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Lecture Notes

Part 1

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CLIMATE CHANGE RELATED MARINE ECOSYSTEM REGIME SHIFTS AND THEIR IMPACT ON FISHERIES

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Introduction

Global changes affect the biotic and abiotic elements that influence the numbers and distribution of fish species. It is now understood that marine ecosystems change on a variety of time scales, from seasonal to centennial and longer. Atmospheric and climate-related processes force many of these time scales, and therefore it is well understood by marine scientists that climate variability is a strong driver of changes in fish populations and in fisheries. 'Regime shifts' were first identified in terrestrial communities (Noy-Meir, 1975) and applied to marine ecosystems to describe concurrent fluctuations in anchovy (*Engraulis encrasicolus*, Engraulidae) and sardine (*Sardina pilchardus*, Clupeidae) populations in several regions of the world (Lluch-Belda et al., 1989). The term has since been applied to apparent shifts in oceanic and climatic conditions and marine community structure around the world (Collie et al., 2004). Marine ecological regime shifts are attributed to climate change, overfishing or both (Beaugrand et al. 2002; Daskalov 2002).

McKinnell et al. (2001) defined regime shifts as low-frequency, high-amplitude and sometimes abrupt changes in species abundance, community composition and trophic organization that occur concurrently with physical changes in the climate system. More recently, Collie et al. (2004) defined regime shifts as low-frequency, high-amplitude changes in oceanic conditions that may propagate through several trophic levels and be especially pronounced in biological variables. Cury and Shannon (2004) consider the regime shift to be a sudden shift in the structure and function of a marine ecosystem, affecting several living components and resulting in an alternate stable state. Wooster and Zhang (2004) proposed that a regime shift is an abrupt change in a marine ecosystem and its abiotic environment from one stationary state to another. de Young et al. (2004) suggested that regimes shifts are changes in marine system functions that are relatively abrupt and persistent. They occur at large spatial scales, and are observed at different trophic levels, and are related to climate forcing.

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).

Marine regime shifts

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; Knights, 2003; Peterson and Schwing, 2003; Mantua, 2004; 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).

Regime shift detection methods

It was generally agreed that to qualify as a regime shift, there must be organized changes in a variety of biological and environmental characteristics (Hare and Manuta, 2000). Several statistical methods such as principal component analysis (PCA), average standard deviates (ASD), Fisher Information (FI) and vector autoregression (VAR) model have been proved useful for detecting the ecosystem regime shifts (Manuta, 2004). The brief description of these methods and their pros and cons are shown in Table 1. Different time series data on ocean atmosphere parameters like sea surface temperature, sea level pressure, wind speed, ENSO index, Southern Oscillation Index (SOI), Pacific Decadal Oscillation Index (PDI), Aleution Low Pressure Index (ALP), rainfall etc. together with biological parameters like primary productivity zooplankton biomass, fish abundance, fish egg abundance etc. can be used for detecting regime shift in the marine environment. The regime shift analysis using average standard deviates (ASD) method for Indian waters is shown in Fig. 1.

Table 1. Major statistical methods used for detecting shifts in the system (compiled from Manuta, 2004; Rodionov, 2004)

Method	Brief Description	Pros	Cons
Principal component analysis	The method is widely used to identify coherent patterns of variability among large sets of time series (Mantua, 2004)). Although not a regime shift detection method per se, it has been applied to 100 biotic and abiotic time series in the North Pacific to analyze the scale of regime shifts in 1977 and 1989 (Hare and Mantua, 2000).	Reduces the dimensionality of the data matrix. Requires no a priori assumption about candidate regime shift years.	Additional time series analysis methods must be used to assess the statistical significance and character of temporal changes in the PCs.
Average standard deviates	An ad hoc composing method that creates a single "regime index" consisting of average standard deviates (Ebbesmeyer et al., 1991; Hare and Mantua, 2000; Mantua, 2004).	Easy to use.	Requires an a priori specification of a regime shift date and a sign reversal of some time series, which leads to a spurious amplification of the shift.

