Empowered lives.
Resilient nations.

Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems

Large Marine Ecosystems
Volume 17

Empowered lives.
Resilient nations.

UNDP partners with people at all levels of society to help build nations that can withstand crisis, and drive and sustain the kind of growth that improves the quality of life for everyone. On the ground in 177 countries and territories, we offer global perspective and local insight to help empower lives and build resilient nations.

www.undp.org

The GEF unites 182 countries in partnership with international institutions, non-governmental organizations (NGOs), and the private sector to address global environmental issues while supporting national sustainable development initiatives. Today the GEF is the largest public funder of projects to improve the global environment. An independently operating financial organization, the GEF provides grants for projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants. Since 1991, GEF has achieved a strong track record with developing countries and countries with economies in transition, providing $9.2 billion in grants and leveraging $40 billion in co-financing for over 2,700 projects in over 168 countries.

www.thegef.org

June 2012

Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems

304 East 45th Street, 9th Floor
New York, NY 10017, USA
www.undp.org/water

GEF Secretariat Global Environment Facility
1818 H Street, NW
Washington DC 20433, USA
www.thegef.org

Editors: Kenneth Sherman and Galen McGovern

Cover photo: © Front and back cover image of earth from space, courtesy of NASA from Apollo series.

Frontline Observations on Climate Change and Sustainability of Large Marine Ecosystems

Edited by Kenneth Sherman and Galen McGovern

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Large Marine Ecosystem Program
Narragansett Laboratory
Narragansett, RI

Table of Contents

5

CLIMATE CHANGE AND VARIABILITY OF THE AGULHAS AND SOMALI CURRENT LARGE MARINE ECOSYSTEMS IN RELATION TO SOCIOECONOMICS and GOVERNANCE

David H. Vousden, James R. Stapley, Magnus A.K. Ngoile, Warwick H.H. Sauer and Lucy E.P. Scott

INTRODUCTION

In 2008, the GEF and nine countries of East Africa and the western Indian Ocean region (Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa and Tanzania) agreed to provide financial and logistical support to a project for restoring and sustaining the goods and services of both the Somali Coastal Current LME, and the Agulhas Current LME and adjacent areas, in a single project entitled the Agulhas and Somali Current LMEs Project (ASCLME).

Figure 1. Location of the Somali Coastal Current LME and the Agulhas Current LME along the coast of east Africa (from Sherman and Hempel, 2008).

The Somali Coastal Current LME extends from 10°S in the south to 11°N in the north. The eastern boundary of the Somali Current LME extends northward along the coasts of Tanzania, Kenya, and Somalia, gradually tapering off as it approaches the Horn of Africa's tip.

Despite a series of direct observations of the Somali Coastal Current, a unified concept is still missing that could explain the observed variability of this western boundary current. Yet the two opposing views of regional circulation recognize a key role played by the monsoon (Schott and McCreary, 2001; Fieux, 2009). According to the first view (Schott and McCreary, 2001), the Somali Current is driven by the southwest monsoon during the boreal summer and extends northeastward all the way to Ras Hafun, a major cape at 10.4°N; during the boreal winter the current reverses due to the northeast monsoon and flows southwestward. The second view (Fieux, 2009) postulates the existence of two large-scale gyres that are most prominent during the summer monsoon when the southwesterly winds drive upwelling circulation off the coasts of Kenya and especially Somalia. During the boreal winter, the dominant northeasterly winds result in the spin-down of the Somali gyres. The regional circulation is further complicated by current reversals in the subsurface, intermediate, and deep layers (Reid, 2003). During the south west monsoon, wind-induced coastal upwelling brings cold, nutrient-rich water to the surface layer, creating favorable conditions for fisheries, while the sharp contrast between cold upwelled water and warm offshore waters creates sharp SST fronts easily detected from satellite imagery (Belkin, Cornillon, and Sherman 2009; Heileman and Scott 2008).

The Agulhas Current LME extends from 10°S in the north to 37°S in the south, covering a large area of southern African waters off the coasts of Mozambique and the Republic of South Africa, and encompassing the islands of Madagascar and Comoros. The Agulhas Current is a warm western boundary current flowing southwestward along the east coast of South Africa, retroflecting south of the Cape of Good Hope, then flowing eastward as the Agulhas Return Current (Lutjeharms 2007, Heileman, Lutjeharms, and Scott 2008). The source area of the Agulhas Current is characterized by a series of clockwise and counterclockwise eddies south of the Madagascar and Mozambique Channel; this area is also affected by the East Madagascar Current (Siedler et al. 2009). The Agulhas Current, Agulhas Retroflection and Agulhas Return Current are, respectively, the northern, western and southern limbs of the Southwest Indian Ocean subtropical gyre.

