackerel in the northern and southern Benguela between 1949 and the present. More detail on the South African pelagic catches is shown in Figure 15, and on the Namibian catches of sardine between 1990 and 2000 in Figure 16. The main features to note from these figures are:

- The increase in catches of sardine in South Africa from the early 1950s (when juvenile horse mackerel-not shown- were important in the fishery) to a peak and subsequent sharp decline in 1962.
- The entrance of anchovy into the South African fishery when the sardine declined in 1962 (brought about by a change to a smaller mesh size), and the dominance of anchovy in the catches until the early 1990s, when anchovy catches decreased and sardine catches increased, resulting in the two species being of roughly equal importance in terms of landings by the turn of the century. Since then the sardine and anchovy catches have been of similar magnitude on average, although the anchovy have dominated in the last 3 years.

- The steady increase in sardine catches off Namibia from the start of the fishery to a peak of 1.4 million tonnes in 1968. (Boyer and Hampton (2001) regard this as a minimum as it excludes under- or unreported catches from various sources). The subsequent decline was followed by a secondary peak in the mid-1970s and then a collapse in 1977/78 to levels consistently well below 100 000 tonnes per annum, at which level the sardine fishery has remained to this day. (In recent years, only a very low catches, aimed at keeping the fishery open for socio-economic reasons, have been allowed).
- The increase in importance of anchovy in the Namibian fishery from the early 1970s as sardine catches started to decline, and the decline, with a peak in 1987 (when it was believed that there was unusual recruitment from the south) to very low levels by the mid-1990s, which effectively marked the end of the anchovy fishery in Namibian waters.
- The original importance of juvenile horse mackerel in the South African purse seine fishery, followed by a steady decline to consistently low catches from the early 1970s.
- The appearance of juvenile horse mackerel in the Namibian fishery after the sardine collapse, and the continuation of this fishery at an erratic low level until the end of the time series.

In South Africa, the annual purse seine catch of round herring (which is considered to be under-exploited) over the last three to four decades has remained consistently below 100 000 tonnes (Figure 15) with no pronounced trends. The catches of round herring off Namibia have been negligible compared to this.

Commercial exploitation of small pelagic fish in Angola (sardinella spp., sardine and juvenile Cape and Cunene horse mackerel) started in the 1940s and expanded through the 1950s and 1960s. Catches increased sharply in the early 1970s following the introduction of larger, more efficient vessels, and peaked at around 600 000 tonnes in 1972. At this point the sardine fishery in the south, which up until then had been contributing around 50 000 tonnes per annum to the landings on average, declined abruptly, presumably following the sharp decline of the sardine stock in Namibian waters at that time. After a period of very low catches between 1974 and 1976 during the first years of independence, the sardinella and horse mackerel fisheries resumed. Catches of sardinella and horse mackerel reported to the International Commission for South East Atlantic Fisheries (ICSEAF) from 1976 to 1991 show that throughout this period Cape horse mackerel dominated the catch, and that there was a sharp decline in sardinella catches towards the end of the period. Note that these statistics cover catches from the entire Angolan coast, and that the proportion which was taken from within the BCLME itself (however defined) is unknown.

Since the introduction of acoustic surveys of pelagic fish in South Africa in 1983 (Hampton, 1992), Angola in the late 1985 (Sætersdal *et al.*, 1999) and Namibia after independence in 1990 (Boyer *et al.*, 2001), direct estimates of abundance, and fishery-independent maps of stock distribution have become available. Time series of acoustic estimates of sardinella and horse mackerel abundance in Angola between the early 1990s and the late 2000s are shown in Figure 17.

Figure 16, taken from Boyer and Hampton (2001), shows acoustic estimates of sardine biomass in the northern Benguela (including southern Angola in some years) between 1990 and 2000. The estimates fluctuate between around 500 000 tonnes in the early 1990s and almost zero in 1996 following the prolonged and intense environmental perturbations in 1994 and 1995, after which they increased somewhat to around 200 000 tonnes on average. The most recent available acoustic estimate of sardine spawning biomass (for 2009) is 62 000 tonnes. The total biomass estimate (including incoming recruits) for this year was 334 000 tonnes indicating good recruitment in the previous year. The final estimates for 2010 are not yet available.

