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Évaluation des stocks canadiens Séries des comptes rendus 98/18

Proceedings of a Workshop on Implementing the Precautionary Approach in Canada

5-9 October 1998

Pacific Biological Station
Nanaimo, BC

J. Rice and J. Schnute
Co-Chairmen

R. Haigh
Editor

Fisheries and Oceans Canada
Fisheries Management, Pacific Region

Pacific Biological Station
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Canadian Stock Assessment Secretariat
200 Kent Street, Ottawa, Ontario K1A 0E6

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Preface (Jake Rice)

The Executive Summary (p. vi) reflects consensus wording approved by meeting participants. It is not so much an executive summary of the contents of the report as it is a consensus viewpoint, shared by meeting participants, of where DFO and Science Branch stand with regard to preparedness for implementing the precautionary approach.

The text of the rest of the report was not reviewed in plenary. Presenters prepared their own summaries, which were only edited for compatible style through the document. The reports of discussions were prepared by volunteer rapporteurs. The discussion notes are intended to reflect the range of questions (and answers) posed and opinions expressed during the discussion, generally in point form. Unless a point in the discussion sections is labeled clearly as a point of agreement by the group, it should not be taken as more than the expression of a position in the range of professional opinion on the topic being discussed. The Strategic Research Project, of which this Workshop is a component, is only at its midpoint. Important results are still expected from most case histories. It is appropriate that conclusions on many points not be drawn before the project is completed.

Workshop Parable (contributed by Bruce Atkinson)

Some Scientist / Manager Interaction Problems Illustrated by a Parable

A man, flying in a hot air balloon, suddenly realizes he is lost. He reduces height and spots a man down below. He lowers the balloon further and shouts to get directions, “Excuse me, can you tell me where I am?”

The man below says, “Yes, you’re in a hot air balloon, hovering 30 feet above this field.”

“You must work in Science,” says the balloonist.

“I do,” replies the man. “How did you know?”

“Well,” says the balloonist, “everything you have told me is technically correct, but it is of no use to anyone.”

The man replies, “You must work in Policy.”

“I do,” replies the balloonist, “but how’d you know?”

“Well,” says the man, “you don’t know where you are, or where you’re going, but you expect me to be able to help. You’re in the same position you were before we met, but now it’s my fault.”

Acronyms

Discussions of the Precautionary Approach typically involve acronyms referring to technical concepts, agencies, and international agreements. Appendix III (p.71) gives definitions of most acronyms used in this report.

Acknowledgements

We wish to thank the participants who volunteered to be rapporteurs – Michael Chadwick, Stratis Gavaris, Robert Mohn, Robert O’Boyle, Jake Rice, Denis Rivard, and Jon Schnute. We would also like to thank Norm Olsen for his in-session technical support and Ghislaine LaPorte for work on the initial draft of the proceedings and coordination of contributions from across Canada.

Executive Summary (Stratis Gavaris)

The language of the various Precautionary Approach (PA) agreements is taken as the context within which we must operate. There is presently no stated DFO policy which compels us to accept the context of these PA agreements. The working group asks that guidance be provided to DFO staff by senior management on policy in implementing the PA. The working group considers that the role of science is to develop the tools necessary to facilitate implementation of the PA and to evaluate candidate management procedures which may be developed in this context.

The PA clearly directs us to (i) define unacceptable outcomes, (ii) take uncertainty into account, and (iii) implement a decision process. Further, the PA identifies several objectives, including those with respect to overexploitation, overcapacity, social and economic dislocation, loss of biodiversity, and major ecosystem disruption

The working group focused on objectives related to resource conservation. Specifically in relation to resource conservation objectives, the PA (as defined in the agreements) requires both biomass[1] and exploitation rate reference points. The PA refers to exploitation rate references as upper limits and biomass reference points as rebuilding targets or lower limits. Reference points need not be restricted to these two dimensions but should include these as a minimum.

A PA would involve management procedures that avoid resource collapse and maintain high productivity and associated sustainable harvests. Both limit and target reference points may be useful in defining such management procedures. UNFA states that within a PA, F_{MSY} should serve as a default limit reference and B_{MSY} can serve as a rebuilding target. The working group considered that the concept of "maximum sustainable" harvest may not be applicable to all harvested resources and in such cases, B_{MSY} and F_{MSY} could not be prescribed as default reference points.