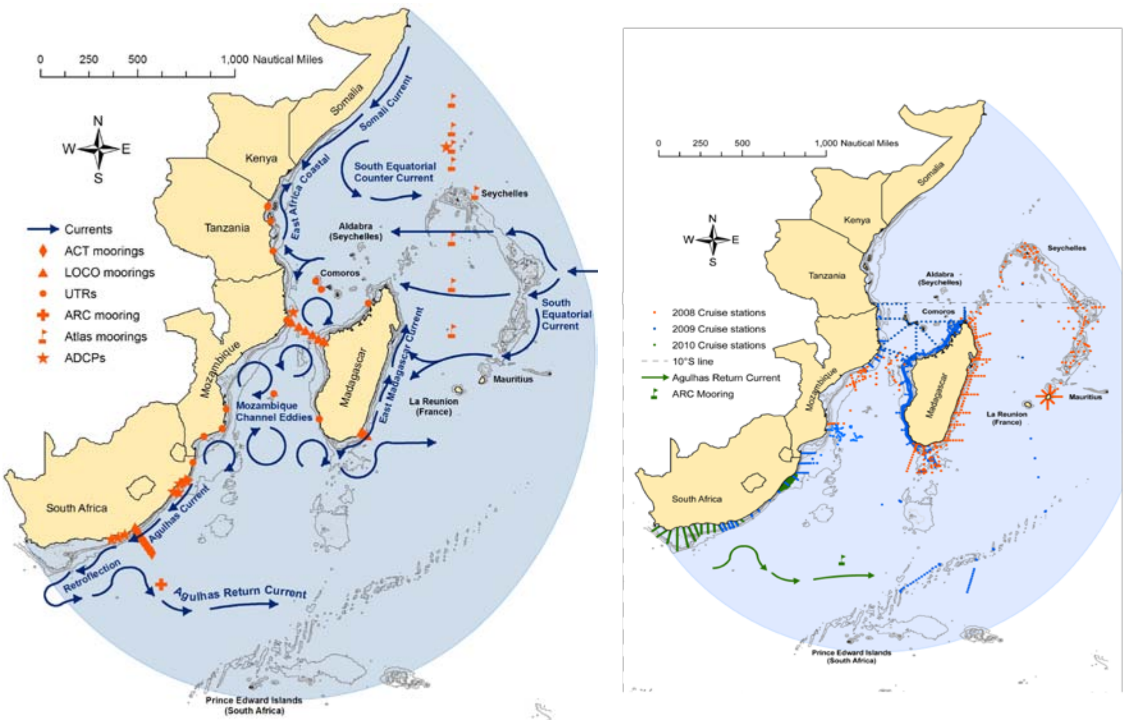

Figure 2. The ASCLME system boundary for project activities and data capture is denoted by the blue ellipse. The left hand panel denotes the known prevailing current patterns in the region (as defined or confirmed through the Project) along with deployed long-term monitoring instrumentation currently in place. In the summer, the prevailing current directions and their positions alter under the influence of monsoons, the circulation pattern of the Somali Current and the East African Current is reversed while the South Equatorial Counter Current tends to move northwards. The right-hand panel shows cruise sampling stations to date. It is notable that piracy activity in the northern region has precluded the deployment and maintenance of the northernmost ATLAS and ADCP moorings. Maintenance of the more southerly moorings is also increasingly threatened by such security issues.

The region's sectoral management and research bodies operate as a "western Indian Ocean" bloc, particularly in East Africa and the island states (Comoros, Madagascar, Mauritius, Seychelles and the French Indian Ocean Territories). This long term cooperation is proving useful for effective management of transboundary issues. To this end, the UNDP-supported, GEF-financed ASCLME Project (www.asclme.org) is coordinating regional efforts to manage the region's marine and coastal resources. This approach is enhanced by building partnerships and alliances and strengthening existing institutions, along with a comprehensive data and information collection program (Vousden et al. 2008).

Efforts to Consolidate and Build Scientific Knowledge through Development of Partnerships

The multi-national, transboundary management actions needed in the ASCLME require as much relevant information as possible at national level and garnering additional scientific information where data gaps are identified. The ASCLME Project created a novel approach to the traditional Transboundary Diagnostic Analysis (TDA)/Strategic Action Programme (SAP) approach adopted by GEF-funded International Waters projects - comprehensive Marine Ecosystem Diagnostic Analysis (MEDA) reports. These reports, compiled at a national level, give detailed insight into the state of knowledge and help harness sparse literature and other difficult to access information. The MEDA reports are vital and build support and understanding for the project. The MEDAs include comprehensive bibliographies of existing information, which will be invaluable in long term management. Ultimately, this information will be distilled into the regional TDA and be essential background information for the SAP, which will drive the implementation of management actions throughout the region. The MEDAs also provide a valuable foundation for National Action Plans/Programs and therefore provide a useful anchor for the TDA and SAP process in each country.

The ASCLME Project and its partners have undertaken several research cruises in the region. However, these efforts have been hampered by the effects of piracy on security in the northern part of the ASCLME region, and have precluded international research activities (Jones, 2011; Smith et al. 2011). A "Piracy Exclusion Zone" was put into effect, marking the area where the risk of attack was considered unacceptable. This was initially set at 10°S in 2008, but was subsequently moved to 12°S. As a result, there is a significant gap in our knowledge of the region including the extent of moored *in-situ*, long-term monitoring equipment in the exclusion zone. Given the dynamic nature of the Somali Current area, with seasonally reversing currents and an unusual tropical upwelling system, more *in situ* research is warranted. There is a large knowledge gap in the more northerly regions of the ASCLME. Plans are under development to try and address this gap through more detailed analysis of remote sensing products, repatriation of historic data, reconstruction of fisheries data, and a more recent objective to deploy autonomous gliders (self-propelled data collection platforms) within this system.

To supplement targeted research cruises and gain insight into variability caused by seasonal and other patterns, the ASCLME Project has deployed long term instrumentation and made use of existing datasets. Currently, ocean observing systems are sparse in their coverage compared with corresponding terrestrial and atmospheric systems, although programs like Argo (a global network of drifting floats that measure temperature and salinity in the upper 2,000 meters of the ocean) are helping to fill in this critical gap, along with a growing constellation of increasingly sophisticated environmental monitoring satellites.

The subsurface Long-term Ocean Climate Observations (LOCO) array has monitored current flow in the Mozambique Channel for nearly a decade (Ridderinkhof & de Ruijter, 2003; Ridderinkhof et al. 2010). In 2010, this network was extended off southwest Madagascar to monitor variability of the poorly understood East Madagascar Current. This data will form a key foundation of understanding of the broader system and provide a detailed baseline record for measuring future variability.

Further long term monitoring sites include a network of Underwater Temperature Recorders (UTRs) and current meters (ADCP – Acoustic Doppler Current Profilers) throughout the region. The Agulhas Current Time-series (act.rsmas.miami.edu/) will supply a detailed three year record of the Agulhas Current, the first such long-term data set. The ACT will likely prove vital in understanding and modeling this important oceanographic feature.

The ASCLME Project also seeks to understand the interaction between the ocean and the atmosphere. Arrays like ATLAS (Autonomous Temperature Line Acquisition System) moorings will help to correlate oceanographic parameters in the upper 500m of water column with *in situ* atmospheric measurements. In essence, an ATLAS mooring is a comprehensive atmospheric weather station above an "ocean weather station." In the Indian Ocean, this array is called RAMA (The Research Moored Array for African- Australian Monsoon Analysis and Prediction; McPhaden et al. 2009). See Figure 3 below.

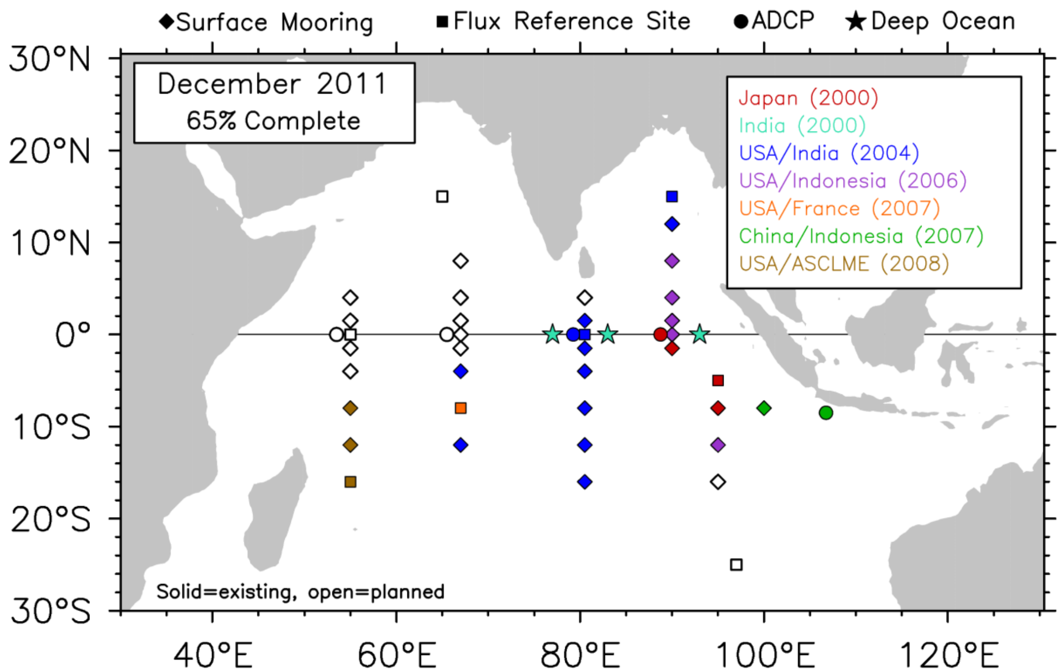

Figure 3. RAMA sites in the Indian Ocean. Note the absence of sites in the areas affected by piracy. Continued maintenance of the northerly 55ºE moorings is now threatened. Unfilled shapes denote sites with no currently deployed instrumentation. Image courtesy PMEL/NOAA http://www.pmel.noaa.gov/tao/rama/.