Figure 17 shows a number of major trends in acoustic estimates of sardine and anchovy abundance in South African waters since the start of the time series, viz.:

- The increase in sardine spawner biomass from a very low level in 1984 to a peak of nearly 5 million tonnes in 2003, and the subsequent steady decline to levels of well below 1 million tonnes since then, albeit with a slight increase in the past two years. Note the similar pattern in the estimates of sardine recruitment earlier in the year, and particularly the 6 years of poor recruitment between 2004 and 2009.
- The fluctuating estimates of anchovy recruitment and spawner biomass) between 1985 and 1995, followed by the rise to a strong peak in spawner biomass of over 6 million tonnes in 2001, and the decline over the next two years to levels of about half this. Note the strong correspondence between the recruitment and spawner biomass estimates in each year throughout the time period.
- The fact that over a 4-year period between 2000 and 2003 the estimates are exceptionally high for both species, which is counter to what has often been found in other upwelling systems where sardine and anchovy commonly undergo periods of alternating abundance (eg. Schwartzlose *et al.,* 1999). Although the mechanisms have not been elucidated, it seems reasonable to assume that such a large, simultaneous increase in abundance of both species was mediated by environmental conditions becoming favourable for both of them at more or less the same time.

There have also been some major long term changes in the distribution of sardine and anchovy in both the northern and the southern Benguela since the start of the fisheries there, brought about by a combination of fishing and (possibly) environmental effects.

Night-time aerial surveys in the first half of the 1970s covering much of the Namibian coast (Cram and Hampton, 1976) showed that at this time (when the fishery was still strong) sardine tended to be aggregated in large discrete groups of varying size (termed "shoal groups") distributed along most of the coast from Cape Frio to south of Walvis Bay. Since the collapse of the stock, such groups appear to have become rare and much smaller, and to have been concentrated in the north of Namibia, where most of the spawning occurs, as opposed to earlier times when there was an important spawning area around Walvis Bay. (Note however the recent contention by Kreiner *et al.* (2011) that spawning in the south has become more common in the south in the 2000s, in keeping with a general warming of the northern Benguela during this period). There is less direct information on the distribution of anchovy when the fish were abundant, although it can be inferred from egg and larvae distributions (eg. O'Toole, 1977) that their distribution at that time was widespread north of Walvis Bay. Of interest is the unexpectedly large catch in 1987, which Boyer and Hampton (2001) suggest came from anomalous recruitment from south of Lüderitz and/or from further offshore.(This is the only direct evidence for either species of a connection between the Namibian and South African pelagic fish stocks). It can be assumed that with the almost total disappearance of anchovy from Namibian waters since 1995, the distribution of whatever stock remains is likely to be very contracted and sparse compared to that prior to the collapse (Boyd and Hampton, 2001).

In the early 1960s, sardine in South African waters spawned on both the west coast and the south coast, but later in the decade, spawning was confined to the south coast, coinciding with the decline in sardine abundance in the mid 1960s (van der Lingen *et al*., 2006). From then until 2001, the proportion of the spawning which occurred on the west coast fluctuated markedly, seemingly in response to increases in population size and in the biomass of sardine in relation to anchovy (van der Lingen *et al*., 2001). From the early 2000s, there was a return to predominant spawning on the south coast and an eastwards shift in the distribution (Figure 18, from Coetzee *et al*., 2008), co-incident with the increase in biomass, as evidenced by acoustic surveys and commercial catch patterns. No conclusive explanation for the apparent shift in distribution has been advanced, but Coetzee *et al.* (2008) considered it most likely that it was a consequence of the increase in biomass and area occupied by the eastern part of the population, exacerbated by a spatial mismatch between fishing effort and the resource, resulting in a disproportionally high rate of exploitation on the west coast. They did not however rule out environmental influences and enhanced local recruitment from the south coast (as opposed to the better- understood recruitment from the west coast) as alternative explanations. Very recent survey and catch information indicate some shift of the distribution back to the west, where spawning is once again occurring (Coetzee, *pers. comm.*).

There has also been an eastward shift in anchovy distribution in the southern Benguela over the past two decades (Figure 18), with more than half the biomass being found east of Cape Agulhas by the mid-2000s. As in sardine, the reason for this general, long-term trend is not understood, but Roy *et al.* (2007) have argued that the abrupt shift in 1996 and the subsequent consistently high proportion of the population east of Cape Agulhas was environmentally mediated by an abrupt increase in 1996 in upwelling on the south coast, and hence in favourable feeding conditions there. Unlike sardine, there are no indications from acoustic and ichthyoplankton surveys of a recent shift in distribution back to the west of the spawning population, or in the spawning itself (Coetzee, *pers comm*.), from which it would appear that conditions for spawning on the central and eastern Agulhas bank remain favourable at present. Whether this situation is beneficial for recruitment on the west coast (from which the bulk of the recruitment still originates), is unknown at present, although the good recruitment in all but two of the years during which the spawner biomass has been concentrated east of Cape Agulhas (Figure 17) suggests that it may well be.

