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Cochin, India

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Assessing the impacts of climate change on marine fisheries of Karnataka and identifying regime shifts

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Abstract

Climate related regime shifts, namely the rapid reorganization of marine ecosystems from one relatively stable state to another, have been reported from several parts of the world, and found responsible for the fluctuations of major fisheries. Time series on ocean-atmosphere parameters together with time series on plankton and/or fish abundance has been extensively used for identifying regime shifts in the oceans from several parts of the globe. For the first time, we have attempted to detect ecosystem regime shifts from the Karnataka waters by using time series (1961-2003) on ocean-atmospheric (physical) parameters and marine fish production. Here we show that marine regime shifts have been occurred in 1970, 1983, 1976/77, 1988/89 and 1998 in the region. Regime shifts have altered the production and distribution of some commercially important marine fishes (Indian oil sardine, Indian mackerel, and catfishes) from Indian waters. Regime shifts occur when a strong El Nino *(*La Nina*) event is closely preceded or followed by a strong/weak* La Nina *(*El Nino*) event, causing loss of resilience in the ecosystem.*

Keywords: *Climate change, Marine fisheries, Regime shifts, Time series, El Nino*

1. Introduction

Global changes affect the biotic and abiotic elements that influence the numbers and distribution of fish species. The First and Second Assessment Reports on ocean systems conclude that global warming will affect the oceans through changes in sea-surface temperature (SST), sea level, ice cover, ocean circulation, and wave climate (IPCC, 2001). Recently "regime shift" in the marine ecosystem has been reported from several parts of the globe (Francis and Hare, 1994; Graham, 1994; Miller *et al.*, 1994; Hare and Mantua. 2000; Yasuda *et al.*, 2000; Zhang *et al.*, 2000; Rebstock, 2002; Peterson and Schwing, 2003; Mantua, 2004; Rodionov and Overland 2005). A "regime" in climate and ocean conditions, is a fairly consistent and stable pattern in such factors as atmospheric pressure, sea-surface temperatures, population dynamics of various fish species, and density of plankton and other forage species that provide vital food for various fish species. A regime shift occurs when a change takes place in several or all of such patterns, at more or less the same time. There is much discussion and debate among biologists, oceanographers, statisticians and other scientists about the nature of regimes, whether shifts in regimes can be anticipated, and how much human activity contributes to such phenomena (Klyashtorin, 2001).

Regime shifts in the marine environment are the rapid reorganization of marine ecosystems from one relatively stable state to another. Regimes may last for few years to several decades and shifts often appear to be associated with change in the climate system (McFarlane *et al.*, 2000). Recent studies have detected regime shifts in the atmospheric-oceanic environment and marine ecosystem during 1976/77, 1988/89 and 1998 in the Northeast and Northwest Pacific Ocean, Bering, Atlantic, Korean and Japanese Seas (Francis and Hare, 1994; Graham, 1994; Miller *et al.*, 1994; Hare and Mantua. 2000; Yasuda *et al.*, 2000; Zhang *et al.*, 2000; Rebstock, 2002; Peterson and Schwing, 2003; Mantua, 2004; Rodionov and Overland 2005). Biological responses to regime shift have been documented in a wide array of species at all trophic levels, from plankton to fish to marine birds and mammals (Rebstock, 2002; Scheffer *et al.*, 2001). Fish abundance time series have been extensively used for identifying regime shifts in the oceans together with time series on climatic and oceanographic variability (Francis and Hare, 1994; Graham, 1994; Miller *et al.*, 1994; Beamish *et al.*, 1999; Hare and Mantua. 2000; Anderson, 2000; McFarlane *et al.*, 2000; 2002; Yasuda *et al.*, 2000; Zhang *et al.*, 2000; McFarlane and Beamish, 2001; Peterson and Schwing, 2003; Mantua, 2004; Knights, 2003; Tian *et al.*, 2004; Rodionov and Overland 2005).

It is generally agreed that climatic regimes influence species abundance and distribution from polar terrestrial to tropical marine environment (Walther, *et al.*, 2002). Climate related regime shifts are considered as one of the major factors responsible for the fluctuations of major fisheries of the world such as Pacific sardine, Pacific salmon, Bering Sea Pollock, Japanese sardine, Alaskan pandalid shrimp, Atlantic cod, Pacific saury, European, American and Japanese eel (McFarlane *et al.*, 2000; 2002; McFarlane and Beamish, 2001; Beamish *et al.*, 1999; Anderson, 2000; Knights, 2003; Tian *et al.*, 2004). To our knowledge, similar regime shifts are not reported from the Indian Ocean region, even though marine fisheries play a major role in the socioeconomic development of the countries from this region.