Such instrumentation is augmented with remote sensing (satellite) observations which require regular calibration from *in situ* measurements and are often hampered by cloud cover. The ATLAS moorings also cannot penetrate much beyond the surface of the ocean, leaving vast areas of the oceans effectively unmonitored (and usually unstudied).

The ATLAS moorings also record temperature and current data to a depth of 500 m and the LOCO moorings provide similar data down to 1000 m plus (with CTDs down to 2,600m). However, their limited coverage (3 ATLAS moorings along the 55 degree east longitude and a recently reduced coverage of 8 LOCO moorings east and west of Madagascar) leaves vast areas of these oceans effectively unmonitored on a permanent basis (and much of it unstudied).

Much of this instrumentation and data capture and analysis are being orchestrated through partnership agreements between ASCLME and a number of national, regional and overseas institutions (e.g. NOAA – US National Oceanic and Atmospheric Administration: NIOZ – the Royal Netherlands Marine Research Institute; ACEP – the African Coelacanth Ecosystem Programme; DEA – the South African Department of Environmental Affairs; DAFF - the South African Department of Agriculture, Forestry and Fisheries).

The ASCLME Project is also a partner in a number of regional and global ocean and atmosphere observing initiatives and contributes towards the objectives of GOOS (www.ioc-goos.org) in the western Indian Ocean. GOOS is designed to be a permanent system of observations, modeling and analysis to support operational ocean services worldwide. Members contribute platforms of observation, including ARGO floats, drifting buoys, installed devices on commercial and recreational vessels, research vessels, commercial ships and open-ocean moorings.

It may sometimes be challenging – if not impossible – to determine whether the ecosystem-level effects of environmental change are due to climate change *versus* environmental change caused by other human activities (e.g. fisheries, coastal development, pollution). In most cases, these impacts will likely act in concert.

Challenges to Communication and Implementation

There is often a somewhat uneasy relationship between management/governance and research/science realms. Much of this likely stems from miscommunication and misunderstanding than from truly different goals or insurmountable differences. A route must be found to surmount the “disconnect” between the two realms.

Researchers typically want to ensure their research has achieved statistically significant results at the 95% or greater level before making recommendations, while policy-makers and managers typically need answers in very short timescales. Good research takes time, and much of this research requires decadal or longer time series data for rigorous scientific consensus to emerge. Unfortunately, management of the marine environment often cannot wait until such studies are completed (where they have even begun), and requires a much more dynamic and responsive interplay between the research community and governance/management bodies.

Many policy-makers feel that scientific language is impenetrable, and conversely, researchers feel they are misunderstood by policy-makers. Clearly, there is a role for skilled scientific communicators who translate the data and information created by research for the needs of policy and management agencies. Such policy advice must convey not only factual information, but should also provide several alternative management scenarios with associated risks, which policy-makers can use to balance the various, often conflicting, needs of society as a whole.

Political changes can lead to the loss of government officials who are well acquainted with the marine environment. Assuming that all policy-makers will be familiar with these issues is unrealistic. It is likely that communication and mentorship efforts are best focused upon middle and senior management in civil service and management institutions, rather than party political structures.

The private sector has a profound impact on the marine environment and is often overlooked. Key sub-sectors engaged in utilizing the goods and services of the ASCLME are marine transport, tourism, aquaculture, mining and fisheries. Many companies within these industries see environmental issues as a marketing or social responsibility. This provides significant opportunities. Rather than forcing behavior through legislation, private sector participation can be encouraged through, for example, vessel of opportunity programs which provide monitoring data; voluntary installation of vessel monitoring systems; fisheries observers programs; and other commercially supported research/monitoring activities by offering incentives such as tax credits. Consumer perception is another powerful incentive in societies that place a premium on environmental concerns. Given that large corporations control larger budgets than many governments, these potential avenues of support should certainly be explored.

Further challenges exist in fiscal, human and infrastructural capacities within the region. Composed of developing world economies and small island states, areas of expertise can be fragmented, particularly in terms of offshore marine science. Here the ASCLME has taken a novel approach, where each country has produced a National Training Plan, which not only summarizes present capacity and training available in each of the participating countries, but proposes key national areas for priority intervention. A key starting point has been the recognition that while the ASCLME project has been able to train a significant number of individuals in the region, to be sustainable we need to work on institutional support. States also face other pressing developmental commitments, and much of the research equipment available, including research vessels, is of advanced age. Where equipment does exist, there is often a lack of expertise available, due a lack of training and staff turnover. Taking this into account, the ASCLME is compiling a Regional Training Plan. One key element of this plan is the formation of a Capacity Building and Training Alliance, made up of key training institutions throughout the region. Thus, regional training priorities can be discussed and regional priorities can be addressed. On-going and future monitoring programs will make the best use of the limited research vessels available and data from remote sensing, drifting sensors and moorings.

Environmental Variability

"Environmental Variability" consists of seasonal or other periodic cycles, distinct from climate change, and results in shifting patterns or intensities.

The continued political instability in Somalia and the related piracy activities have precluded international research activities in the northern parts of the ASCLME (Jones, 2011; Smith et al. 2011). This reduces our ability to detect change and precludes the generation of a contemporaneous detailed baseline assessment as conducted in the South.

Aside from seasonal changes and weather, the two overriding drivers of large scale environmental variability in the ASCLME region are the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). The impacts of these events can have profound effects on the region and it would be useful to be able to accurately predict them, or at least have some advanced warning of them, at the governance level.

Observed Impacts of Environmental Variability and Climate Change

Existing literature, international research, and findings from the ASCLME project illustrate the environmental variability and effects of climate change in the region. Sea level rise and warming are having specific impacts in the region. Although the global mean for sea level rise since 1992 (observed by altimetry) has been on the order of 3.4 mm per year, it has become clear that this rise is not uniform; in particular, a trend of up to 10 mm per year has become apparent around the Indian Ocean islands (Cazenave and Llovel, 2010). Although the Indian Ocean has experienced some of the strongest warming globally (up to 1ºC increase since 1950), work undertaken in the WIO region during the ASCLME project has shown that the Agulhas Current has significantly warmed by up to 1.5^{o} C since the 1980s (Rouault et al. 2009; Mathieu Rouault, University of Cape Town, pers. comm.). There is evidence that this warming is due to an intensification of the Agulhas Current system in response to an increase in trade winds in the south Indian Ocean.