An important question is whether the major long-term changes that have occurred in the sardine and anchovy biomass in the northern and southern Benguela were caused primarily by changes in their environment, or by the heavy fishing pressure to which these resources have been subjected for a long period (ie. a form of "top down" control). Boyer and Hampton (2001) noted that the collapse of the Namibian sardine in the mid-1970s followed the protracted warm water event between 1972 and 1974, classified by Shannon *et al.* (1986) as a *Benguela Niño* event, while Boyer *et al.* (2001) concluded that unfavourable environmental conditions such as the major *Benguela Niño* in 1995, exacerbated by heavy fishing pressure, were important factors in the decline of the Namibian sardine stock during the 1990s. Shannon *et al.* (2004) have concluded from trophic models that the changes in the populations of small pelagic fish in the southern Benguela were also environmentally driven. They found that variations in fishing pressure explained only 2 to 3 percent of the variability in catches and biomass between 1978 and 2002, whereas an environmental forcing function applied to phytoplankton production explained between 4 and 12 percent of the variability in the data set. A much larger amount of the variability (up to 40 percent) could be explained by variations in prey vulnerability to their predators. The study supports the hypothesis that small pelagic fish in the Benguela exert a "wasp-waist" form of control over the trophodynamics of the ecosystem (Cury and Shannon, 2004), in that they critically affect both their prey, and the predators which feed on them. In such systems, environmental changes may initiate ecosystem changes through direct effects on these species, which in turn effect other pelagic fish species as well as higher and lower trophic levels (Hutchings *et al*., 2006). Whatever the mechanisms, an argument in favour of control by environmental factors (including natural mortality) rather than fishing mortality in the past few decades is that large fluctuations in the catch and biomass of sardine and anchovy have occurred in both the northern and southern Benguela in the last 20 years or so despite the relatively low level of catches in both areas (particularly in Namibia) during this period.

Hake

Figure 14 shows annual catches of *Merluccius capensis* and *M. paradoxus* combined in the northern and southern Benguela since 1950, and Figure 19 more detail on the catches of the two species in South African waters from the start of the fishery to 2008. The large catches off Namibia prior to independence in 1990 were largely made by foreign fleets, which were excluded from the Namibian EEZ after independence. Figure 14 shows that catches have been sustained at a much lower and less variable level by local vessels since then. Figure 19 shows that hake catches in the southern Benguela have been lower on average, and less variable than off Namibia, although they were also highest in the first half of the 1970s, prior to South Africa's declaration of an EEZ in 1977. Note that in both regions the catches are more an indication of trends in the fishery than in the stock due to substantial changes in the nature and magnitude of the fishing effort and in the management measures employed at various times.

A more reliable indication of changes in the size of the region's hake stocks is provided by population assessment models fitted to commercial catch data and biomass indices derived from swept area bottom trawl surveys. The most recent model outputs are shown in Figs. 20 and 21 for the northern and southern Benguela respectively. Not evident in Figure 20, but clearly shown in the trawl survey estimates (van der Westhuizen, 2001) was a sharp reduction in biomass in 1997, which is consistent with the previously noted poor recruitment in 1995 which resulted from the intense and prolonged environmental perturbations in 1994 and 1995. Figure 21 indicates that in the southern Benguela, the *M. capensis* stock has recovered to nearly 40 percent of its pristine biomass since the introduction of the EEZ, and that over the same period the *M. paradoxus* stock has remained relatively stable at about 10 percent of its pristine level.

Since the early 1990s the distribution of *M. paradoxus* in Namibian waters has expanded northwards considerably, to the extent that it is now the major component of the Namibian hake catch, unlike in the 1980s when *M. paradoxus* were seldom found north of Lüderitz and the bulk of the hake catch in Namibian waters was *M. capensis.* Burmeister (2001) has attributed the expanded distribution to an increase in the size of the stock, which most evidence indicates is a single transboundary stock, shared with South Africa and fed by spawning in South African waters, predominantly on the Agulhas Bank (Burmeister, 2005). (As previously noted, all current evidence suggests that *M. paradoxus* do not spawn in Namibian waters). The commercial importance and transboundary nature of this stock, and consequently the need for regional management of the *M. paradoxus* fishery, has been a major motivation in the setting up of the Benguela Current Commission, *inter alia*, to facilitate a regional response to effects of climate change on the stock.

