Accommodating uncertainty in assessing returns from research for Tasmanian orange roughy management

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Abstract

Uncertainty in stock structure and size is accounted for explicitly using Bayes' theorem to assess expected returns from various management strategies and fishery-independent data collection. Expected returns are assessed relative to quantitative measures that arise from fishery management objectives. A range of constant-catch strategies and simple feedback controls are examined for Tasmanian orange roughy.

Introduction

This paper is focussed on taking explicit account of uncertainty when attempting to evaluate anticipated returns from research for fishery management. One of the most important sources of uncertainty in this regard is that surrounding the size of the fish stock. It is almost invariably the case that we have imprecise estimates of the fish population size and it is therefore desirable that we acknowledge this openly when attempting to analyse situations that are linked closely with stock size.

Our approach is to specify uncertainty in the fish stock in terms of probabilities. We assign probabilities to various stock-size intervals by specifying a probability distribution for all conceivable stock sizes and we then change this distribution as new information warrants. Bayes' theorem is used to obtain a new distribution that is the result of combining the first-specified distribution with data from the fishery or other relevant sources such as surveys.

In the present paper we simply present the results of our analysis for specific management strategies. This provides an opportunity to illustrate the effect of uncertainty in stock structure on our assessment of returns from research for Tasmanian orange roughy management.

Orange roughy (*Hoplostethus altanticus*) is a deep-sea species found at depths of 750–1400 metres and distributed widely in the temperate latitudes of both northern and southern hemispheres. It is a very slow-growing species, maturing at 20 to 40 years of age, at lengths of between 30 and 36 cm, and is thought to have a lifespan in excess of 100 years. Recruitment to fisheries is coincident with first spawning, although little is known about pre-recruitment behaviour or recruitment processes (Staples *et al.* 1994).

Commercial fishing for orange roughy began off western Tasmania in 1986. There are currently about 20 fishing vessels operating in the fishery, having declined from 50 vessels in the early 1990s. The fishery is now based primarily in the eastern and southern management zones which are treated as separate fisheries with independent stocks. At present the annual total allowable catch (TAC) is 2000 tonnes (t) for the southern zone and 3000 t for the eastern zone. It is thought that current stocks are at about 30% of virgin biomass. There is considerable doubt, however, about whether the two zones have separate stocks.

The management strategy adopted in the fishery depends on stock structure. Management based on the assumption of a single stock might, for example, lead to total allowable catch being allocated with no restriction on spatial concentration of effort. If, in fact, two stocks exist then fishing pressure on each of the two stocks could be suboptimal. Likewise, if management is based on a false assumption of separate stocks then fishing costs are likely to be higher than they would be otherwise.

Management objectives for the Tasmanian orange roughy fishery are set by the Australian Fisheries Management Authority (AFMA) and are detailed by Chesson (1996). The primary objective is to ensure that the orange roughy resource is exploited in an ecologically-sustainable manner. This has been interpreted as attempting to maintain the spawning biomass of each stock above 30% of the equilibrium spawning biomass prior to the onset of significant commercial fishing in 1989 (that is 30% of the pre-1986 biomass).

The second management objective stated is to maximize the economic efficiency of the fishery. It is assumed that what is meant by this statement is that managers, having satisfied the first objective, will allow fishers to catch their allocation in an economically-efficient manner. In the process of achieving the first objective, therefore, the second objective ensures that managers attempt to use policies that are consistent with maximization of the net present value (NPV) of the flow of harvests.

Method

The measure that we use to assess returns from research for Tasmanian orange roughy management is the expected net present value of catches over a 100-year time horizon. Under the assumption of constant real prices and costs, several management strategies are considered, the optimal one being that which corresponds to the maximum expected net present value of catches, subject to sustainability of the fishery. We consider both constant-catch and feedback (percentage-of-expected-biomass) management strategies.

Of particular importance is the way we deal with uncertainty in stock structure and biomass. We assume equal probabilities over feasible pre-fishery biomass levels and over values of a mixing parameter that might provide a quantitative indication of the degree of separation of the populations in the two zones of the fishery. Fishery and research data, along with Bayes' theorem, are used to modify these probabilities.