Marine Life

Several living marine resources (including sardine, anchovy, west coast rock lobster and horse mackerel) seem to be shifting from the neighboring BCLME into the ASCLME region, presumably due to a response to climate change (van der Lingen et al. 2006, Cockroft et al. 2008). Sardine, *Sardinops sagax* and anchovy, *Engraulis encrasicolus* are particularly important in the diet of several seabirds, notably penguin. Shifts in west coast rock lobster distribution are affecting the breeding of bank cormorant, *Phalacrocorax neglectus* (Crawford et al. 2008). These movements have lead not only to knock-on effects on the ecosystem (notably on the African penguin, *Spheniscus demersus* (Crawford et al. 2011) and the Cape gannet, *Morus capensis*, along with other seabird and predatory species) but also on the socio-economic status of coastal communities. Canneries along the western coast of South Africa and Namibia have closed in response to the shift in stocks to the southeast.

Another concern is the effect of climate change on temperate marine flora and fauna, including endemic species, along the southern and Eastern Cape regions of South Africa. Strengthening prevailing westerlies are driving increased inshore upwelling of cold, deep water in the west, making inshore waters colder - while the Agulhas Current seems to be strengthening and warming (up to 1.5°C since 1980; Rouault et al. 2010) in the East. This may also be contributing to inshore upwelling along the landward edge of the Agulhas Current (Lutjeharms et al. 2000). The combined “pincer effect” from simultaneous warming and cooling will undoubtedly affect those species which depend on the temperate conditions which once prevailed. The effects will likely manifest as range shifts, contractions and/or extinctions. Current-driven upwelling brings water unsaturated with carbonate minerals up onto the shelf. With the possibly compounding threat of ocean acidification, it is unclear what effects such upwelling will have on calcifying organisms. It may pose a threat to southerly reefs which are considered “refuges” for corals in a warming climate. Inshore upwelling occurs both along the landward edge of the Agulhas Current (Lutjeharms et al., 2000) and along the landward edges of eddies in the Mozambique Channel when these eddies impinge on the shelf (for a recent summary of observational characteristics of such eddies see Swart et al. 2010).

It is unknown what effects warming oceans are likely to have on much of the rest of the ASCLME region. Of particular interest are the Mozambique Channel eddies, which have shown a trend in increasing Eddy Kinetic Energy (EKE) in the past, but this now seems to be decreasing again. These eddies create localized upwelling and productivity and interact with the coastal shelves, creating upwelling and drawing inshore water offshore. The eddies have been shown to be of major importance to the productivity in the area and they strongly affect distribution and behavior of top predators (Kai and Marsac 2010, M. Roberts pers. Comm.). The eddies are also related to downstream effects on the Agulhas Current, notably in the formation of Natal Pulses and, in turn, the shedding of Agulhas Rings (van Leeuwen et al. 2000). Studies of greater frigate birds, *Fregata minor*, show foraging activity is strongly correlated with eddies. The birds are dependent on these systems for food supplies and their feeding is associated with the presence of tunas. It is likely that these fish utilize the eddies due to their associated enhanced productivity (Weimerskirch et al. 2004).

The Agulhas Current as part of a global system

Increasing research in the region has begun to illustrate just how dynamic the Agulhas Current system and its upstream sources are. The research shows the current system forms a critical link in the global thermohaline circulation and climate system (e.g. Beal et al. 2011). Modeling studies and observations to date have suggested that increasing temperatures will likely lead to an increase in the transport of warm, salty Agulhas Current LME water into the South and ultimately North Atlantic. This transport can offset the disruptions to the Atlantic Meridional Overturning Circulation (AMOC) from increasing freshwater inputs from melt water. Paleooceanogeographic records further indicate the pivotal role of the Agulhas Current in the world's climate, particularly its behavior (cessation) during glaciations and inter-glacial (strengthening) periods in the Northern Hemisphere. However, it is also possible Agulhas Current leakage may cease if transport increases too much. Van Sebille et al. (2009) suggested the leakage of the ASCLME into the Atlantic would cease at 87 Sv (1 Sv = 10^6 m^3 s^{-1}). Rouault et al. (2009) note Agulhas Current transport is increasing at 3.9 Sv/decade from a current level of approximately 69.7±4.3 Sv (Bryden et al. 2005). Such measurements confirm the Agulhas Current, along with the Gulf Stream Extension, to be one of the strongest western boundary currents in the world.

Impacts of ENSO

The El Niño Southern Oscillation (ENSO) impacts the region generally during the warm phase of ENSO (El Niño), and causes drier than normal conditions in Southern Africa, and wetter than normal conditions over equatorial East Africa (normally from December to February). Conversely, the cool phase of ENSO (La Niña), causes wetter than normal conditions in Southern Africa, and drier than normal conditions over equatorial East Africa (from December to January). In the extreme, these are coupled with flood and drought conditions in respective parts of Africa. In 1997-1998 ENSO was associated with extremely wet conditions in East Africa, while the 1999-2000 event probably caused the devastating flooding in Mozambique. Although the linkages between ENSO and rainfall in the region are not totally clear, monitoring sea surface temperatures together with additional work on modeling will yield models with predictive capacities for government use. A significant link between prevailing sea surface temperatures associated with ENSO events and outbreaks of the economically important and potentially life-threatening Rift Valley Fever in East Africa illustrates the importance of such models. It is possible to provide a several-month warning before outbreaks are likely to occur, allowing time to install mechanisms to manage or mitigate the potential outbreak in both livestock and people (Anyamba et al. 2009).

Impacts of IOD

The Indian Ocean Dipole (IOD) is an irregularly oscillating ocean-atmosphere phenomenon in the Indian Ocean whereby sea surface temperatures in the western Indian Ocean become alternately warmer or cooler than the eastern part. It is normally characterized by anomalous cooling of SST in the south-eastern equatorial Indian Ocean and anomalous warming of SST in the western equatorial Indian Ocean (Vinayachandran et al. 2009). Approximately 50 percent of IOD events are associated with ENSO events, but the rest are not. IOD events cause the normal convection situated over the eastern Indian Ocean warm pool to shift to the west. This brings heavy rainfall over East Africa and severe droughts and forest fires over the Indonesian region. Convection (and the associated vertical transfer of heat) over the eastern and western Indian Ocean during the monsoon behaves like a seesaw - enhancement of one is associated with the suppression of the other. During 'positive' Dipole events, there is a tendency for increased rainfall in the tropical eastern Africa and WIO region and drought in Indonesia. Recently there have been far more positive events and far less negative dipole modes than recorded in the past. The variability of East African rainfall has a profound impact on the livelihoods of millions of people in the developing countries in the WIO region, who mainly depend on rain-fed agriculture and regional fisheries. The impact of IOD on the climate of the entire Indian Ocean and bordering countries is significant and, therefore, it is absolutely necessary that the scientific community be able to forecast its evolution well in advance. Sea surface temperatures are considered to be a key indicator for monitoring drought and heavy rain conditions in this region.