Horse mackerel

Catches of Cape and Cunene horse mackerel combined in the northern Benguela (including Angola) and the southern Benguela between 1950 and 2007 are shown in Figure 14. Note that the catches of Cape horse mackerel in the northern Benguela, and in the southern Benguela since the late 1960s, have largely been made by trawlers, (particularly large midwater trawlers in the case of Namibia), which target the adult fish. The juveniles are largely caught by purse seine in both regions. The trawl catch of horse mackerel in Namibia has been the largest by volume in that country since the rapid growth in the fishery in the 1970s, and has continued at a level of around 300 000 tonnes per annum under quota control to the present day, with something of a decline in recent years. The trawl catch in South African waters is largely a by-catch of the hake bottom trawl fishery, with some targeted midwater trawling for large adults on the eastern Agulhas Bank. Any catch trends in this fishery therefore probably reflect changes in effort, exploitation strategy and fish behavior rather than changes in biomass. Most of the Cunene horse mackerel catches have come from pelagic fishing of juveniles in Angola, but this sector of the fishery was closed in 2007 due to concerns over the state of the stock.

Acoustic estimates of horse mackerel biomass in Angolan waters have been made since 1985 when annual surveys were started under the Norwegian – funded Nansen Programme (Sætersdal *et al*., 1999). Estimates have been made for Cape and Cunene horse mackerel separately, although it is often difficult to separate the two species acoustically. The estimates for the region between the Cunene River and Benguela (12º 40' S) up until 1992, which were obtained from surveys by the first *R.V. Dr Fridtjof Nansen,* are shown in Figure 22. Note that the estimates should be seen as relative rather than absolute because of great uncertainty concerning the target strength of horse mackerel (Boyer and Hampton, 2001). The estimates in Figure 22 fluctuate over an order of magnitude even over short periods, which is suggestive of marked interannual changes in distribution, acoustic detectability and/or behaviour (affecting, *inter alia*, target strength) rather than changes in stock size.

Since 1990, the combined biomass of adult and juvenile horse mackerel (mainly *T. t. capensis*) off Namibia and southern Angola has been estimated by annual acoustic surveys. The estimates generally fall between 1 and 2 million tonnes, with the most recent available estimate (for 2009) being in the region of 1.3 million tonnes (2009 MFMR Annual Report). As in the Angolan horse mackerel surveys, these estimates should be regarded as relative rather than absolute because of target strength uncertainties. Note that even the apparent trends are questionable because of the possibility of interannual variations in the acoustic detectability of the fish related to changes in their behaviour, and in their average target strength. Nonetheless it would appear, both from the reasonably consistent catches and acoustic estimates that there have been no changes in horse mackerel abundance off Namibia over the past two decades of the order of those experienced by sardine and anchovy there in the 1970s, 1980s and early 1990s

Although there are estimates from bottom trawl and acoustic surveys of various components of the horse Cape horse mackerel stock in South African waters (eg. Kerstan and Leslie, 1994, Barange *et al*., 1998), there are no comprehensive survey estimates for the entire stock in South African waters, nor of trends in stock size.

There is no compelling evidence of long term shifts in the distribution of either Cape or Cunene horse mackerel in the region as a whole, although there is evidence to suggest that the distribution of both species in northern Namibia and southern Angola is sensitive to movements of the Angola Benguela Front (e.g. Sætersdal *et al*., 1999). It therefore seems reasonable to assume that any major long-term shift in the position of this Front would affect the distribution (and thereby possibly the abundance) of horse mackerel in this area on similar temporal and spatial scales.

West Coast rock lobster

It can be seen from Figure 14 that catches of West Coast rock lobster in both Namibia and South Africa have fallen to very low levels since the height of the fisheries in the 1950 and 1960s. The decline was particularly dramatic in Namibia, where catches fell from a peak of nearly 9 000 tonnes in 1966 to a level of a few 1 000 tonnes per annum in the 1970s and 1980s, followed by an abrupt decline to around 100 tonnes per annum in the early 1990s. Estimates of biomass from a variety of observational and modeling techniques have confirmed that the exploitable biomass has declined to only a few percent of pristine in both areas, although there are encouraging signs of a slight recovery in the Namibian stock in recent years (MFMR 2009 Annual report).

The declines in rock lobster production in both areas in the early decades of the fisheries are clearly a result of over-exploitation, but there is evidence to suggest that the simultaneous declines in the late 1980s/early 1990s were at least partly induced by some common environmental effect (Boyer and Hampton, 2001). Off Namibia it has been attributed partly to changes in availability brought about by intrusions of low oxygen water into the fishing grounds, whereas the decline in South Africa over the same period is thought to have been a result of reduced somatic growth rates in response to adverse feeding conditions (eg. Pollock *et al*., 1997). The continuation of the decline in the southern Benguela during the 1990s and early 2000s has been attributed to an increase in mass strandings and reduced growth caused by an increase in low oxygen events along on the West Coast during this period.