Karnataka, one of the leading and progressive maritime states of India is endowed with a 300 km coastline, a continental shelf area of 27,000 km^2 and an EEZ area of 87,000 km^2. The state's annual contribution to the total marine fish production of the country has varied from 2.6 to 13.4 % (1956-96). With the present annual average catch (1992-96) of 155,777 t, it ranks fifth among the maritime states of the country in the marine fish production. The impact of the regime shifts on fish survival and production is complex and speculative. It has become clear that climatic variability exerts a powerful effect on the population dynamics of the very large fish stocks that are the basis for the major commercial fisheries of the world. In this study we evaluate the long term changes in selected ocean-atmospheric parameters such as Air Temperature (AT), Sea Surface Temperature (SST), Sea Level Pressure (SLP), rainfall and marine fish production from the Karnataka waters and the occurrence of regime shifts in the marine ecosystem from the region.

2. Materials and methods

2.1 Abiotic (Ocean-Atmosphere) time series

The following abiotic parameters have been selected because they act on large spatial scales, are generally implicated in regime shifts, and are important indicators of habitat that likely influence biological productivity. Area averaged time series (1961-2002) of monthly mean AT, SST and SLP were extracted from the original 2 ° grid (latitude x longitude) covering Karnataka waters from the International Comprehensive Ocean-Atmosphere Data Set (ICODAS) website (http://dss.ucar.edu). The rainfall data was procured from the Indian Meteorological Department. Twelve monthly values within each calendar year were averaged to obtain an annual index and normalized before analysis.

2.2 Biotic (Fish production) time series

The groupwise marine fish landings (1961-2003) in Karnataka State estimated by employing the stratified multistage random sampling design was collected from the database of Central Marine Fisheries Research Institute (CMFRI), Cochin (Srinath, 1989; 2003). The fish landing (catch minus discard) is the only abundance measure that has been routinely collected from India. We contend that, to a first order approximation, landing/catch is generally indicative of fish abundance and we use the terminology 'fish production'. Further justification for the use of fish landing/catch data (productivity) as an index of abundance can be found in several other studies that have also examined large-scale patterns of variability (Francis and Hare. 1994; Miller *et al.*, 1994; McFarlane *et al.*, 2002; Attrill and Power 2002). Fish production data was de-trended before the analysis. Our analysis does not account for the gradual and effective region-specific changes in harvest strategies that have taken place over the past 50 years.

2.3 Data analysis

The regime shifts in fish landings and ocean-atmosphere data sets were computed using Principal component analysis (Mantua, 2004) and Sequential t-Test Analysis of Regime Shift (STARS) software (Rodionov, 2004). STARS detect statistically significant shifts in the mean level and the magnitude of fluctuations in time series. Principal component analysis (PCA) was carried out using SPSS.12 software.

3. Results

To identify the regime shifts in the marine ecosystem of Karnataka waters the following time series has been analysed using statistical techniques such as principal component analysis (PCA) and Sequential t Test Analysis of Regime Shift (STARS): i). Time series (1961-2002) on abiotic (ocean-atmospheric parameters) such as Air Temperature (AT), Sea Surface Temperature (SST), Sea Level Pressure (SLP) and Monsoon Rainfall (MF), ii) Time series (1961-2003) on production of commercially important marine pelagic and demersal fishes from Karnataka waters.

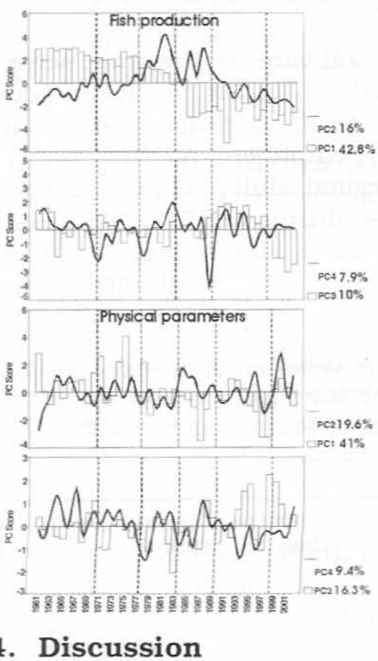
Regime shifts identified using STARS software in the time series on abiotic parameters ($P>0.5$, cutoff length = 10) for the Karnataka region is shown in Table 1 and the shifts identified in biotic parameter- marine fish production ($P>0.01$, cutoff length=10) is shown in Table 2. The STARS has identified regime shifts in both abiotic ($P>0.1$) and biotic ($P>0.01$) time series during 1970–1998. Fish production time series showed several regime shifts during 1970s, 80s, 90 and 2000s with strongest shifts during 1988/89 followed by 1984, 1970, 1998 and 1976/77.