Aside from the obvious impacts of the IOD on rainfall, another effect is on the tuna fisheries of the region. IOD events are associated with reduced tuna catches in the Indian Ocean due to an apparent shift in the vertical distribution of these fishes; IOD conditions result in a deeper suitable temperature habitat range, reducing availability to the purse seine fisheries (Marsac & Le Blanc 1999, Vialard et al. 2009). This also potentially affects the economies of the region dependent on this fishery, notably the Seychelles (Res et al. 2010).

Mozambique Channel Eddies

Within the ASCLME Region, another cause of large scale variability is the presence of mesoscale dipole eddies in the Mozambique Channel. Research over the last decade has shown that no persistent north to south current exists; rather, several large eddies propagate down the channel (e.g. Swart et al. 2010). Such flow patterns have several important impacts on the channel, including fisheries, productivity, nutrient movement and presumably larval dispersal. Much of the nutrient input into the region is derived from eddy-driven upwelling. The exact triggers for the formation of an eddy in this region are not well understood. On average approximately four eddies travel down the channel per annum (Schouten et al. 2003, Swart et al. 2010). Eddies are also associated with the Agulhas Current and linkages have been observed between eddies, Natal Pulses and Agulhas Ring shedding (van Leeuwen et al. 2000). Understanding the dynamics of this system will be critically important for the management of the region's marine resources.

Impacts on Human Population

An estimated 55 million people depend on the marine and coastal resources of the ASCLME region. The coastal population is increasing at a rapid rate, partly through population growth, and partly from inland to coastal migration. This rate can exceed 10 percent per annum in some areas of East Africa.

Reconstructions of fisheries data by the *Sea Around Us* group at the University of British Columbia indicate that so-called "small scale" artisanal and subsistence fisheries produce catches that have been under-reported by as much as 500 percent. This catch may well equal, if not dwarf that of "industrialized" fisheries throughout the region. Studies in Mozambique (Jacquet and Zeller, 2007a) and Madagascar (Le Manach et al. 2012) show the artisanal and subsistence fisheries account for up to 87% and 72% of the total national catch respectively. In Tanzania, population growth has increased pressure on the fishery and unsustainable fishing methods may be threatening food security. Actual catches may be about 1.7 times larger than those reported to FAO from 1950-1970, due to chronic under-reporting and the omission of Zanzibar from official catch reports (Jacquet and Zeller, 2007b; Jacquet et al. 2010). Zeller and Pauly (2007) outlined the disparity in fishing efficiency, by catch, carbon costs, and economic and social benefits of "small scale" fisheries vs. large scale/industrialized fisheries. Such "small scale" artisanal and subsistence fisheries likely employ the bulk of people working in the fisheries sector. In addition, these fisheries normally use little, if any fossil fuels and produce little if any discards/bycatch compared with industrialized fisheries, and may be a more socio-economically and environmentally sustainable option, although in some cases (South Africa) industrialized fisheries have been shown to be a better option. The state of such small scale fisheries directly impact three Millennium Development Goals (www.un.org/milleniumgoals/), namely food security, poverty alleviation and long-term fisheries stability. In a situation where increasing numbers of people are growing ever more reliant on living marine resources for their livelihoods, the allocation of fisheries resources may be viewed as a human rights issue and a critical consideration in the development and management frameworks of countries throughout the region, and indeed throughout the developing world.

Climate change and the related problem of ocean acidification are likely to exacerbate threats to many livelihoods throughout the region, particularly those dependent on living marine resources. Many fisheries in the region are associated with coral reef ecosystems. Both warming, a known trigger of coral bleaching, and ocean acidification are likely to decrease the ability of corals to build their calcium carbonate skeletons. Weakening corals threaten to undermine the fisheries that depend on this habitat and the communities who depend on these fisheries. This may also threaten other ecosystem goods and services such as the protection of coastlines from erosion and storm surges.

Of course, the effects of climate change and environmental variability are far-reaching, and climate change will not be restricted to only the coastal zone. It is expected that ocean warming will exacerbate the frequency and perhaps intensity of severe weather events, and make environmental variability more chaotic. A dynamic and near-real time Long Term Monitoring system, tied into appropriate regional and national mechanisms, should help decision-makers to react to developing extreme conditions (Early Warning System) in time to prevent and/or mitigate catastrophic impacts on local communities. Also, detailed models may lead to fine-scale climate projections which can be used to plan adaptation and mitigation at local levels. We anticipate that developing monitoring networks will feed into such models, to keep them adjusted to real-world changes in addition to helping verify their predictive power through hind cast simulation.

Climate change will drive the resurgence and spread of tropical diseases, notably malaria (Hay et al. 2002). Approximately 90 percent of the mortality caused globally by malaria takes place in sub-Saharan Africa. In 2009, there were 781,000 deaths caused by malaria and in 2000, 985,000 people died from malaria, while well over 200 million people were affected by the disease. The negative effect on GDP in the region was 1.3 percent (www.who.int/mediacentre/factsheets/fs094/en/). This disease represents an extremely large burden on health care systems in the developing world, and accounts for 40% of health care budgets, 30-50% of hospital admissions and 60 percent of outpatient visits. Malaria, like so many pressures, disproportionally affects those living in poverty who least can afford illnesses. Besides issues like malaria, cardio-vascular and respiratory effects associated with heat waves and climate change, as well as malnutrition, cause additional deaths. The Indian Ocean and ENSO-affected hinterland sub-Saharan African regions are particularly at risk (Patz et al. 2005).

Economic Value of the ASCLME Region

The ASCLME/South West Indian Ocean Fisheries Project (SWIOFP) joint Cost Benefit Analysis has estimated that the coastal and marine resources of the ASCLME region contribute approximately US$22 billion a year to the GDP of the countries of the region. Coastal tourism contributed the largest amount to GDP at an estimated US$11 billion a year, followed by fisheries, coastal agriculture and forestry. Currently, the fisheries of the ASCLME region generate approximately US$68 million per year as resource rent (i.e. the difference between the price at which a resource can be sold and its respective extraction or production costs, including normal returns). US$59 million of this amount is generated by ASCLME countries. The fisheries of the ASCLME support about 2.7 million full and part time workers (Teh and Sumaila, 2011), generating wages of about $366 million per year. On the other hand, owners of fishing capital earn normal profits of US$60 million per year. Rebuilding and effectively managing fisheries of the ASCLME could result in annual gains of US$ 221 million while wages and the overall economic impact could increase by US$10 million and $43 million per year, respectively. In terms of distribution and equity, we find that most of the economic benefits from the coastal and marine resources of the ASCLME remain in the countries of the region.