The PA prescribes the use of a pre-defined decision process, which implies the implementation of a harvest control rule. We consider that harvest control rules are useful for exploration of harvest strategies, but are not essential for implementing management regimes that respect the PA spirit. Simulation experiments of harvest control rules are the most promising tool for assessing the feasibility and reliability of candidate management procedures.

Successful implementation of PA is dependent on effective management structures and consultations among stakeholders, managers and scientists to achieve consensus on principles, objectives, operational definitions of performance measures and unacceptable outcomes.

UNFA article 6.2 asserts that "States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measure." Though many of the elements of PA are being explored in current resource evaluation and management practices within DFO, the added value of implementing a PA is the packaging of all of these elements together as a guiding framework.

[1] The term biomass is used as a proxy for spawning potential and may be measured as biomass or abundance.

1. Introduction

1.1. Objectives of the workshop (Rice)

The stated objective of the Workshop is to move ahead quickly with the implementation of the precautionary approach for domestic stocks; to pursue the quantification of uncertainty and risk; to develop conceptual frameworks/approaches for testing harvest strategies; and to plan further work for the high priority project on the precautionary approach.

The precautionary approach cannot be implemented by DFO Science activities alone. There are important roles for Fisheries Management, for diverse clients, and for policy actions. Nonetheless, a number of component tasks are inherently the responsibility of Science Branch. To discharge that responsibility many Branch scientific staff have been working on aspects to the precautionary approach, particularly methods to quantify risk and uncertainty within assessment and advisory contexts. This work began before the High Priority Project on the Precautionary Approach, but received added impetus from that project, which has reached its mid-point. The Workshop provides an opportunity for scientists from across the country to share their advances, have their work evaluated by peers, consolidate progress, and set a course both for the remainder of the project, and for Science Branch aspects of implementing the precautionary approach in annual assessment and advisory practices.

In that context, during the Workshop participants will consider whether it is possible, at this stage, to give some interim guidance for adopting a precautionary approach during assessment practices in 1999. It is also appropriate to consider ways to encourage greater coordinated action with the many partners in other Branches and in the public sector, whose contributions are essential for implementation of a precautionary approach in assessment and management of Canada's fish stocks.

Discussion

1. Outcome of the workshop needs to be communicated effectively, but the target audiences have not been fully specified.
2. The proceedings will be published in the CSAS Proceedings series.
3. Rapporteurs notes should be printed and distributed for comment each morning.
4. Software will be discussed on Wednesday afternoon.
5. We need to discuss specifically coordination of precautionary activities of transboundary stocks.

1.2. History of high priority project (Schnute)

This project began with a proposal from the Pacific Region in November, 1996. It received official funding on March 20, 1997, when Scott Parsons approved a collection of projects to be financed with Strategic Science Funds in FY 1997/1998. The entire package totaled $13.5 M, of which $4.5 M was directed to High Priority Strategic Research. The PA project was not listed in the printed memo; apparently, the project had not made the final cut. Nevertheless, when Scott added his signature, he amended the memo with exactly one handwritten note:

> "Approved with amendment of High Priority to add $50 K for precautionary approach – the money for a national network of researchers. This is to be managed by Bill Doubleday . . ."

I like to think of this note as evidence that the pen is mightier than the word processor. It also shows interest at a high level in the subject we're addressing at this workshop.

Bill Doubleday organized an initial project meeting in Dartmouth, NS, on June 8, 1997. He suggested that case studies be used to give the project specific focus. The participants agreed to start work on eight case studies, and currently that list has been expanded to nine. Based partly on initial developments in the Pacific Region, a few team members from eastern Canada visited us in the west to help get things started. These included Bob O'Boyle (Jul 28-29, 1997), Stratis Gavaris (Oct 14-16, 1997), and Alan Sinclair (Nov 24-28, 1997). In each case, members managed to come here while accomplishing other tasks that brought them relatively close to Nanaimo. We also used the telephone as a frequent means of contact. For example, Denis Rivard and I exchanged documents by mail and e-mail, so that we could discuss them easily by phone.

