Regime shifts and fishery management

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Regime shifts and fishery management

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Abstract

Understanding regime shifts is important to management. Optimal allocation of fishery effort can be improved if it were known whether or not the regime was positive or negative. This determination is difficult because a high recruitment, when the stock is at a low level of abundance (or vice versa), may be the indication of the onset of a multidecadal regime shift, or just a chance occurrence. Accordingly, the determination of an increase or decrease in productivity from observations independent of those made directly on fish populations is important.

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Contents

1. Introduction ................................................................. 397
2. Fishing and regime shifts .................................................. 398
3. Analysis of regime shifts ................................................... 399
4. Regime shifts and fisheries management ............................. 400
References ........................................................................ 401

1. Introduction

Multi-decadal fluctuations in fish-population abundance have been known for centuries. The fluctuations are often dramatic in magnitude. The scientific literature is replete with examples and analyses (see, e.g., Cushing, 1982; Cushing, 1988; Rothschild, 1986; Rothschild, 1995; Uda, 1952; Uda, 1961). Some of...
the more dramatic fluctuations are even described in popular literature (examples of the latter include the California sardine, the northern cod, and various populations of herring in the eastern Atlantic Ocean). In this note, we point out that understanding these multi-decadal fluctuations or “regime shifts” is important to fishery management. Understanding the variability in fish populations related to regime shifts is complicated because the abundance of fish populations is driven by both environmental forcing and fishing. Separating environmental effects from fishing effects continues to be a major research problem. New insights into the cause of regime shifts will be valuable because managers will be able to adjust fishing effort to match the productivity of the ocean environment.

As direct observations and retrieval of historical records contributed to a building number of examples of multi-decadal variability in stock abundance, interest began to build in the correlation among the abundance of various fish-stocks in individual ecosystems. Many workers inferred a negative correlation between similar species (e.g., sardines and anchovies) in the same ecosystem (e.g., Lluch-Belda et al., 1992). This negative correlation was called “replacement.” However, careful study (e.g., Daan, 1980) reflected that the concept of replacement required critical analysis and that a suite of factors may act to determine species dominance (Matsuda, Wada, Takeuchi, & Matsumiya, 1991, 1992). Subsequent examinations of time-series data of similar species in the same ecosystem reflects that for any pair of species, there are periods during which the time series appear to be positively correlated (e.g., Kawasaki & Omori, 1988) other periods when the abundance time series are negatively correlated (e.g., Lluch-Belda et al., 1992), and yet others when they are not correlated at all. This temporal variability in apparent correlation between species within an ecosystem is typical of many time series and characteristic of coupled non-linear dynamics.

The use of the term “regime shift” is fairly recent (Isaacs, 1976; de Young et al., 2004). It was used to characterize the phenomenon of a positive correlation among the time series of Far Eastern, Chilean, and California sardines (Kawasaki, 1983), which appeared to be out of phase with pelagic fish fluctuations in the Benguela and Canary Current systems (Lluch-Belda et al., 1989; Schwartzlose et al., 1999). It was initially questionable as to whether this remarkable observation related to simultaneous highly correlated changes in the ocean environment off Chile, the northwest Pacific Ocean, and off western North America, or whether the relationship was just a chance occurrence. Subsequently, many studies have investigated and found support for trans-oceanic linkages between the Atlantic and Pacific, and between the systems within these, mediated through atmospheric forcing (e.g., Crawford et al., 1991; Lluch-Belda et al., 1989; Lluch-Belda et al., 1992).

Currently, the regime shift concept continues to elicit a search for causes of multi-decadal variability in fish stocks with perhaps more emphasis on the ocean environment than was possible in the past. However, as emphasis on studying the ocean environment increases, it is also necessary to study the influence of fishing and how environment-fishing effects are confounded. The environment-fishing interaction has been a central dilemma of fishery management for decades (see, e.g., Bakun, 1996; Clark & Marr, 1956; Cushing, 1982; Drinkwater, 2002). This short communication serves to highlight the need for regime shifts to be taken into account in fisheries management.