There has been a gradual, large-scale shift to the east in the distribution of rock lobster in South African waters since the early 1990s, evident for example from changes in the proportion of the catch taken from the West and South Coasts shown in Figure 23. Cockcroft *et al*. (2008) have attributed the shift, which has resulted in heavy depletion of sea urchin and thereby abalone stocks in the newly-inhabited nearshore areas on the South Coast, to the long-term decline in the oxygen content of water below the thermocline in inshore areas along the West Coast (cf. Figure 11).

Other resources

Other commercially important resources in the Benguela which have undergone major long-term changes in abundance and/or availability to the fishery since the start of catch records include snoek in both the northern and the southern Benguela (see Figure 14), orange roughy *Hoplostethus atlanticus* off Namibia, where catches have dropped from over 10 000 tonnes per annum in the late 1990s (Boyer and Hampton, 2001), to virtually zero at present, and a wide range of linefish species, many of which have declined in abundance, to the point of near extinction in some cases. Although the possibility of environmental influences on some of these declines cannot be ruled out, it is probably safe to conclude that most, if not all of them were primarily due to overfishing in earlier decades before effective management controls could be introduced.

2.4 TOP PREDATORS

The Cape fur seal population in the southern Benguela was over-exploited to near extinction off the Cape coast in the 18th and 19th centuries, primarily for oil production, but has recovered after the introduction of conservation measures in the early 20th century. Aerial census figures show that the number of pups increased at a rate of about 2 to 4 percent per annum between 1970 and 1990, and that since then the birth rate has stabilized at about 100 000 pups per annum, with no major fluctuations in abundance (Figure 24). The situation is somewhat different in the northern Benguela, where there is still a small harvest for pelts. Here the records show that the recruitment has undergone a number of large inter-annual fluctuations since the first census in the mid-1970s (Figure 24). These are believed to be linked to changes in both food availability and environmental conditions (Roux, 1998). The major environmental anomaly in the mid 1990s was particularly harmful, causing a drastic reduction in the condition of both pups and adults, and high mortality and breeding failure at all the Namibian colonies (Boyer and Hampton, 2001). This was clearly a result of poor food availability over most of the seals' habitat. Nonetheless, it is interesting to note that the birth rate did not appear to be affected by the major decline in the sardine population in the mid 1970s, demonstrating the animal's ability to switch diet in response to changes in prey availability (sardines were the preferred prey up until that point) in all but the most extreme situations. The maintenance of the birth rate in recent decades at roughly the levels of the 1970s and 1980s, despite the very low level of pelagic fish stocks in Namibia during this period, is further evidence of this ability.

The major long-term changes in seal distribution that have occurred since the introduction of protection measures have mainly been in the establishment of new mainland colonies off Namibia. Occasional extensions of the Namibian population into southern Angola have been recorded in recent decades. It is not known whether similar excursions occurred in earlier times, nor whether these excursions have been primarily driven by changes in environmental conditions or food availability, or perhaps by some combination of the two.

Figure 24 also shows the changes in breeding area of Cape gannets and in the number of breeding pairs of African penguins in the northern Benguela and southern Benguela in the past 6 decades. It can be seen that in the northern Benguela the gannet breeding area declined drastically between the mid-1950s and 2000, but that in the southern Benguela the area has been increasing steadily since the early 1980s. In the Benguela system as a whole, the numbers of African penguins decreased approximately 10-fold during the 20th century (Crawford *et al*., 2001). In the northern Benguela, where there was a particularly strong decline in the second half of the century, the decline has continued at a rate of about 1.8 percent per annum (in van der Lingen *et al*., 2006). Figure 24 shows that in the southern Benguela, numbers decreased fairly rapidly from the 1950s to the late 1990s, but that they have fluctuated about a somewhat higher level since then.

The long-term declines in the gannet and penguin populations in Namibia since the mid-1970s are clearly related to the collapse of the populations of sardine and anchovy (their preferred prey) there in the 1970s and 1980s. Similarly, the general increase in the number of breeding penguins in the southern Benguela in the late 1990s could well be related to the unusually large populations of both sardine and anchovy on the Agulhas Bank in those years. Note that the eastwards shift in the sardine and anchovy populations in the southern Benguela in the late 1990s has been accompanied by an eastward shift in both the gannet and the penguin populations in the southern Benguela, whereas in the northern Benguela, the decline in the penguin population has been accompanied by a northward shift of the breeding colonies (Kemper *et al.*, 2001).