In November, 1997, the Pacific Region started a Web site that has now become a convenient focal point of communication for all of us. By December, 1997, we had compiled a national proposal for the next fiscal year, and this remains visible on the site. On August 14, 1998, we received official notice of funding for the second and third years of the project in 1998/1999 and 1999/2000. Although only half the proposed funding was actually approved, we are better off now than in the initial year 1997/1998. In particular, we have been able to convene this workshop (October 5-9, 1998), which is surely a milestone in our project history.

From a personal perspective, I've tried to articulate a vision of the project as I see it. Here are some of the key features:

- I'd like to see a national community of researchers, bound together by mutual trust and understanding. We can start by trying to understand each other at this workshop. Given limited resources, we can at least continue our communications via the Web site. The precautionary approach poses difficult scientific problems. We can use this project as a forum for completely new ideas, giving ourselves the intellectual room to examine the problems with fresh eyes.
- Our case studies provide useful starting points, grounded in reality. We can use the Web site to exchange data, documentation, and technical content. In the long term, we might do comparative analyses, seeing how members from different regions would approach each other's problems.
- Realizing that all of us have different backgrounds, I'd like to see us develop a common analytical framework that clarifies our differences. I'll give the outline of such an approach in a talk on state space models tomorrow.
- Developing a precautionary approach will require flexible thinking about practical problems. I hope we can be motivated by common sense and achieve scientific rigor without rigidity.

<u>Discussion</u>

1. Web site access and issues of password access will be discussed further on Friday.
2. The group **agreed** that information presented during the workshop can be posted on the website. Best if presentations are in WORD or PowerPoint. The full text of documents are

best posted in Acrobat Reader. Posting is the author's choice. A disclaimer can be included if the author desires.

3. The future of this project will be discussed on Friday.

1.3. Legal framework for precautionary approach (Richards)

The precautionary approach is now embodied in a variety of agreements, including

(i) 1992 Rio Declaration on Environment and Development;
(ii) FAO Code of Conduct for Responsible Fisheries;
(iii) Agreement for the implementation of the provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks (UNFA);
(iv) Canada Oceans Act.

Of these agreements, only the Oceans Act is legally binding for Canada. The Code of Conduct is a voluntary agreement and most of the provisions related to the precautionary approach are repeated in UNFA. However, the number of countries that have ratified UNFA is not yet sufficient for it to be incorporated into the Law of the Sea. In particular, Canada was one of the first signatories to UNFA, but has not yet ratified it.

The Oceans Act defines the precautionary approach as "erring on the side of caution" (Article 30). The Code of Conduct and UNFA are much more explicit and provide detailed implementation guidelines. The essence of the precautionary approach is stated in UNFA Article 6.2: "States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures". Furthermore, according to UNFA Article 6.3a, States shall "improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty".

For developed fisheries, UNFA recognizes stock-specific reference points as the primary mechanism for applying precautionary approach. "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low" and "that target reference points are not exceeded on average" (UNFA Annex II.5). Furthermore, the fishing mortality that corresponds to maximum sustainable yield is identified as a limit reference point for stocks that are not overfished. For overfished stocks, the biomass that corresponds to maximum sustainable yield is identified as a rebuilding target.

Discussion

1. Do agreements cover resources other than fish, like mammals or species not currently harvested? The answer is "Yes". Impacts on other species through bycatch or ecological overlap are included. Some agreements talk about living resources., others do not.
2. The Straddling Stocks Agreement has not been signed by Canada and the timetable is unclear. There was some attempt to put legislation through last year and it may go ahead again this year.
3. Does the Oceans Act give a legal definition of precautionary approach? Clear answers are not available.
4. There was differing opinions on whether our direction for the project participants was to write something that would provide a Canadian interpretation of the precautionary

approach. It was **agreed** that the meeting's focus should be on the science issues because the application of PA requires more than scientific inputs and not all the appropriate constituencies are represented here.

5. The RAP process requires interpretation of regulation and laws to make clear what can be said from a science perspective. The science peer review and advisory process should follow agreements as much as possible, but the legal framework of what is "precautionary" in Canada is not really explicit.
6. Need clear definitions. Participants hope to define as many terms as possible by the end of workshop. Unlike the US, Canada has not explicitly defined "overfishing" for example. B_{MSY} is identified as a rebuilding target in some places. The meeting participants will revisit terminology at the end of the workshop.
7. UNCLOS is very specific for straddling stocks but Canada does not have a useful framework for domestic stocks. We have a moral obligation but not a legal one at this point.
8. It would be premature for this workshop to come up with legal wording for Canada's approach. Participants are looking to see what works and what does not – a start, not an end.

