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Elements of a precautionary risk-management framework for Canadian cod stocks

Éléments d'un cadre de gestion du risque prudent pour les stocks de morue du Canada

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ABSTRACT

We describe the elements of a risk-management framework for implementing the precautionary approach on Gadoid stocks off Canada's east coast. The need for such an approach is very evident at the present time. Seven out of the ten east coast cod stocks collapsed as a result of overfishing in the 1980s and early 1990s. Fisheries reopened on three of these stocks in 1997/98 despite a lack of scientific evidence for any significant recovery (northern cod, northern Gulf cod and southern Gulf cod) and there is now evidence that these fisheries, although small relative to historic catches, are being pursued at unsustainable levels. What seems, in part, to be delaying implementation of the precautionary approach is the lack of a clearly articulated framework that takes into account limits to overexploitation, scientific uncertainty in the state of the resource and rules for taking the appropriate actions. The current depressed state of most cod stocks in Atlantic Canada and the realization that groundfish stocks in general are very susceptible to impaired productivity, gives this undertaking both momentum and a sense of urgency.

RÉSUMÉ

Nous décrivons les éléments d'un cadre de gestion du risque pour la mise en oeuvre de l'approche de précaution à l'égard des stocks de gadidés au large de la côte est du Canada. La nécessité d'une telle approche est indéniable à l'heure actuelle. La surpêche des années 1980 et du début des années 1990 a entraîné l'effondrement de sept des dix stocks de morue de la côte Est. En 1997 et 1998, la pêche a été rouverte pour trois de ces stocks (morues du Nord, du nord du Golfe et du sud du Golfe) sans preuve scientifique d'un rétablissement notable de leur part et nous avons désormais la preuve que ces pêches, quoique peu importantes par rapport aux captures historiques, se poursuivent à des niveaux insoutenables. Il semble que la mise en œuvre de l'approche de précaution ait été retardée en partie par l'absence d'un cadre de travail clairement énoncé qui tient compte des limites de la surexploitation, de l'incertitude scientifique liée à l'état des stocks et des règles pour la prise de mesures appropriées. L'épuisement actuel de la majorité des stocks de morue du Canada atlantique et le fait que les stocks de poisson de fond sont en général très vulnérables aux baisses de productivité impriment à la fois un élan et un caractère d'urgence à cette mise en œuvre.

INTRODUCTION

We describe the elements of a risk-management framework for implementing the precautionary approach on Gadoid stocks off Canada's east coast. This paper was presented orally at the National Workshop on Reference Points for Gadoids, Ottawa, November 2002 (Rivard and Rice 2003). The need for a framework for implementing the precautionary approach is very evident at the present time. Seven out of the ten east coast cod stocks collapsed primarily as a result of overfishing in the 1980s and early 1990s. Fisheries reopened on three of these stocks in 1997/98 despite clear scientific evidence that the stocks remained depleted (northern cod, northern Gulf cod and southern Gulf cod) and there is now evidence that these fisheries, although small relative to historic catches, are being pursued at unsustainable levels (see Smedbol et al. 2002 for a review in the context of species at risk). Unsustainable fisheries on collapsed non-recovered fish stocks is clearly not consistent with a precautionary approach. Although scientific uncertainty contributed to some extent to delays in decisions to take necessary conservation actions just preceding and during the collapses in the 1980s and early 1990s, there is little ambiguity regarding the present situation. Management actions consistent with the precautionary approach are overdue for valuable renewable fish stocks off the east coast of Canada. What seems, in part, to be hindering implementation of the precautionary approach up until now, is the lack of a clearly articulated framework that takes into account limits to overexploitation, scientific uncertainty in the state of the resource and rules for taking the appropriate actions. Although this is a challenging undertaking, it is within the scope of existing science expertise within DFO and all the components have clear precedents internationally. The current depressed state of most cod stocks in Atlantic Canada and the realization that groundfish stocks in general are very susceptible to impaired productivity, gives this undertaking both momentum and urgency.

The respective roles of science and fisheries management in the application of the precautionary approach in the management of Canadian gadoid stocks is beginning to take shape. Science needs to define what constitutes serious or irreversible harm on a stock by stock basis (Rice and Rivard 2002). A systematic, science based, analytical approach should then be put in place for setting conservation limits and for quantifying uncertainty about current and future states with respect to these limits. Scientifically defendable biological and statistical rationales for these approaches need to be provided. Next, rules need to be developed which explicitly connect limits and risk in support of the decision-making process. Such a framework will provide the necessary guidance to fisheries management on the linkage between analytical treatments of uncertainty and decision rules to ensure risk-averse decision making in the application of precaution in management. This framework is particularly attractive because it can deal explicitly with management objectives or targets, which are themselves a part of good management practices. However, targets, by definition, characterize desirable states of the resource. They must be far from the region of serious or irreversible harm where precaution would be a consideration, and therefore are not addressed further in this paper.