2.5 REGIME SHIFTS

A question of primary concern in this review is whether any of the long-term ecosystem changes that have been observed in the Benguela since the start of comprehensive data collection constitute regime shifts, and if so, whether any of them can be primarily attributed to climate changes of the kind which may be expected in the region in future.

For the purposes of this discussion, the definition of a regime shift proposed by de Young *et al*. (2004) is adopted, viz: *a rapid change from a quantifiable state, representing substantial restructuring of the ecosystem, acting over large spatial scales and persisting for long enough that a new quasi-equilibrium state can be observed*. (This definition was also adopted by Jarre *et al.* (2006) in their discussion on possible bases for detecting and predicting long-term ecosystem changes in the Benguela).

The changes in the trophodynamics of the northern Benguela ecosystem following the collapse of the pelagic fisheries there in the 1970s and 1980s, discussed in the previous Section, clearly constitute a regime shift which was in all likelihood caused primarily by overfishing of first the sardine and then the anchovy resource. Watermeyer *et al*. (2008a) calculated that between 1967 and 1990 the mean trophic level (MTL) of the catches in the northern Benguela increased, as did the weighted trophic level of the community (excluding detritus and plankton) after the collapse of the small pelagic stocks. They attributed these increases in MTL to the declines in biomass of the small pelagic fish and the increase in the relative importance of horse mackerel catches during this period, rather than as being indicative of a healthy ecosystem. It is less certain whether the prolonged hypoxia and warming events in 1994 and 1995, and the subsequent severe effect on many of the resources, resulted in a regime shift, since many of the resources affected have subsequently recovered, and there is no conclusive evidence to suggest that the ecosystem now is functioning any differently to the manner in which it functioned immediately prior to these events. Watermeyer *et al.* (2008a) have however pointed out that, in line with Odum's (1985) hypothesis on the increased vulnerability of stressed ecosystems to environmental change, these events could well have had a greater negative influence over the already depleted stocks than previous such events, and hindered attempts to rebuild stocks through reducing fishing pressure on them. If so, it would mean that the present system is more sensitive to changes in the physical and biological environment than in earlier times, particularly before the onset of commercial fishing. It could be increased sensitivity to environmental perturbations, together with the reduced efficiency with which primary production is now being passed on to higher trophic levels, that has prevented the system from returning to a more productive state despite the greatly reduced catches of small pelagic fish in the past two decades.

Changes in the southern Benguela ecosystem since the beginning of the 1950s have not been as drastic as those which occurred in the northern Benguela in the 1970s and 1980s. Nonetheless, two long term changes which qualify as regime shifts according to the definition adopted here have been identified by Howard *et al.* (2007), using a sequential t-test algorithm for analyzing regime shifts (START). The first occurred in the late 1950s, when horse mackerel were replaced by sardine in the pelagic fishery, possibly co-incident with the period of increased upwelling identified by Shannon *et al.* (1992), and the second in the late 1990s and early 2000s, when sardine and anchovy biomass was simultaneously high, and the populations and spawning areas of both species were concentrated on the South Coast rather than the West Coast. Howard *et al.* attributed the first shift to fishing with some environmental influence, and the second primarily to the environmental changes on the Agulhas Bank described by Roy *et al.*, (2007). Calculations by Watermeyer *et al.* (2008b) indicate that the MTL of the catch changed little between the 1960s and the 2000s, although this may not be true of the ecosystem as a whole (cf. recent criticism by Branch *et al.*, 2010, of the use of the MTL in catches as an indicator of the trophic structure of an ecosystem). The other fluctuations in the distribution and abundance of small pelagic fish and their prey which have occurred since the start of the sardine fishery in the 1950s are not thought to be indicative of regime shifts as here defined since they have been highly variable, reversible and often of short duration. In that sense, even the major shift in the distribution of sardine to the South Coast in the late 1990s and early 2000s could be questioned as an indication of a regime shift since there is evidence of a recent shift in the distribution of the fish and their spawning back to the West Coast (J. Coetzee, *pers. comm.*). Whatever the reason for the fluctuations in abundance and distribution of sardine and anchovy since the 1960s, the fact that at no stage have both species effectively disappeared from the ecosystem (unlike in Namibia) suggests that they have continued to perform their important function as wasp-waist species in the ecosystem since the start of the commercial fishery on them. According to Odum's (1985) hypothesis, the southern Benguela ecosystem should therefore be less sensitive to environmental change than the northern Benguela is at present.