2. Development of Precautionary Approach in Canada

2.1. The NAFO experience (Rivard)

At the 1996 Annual Meeting, the Fisheries Commission requested the Scientific Council to comment on Article 6 (Application of the Precautionary Approach) and Annex II (Guidelines for Application of Precautionary reference points in Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks). In June 1997, the NAFO Scientific Council proposed a provisional framework for the implementation of the precautionary approach and recommended that a workshop be held in March 1998 to develop the concepts further.

The provisional framework (Figure 1) attempts to accommodate the terms of the UN Agreement on Straddling Stocks and Highly Migratory Species which specifies that a precautionary approach should:

- implement limit and target reference points;
- express those both in terms of fishing mortality and spawning stock biomass (SSB);
- take uncertainties into consideration and, when in doubt, err on the side of caution;
- use F_{MSY} as Minimum Standard for limit fishing mortality; B_{MSY} can also be used as a rebuilding target;
- have pre-agreed management actions when limits are exceeded.

While the NAFO used to have a strategy based only on target fishing mortalities (e.g., $F_{0.1}$), the new framework now recognizes limits which should be expressed in terms of fishing mortality and biomass. The provisional framework identifies also a target recovery level for spawning biomass.

The March 1998 workshop served to review the models and the data available for defining reference points for each stock in the NAFO Regulatory Area. The models available for defining reference points included: Stock Production Analysis (used for F_{MSY} and B_{MSY},

F_{CRASH}); Spawner per recruit relationships (used for Minimum Spawning biomass), Yield per recruit models (Used for $F_{0.1}$ and F_{MAX}), ICES Precautionary Points (F_{PA}, B_{PA}) and Risk Analyses (to quantify uncertainty and estimate buffer zone).

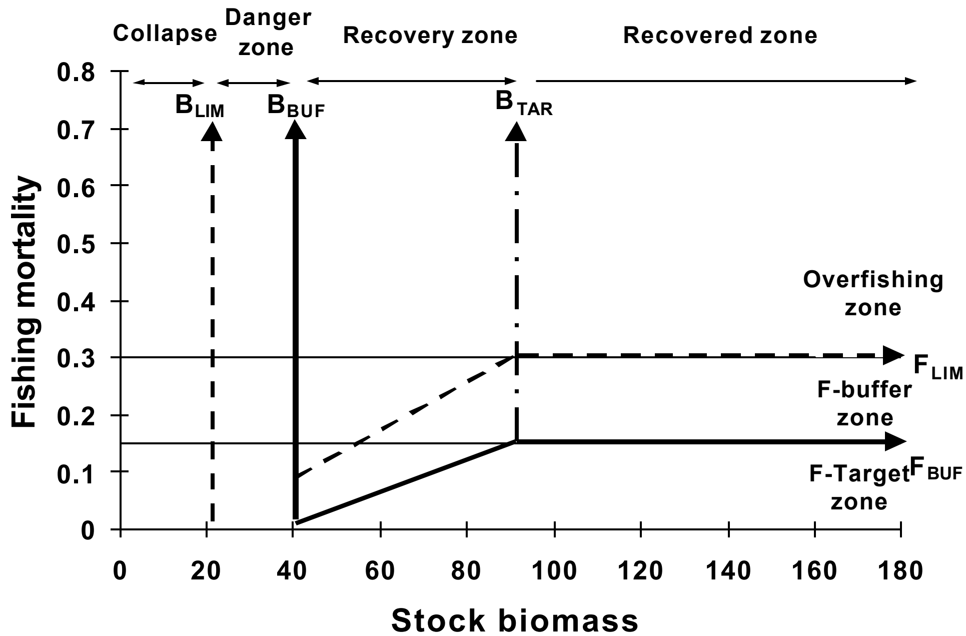

Figure 1. Provisional framework where targets and limits are expressed both in terms of fishing mortality and biomass as follows:

B_{LIM}: Level of SSB that stock should not be allowed to fall below
B_{BUF}: Level of SSB acting as buffer to ensure high probability that B_{LIM} not reached
B_{TAR}: Target recovery level for SSB (B_{MSY} ?)
F_{LIM}: F that should not be exceeded (no higher than F_{MSY})
F_{BUF}: Level of F acting as buffer to ensure high probability that F_{LIM} is not reached
F_{TAR}: Depends on management objectives but <= F_{BUF}

While the provisional framework recognizes three data-environments (data-rich, data-moderate, and data-poor environments), it was concluded that working on specific cases would allow faster progress in the development of concepts. American plaice on the Newfoundland Grand Banks (NAFO Divisions 3LNO) was identified as one stock for which sufficient information was available (i.e., data-rich) to explore the concepts. The Workshop participants made significant progress in identifying for that stock reference points and their potential use within a precautionary approach.

In May 1998, a working group composed of managers and scientists met in Copenhagen to review the progress of the Scientific Council and establish a wider forum for discussing the implementation of a precautionary approach. It became clear that the respective roles for scientists and managers needed some definition (Table 1) and that the managers needed to be involved in the selection of reference points (e.g. buffers) and the implementation of decision rules. It was also recognized that other types of precautionary measures (e.g. closed areas, fish size restrictions, gear regulations and effort controls) needed to be brought into the precautionary approach.

Table 1. Roles for the Scientific Council and the Fisheries Commission

Scientific Council	Fisheries Commission:
• Determine status of stocks • Classify stock with respect to SSB/F zones • Calculate limit reference points and security margins • Describe uncertainty • Conduct risk assessments	• Specify management objectives, select target reference points and set limit reference points • Specify management strategies for SSB/F zones • Specify time horizon for F adjustments • Specify acceptable levels of risk

In conclusion, there are no detailed guidelines yet on how to set limits for each of the stocks managed by the NAFO. Ultimately, the reference points (limits and targets) are likely to be stock specific and are likely to be based on observed data rather than on analyses which are model dependent.

The NAFO experience illustrates that managers need to be involved early in the process and that a forum is required to foster exchanges on the implementation on a precautionary approach. NAFO recognized that, beyond fishing mortality and biomass considerations, there is a need to include other considerations in a discussion of a precautionary approach (e.g., distribution, bycatch, etc.) so that the full range of conservation measures (e.g., area closures, fish sizes, bycatch, etc.) could be evaluated.

Finally, it is clear that the data-moderate and data-poor situations will require innovative approaches (models, analyses, etc.). Also, new software tools will be required, together with proper training.

Discussion

1. Is natural mortality assumed to be constant? Generally, yes.
2. Where is risk represented? The concept of risk is represented by which zone a stock is in. Quantified uncertainty is supposed to be captured by the distance between B_{BUF} and B_{LIM}. Mangers have a major role in deciding how wide that space is.
3. Does the time frame for recovery need to be defined? Management objective.
4. Can we distinguish among the different zones? The "distinction" is in the actions taken as much as in the state of the stock. This formulation presents no special problems that do not already exist with assessments and advice.
5. There was a diversity of opinion about what action should be taken in zone 2, where F is too high but B is satisfactory. It was clear that we must reduce F, but the time frame needs to be defined. It was also asked if there was a rule for following a schedule to keep B above B_{TAR}.
6. Try to capture all the uncertainty in the space between the buffer and the limits.
7. What would the advice look like? Advice states what zone the stock is in. There are supposed to be pre-agreed actions, once the zone is specified.
8. The gap between B_{LIM} and B_{BUF} encompasses both the uncertainty in estimating the reference point and the annual status. Managers decide how wide the gap needs to be between the limit and the buffer. In practice, once the zones are created, F_{LIM} and B_{LIM} and target go away and there are only F_{BUF} and B_{BUF}.
9. Looseness in the reference points must be compensated for by the stringency of the

harvest control laws.

10. There are many complications that are not dealt with here.
11. Canada seems to have done a better job internationally than domestically in specifying a consistent framework.
12. Scientists and managers need to discuss the time frames for getting into desirable zones. Managers will want to maintain some flexibility with time frames.
13. What happens when there is a major change in perception of the stock? How quickly will the system respond? Unknown in practice; conceptually the pre-agreed actions mean the response should be swift.