Table 1. Regime Shifts identified in the time series on abiotic parameters ($P>0.5$, cutoff length = 10) for the Karnataka region using the software Sequential t Test Analysis of Regime Shift (STARS)

Ocean-Atmosphere Data	1960s	1970s	1980s	1990s	2000s
Maximum Atmospheric Temperature (Max AT)		1976	1985	1995	
Minimum Atmospheric Temperature (Min AT)		1977		1994	
Sean Surface Temperature (SST)		1971	1980	1997	
Sea Level Pressure (SLP)		1977	1988	1998	
Rainfall (RF)	1968	1979 1977,	1988	1996	
Combined summary	1968	1979	1988	1998	

Table 2. Regime Shifts identified in the time series on group wise marine fish production (P>0.01, cutoff length = 10) from Karnataka using the software Sequential t Test Analysis of Regime Shift (STARS)

Fish Production	1960s	1970s	1980s	1990s	2000s
Sardine					
Stolephorus			1980	1996	
Perches			1987	1996	
Croakers			1987		2003
Ribbon fishes			1986		2000
Carangids			1985		2000
Mackerels					
Tunnies			1985		
Soles			1984		2000
Prawns			1987		2002
Total fish production		1978			
Combined summary		1978	1980, 1984, 1985, 1986, 1988	1996	2000



Compared to STARS, PCA has objectively isolated the most important patterns of common variability in the abiotic and biotic time series used in this study (Fig. 1). Scores for the first four PCs on abiotic and fish production time series are illustrated in Fig. 1, showing five distinct regime shifts during 1970, 1976/77, 1983, 1988/89 and 1998.

Fig.1 The first four principal component scores from a Principal Component Analysis of the abiotic (fish production) and biotic (physical parameters) time series. The scores are normalized time series and dashed vertical lines are shown before the data points for 1970, 1976, 1983, 1988 and 1998, indicating regime shifts. The % values shown indicate the %variation of PC Scores

4. Discussion

Unlike abiotic indices, regime shifts for fishes were not concentrated around certain years (Table 1 and 2) suggesting that different species experienced shifts in different years as reported from Bering Sea (Rodionov and Overland, 2005). Tropical fishery consists of several pelagic and demersal species and regime shifts in one species may affect another species during a later period due to their prey predator relationships and trophic interactions.

Regime shifts have altered the production and distribution of some commercially important marine fish species from Karnataka waters. Coinciding with the 1988/89 regime shift, a general increase in marine fish production was registered from Karnataka, owing mainly to the bumper production of Indian oil sardine *(Sardinella longiceps)* and Indian mackerel (*Rastrelliger kanagurta)*. However, during the same period the stocks of catfish *(Tachysurus* spp.) almost vanished along the southwest coast of India (Srinath, 1989). Historically, the distribution of Indian oil sardine was restricted to the southwest coast of India (Srinath, 1989). However, after the 1983 regime shift, oil sardine stocks started appearing along the southeast coast of India and after the 1988/89 regime shift, its production from the coast increased substantially. Again coinciding with the 1998 regime shift, the Indian oil sardine emerged as the single largest contributor to the total fish production from the southeast coast of India (Srinath, 1989). In response to shifts in the ocean and atmosphere climate, variation occure in marine ecosystems involving changes in community composition, species abundances, distribution, and trophic structure (Srinath, 2003).

Many of the largest fish stocks of the world seem to be growing and declining rhythmically, with a high degree of synchrony between them. The early period from the 1970s to the mid-1980s, which saw the massive rises in population sizes of the sardine stocks and the collapses of the Peruvian anchoveta in the Pacific Ocean and the Southern African pilchard in the Atlantic Ocean was also remarkable as a period of global average temperature rise, suggesting the likelihood that climatic variability may be the driving force linking these variations (Polovina, 2005). The *El Niño* Southern Oscillation (ENSO) is now recognized as a climatic event of global significance and this periodic variation in oceanic and climatic conditions has influence on the abundance and distribution of several marine organisms including marine mammals. The collapse of the Peruvian anchovy industry in the early 1970s was a direct result of the *El Niño* of 1972-73 and the 1982-83 *El Niño* affected all of the main pelagic resources leading the Peruvian fishery to its lowest record of catches (Bakun and Broad, 2003).