Toward a novel management paradigm

The LME approach offers many innovative ideas towards the implementation of effective and holistic marine ecosystem management. Further challenges still exist to ensure that policy and governance structures not only embrace the approach, but ensure it receives long term support (financial, infrastructural and political). Bridging the disconnect between policy/governance/management structures and research bodies presents a challenge, and will be imperative to achieve successful interaction between data and management.

During the development and implementation of the ASCLME Project, it became clear that communication between policy/management (governance) and the technical (scientific) level was generally insufficient throughout the region. While this is a global problem, successful implementation of the LME approach demands dynamic interaction between the governance and scientific components to ensure adaptive management and required action by the countries. To this end, the ASCLME Project engaged the post of a “Policy and Governance Coordinator” to specifically focus attention and effort on building relationships with government officials. The “science-to-governance” process is not uni-directional and is equally a “governance-to-science” process. The need for this process is supported by the momentum generated by the project’s activities and partnerships at all levels, leading to a Science-to-Governance workshop/roundtable in Grahamstown in June 2011, which spurred many ideas conveyed in this paper. Based on the results and discussions arising at this roundtable meeting, ASCLME and its partners (i.e. SWIOFP, IUCN et al.) decided to place more emphasis on what is now referred to as a Science-Based Governance (SBG) approach, both at the national and regional level. National level SBG roundtables are now planned throughout 2012 to seek inputs and guidance from countries on how best to improve the communications process, as well as to guide the evolution of an effective mechanism to deliver scientific results and conclusions to the adaptive management process.

Clearly, novel mechanisms to ensure multilateral engagement and communication must be sought and implemented. In one potential tool, ASCLME and its partners are moving toward exploring and developing a dynamic management process based on a “Weight-of-Evidence” approach, which acknowledges that scientific consensus and existing datasets will not always be able to answer management/policy/governance information needs at high levels of statistical certainty, yet realizing decision-makers will still have to act – despite such informational constraints. This approach recognizes the Precautionary Principle as the starting point for identifying a need for adaptive management but steps beyond that to ensure that enough data can be collected to convince a comprehensive and multidisciplinary peer group of experts that trends are obvious despite the possible absence of 95% plus confidence limits. This weight of evidence is then further substantiated by prioritizing those issues for further study and data capture and thus gradually improving the confidence limits. In the meantime, adaptive management measures and actions are recommended though an interaction between the peers/experts and management /policy groups. With the rapidly changing status of ecosystems and their drivers (climate, water quality, resource exploitation/extraction) such proactive management is a necessity.

The Weight-of-Evidence approach (Figure 4) should encourage researchers to offer information and perhaps several alternative management scenarios with their associated risks, and with the implicit understanding that such advice may be incomplete and subject to change. Conversely, if policy-makers find their information is incomplete, they can advise the scientific and academic community and active research programs can be developed/modified to address those needs. This has clear benefits for both parties.

For managers and decision-makers at the policy level, this approach will take decision-making beyond the 'precautionary' approach which is often seen as being based more on supposition than strong evidence and which therefore leaves policy-makers feeling vulnerable and indecisive. It will also provide senior government leaders at the economic/finance level and management level with clearer guidance on where to prioritize activities and funding in terms of both immediate management needs and further research (this also extends to the funding agencies of course).

For scientist and research groups, this will raise the profile and importance of science generally in the policy-making and management process and encourage more support and funding to arrive at more reliable results as quickly as possible. It will also provide more precise guidance to the scientific community on which areas of research are priority and most likely, therefore, to attract funding

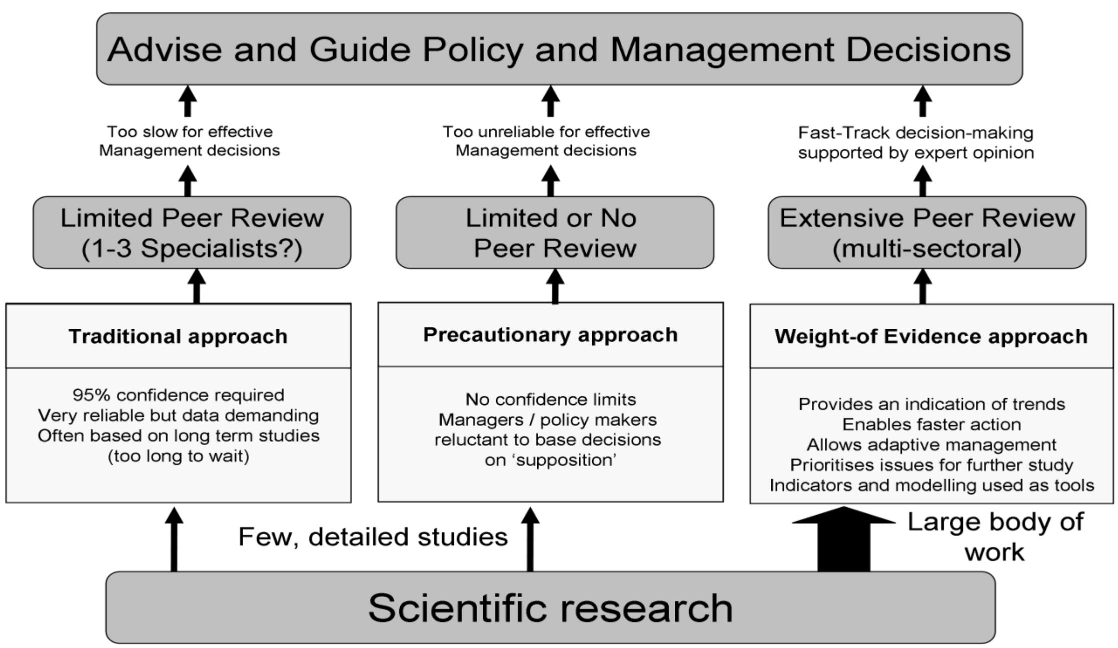

Figure 4. Diagram illustrating the proposed Weight-of-Evidence approach compared to the traditional 'confidence limits-based' and precautionary approaches.

Translating research information into policy advice and funneling policy/management information needs into targeted research projects has been a problem. In the past, this two-way flow of information has rarely been effectively implemented. There is a need to involve not only researchers and decision-makers but also a diverse range of stakeholders, including high-level funders, the private sector, civil society and communities. The process will require skilled practitioners who not only have the requisite understanding of sometimes complex, multidisciplinary scientific fields, but also a comprehensive understanding of the harsh realities of politics and the socio-economic balancing act that policy-makers must tackle. To some extent, the burgeoning field of "science communication" has an important role to play, but researchers, managers and policy-makers must also commit to working together to overcome these challenges.

The pressing issues of climate change and environmental variability underline the importance and critical nature of an adaptive, integrated management process to ensure the ongoing health and prosperity of the region.