2.2. The ICES experience

2.2.1. Comprehensive fishery evaluation working group (Sinclair)

The ICES Comprehensive Fishery Evaluation Working Group has met twice, first in June 1996 (ICES CM 1996/Assess:20) and then in June 1997 (ICES CM 1997/Assess:15). The working group's terms of reference are (i) to develop tools for comprehensive assessments, (ii) to develop methods for medium term projections that include harvest control laws, (iii) to evaluate comprehensive assessments, (iv) to evaluate the implications of stability or trends in catchability in assessments, and (v) to evaluate the reliability of catch forecasts when catch data are unreliable. The working group has given considerable attention to reviewing the implications of the precautionary approach on the process of providing scientific advice on fisheries management. The next meeting is scheduled for January, 1999.

The working group reviewed the international agreements defining the precautionary approach at its first meeting. It was concluded that, in order to be consistent with the PA, acceptable harvest control laws would have the following qualities:

- fishing should be limited to sustainable levels;
- uncertainty should not be a reason to maintain high fishing mortality;
- the stock biomass should be kept above B_{MSY} ;
- fishing mortality should be kept below F_{MSY} ;
- in the absence of other information, B_{MSY} and F_{MSY} should be taken as limit reference points;
- there should be only a low probability that limit reference points are exceeded.

This first report also has useful definitions for several biological reference points including those dealing with yield per recruit, SSB per recruit, and stock production. The second report provides methods for estimating the variance of these reference points using bootstrap, delta, and analytical approaches. A framework for evaluating management procedures is described in both reports. The framework includes the following elements in the underlying system: fish (growth, recruitment, fishery, process error), assessment (catch sampling, abundance indices, technique, observation error, model error), management (control law, implementation error), and performance statistics ($F>F_{CRASH}$; $F>F_{MSY}$; $B>B_{MSY}$ in 5, 10, 20 years; $B<B_{LIM}$; expected yield a % MSY).

The working group examined the issue of default precautionary reference points for fishing mortality and stock biomass at its 1997 meeting. The evaluation was based on simulations of populations with a range of life histories. The following is the list of default reference points.

$F_{PA} = F_{0.1}$
$B_{LIM} = 0.5\ B_{MSY}$
$B_{PA} = B_{MSY}$

The working group is also following a number of case studies of comprehensive assessments. These include North Sea Flatfish, North Sea Herring, Norwegian Spring Spawning Herring, Icelandic Haddock, Barents Sea Cod, and Southern Gulf of St. Lawrence Cod.

2.2.2. Study group on the precautionary approach (Rice)

This Study Group followed after the ComFiE and other ICES meetings whose activities are described above. Its Terms of Reference were specifically to propose candidate B and F limit and precautionary reference points for as many stocks assessed by ICES as possible, including stocks for which analytical assessments were not available, and taking into account both estimation and process errors. It was also to propose generic characteristics of harvest control rules for the precautionary approach, including recovery plans for stock outside of safe biological limits. Its mandate specified consideration of multi-species interactions, technical interactions, and mixed species fisheries.

The Study Group stressed that all estimates contributing to reference points should be based on "best" parameter estimates, and not ones chosen to be particularly conservative. The "precautionary approach" applied to how the advice was provided and used, not how the estimates were obtained. Decisions on analyses should be based on statistical, biological, and ecological knowledge, and not on which analyses gave low, average, or high results.

With regard to treatment of uncertainty, the Study Group concluded that: few studies have estimated full uncertainties associated with assessing stock sizes and forecasting catches; hence the overall uncertainty is likely >> 20-40% CV's. Status and productivity are also not usually accurately estimated, and the usual assumption of environmental stationarity is unlikely to be true. Implementation uncertainty is often very large, but is rarely considered in analyses of uncertainty.

With regard to MSY based reference points, the Study Group noted that in the agreements F_{MSY} now considered a limit, not a target.. From reviewing known cases of collapses, n stocks are known to have collapsed when F was kept <= F_{MSY}. However, F_{MSY} ignores multi-species interactions, mixed fisheries, and technical interactions, and is often hard to estimate. The Study Group also noted that for equal risk, the probability of exceeding F_{MSY} and the probability of exceeding F_{CRASH} are not the same.