The combination of techniques in our method yields numerical estimates that can be used to assess returns from research for fishery management and, at the same time, provide an indication of how uncertainty changes as information evolves. Details of the approach we take can be found in McDonald and Smith (1997) and McDonald *et al.* (1997).

Results and Conclusion

The initial specification of probabilities to feasible biomasses and mixing parameter values is termed specifying a prior (or prior distribution). This prior takes account of specific fishery and research data only if they are available at the time the prior is specified. As information becomes available the revised probabilities give rise to what is termed a posterior (or posterior distribution). When one considers what might result from research (before it is carried out) the postulated results can be used to modify the posterior to obtain a pseudo posterior (or pseudo-posterior distribution). We make use of each of these distributions to assess the expected returns from the fishery without fishery and research data, with fishery and research data, and with possible future research data. When account is taken of the optimal management strategy in each case, measures of the expected returns from research can be obtained. In addition, the way the distributions evolve is indicative of the data-induced change in perception of the uncertainty surrounding both biomasses and stock structure.

We considered constant-catch strategies for each zone ranging from zero to 8000 t per annum in increments of 400 t and evaluated the expected net present value of the fishery with each. This was done (i) using only fishery data, (ii) using both fishery and research data, and (iii) using both fishery and research data as well as consideration of a possible future research survey. The results of this analysis are reported in McDonald *et al.* (1997). A summary of the results follows.

For a zero discount rate, under the prior the maximum expected NPV of R$252 591 is obtained with TACs of zero in zone 1 and 4000 t in zone 2[1]. Under the posterior this strategy yields an expected NPV of R$363 178. This compares with R$421 749 from TACs of 2000 t in zone 1 and 2400 t in zone 2, which is optimal under the posterior. These results imply an expected return from past experimental research of R$58 571.

Expected returns attributable to a 10-year trial strategy, followed by experimental research in the year 2005 and an optimal catch strategy thereafter, are as follows. In the no discounting case, the maximum expected NPV of R$566 373 results from TACs of 4400 t in zone 1 and 7600 t in zone 2 for 1995–2005. To compare with this, the appropriate expected return from the optimal strategy under the posterior is R$480 931. This implies an expected return from the planned research of R$85 442. Similar results were obtained using discounting rates of 3% and 6%.

Based on historical data, the chosen model and particular parameter restrictions, it is clear that for all chosen discount rates expected returns from completed stock-structure research for the Tasmanian orange roughy fishery are positive. In particular we have found that the expected return from previous research is approximately R$58 571, R$49 177 and R$31 852 at discount rates of 0.00, 0.03 and 0.06. For the proposed research the expected returns are R$85 442, R$74 648 and R$69 619.

[1] R$1 is the assumed constant real value of 1 tonne of fish.

We also examined management strategies that are best described as simple feedback controls for the fishery under the prior and posterior distributions (but not for the case of proposed future research). In these cases, we considered the possibility of revising the control after a period of 10 years: that is, after management authorities had time to evaluate information from fishery and research reports. The controls considered were applied to each zone separately and were enumerated as the TAC for the next year as a percentage of the expected biomass. The percentages of expected biomass examined were 0, 1, 2, 3, 4, 5, 6, 8, 10, 20, 50, 75 and 100. Any one of these percentages could be chosen for the first 10 years and any one of them for the next 90 years, based on maximizing the expected NPV of the stream of fish catches.

The result of our preliminary examination of each of these control levels is that the optimal strategy might, from a fishery point of view, be to set the TAC at the expected biomass for the first 10 years and then at between 0 and 3 percent of expected biomass for the next 90 years. Such a strategy would both maximize expected economic returns and allow recovery of the stock sufficiently to satisfy the sustainability constraint. It must be emphasized, however, that these results are subject to uncertainty. They are preliminary and are based on a particular model and set of assumptions that do not match those used for Tasmanian orange roughy stock assessment. In particular, the sustainability constraint is applied in the present paper at the end of the 100-year time horizon only. This would not be acceptable for stock assessment purposes, given the diversity of sources of uncertainty.