Elements of the framework

The recent Canadian federal inter-departmental discussion paper on "A Canadian Perspective on the Precautionary Approach/Principle" (http://www.pco-bcp.gc.ca/raoics-srdc/docs/precaution/Discussion/discussion_e.pdf) provides the basis for the framework. The approach outlined in the discussion paper can be consistently applied across a wide spectrum of federal decision-making situations. It represents a consolidation of experience with precaution in protection of human health, environmental quality, and resource management, and fairness in international trade. It states that Canada applies the precautionary approach in situations when a decision must be made about a risk of serious or irreversible harm and when there is high scientific uncertainty. Under this framework, the precautionary approach is seen as a distinctive way of making decisions within science-based risk management, influencing how options are developed and how decisions are made. Public consultations on the framework have been completed and only minor revisions are envisaged. The concepts embodied in it are expected to become part of Canadian federal government procedures in Spring 2003.

With respect to implementing the precautionary approach in the context of marine fisheries, the "Canadian Perspective" is very consistent with the FAO Code of Conduct, the United Nations Fisheries Agreement (UNFA), other international agreements and Canada's own Oceans Act. Under Fisheries Management, General Principle 7.5.3 of the FAO Code of Conduct, it says that states should, on the basis of the best scientific advice available, determine stock-specific limit reference points, and the action to be taken if they are exceeded, and that when a limit reference point is approached, measures should be taken to ensure that it will not be exceeded.

The precautionary approach is a special case of risk management. The risk-management framework that we propose in order to apply precaution in a Canadian fisheries context focuses on evaluating the risk of serious or irreversible harm in the face of high scientific uncertainty. It should allow for societal input regarding risk tolerances while at the same time safeguarding that only "best science practice" is applied with expert, case-specific knowledge input. Although, within this framework, "precaution" is only applied relative to serious harm, this "harm" may not only be associated with specific species, but could also have to do with other components of the ecosystem with which they interact. Serious harm can be interpreted in the framework in terms of "impaired productivity" and conservation limits can be related to specific, case by case definitions of what constitutes impaired productivity. Defining the appropriate limits and computing the risks falls on the shoulders of technical experts operating in terms of best science practice. In some cases best science practice may extend to include nonstandard approaches such as those based on traditional knowledge, however, all approaches for defining limits and determining risks must be rigorously evaluated.

To progress in the development of a risk-management framework for Canadian Gadoid stocks we need to examine what indicators are informative regarding impaired productivity and develop systematic, science based, analytical approaches for setting conservation limits and for quantifying uncertainty about current and future states with respect to these limits.

Defining limits

In keeping with the Canadian "Perspective on the Precautionary Approach/Principle" discussion paper, we interpret impaired productivity to be a sufficient condition for there to be a "risk of serious or irreversible harm". This perspective provides the link between a philosophical framework and an operational framework for the application of precaution, which has not previously existed in a Canadian fisheries context. Activities which simply reduced yield may be economically inefficient, but do not comprise "serious or irreversible harm". However, activities which jeopardize the future productivity of a stock do constitute such harm. Moving this into conventional fisheries models and terminology, growth overfishing, in which yield per recruit declines beyond some peak because the benefits accruing from fish growth are being negated by excessive fishing mortality, does not equate to serious or irreversible harm. Recruitment overfishing on the other hand does constitute serious harm and may be irreversible (or at least take decades to reverse).

Recruitment overfishing can be defined as a level of fishing mortality that results in a sharp decrease in recruitment at equilibrium (Sissenwine and Shepherd, 1987). It is understood to occur when spawning biomass is so low that recruitment decreases substantially and even precipitously. Sissenwine and Shepherd (1987) note that the definition is vague and does not lend itself to the exact specification of biological reference points. Some level of judgment must be applied to decide on when recruitment overfishing is taking place and at what point it constitutes serious or irreversible harm.