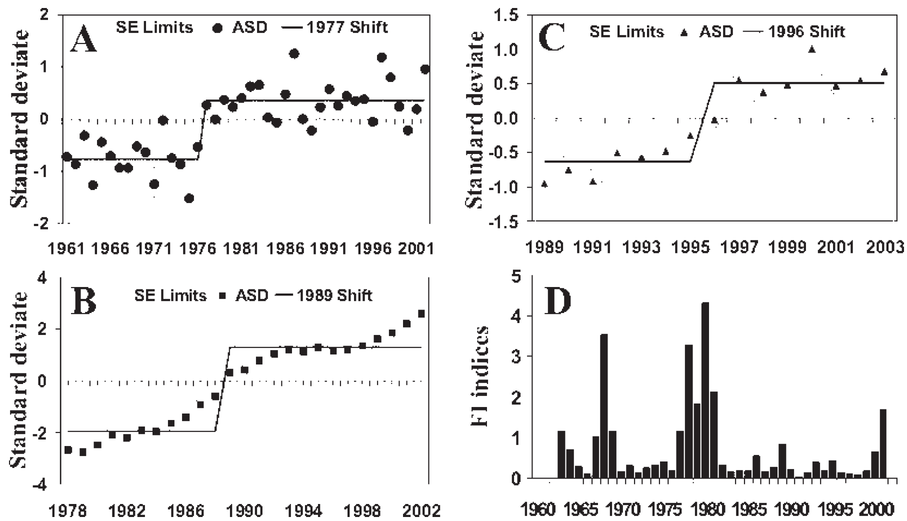
Fisher information	An information theory approach using Fisher information as an indicator for tracking steady and transient ecosystem states (Fath et al., 2003). The information is characterized by a ratio of a system's acceleration to its speed along the state space trajectory.	Simple and easily applied to collections of time series with many variables.	Requires a careful choice of input variables and their weighting. Interpretation of the results is not straightforward. No means for assessing the statistical significance.
Vector autoregressive method	A formal statistical approach to detecting regime shifts in a multivariate system (Solow and Beet, 2005). The regime shift is identified objectively as the point at which the system changes from one steady state to another. The states are described by a vector autoregressive model of the first order.	Relies on standard statistical theory to provide a significance test. Allows for serial dependence in the vector of time series.	Requires a large number of observations to fit the model. The results are sensitive to the selection of variables. Computationally demanding.

Application of regime shift

One can see great cycles in the natural abundance and geographic location of sardines and mackerel, with periods of few decades. We also have witnessed dramatic switches in the abundance of oil sardine and mackerel stocks. On Georges Bank off New England, cod are replaced by dogfish and mackerel. Off Newfoundland, flatfish then crustaceans became abundant after the replacement of cod. These switches can have great economic consequences; especially they have great impact on the fishing communities. Yet these large rearrangements in species composition appear to be

Figure 1 shows the results of regime shift analysis using average standard deviates (ASD) method for the Indian waters. The step passes through the mean standard deviate within each regime and the standard error of the time series is shown for each year. (A) Regime shit in 1977 for the 13 abiotic (ocean-atmospheric) time series, (B) in 1989 for annual marine fish production time series for eighteen Asian countries, (C) in 1996 for group wise annual Indian marine fish production time series and (D) regime shift analysis using fisher information (FI) method based on a three year integration window applied to group wise annual Indian marine fish production time series ecologically acceptable responses, utilizing alternative pathways within the upper levels of the ecosystem. Most of these ecological regime shifts are forced by major shifts in the ocean-atmosphere parameters. Hence, understanding the regime shift in the marine environment is essential for proper management of marine fisheries. For the future, however, the hypothesis of regime shifts within marine ecosystems, resulting in alternative communities at several trophic levels, could provide an organizing principle for management as well as for research. Recognition of the importance of the environments on which fish stocks depend will require fishery management to expand into the arena of ecosystem conservation and protection.

Fig. 1. Regime shift analysis using ASD method for the Indian waters



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