The Study Group noted that assumptions about stock and recruitment relationships are vital in identifying reference points, yet these relationships are often poorly specified in real data sets, and selection generally requires significant biological insight. Selection of the wrong functional form can cause large errors in forecasts of consequences of changes in stock size. Moreover, parameters of stock - recruit functions are often poorly determined, and small subsets of the data points often have very high leverage.

The study Group provided the following guidance to assessment Working Groups, with regard to selection of precautionary reference points, and following them in developing its list of candidate reference points as well:

- B_{LIM} will usually be based on estimate of B_{LOSS}, but when recruitment appears to increase as SSB decreases, then B_{PA} is estimated from B_{LOSS}

- When only B_{LOSS} can be estimated $B_{PA} = B_{LIM}\, e^{1.645\sigma}$, where σ is an estimate of the uncertainty in B (usually taken from the range 0.2-0.3).
- If MBAL (the ICES Minimum Biologically Acceptable Level for a stock is ~B_{LIM}, then MBAL is set equal to B_{LIM}.
- If MBAL is ~B_{PA}, then B_{PA} = MBAL.

In addition, specific rules were suggested for groups of species with special life histories, including deep-sea fishes and salmonids, appropriate to the life histories and data records for those species. The Study Group noted that ICES advice will generally refer only to the F_{PA} and B_{PA} values, and not the limits. When F exceeds F_{PA} then the situation will be called "overfishing", and when B is less than B_{PA}, then the stock will be considered "overfished".

With regard to harvest control laws, the Study Group defined them as "pre-agreed management actions" in response to estimated "states of nature". The study Group stressed that they were essential for timely action, and require extensive industry-management-science consultation. It further noted that when explicit decision rules are lacking, a precautionary approach has to include allowance for implementation uncertainty

Discussion

1. How is ICES different from NAFO? They appear to operate in parallel. Harvest control laws have similar strategies. ComFiE has not considered the NAFO zone idea.
2. Is the process convergent? Yes, the recovery strategies of NAFO have not yet been considered by ICES. Both have chosen the harvest control laws as opposed to an annual quantification of risk.
3. ICES does not include the concept of a buffer. The idea of the buffer is in the testing phase. Not useful to define ahead of time. If you are testing the control law then you have to live with what comes out.
4. There are no stocks in the North Sea that are fished < $F_{0.1}$, indicating that there was no acceptance of this target.
5. Catch data from most countries are not reliable.

2.3. The FRCC experience (summary by O'Boyle)

1. A handout was circulated. Only highlights are given here.
2. As part of the discussion on reopening criteria, the FRCC conducted broad consultation with industry to develop a report card on stock status and reopening criteria. This was considered by industry as not applicable due to complaints on knowledge deficiencies. It was decided to adopt a more qualitative approach, accepting a certain level of tolerance and flexibility.
3. The current PA working group wishes to develop a practical guide for a PA (5-point definition of the PA).
4. Basic tasks were defined: (i) conservative harvesting, (ii) adequate SSB, (iii) diverse age structure, (iv) genetic diversity, (v) ecosystem protection, and (vi) habitat protection. This infers more fishing constraints along with more responsibility.
5. We need to define a strategy before implementation, including limits, targets, and trajectory.
6. An implementation process for the DFO and FRCC was presented.

7. FRCC wants to consider assessing a fisheries system, not just the biology.
8. Process based on indicators (stock, fishery and environment) to assess system along with rating system.
9. Global (science dominant) and local (fishermen dominant) recommendation structures were presented.
10. Presented structure to deal with uncertainty - quantitative vs. qualitative. "Rigor without rigidity"
11. Provided examples of report cards that could be used as a starting point.
12. Presented a synthesis flowchart.
13. What is next? Discussion paper. Workshop in December to evaluate the proposal. After this, wider consultation in winter, 1999.