Finding the boundary between growth overfishing and recruitment overfishing is central to establishing limit reference points in the context of the application of precaution. To be defendable as a definition of serious harm, a limit needs to have a sound scientific basis. Recruitment and production responses may appear to be smooth functions of spawner biomass or fishing mortality, but this does not preclude defining scientifically defendable limit reference points. For example, increased probability of low recruitment or decreased probability of good recruitment at low spawner stock size could be sufficient to quantitatively define a limit reference point.

As another example, stock-recruit data for a large number of stocks may support a heuristic based on fishing mortality or spawner biomass demarcating a point beyond which stocks tend to collapse based on empirical data. Similarly, there may be an empirical basis for defining a spawning biomass below which recovery is not rapid and secure, or is much delayed, upon cessation of fishing. Several approaches for developing limit reference points are available in the fisheries literature. These approaches and their model contexts are briefly reviewed in Shelton and Rice (2002), and conclusions are drawn regarding the characteristics which may make certain reference points more suitable for selection as possible limits in the context of the framework which we describe.

An approach for setting the boundary at which future productivity is jeopardized must comprise a biological statement of what characterizes the boundary and a computational method for making the statement operational. As an example, the boundary may be an *SSB* below which the probability of poor recruitment (defined as some level based on past history) exceeds some level. This may be expressed as: "The *SSB* below which $\mathrm{P}(R \leq 200 \times 10^6) > 0.2$". This would be linked to an analytical approach for developing estimates of *R* and *SSB*, and a mathematical approach for providing probabilistic statements regarding recruitment at different spawner biomass levels.

In this example there is a clear biological statement of what characterizes the boundary and the computational methods for making the statement operational are explicit (SPA and, for example, kernel weighted smoothers). The link to jeopardized future stock productivity should also be made clear. For example, if recruitment below the boundary has a low probability of exceeding that required for *SSB* replacement at current body growth, maturation and mortality rates, then it is clear that future productivity will likely be impaired.

Analytical approaches for defining the boundary between growth overfishing and recruitment overfishing are generally based on the currencies of "mortality rate" and "spawner biomass". While these approaches are preferred, they may not be feasible or considered "best science" for all stocks due to data limitations or underlying population dynamics. Alternative approaches using currencies other than fishing mortality and spawner biomass may therefore have to be explored for setting the boundary at which future productivity is jeopardized, provided there is a rational argument for why mortality rate and spawner biomass are insufficient or inappropriate.

Under the framework we outline, the limit reference points associated with serious harm are not going to be as restrictive on harvesting as some that were suggested in previous DFO Science deliberations (Rice and Schnute 1999, Richards and Schnute 2000). However, in exchange for working with a lower limit biomass and a higher limit exploitation rate, there is strong empowerment for risk aversion (Shelton and Rice 2002). Any harvest with a risk exceeding a pre-identified risk tolerance for a limit can be labeled as inconsistent with a precautionary approach in a public document such as a Stock Status Report.

Quantifying uncertainty

In dealing with uncertainty in the context of limit reference points, the objective is to quantify uncertainty in terms of whether or not stock size is less than a specified limit over some time horizon. Probability metrics are commonly used to quantify such uncertainty, and have appeared in a number of DFO Stock Status Reports in recent years. However, it is not clear that these metrics have had the desired impact on the decision making process thus far. Whether this is because the decision-making process has not adopted the risk-averse strategies consistent with the Federal Framework on the Application of Precaution in Government Decision-Making, or because the uncertainties and risks were not communicated effectively, is open for debate. However, some rethinking and additional discussion regarding the appropriate approach to quantify and communicate uncertainty appears to be warranted to promote effective application of the precautionary approach framework we describe.

In groundfish assessments in Atlantic Canada, the current practice is to apply the ADAPT procedure to estimate stock size, and to provide standard errors and other assessments of the uncertainty in stock size estimates. Preliminary evidence for ADAPT suggests that it is better to use the bias adjusted bootstrap rather than the percentile method for quantifying uncertainty. Many other methods exist to estimate stock size, and some of these methods may be more appropriate for quantifying major sources of uncertainty (or certainties) than ADAPT. Stock assessors should be encouraged to include these approaches where appropriate.

Probability statements provided by ADAPT are based on the "frequentist" method, which is the most common approach used for statistical inferences in most disciplines including fisheries science. For example, ADAPT can be used to estimate the probability that the estimator of SSB declines next year. An estimate is a fixed number, while an estimator is a function of random variables and is therefore itself random. Such inferences are commonly communicated as the probability that SSB declines next year. This is not strictly correct because in the frequentist approach stock size (whether well or poorly known) is not random, it is some specific value and it will either decline or not next year. Stock size is simply assumed to be fixed but unknown; however, the estimator of stock size is random because, among other reasons, it is a function of randomly sampled data. Probability statements based on a frequentist approach should be consistent with this notion.