CONCLUSION

There is an urgent need to complete on-going studies within the ASCLME region to establish an effective baseline for both coastal and offshore indicators in the productivity, fish and fisheries and ecosystem health and pollution modules of the LME approach. Relating these to the communities of the region through the socioeconomics module, and particularly the impacts of and vulnerability to environmental variability and climate change is important. It is imperative that this information is translated into robust mechanisms for adaptive management in the governance module. To sustain these efforts in the long term, it is necessary to create not only sound and well-supported policy and governance structure(s), but also a robust network of research and training institutions and monitoring programs which will feed reliable and timely information into resource management actions.

ACKNOWLEDGEMENTS

The Agulhas and Somali Current Large Marine Ecosystems Project is supported by the United Nations Development Program (UNDP) and funded by the Global Environment Facility (GEF). The partner countries, Comoros, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, South Africa and Tanzania, provide in-kind co-financing, and Somalia has special "country observer" status. Significant additional resources have built on the Project's cruise schedule through partnerships including with fellow GEF financed projects (Seamounts, SWIOFP and WIO-Lab), international research organizations (IRD, NIOZ, NOAA), IGOs (IOC/UNESCO) and NGOs (IUCN, WWF).

REFERENCES

Anyamba, A., J-P Chretien, J. Small, C.J. Tucker, P.B. Formenty, J.H. Richardson, S.C. Britch, D.C. Schnabel, R.L. Erickson, and K.J. Linthicum. 2009. Prediction of a Rift Valley fever outbreak. PNAS Jan 20, 2009 106(3):955-959.

Beal, L.M., W.P.M. De Ruijter, A. Biastoch, R. Zahn, and SCOR/WCRP/IAPSO Working Group 136. 2011. On the role of the Agulhas system in ocean circulation and climate. Nature 472:429-436.

Belkin, I.M. 2009. Rapid warming of large marine ecosystems. Progress in Oceanography 81: 207-213.

Belkin, I.M., P.C. Cornillon, and K. Sherman. 2009. Fronts in large marine ecosystems. Progress in Oceanography 81: 223-236.

Bryden H.L., Beal, L.M. and L.M. Duncan. 2005. Structure and transport of the Agulhas Current and its temporal variability. J. Ocean. 61(3):479-492. DOI: 10.1007/s10872-005-0057-8

Cazenave, A. and W. Llovel. 2010. Contemporary Sea Level Rise. Annual Review of Marine Science, Vol. 2: 145 -173.

Cockcroft A.C., D. van Zyl, and L. Hutchings. 2008. Large-scale changes in the spatial distribution of South African West Coast rock lobsters: an overview. Afr. J. Mar. Sci. 30(1):149–159

Crawford, R.J.M., A.C. Cockroft, B.M. Dyer, and L. Upfold. 2008. Divergent trends in bank cormorants *Phalacrocorax neglectus* breeding in South Africa's Western Cape consistent with a distributional shift of rock lobsters *Jasus lalandii*. Afr. J. Mar. Sci. 30(1):161-166.

Crawford, R., R. Altwegg, B. Barham, P. Barham, J. Durant, B. Dyer, D. Geldenhuys, A.B. Makhado, L. Pichegru, P.G. Ryan, L.G. Underhill, L. Upfold, J. Visagie, L.J. Waller, and P.A. Whittington. 2011. Collapse of South Africa's penguins in the early 21st century. Afr. J. Mar. Sci. 33(1):139-156.

Fieux, M. 2009. Somali Current. In: Encyclopedia of Ocean Sciences, edited by John H. Steele, Steve A. Thorpe, and Karl K. Turekian, 2nd edition, Elsevier Ltd., pp. 153-162.

Hay, S.I., J. Cox, D.J. Rogers, S.E. Randolph, D.I. Stern, G.D. Shanks, M.F. Myers, and R.W. Snow. 2002. Climate change and the resurgence of malaria in the East African highlands. Nature 415:905-909.

Heileman, S., Scott, L.E.P. 2008. Somali Coastal Current LME. In: Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas, editors: K. Sherman and G. Hempel, UNEP Regional Seas Report and Studies No. 182. p. 159-171. United Nations Environment Program. Nairobi, Kenya.

Heilman, S. J. Lutjeharms, and L. Scott. 2008. Agulhas Current LME. In: Sherman, K. and G. Hempel. The UNEP Large Marine Ecosystem Report : A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No. 182. p. 145-158. United Nations Environment Program. Nairobi, Kenya.

Jacquet, J.L. and D. Zeller. 2007a. National conflict and fisheries: Reconstructing marine fisheries catches for Mozambique, 1950-2004. Fisheries Centre Working Paper#2007-02 2007. University of British Columbia.

Jacquet, J.L. and D. Zeller. 2007b. Putting the 'United' in the United Republic of Tanzania: Reconstructing marine fisheries catches.

Jacquet, J., H. Fox, H. Motta, A. Ngusaru, A. and D. Zeller. 2010. Few data but many fish: marine small scale fisheries catches for Mozambique and Tanzania. African Journal of Marine Science 32(2): 197-206.

Johnson, D.R., M. Mutua Nguli, E.J. Kimani. 1982. Response to annually reversing monsoon winds at the southern boundary of the Somali Current. Deep Sea Research 29(10A) :1217-1227.

Jones, N. 2011. Pirates scupper monsoon research. Nature. 7 July 2011. doi:10.1038/news.2011.402

Kai, E.T. and F. Marsac. 2010. Influence of mesoscale eddies on spatial structuring of top predators' communities in the Mozambique Channel. Progress in Oceanography 86: 214-223.

Le Manach, F., C. Gough, A. Harris, F. Humber, S. Harper and D. Zeller. 2012 Unreported fishing, hungry people and political turmoil: the recipe for a food security crisis in Madagascar? Marine Policy 36(1):218-225.

Lutjeharms, J.R.E. 2007. Three decades of research on the greater Agulhas Current. Ocean Science 3:129-147.

Lutjeharms, J.R.E., J. Cooper, and M. Roberts. 2000. Upwelling at the inshore edge of the Agulhas Current. Continental Shelf Research 20:737–761.

Marsac, F., and J.-L. Le Blanc. 1999. Oceanographic changes during the 1997–1998 El Niño in the Indian Ocean and their impact on the purse Seine fishery. Proc. First IOTC Working Party on Tropical Tunas, Mahe, Seychelles, IOTC, 147–157.

McPhaden, M.J., G. Meyers, K. Ando, Y. Masumoto, V.S.N.. Murty, M. Ravichandran, F. Syamsudin, J. Vialard, I. Yu, and W. Yu. 2009. RAMA The Research Moored Array for African– Asian–Australian Monsoon Analysis and Prediction. Pacific Marine Environmental Laboratory Publication Number 3199, National Institute of Oceanography Contribution Number 4437 and American Meteorological Society 2009.