Finally, it is worth examining the change in our perception of uncertainty in the stock structure of Tasmanian orange roughy that arises from this work. This is most easily demonstrated graphically.

The posterior distribution (which incorporates all historical research data) for the mixing parameter, displayed in Figure 1, indicates little departure from the uniform prior distribution and so available historical data appear to be uninformative with respect to the mixing parameter. Under both the prior and posterior distributions, however, the optimal TAC for zone 1 is consistently lower than that for zone 2, a pattern that is compatible with zone 1 being a source of recruitment to the zone 2 fishery *via* spawning migration.

Consistent with this latter evidence Figures 2 and 3 display the posterior distributions for pre-1989 biomass in zones 1 and 2. These distributions indicate that pre-1989 biomass in zone 1 is most likely to be within the range 75 000–160 000 t and that pre-1989 biomass in zone 2 is most likely to be between 30 000 t and 135 000 t.

The upshot of this graphical evidence is that the assumption, for management purposes, of completely separate stocks in zones 1 and 2 is not supported by the evidence, given the chosen model and the restrictions applied to it. The catch strategy changes that flow from making use of this information result in changes to the expected NPV of the fishery and, therefore, positive expected returns from stock-structure research for Tasmanian orange roughy. These expected returns must obviously be compared to expected costs before a decision is made on whether to proceed with the proposed research.

In terms of research that might lead to a reduction in stock-structure uncertainty, the results point to the need for adaptive management of the two zones of the fishery. Such adaptive management would necessarily involve use of different TACs in the two zones, differences being large enough to yield obvious differences in current populations and their recovery, depending on the time level of mixing.

References

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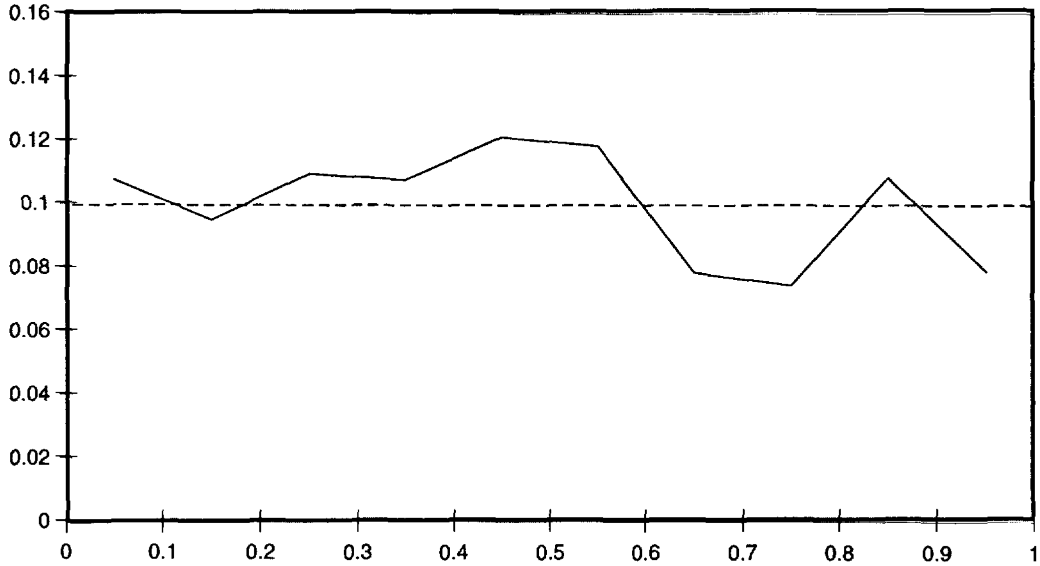

Figure 1. Posterior (solid) and prior (dashed) for mixing parameter.