Probability statements based on the frequentist approach are commonly explained in an appropriate manner when poll results are released to the public, so it is not unreasonable that they should be similarly communicated when providing scientific advice from fish stock assessments within a precautionary approach framework. For example, there is some familiarity and acceptance of the statement from a survey poll that the result is accurate to within ±2%, 19 times in 20. This a way of communicating a description of a 95% confidence interval that is consistent with frequentist inferences.

A disadvantage with the frequentist probabilities supplied by ADAPT is that the probabilities usually have to be estimated, and consequently there are uncertainties in these probabilities. Bayesian methods that use prior information can give exact probabilities; however, the priors are often subjective and Bayesian probabilities may not have a valid frequency interpretation. This can make Bayesian probabilities difficult to communicate; for example, these probabilities do not mean that the result would occur x% of the time under repeated sampling.

Another strategy for communicating uncertainty in the context of the precautionary approach is the hypothesis test framework familiar to most scientists. The connection between the probability statement and the data is made explicit in this model-based framework. Risks are communicated as *p*-values; for example: " indices have continued to decline, which suggest that *stock*< *reference*; that is, if *stock*< *reference* then the probability of the catch and survey data is high (>x%) based on the VPA". The p-values are often bounds on probabilities, and the bounds may be estimated more precisely than the probabilities. Within the hypothesis test framework, it may also be easier to communicate what is the impact of noisy or sparse data. If new data becomes available that alters the probability statement, then it may be easier to communicate why this has occurred. The hypothesis test framework naturally brings into question the statistical power of the test. It is important to understand how large *stock size reference* has to be if the event *stock*< *reference* is to be rejected with the required probability; that is, it is important to make the link between data quality and modelling practices, and the ability to reject whether *stock*< *reference*.

In current practice, it is clear that our methods cover only some of the overall uncertainty. In the medium term there are many issues related to quantifying uncertainty that need to be addressed in developing the framework for the application of precaution. Other agencies and disciplines outside the fisheries science “box” may have insights to offer, for example in the area of human demographic forecasting. DFO should utilize knowledge from other disciplines where appropriate in developing a framework for a precautionary approach to fisheries management.

Developing rules

In our focus on developing the precautionary framework for cod stocks off the east coast of Canada, the conclusion is inevitable that several of these stocks are at or below any reasonably defined limit reference point and that, on biological grounds, directed fisheries should be closed, or, as is the case for eastern Scotian shelf cod, should remain closed. However, for stocks that are above the limit reference point, such as the St Pierre Bank (3Ps) cod stock, and for cod stocks which may recover in the future, clearly articulated rules governing future removals would be a core element of the precautionary framework. Ideally, the suite of harvest control rules applied to a stock would ensure meeting management objectives as often as possible whilst keeping the risk of serious harm to a minimum. Clearly there is a trade off – zero harvests on a healthy stock minimizes the risk of serious harm but does not address social, economic and political objectives. The multi-attribute nature of management objectives for marine fisheries makes it very difficult to develop useful objective functions – simplified surrogate objective functions often have limited value. Analytical approaches for evaluating the trade-offs and for finding solutions that satisfy, to some acceptable level, a number of different attributes, need to be explored instead. Clearly, as a stock deteriorates, the emphasis has to shift from attempting to satisfy attributes related to social and economic factors, to minimizing the risk of serious harm to the resource. This process could include the use of buffers, as is the case in the NAFO PA framework, or the use of “precautionary” reference points aimed at allowing only a small probability of the stock falling below the limit reference point, as is the case in the ICES PA framework.

Discussion about harvest control rules in the context of a Canadian framework for implementing the precautionary approach is its infancy. Simulation testing, probably using an “operating model” to represent the fishery system, will be essential to gauge the efficacy of alternative rules. Rules that adjust harvests based on model estimates of quantities of interest, such as risk of spawner biomass falling below some level, need to be compared with rules that respond more directly to measurable quantities, such as the research vessel survey index. Experience gained by scientists at the International Whaling Commission and elsewhere suggest that the development and evaluation of harvest control rules is not a trivial exercise. Progress will require allocating considerable resources to the problem, drawn from a range of disciplines including biology, mathematics, economics and sociology. It will also require a commitment to a more rule-based approach to management decision making, as implied by DFO’s Objectives-Based Fisheries Management initiative proposed a few years ago.

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