3. Predictability/forecasting

In this Section, the possibility of predicting change in the Benguela ecosystem on the basis of current information and understanding of the system's functioning is briefly examined. Model-based forecasts of environmental responses to generally anticipated changes in global climate are considered, and various possible scenarios which have been put forward regarding the way in which the biota could respond to such responses are discussed. The Section concludes with a brief consideration of the utility for fisheries management of any predictions or forecasts about the state of the resources which could currently be made on the basis of prior information on the environment.

3.1 MODEL PREDICTIONS OF ENVIRONMENTAL CHANGE

Of the various manifestations of global climate change which have been identified, that which appears to be least disputed is that there has been a general warming of the earth's lower atmosphere in recent decades, at last partly due to anthropogenic effects, particularly the build-up of greenhouse gases. The likely effects of continuing atmospheric warming on the world's oceans are less clear, due partly to deficiencies in the current Global Circulation Model and in models of the coupling between the atmosphere and the ocean on appropriate scales. For example, the ocean-atmosphere model of Bryan et al., (1988) suggests that in the southern hemisphere, there will be a lag of more than 20 years between warming of the atmosphere and the surface layer waters due to upwelling and downwelling processes on either side of the Antarctic Circumpolar Current. If true, this would give a long lead time for developing the understanding necessary to predict the effects of observed atmospheric warming on sea surface temperatures and the consequential effects on the Benguela ecosystem. Note however that the general increase in SST in the waters around southern Africa over the past few decades suggests a much shorter lag time if this warming has indeed been caused primarily by global warming in the earth's lower atmosphere. Clearly, greater understanding of links between the atmosphere and the ocean is crucial for forecasting the long term effects of climate change on the Benguela ecosystem, and for developing long range strategies for responding to predicted changes.

Although numerical modeling of large scale interactions between the atmosphere and the ocean in the Benguela, and of physical and chemical responses in the ocean environment has advanced rapidly over the past decade (eg. Shillington *et al.*, 2006, Monteiro *et al.*, 2006), it is probably true to say that none of the existing models is capable of predicting the effects of atmospheric warming on the hydrodynamics of the Benguela ecosystem with an adequate degree of certainty at present. This is partly due to a shortage of not only ocean data, but also the land surface and atmospheric data needed to improve the models and validate their outputs (Reason *et al.*, 2006); a problem which is likely to persist for some time.

Shillington *et al.* (2006) pointed out that the potential for forecasting large scale variability in the BCLME depends mainly on how well the processes that transfer remote signals from the equatorial region and the Agulhas retroflection area to the Benguela are understood, and identified a number of processes which have been characterised well enough to be built into an early warning/forecasting system for the BCLME. They concluded that the best prospects are for inter-annual or seasonal processes such as variations in equatorial upwelling intensity and timing of trade winds, movement of the Angola/Benguela Frontal Zone and ring shedding from the Agulhas retroflection, and that the most difficult processes to forecast are the local influences on upwelling at relatively short time scales (days – months).

Certain extreme events in the Benguela, notably *Benguela Niños*, the formation of low oxygen water and hydrogen sulphide eruptions, do appear to be predictable to some extent from current understanding. Florenchie *et al.* (2003 and 2004) postulate that *Benguela Niños* may be anticipated about 2 months in advance by tracking the oceanic disturbance which results from the sudden change in zonal wind stress in the western equatorial Atlantic as it crosses the Atlantic and then travels poleward along the coast. Note however that modulating influences from local processes such as variations in upwelling intensity and the intrinsic variability in the Angola/Benguela Frontal Zone (Colberg, 2006) may weakening the strength of any such predictions. Monteiro *et al.* (2006b) noted that the 2 month lead time would also apply to the prediction of large scale intrusions of LOW from the north which are associated with *Benguela Niños* events. (By implication, hydrogen sulphide eruptions off the Namibian coast, which are associated with LOW intrusions, may also be predictable this far ahead). Monteiro *et al.* (2006b) also considered that LOW events leading to the walk-out of rock lobster in certain areas in the southern Benguela such as St Helena Bay could be forecast about a week ahead of time on the basis of a two phase wind-driven model of the development of harmful algal blooms in the region. Bernard *et al*. (2006) have considered the monitoring requirements for such a forecasting system.