Newell, B.S. 1957. A Preliminary Survey of the Hydrography of the British East African Coastal Waters. Colonial Office, Fishery Publication 9. Her Majesty's Stationary Office, London, U.K.

Patz, J.A., D. Campbell-Lendrum, T. Holloway, and J.A. Foley. 2005. Impact of regional climate change on human health. Nature 438: 310-317. doi:10.1038/nature04188

Reid, J.L. 2003. On the total geostrophic circulation of the Indian Ocean: flow patterns, tracers, and transports. Progress in Oceanography, 56:137–186.

Res, C., J. Robinson, P. Guillotreau, R. Jiménez-Toribio, F. Lantz, L. Nadzon, J. Dorizo, C. Gerry, and F. Marsac, F. 2010. Impacts of climate variability on the tuna economy of Seychelles. Climate Research 43:149-162.

Ridderinkhof, H. and W.P.M. De Ruijter. 2003. Moored current observations in the Mozambique Channel. *Deep-Sea Res. II*, 50:1933-1955.

Ridderinkhof, H., P.M. van der Werf, J.E. Ullgren, H.M. van Aken, P.J. van Leeiwen, and W.P.M. de Ruijter. 2010. Seasonal and interannual variability in the Mozambique Channel from moored current observations J. Geophys. Res. 115: 18pp C06010, doi:10.1029/2009JC005619.

Rouault, M., P. Penven, and B. Pohl. 2009. Warming in the Agulhas Current system since the 1980s. Geophys. Res. Let. 36 L12602, doi:10.1029/2009GL037987.

Rouault, M., B. Pohl, and P. Penven. 2010. Coastal oceanic climate change and variability from 1982 to 2009 around South Africa. Afr. J. Mar. Sci. 32(2):237-246

Schouten, M.W., W.P.M. de Ruijter, P.J. van Leeuwen, and H. Ridderinkhof. (2003) Eddies and variability in the Mozambique Channel. Deep Sea Research II 50:1987-2003. doi:10.1016/S0967-0645(03)00042-0

Sherman, K. and G. Hempel. 2008. Perspectives on regional seas and the large marine ecosystem approach. In: Sherman, K. and G. Hempel, G. eds. 2008. The UNEP Large Marine Ecosystems Report: A perspective on changing conditions in LMEs of the world's Regional Seas. UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme. Nairobi, Kenya.

Schott, F.A. and J.P. McCreary Jr. 2001. The monsoon circulation of the Indian Ocean. Progress in Oceanography 51:1–123.

Siedler, G., M. Rouault, A. Biastoch, B. Backeberg, C.J.C. Reason, and J.R.E. Lutjeharms. 2009. Modes of the southern extension of the East Madagascar Current. Journal of Geophysical Research-Oceans 114, C01005.
Spalding, M.D., H.E. Fox, G.R. Allen, N. Davidson, Z.A. Ferdaña, M. Finlayson, B.S. Halpern, M.A. Jorge, A. Lombana, S.A. Lourie, K.D. Martin, E. McManus, J. Molnar, C.A. Rechhia, C.A. and J. Robertson. 2007. Marine ecoregions of the world: A bioregionalization of coastal and shelf areas. BioScience. 57(7): 573-583.
Smith, S.R., M.A. Bourassa, and M. Long. 2011. Pirate attacks affect Indian Ocean climate research. EOS. Trans. A.G.U. 92: 225. doi:10.1029/2011EO270001.
Swart, N.C., J.R.E. Lutjeharms, H. Ridderinkhof, and W.P.M. de Ruijter. 2010. Observed characteristics of Mozambique Channel eddies. Journal of Geophysical Research-Oceans 115, C09006.
Teh, L. and R. Sumaila. 2011. Contribution of marine fisheries to worldwide employment. Fish and Fisheries. DOI: 10.1111/j.1467-2979.2011.00450.x
van der Lingen C., L.J. Shannon, P. Cury, A. Kreiner, C.L. Moloney, J.P. Roux and F. Vaz-Velho. 2006. Resource and ecosystem variability, including regime shifts, in the Benguela Current system. In: V. Shannon, G. Hempel, P. Malanotte-Rizzoli, C. Moloney, and J. Woods, eds. Benguela: Predicting a Large Marine Ecosystem. Large Marine Ecosystems, Vol. 14. Elsevier, Amsterdam: 147–185.
van Leeuwen, P.J., W.P.M. de Ruijter, and J.R.E. Lutjeharms. 2000. Natal pulses and the formation of Agulhas rings. Journal of Geophysical Research-Oceans 105: 6425-6436.
van Sebille, E., A. Biastoch, P.J. van Leeuwen, and W. P. M. de Ruijter 2009. A weaker Agulhas Current leads to more Agulhas leakage, Geophys. Res. Lett. 36: L03601, doi:10.1029/2008GL036614.
Vialard, J., J. P. Duvel, M. J. McPhaden, P. Bouruet-Aubertot, B. Ward, E. Key, D. Bourras, R. Weller, P. Minnett, A. Weill, C. Cassou, L. Eymard, T. Fristedt, C. Basdevant, Y. Dandonneau, O. Duteil, T. Izumo, C. de Boyer Montégut, S. Masson, F. Marsac, C. Menkes, and S. Kennan. 2009. Cirene: Air—sea interactions in the Seychelles—Chagos thermocline ridge region. Bull. Amer. Meteor. Soc. 90:45–61.
Vinayachandran, P.N., P.A. Francis, and S.A. Rao. 2009. Indian Ocean dipole: Processes and impacts. In: N. Mukunda, ed. Current Trends in Science. 569-589.
Vousden, D., L.E.P Scott, W. Sauer, T.G. Bornman, M. Ngoile, J. Stapley, and J.R.E. Lutjeharms. 2008. Establishing a basis for ecosystem management in the western Indian Ocean. S. Afr. J. Sci. 104:417-420.
Weimerskirch, H., M. Le Corre, S. Jaquemet, M. Potier, and F. Marsac. 2004. Foraging strategy of a top predator in tropical waters: great frigatebirds in the Mozambique Channel. M.E.P.S. 275:297-308.
Zeller, D. and D. Pauly eds. 2007. National fisheries and conflicts: Reconstruction of marine fisheries catches for key countries and regions (1950-2005). Fisheries Centre Research Reports 15(2). Fisheries Centre, University of British Columbia [ISSN 1198-6727]

Websites

http://www.asclme.org
http://act.rsmas.miami.edu/
http://www.ioc-goos.org
http://www.un.org/millenniumgoals/
http://www.who.int/mediacentre/factsheets/fs094/en/
http://www.thegef.org
http://undp.org

It is inevitable that the 7,021,213,399 people who inhabit the planet as of June 20, 2012 will leave their mark.

It is still possible to make individual and collective choices that will result in restoring and sustainably developing the ocean's full potential for present and future generations.

Empowered lives.
Resilient nations.

United Nations Development Programme 304 East 45th Street, 9th Floor New York, NY 10017, USA
www.undp.org/water