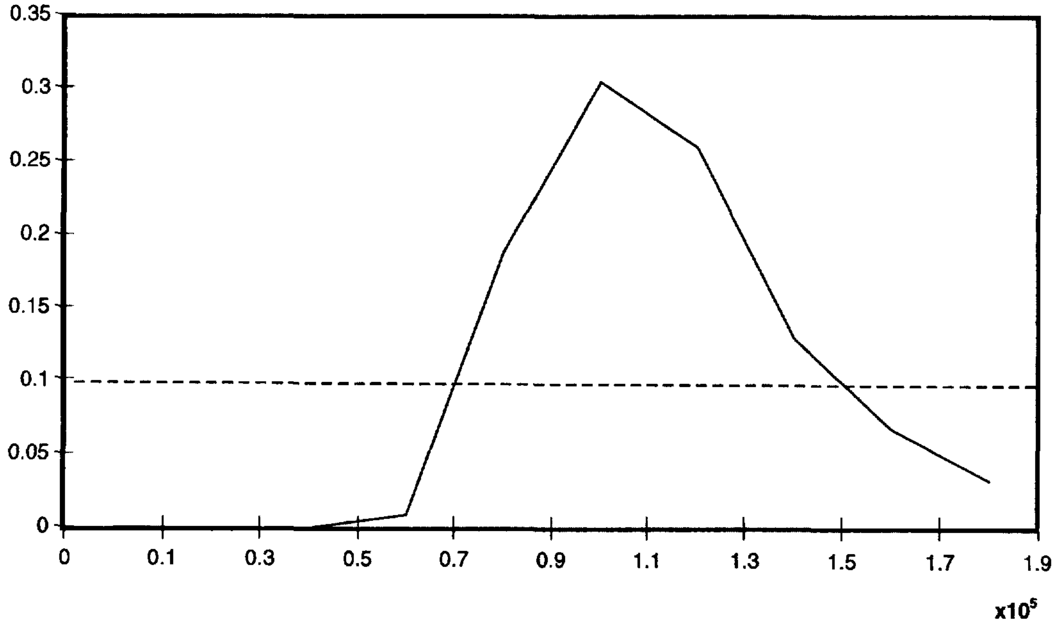

Figure 2. Posterior (solid) and prior (dashed) for zone 1 biomass.

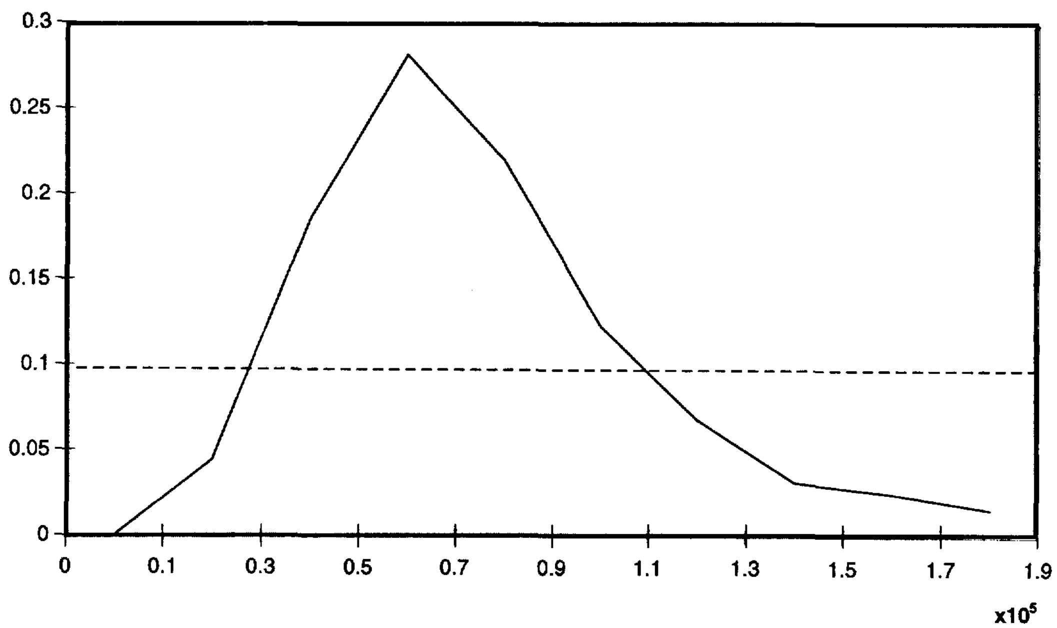

Figure 3. Posterior (solid) and prior (dashed) for zone 2 biomass.