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Adaptive management of declining fisheries: When is it worth trying to rebuild stocks through fishery regulation?

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ABSTRACT

Declining catches are typically taken to be a warning sign of overfishing. But in fact, many such declines have been driven by recruitment changes unrelated to stock size, as evidenced by the failure of stocks to recover after reduction in fishing or recovery despite the failure to reduce fishing. Given a declining pattern, supposedly precautionary decisions to reduce fishing should be treated as experimental management options with a high probability of not resulting in the desired recovery to more productive stock sizes. Simple decision tables can be used to compare such experimental options to “wait and see” options that do not involve fishing reductions. A case example with a grouper fishery in Kuwait demonstrates that experimental effort reduction may not be the best policy from a decision analysis perspective, at least when there are substantial reasons to expect recruitment changes unrelated to stock size. In this case, virtual population analysis and stock reduction analysis models indicate either unusually weak recruitment compensation (steepness $h < 0.4$) or progressive decline in recruitment carrying capacity, possibly caused by decreases in estuarine rearing habitat associated with declining flows of the Tigris and Euphrates Rivers.

1. Introduction

Declining catches and population abundances are causes of much concern in modern fisheries management, and the recommended management response is typically to reduce fishing mortality rates so as to allow recovery to more productive stock sizes. This recommendation is based on the assumption that the most likely cause of the decline in the first place is fishing, and it is pragmatic in the sense that it is the only factor that fisheries managers have a chance of impacting. But it is equally typical for fishing interests to argue against fishing restrictions while asserting that decline has been due to other factors like availability (the fish have just moved), increases in predation, or regime changes that will reverse the decline even if no action is taken. Unfortunately for fisheries scientists, it is difficult to claim that fishing does cause most declines and that there is a high probability of good long-term results from restrictive regulation (see the debate in [16]). There are just too many cases where reductions in fishing, even complete closures, have completely failed to result in the desired recovery [8,9] and/or recovery has occurred without reduced fishing despite dire warnings from scientists. For example, on the west coast of Canada, complete closures of two of the major herring fisheries and coho and chinook salmon fisheries have been implemented since the mid-1990s [2]. However, none of these stocks have shown any sign of rebuilding; closures continue on the assumption that the low stock sizes need protection to allow eventual recovery when it may still be possible to harvest these stocks at fairly high fishing rates (but producing relatively low catches) without endangering them.

Declining abundance and catch is typically associated with declining recruitment, rather than reduced growth or increasing natural mortality rate of older fish. But there is a serious logical problem when interpreting stock-recruitment (SR) data: if recruitment is declining as spawning stock size declines, should the assumption be that recruitment is declining because of the spawning stock decline (the “overfishing” hypothesis), or instead that spawning stock (which results from recruitment) is declining because recruitment has declined due to other factors (the “environmental factor” hypothesis)? There have been various recent attempts to tease apart this fundamental confounding of effects by using various statistical modeling approaches, (e.g., [21,19,3]). However, none of these can resolve the basic logical problem during periods of progressive decline; all depend on having long enough time series to provide informative reversals in recruitment rates.

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Table 1
Basic decision table that fisheries managers face during periods of stock and recruitment decline.

		State of nature (correct model)	
		Overfishing (weak compensation)	Environmental factor (SR curve changing)
Policy option	Continue fishing	Stock collapse will continue, yields decline toward zero	Collapse will continue, yields continue at lower levels
	Reduce fishing	Stock will recover, higher long-term yields	Stock will not recover, yields will not continue at lower levels

To make matters worse, there are two ways that SR relationships can change over time. First, the slope (or steepness) of the SR relationship can change due to changes in density-independent mortality factors so as to imply a change in the optimum fishing mortality rate. Second, the carrying capacity or maximum recruitment can change due to changes in density-dependent effects, (e.g., juvenile nursery area size), which implies changes in the sustainable catch, but not in optimum fishing mortality rate [28].

At any point in time during a period of correlated decline in recruitment and spawning stock size, fisheries managers are confronted with the basic decision analysis or adaptive management problem shown in Table 1. If "continued fishing" is the default or baseline policy option, then "reduced fishing" can be viewed as an experimental policy option with some promise for improving future yields, (i.e., an untested opportunity for improvement as defined in [24]). Undertaking the experiment will result in an immediate loss in value to fishing interests, with the possibility of a long-term gain that more than makes up for the loss. Failing to conduct the experiment (continuing to fish) may result in collapse, or simply in lower future yields (or an environmentally driven recovery). Walters and Martell [30] note that such decision situations commonly result in "inaction as rational choice", (i.e., in managers waiting to make difficult fishery reduction decisions in hopes that recovery will occur anyway).