2. Fishing and regime shifts

This issue of the “state” of the ocean environment is particularly important because of a societal concern with “overfishing”. The concern with overfishing tends to focus on fishing as a cause of declines in stock abundance or as an inhibitor of stock increase. The direct coupling between stock variability and fishing is not always clear. Stock fluctuations occurred well before the advent of industrialized fishing, as has been observed from fish scale deposits (e.g., Baumgartner, Soutar, & Ferreira-batrina, 1992, 1996; Soutar & Isaacs, 1974). The California sardine did not increase in abundance even though there was a moratorium on fishing (McFarlane, King, & Beamish, 2000); the North Sea cod increased in abundance to a substantial
degree under intense fishing pressure (Rothschild, 1998); the Peruvian anchovetta was thought to have declined precipitously in the early 1970s because of either the El Niño or fishing, yet the collapse was linked with a collapse in the zooplankton populations, which were unlikely to have been the result of either the fishing or the El Niño (Rothschild, 1995); and the northern cod collapse in 1994 was associated with a remarkable decline in weight-at-age of recruiting cod (Drinkwater, 2002; Shelton & Lilly, 2000). The major point is that if fishing causes a decline in a stock, then it might be expected that a reduction in fishing effort will cause the stock to increase in abundance. However, it is increasingly clear that the magnitude of stock fluctuations is influenced by a combination of the environment and fishing. This underlines the importance of “regime shifts” because it reflects the fact that the ocean environment is heavily implicated. An understanding of the regime-shift effect could prove useful for fisheries management (Beamish, Benson, Sweeting, & Neville, 2004).

Understanding the major issues and uncertainties linking fishing, stock fluctuations, and regime shifts is therefore critical to improving fishery management. It is obviously important to know whether a stock is in a high or low state of productivity or whether the regime has shifted. If the stocks are in a high state of productivity, then the intensity of risk is reduced and vice versa.

In addition, the information is required on all time scales. If a large year class of fish is suddenly observed, then can it be concluded that this is the beginning of a regime shift? Or, on the other hand, is the large year class just a chance occurrence? If the recruitment pattern falls within a stanza of relatively high recruitment and a poor year class is observed, then is this indicative of the onset of a negative regime shift? This information is critical if fisheries managers are to make best use of the available resources. In other words, knowing whether a fish stock is in an optimal or less-than-optimal environment would be a powerful tool for fishery managers in their quest to modulate fishing effort.

External effects on species, be they environmental or fisheries related, may well be of major importance during the time over which a regime shift is actually taking place. At the time when stocks are increasing or decreasing (i.e., in the process of undergoing a regime shift), they may be more sensitive to fishing and/or environmental effects, so that the outcome of the imminent regime shift may in fact be influenced. Although fishing is not usually considered to drive regime shifts, it is certainly agreed that fishing may alter the speed, magnitude or nature of the shift (Jennings & Kaiser, 1998). For example, heavy exploitation of a potential “replacement species” immediately after the collapse of another species may determine the success of such a species replacement (e.g., Crawford, Shannon, & Pollock, 1987).

Assessing the productivity of stocks for the purpose of management extends beyond scientific hypotheses, in the sense that the information used in management can effect substantial economic returns. For example, in the light of species replacements, heavy fishing has been proposed on a species considered to be competing with another that is more commercially valuable (e.g., May et al., 1979), although without achieving the success envisaged (e.g., Butterworth et al., 1983).