Through the atmospheric and oceanic processes, El Nino (La Nina) accounts for the basin-wide warming (cooling) over the tropical Indian Ocean (Annamalai and Liu, 2005). We have observed remote connection between the observed regime shifts and the *El Nino* (warm) and *La Nina* (cold) events in the equatorial region of the Pacific. The regime shifts in 1970, 1983, 1988/89 and 98 have occurred when strong / weak *El Nino* events were immediately followed by strong /

weak *La Nina* events, while in 1976/77 a strong *La Nina* event was immediately followed by a weak *El Nino* event (Table 3). The closely occurring *El Nino* and *La Nina* events (or *vice versa*) with very short interval between them may be acting as triggering mechanisms for the shifts in the marine ecosystem. The sudden fluctuations in SST, SLP and SW associated with *El Nino* to *La Nina* (*La Nina* to *El Nino*) shifts may result in changes in distribution, abundance and physiology of marine organisms, associated with changes in the extension, localization, structure, productivity and other characteristics of the ecosystems in which they live. Studies on lakes, coral reefs, oceans, forests and arid lands have shown that loss of resilience in the ecosystems trigger regime shifts (Scheffer *et al.*, 2001). Hence, we hypothesise that when one strong *El Nino* or *La Nina* event is closely preceded or followed by a strong/weak *La Nina* or *El Nino* event, regime shifts are induced depending up on other climatic/ocean conditions. The ocean regime shifts reported in the present study (Table 1 and 2, Fig 1) and similar reports from other parts of the globe since 1961 strengthen this hypothesis. Following the 1976–77 climate shift in the Pacific, many properties of ENSO, such as frequency, intensity, and propagation direction, have changed (Wallace *et al.*, 1998). El Nino (La Nina) events after the climate shift in 1976–77 were stronger (weaker) than those that occurred before (Annamalai and Liu, 2005) which resulted in the increase in frequency of marine regime shifts.

Table 3. List showing El Niño and La Niña years based on the average sea surface temperature (SST) anomalies in the Niño 3.4 area (5 °N to 5 °S and 120 ° to 170 °W) of the eastern and central equatorial Pacific. Average anomaly is shown in parentheses and – ve sign indicates cold water while + ve sign indicates warm water. Average SST anomaly for Strong El Niño is > +0.65 ° C; Weak El Niño is > +0.3 and < +0.65 ° C; Neutral is > -0.3 and < +0.3 ° C; Weak La Niña is > -0.65 and < -0.3 ° C and Strong La Niña is < -0.65°C

Strong El Niñoyears	Weak El Niño years	Neutral years	Weak La Niña years	Strong La Niña years
1983 (+2.30)	1977 (+0.50)	1979 (+0.20)	1996 (-0.63)	1989 (-1.50)
1998 (+2.03)	1988 (+0.50)	1954 (+0.19)	1968 (-0.53)	1974 (-1.38)
1992 (+1.80)	1959 (+0.47)	1990 (+0.19)	1984 (-0.50)	1971 (-1.31)
1958 (+1.42)	1993 (+0.46)	1982 (+0.18)	2001 (-0.49)	2000 (-1.29)
1987 (+1.32)	1980 (+0.45)	1957 (+0.11)	1951 (-0.48)	1999 (-1.21)
1966 (+1.20)	1964 (+0.39)	1994 (+0.11)	1986 (-0.47)	1976 (-1.13)
1973 (+1.20)	1952 (+0.38)	1960 (0.00)	1975 (-0.46)	1985 (-1.02)
1969 (+0.94)	1978 (+0.36)	1961 (-0.06)	1967 (-0.41)	1956 (-0.88)
1995 (+0.79)	1991 (+0.35)	1997 (-0.15)	1965 (-0.34)	1955 (-0.80)
1970 (+0.69)	1953 (+0.34)	1981 (-0.17)		
		1972 (-0.23)		
		1962 (-0.25)		
		1963 (-0.27)		

5. Conclusions

Our study revealed that regime shifts reported from Northeast and Northwest Pacific Ocean, Bering Sea, Atlantic Ocean, Korean and Japanese waters in 1976/77, 1988/89 and 1998 have also experienced in Karnataka waters. In addition to these regime shifts, we have identified two additional regime shifts in 1970 and 1983 (Fig.1). The effects of climate change on fish production/abundance are now being given nearly equal consideration to the competing hypothesis that fish production/abundance is governed solely by an intrinsic stock recruitment relationship and fishing (Bakun and Broad, 2003; Attrill and Power, 2002). Hence, a better understanding of how the climate change and variability of the ocean environment affects the fate of fish abundance at sea would be of great value as a strategic planning tool.

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