This paper demonstrates the use of simple calculations from decision analysis to compare difficult management choices like those shown in Table 1. It first reviews the basic decision analysis approach, then provides a case example from management of a valuable grouper population in Kuwait waters.

2. Decision analysis for comparing experimental policy options

The early literature on adaptive harvest management in fisheries was based on using relatively complex stochastic optimization methods to provide "closed loop" harvest control rules for populations with highly uncertain production parameters [18,22,23]. Such analyses were difficult to understand, and were never trusted or directly applied in harvest management. Further, it was difficult or impossible using those methods to represent complex hypotheses about nonstationarity of recruitment relationships, (i.e., uncertainties about whether recruitment parameters might be changing in some directional pattern over time due to factors like climate change or nursery habitat loss).

A more general and easily understood approach to the comparison of adaptive policy options was suggested by Walters and Green [29]. This approach simply involves the construction of decision tables like Table 1, with broad policy options as rows and broad hypotheses about the ecological response to the policies as columns, then doing time simulations of each policy-hypothesis combination so as to populate the table with some quantitative performance measure representing utility or value aggregated over time. Given such an aggregated utility measure and measures of prior probability or credibility for each hypothesis, it is simple to identify the policy that maximizes expected utility over possible outcomes (hypotheses) and to calculate the expected value of perfect information (EVPI) for knowing which of the hypotheses is correct. The critical assumption in such calculations is of course that one of the hypotheses is, in fact, correct, (i.e., that nature does not behave according to some "none of the above" dynamics). To represent adaptive learning over time for policies involving experimental manipulations, Walters and Green [29] recommended treating the learning process as a two-stage one, by dividing the time simulations into experimental and long-term management periods with the duration of the experimental period determined by simulation gaming methods [27].

When constructing decision tables, it is tempting for scientists to display their knowledge of uncertainties by adding many columns (admitting lots of alternative hypotheses) and by adding many rows to represent various experimental policy choices and/or optimum policy options for each of the hypotheses. Such articulation of the decision problem is not actually necessary for exposing basic uncertainties and for deciding whether or not to adopt an experimental approach; it can lull decision makers into thinking that the mechanics of the decision analysis have provided them with a fully optimum choice, rather than simply an indication of the best direction for policy change. A variety of alternative hypotheses about the details of variation (alternative parameter values for dynamic models) can be represented just by averaging over such variation for each broader hypothesis column. There are, in fact, only two critical rows that should be included in all decision tables for adaptive management: one for "no deliberate action" (business as usual, continue historical policy), and one "experimental" involving changes deliberately aimed at encouraging learning.

Another temptation in decision analysis has been to populate the decision table with a utility measure calculated from some complicated multi-attribute utility function that weights a variety of performance measures, (e.g., mean catch, the variance of catches, and the probability of very low stock size). Use of such utility functions has become common in structured decision making, (see, e.g., [14]). A basic problem with using such weighted utility measures in fisheries decision-making is that there is typically wide divergence in the weights recommended by different stakeholders. For instance, conservation interests call for high weights on measures related to the risk of severe stock decline and fishing interests call for high weights on economic performance measures (net present value, or simply total long-term catch) that reflect greater willingness to accept the risk of stock decline. There is no accepted way to combine these divergent utility functions into a single best one for public policy. One attractive option is to stick with simple economic performance measures that all stakeholders can agree are important to fisheries management. Then, deal with the risk of undesirable situations (bad system states like extinction) by introducing threshold decreases in utility if/when undesirable states (for all stakeholders) are predicted, (e.g., [15]).

3. Case example: declining catches of Kuwait fish stocks

Catch reconstructions for Kuwait fisheries indicate that some stocks, particularly of nearshore serranids and sciaenids that are targeted by artisanal, commercial, and recreational fisheries, have shown relatively severe declines in catch since the early 1990s [1]. Absent other information, these trends would be interpreted as evidence of overfishing. There are enough growth and age-composition data for the main serranid, the Hamour (orange-spotted grouper, *Epinephelus coioides*) sampled during 1981–2008, and by-catch rates from the shrimp fishery recorded over the years 1999–2008. The growth data of the Hamour (von Bertalanffy parameters $k = 0.2$, $L_\infty = 100$ cm) suggest a natural mortality rate (M) near 0.2. This information permits the application of virtual population analysis (VPA, using the [26] method) and stock reduction analysis models (SRA, using the stochastic SRA model of [31]) to estimate biomass and recruitment trends associated with the catch decline shown in Fig. 1. Here the study provides only a brief