3. Analysis of regime shifts

Quantitative techniques are available to assess the risk of drawing conclusions from observations and information. With regard to management decision-making, these techniques have been developed in the field of operations research. For example, decision theory can be used to quantify the information content of stock and recruitment and hence regime shift data. Early studies on shaping the value of fishery information in the stock and recruitment sense include Rothschild and Heimbuch’s (1983) formulation of the decision-theoretic adaptive management. In their paper, an adaptive decision-theoretic framework is used to regulate fishing mortality. However, the regulation depends upon information on the magnitude of recruitment. Their paper enables contrasting the payoff between optimal management with and without recruitment (or regime shift) information. In a companion paper, Rothschild and Mullen (1985) analyze the
information content and the non-parametric classification of stock-and-recruitment data. This paper is in contrast to most analyses that rely on some functional form (e.g., Ricker) to represent stock and recruitment. Using Markov chains, it was possible to compute the transition probabilities of a small stock producing large recruitment and a large stock producing small recruitment, without relying on theoretical stock-and-recruitment assumptions. The importance of this approach is that regime shifts would contribute inter alia to depensatory rather than compensatory changes in the transition probabilities.

Many analyses essentially examine the regime shift problem as the inter-annual integration of recruitment. The dominant approach is to draw inferences from observations on recruitment, spawning stock biomass, and the ocean environment (or factors that are external to the ambient ocean environment such as wind velocity). These studies, apart from stock-and-recruitment theory (to the extent that it is used), are generally not based upon dynamic modeling. The prospect for dynamic modeling of regime shifts is certainly important. In fact, time series of recruitment and its integral, fish-stock abundance, look as if they were derived from dynamic systems. This raises an interesting paradox. A fish-stock abundance time series may be perfectly correlated with some assumed forcing function, and yet the relation could be completely spurious (cf. Carruthers, Lawford, & Veley, 1951; Gulland, 1953). In contrast, a fish-stock abundance time series could have a close to zero linear correlation with a forcing function, and yet in the dynamic sense, the abundance measure and the forcing function are perfectly related; a situation that arises from the fact that the correlation statistic measures a linear relationship over a number of points that are related to one another with the same correlation coefficient.

4. Regime shifts and fisheries management

The dynamic nature of fish stocks puts in relief the management/regime shift problem. As mentioned, fish stocks have been fluctuating on a multi-decadal basis for centuries before industrialized fishing. Industrialized fishing complicates the problem because fishing (fishing mortality, and fishing intensity at various and relevant temporal and spatial scales) now has to be added to the causes for fluctuation. Are fluctuations enhanced or suppressed by fishing mortality? The idea of a regime shift generalizes the recruitment problem in the sense that a regime shift or change is simply an integration of the recruitment problem. But the causal issues in the recruitment problem and, hence, the regime shift problem, are still major research challenges (see reviews by Rothschild, 2000; Rothschild & Fogarty, 1998).

Thus, in a sense, the quality of management depends upon the quality of information available for management; in particular, how well do we understand the causal basis for fish-stock fluctuations? This reflects upon the need for research that continues to probe for a cause-and-effect understanding of the recruitment problem in terms of: (i) the factors that affect recruitment, (ii) the feasibility of representing recruitment and its regime-shift integral in dynamic rather than empirical terms, and (iii) information and risk evaluation techniques to advise managers on the effectiveness of information and research direction.

It is clear that regime shifts have profound implications and should be incorporated into management strategies—an idea consistent with viewing management in the context of ecosystems. The inherent interactions among species within a physically and chemically variable environment (Larkin, 1996) require an ecosystem approach to fisheries (e.g., Beamish & Mahnken, 1999; Gislason, Sinclair, Sainsbury, & O’Boyle, 2000; Sinclair et al., 2002; Sinclair & Valdimarsson, 2002). The ecosystem approach recognizes that single stocks need to be managed as part of dynamic ecosystems consisting of directly and indirectly interacting species. Therefore, regime shifts are particularly relevant in this light, in that fluctuations in stock sizes are of large magnitudes, occur over fairly short time periods, and can have implications for the structure, function and response of the ecosystem.

To summarize, contemporary management does not account for variability in the ocean environment or how this variability affects recruitment and fish-stock abundance. Fishery management does not yet take
into account the multi-year changes in the environment which appear to be related to regime shifts. Intuitively and on the basis of decision-theoretic studies, understanding how the ocean environment affects regime shifts will substantially increase the benefits from fishery management.

References