3.2 PREDICTING RESPONSE OF RESOURCES TO ENVIRONMENTAL CHANGE

Prediction of the response of marine resources to environmental changes has been the goal of long term intensive environmental research in the region for many years, particularly in the southern Benguela. For example, attempts have been made to predict anchovy and sardine recruitment there on the basis of environmental information since the early 1980s. However, despite a wealth of information on environmental conditions, the physiological condition of the fish and the distribution and abundance of all life history stages from eggs and larvae to the oldest spawners, and some success in the prediction of anchovy recruitment over a relatively short time period (eg. Roy *et al*., 2001), no recruitment predictors robust enough to be widely used in management have yet emerged. Recruitment prediction for most other species (even for hake, where the data series are even longer, although not as comprehensive) and of adult survival rates has been equally problematical, with little prospect of significant improvement in the near future. The inevitable conclusion is that even if changes in the marine environment can be forecast sufficiently far in advance, difficulties in predicting the response of marine resources to such changes is likely to limit the use of this information in management. The best that can probably be done at present is to use current understanding of the environmental processes, and of the responses to them in a qualitative sense, to construct plausible scenarios of changes in the ecosystem due to climate change. A number of these which would have negative consequences for the resources of the northern Benguela, presented to the BCLME Climate Change Workshop by Roux and Kreiner (Veitch, *Ed*. 2007), are listed below.

- Widespread reduction in coastal upwelling leading to a warm, tropical and low productivity system with disastrous effects on current fisheries for temperate species.
- Enhanced upwelling leading to enhanced productivity, increased turbulence and offshore advection. Negative consequences of this would include an increase the local production of LOW through biogeochemical processes, and therefore an increased risk of hydrogen sulphide eruptions
- An increase in the severity and frequency of Benguela Niños, leading to a decrease in productivity, and increased vulnerability of fish stocks to over-exploitation.

- A non-linear response of the ecosystem to general, low-amplitude changes in the ecosystem induced by gradual climate change, producing a succession of rapid regime shifts between semi-stable states. It was postulated that such shifts would have the most impact on the pelagic fisheries of the region.

It must be emphasised that these scenarios are purely conjectural, and that their likelihood (or that of alternative scenarios) cannot be quantitatively assessed from current information. Note too that they have been limited to negative outcomes for the resources of the region, whereas a number of positive outcomes (which may be just as likely) could possibly be envisaged.

In a brief summary of the possible effects of climate change on fish resources of the southern Benguela, prepared for the South African Department of Environment Affairs, Brundrit (2010) posed the following possible scenarios which would or could affect the industry negatively:

- General warming of the surface waters leading to them eventually becoming more tropical in nature
- A continuation of the shift in pelagic fish distribution to the South Coast
- Decreased oxygen concentrations in the St Helena Bay region, and in the poleward transport of LOW from Namibia
- Increased frequency of storms and extreme winds
- Increased acidification of surface waters

He speculated on the general effects which might be expected from such changes in the environment, but not on their likelihood or the possible rate at which they could occur.

3.3 USE OF PREDICTIONS IN MANAGEMENT

Viewed overall, it would appear that although much progress has been made in understanding the functioning of the Benguela ecosystem on many different levels since the speculations on its possible response to climate change by Siegfried *et al.*, Shannon *et al.* and Crawford *et al.* in 1990, much has still to be learned before any predictions based on new understanding can be used in management of the region's marine resources. A possible exception is the far greater appreciation of the origin and significance to marine life of *Benguela Niños* in the northern Benguela, which could now be taken into account in management advice, at least in a qualitative sense. In contrast, the net effect on resources of changes in the retroflection of the Agulhas Current (believed to be a major driving force in the southern Benguela) is still totally unpredictable at present despite the greatly increased understanding of its dynamics and the ease with which its surface expression can be monitored through satellite imagery.

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Climate change implications for fisheries of the Benguela current region

Making the best of change

FAO/Benguela Current Commission Workshop
1-3 November 2011
Windhoek, Namibia

These are the proceedings from the Workshop on "Climate change implications for fisheries of the Benguela Current region: making the best of change" held in Windhoek, Namibia, from 1 to 3 November 2011, organized by the Benguela Current Commission in collaboration with the FAO Fisheries and Aquaculture Department.

The meeting included participants representing climate change and fisheries issues from Angola, Namibia and South Africa who discussed the regional biophysical features and decadal trends in the Benguela Current Large Marine Ecosystem (BCLME) as well as the national contexts and implications of climate variability and change for fisheries in the basin. The meeting identified vulnerabilities specific to the fisheries and dependent communities and recommendations for actions to increase adaptability and resilience of the fisheries systems. The meeting recommended that a regional programme be developed with the aim of reducing vulnerability and increasing adaptive capacity of the social-ecological fisheries systems of the BCLME, primarily focusing on: (i) establishing and/or improving national and regional interagency collaboration and communication to facilitate responses and action in relation to climate change; (ii) developing and implementing a holistic and coherent methodology for vulnerability assessment of fisheries; and (ii) developing and implementing pilot projects to develop and test anticipatory and responsive actions, providing for lesson learning/sharing and improvements.

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