Discussion

1. What is the mandate and role of FRCC? Proposal seems to preclude work here at this workshop. Response was that this is within the mandate of FRCC and it is formalizing what is being done now while at the same time addressing requirements of international agreements and the Oceans Act. FRCC has and will continue to pose many questions to Science.
2. The FRCC mandate is restricted to groundfish but case studies at this workshop consider others as well. Is there not the possibility of divergence of definition of what constitutes a PA? Agreed that this is a concern. There is also the Pacific FRCC to deal with salmon. Could not the observations of the FRCC be used here? Maybe.
3. When criteria for re-opening of the cod fishing grounds were proposed by FRCC, there was criticism that the criteria were too arbitrary and lacked sufficient input from fishermen. How has this changed? We are seeking ways to include all the information, from both science and fishermen, while keeping all the quantitative content.
4. Science and fishermen's viewpoints correspond to global and local approaches to evaluating stock status. Are these being integrated successfully anywhere now? Yes, in some places, but not formally on the East Coast. There is, however, a commitment from DFO to have meaningful input from industry. How do we do this? We need to discuss the role of users' knowledge at this workshop.
5. The project and DFO need to clarify the role of DFO managers. The decisions of the managers often are even more conservation-directed that the FRCC recommendations, which are used as a starting point.
6. What is difference between DFO and FRCC consultations? There appear to be two sets of recommendations occurring. The role of Science Branch and the FRCC has a long history, and possible overlaps cannot be resolved at this workshop.
7. Can DFO achieve the implementation of the pre-agreed actions? FRCC intends to become more objective. It wants to define an explicit process while allowing flexibility.
8. There was a long discussion of who has the mandate for identifying reference points. Does FRCC have a mandate to come up with reference points for East Coast groundfish? Not alone. There is a procedural vacuum. The workshop is to review and make progress on science tools. It is to discuss the tools and not focus on who is to use them afterwards. What FRCC is trying to do is reconcile the international agreements and the Oceans Act with a formal process. Many interests have a role in the reconciliation and the process.

2.4. The Pacific experience – Coho salmon (Holtby)

In the past, DFO sought to achieve target spawning escapements in all spawning habitats used by coho. That objective was not achieved for a variety of reasons including the inherent difficulties of managing highly mixed-stock fisheries to simultaneously achieve escapement targets for populations with very different intrinsic productivities. For the 1997 fisheries, an approach incorporating multiple Limit Reference Points (LRP) was proposed. In the context of a specific objective (some examples are given in Table 2) an LRP specifies an escapement floor. The floor is expressed in units of females per km, which is applicable to all streams. The provisional LRP has been defined as:

Spawning densities are to exceed three females per kilometer of accessible stream length in at least 90% of coho-bearing streams within each assessment unit.

This approach allows a simple graphical presentation of assessment advice on the proportions of streams that are predicted to fall below one or more LRPs at any exploitation rate (Figure 2). Such a presentation facilitates decision making by fisheries managers who must satisfy both biological and non-biological objectives. There will likely be a set of LRPs, with each member of the set representing a different objective (Table 2).

Table 2. Seven possible objectives and corresponding possible LRP escapement floors or targets. Possible values for the LRPs were derived from simulations of the Carnation Creek coho population using a whole life-cycle model under conditions of variable climate.

Objective in setting escapement floor	Description	Possible LRP value (females·km^{-1})
preserve ecosystem function	Coho along with other anadromous fish have been identified as important sources of nitrogen and phosphorus, fat and protein to both aquatic and terrestrial ecosystems. Juvenile coho are in some streams dominant members of the aquatic community.	unknown but probably ≥30
maximize production (biological yield)	Coho are viewed as a resource for human consumption	15-30
maximize habitat use	Provide sufficient escapements to insure that coho are present in all available habitats	≈10
conserve production	Coho are very resilient and rebound quickly from low population levels. This conservation level minimizes the demographic risks associated with small population size and allows rapid recovery to either of the two levels above	3-7
prevent extinction from demographic process	At low levels there are considerable demographic risks. This level would be adequate to maintain some probability of avoiding demographic extinction	unknown
genetic conservation-maintain long term viability	Maintain sufficient numbers of spawners to avoid loss of diversity that would eventually lead to loss of fitness and extinction.	unknown
persistence-short term	Some level of probability that the brood line won't disappear in the following year	<3

The approach directly incorporates only one of the two kinds of "risk" that are present. The assessment team working on coho felt that the most significant risk to the resource was over-exploitation of less productive populations, which constitutes a threat to bio-diversity. Consequently, while providing advice on the impacts of harvest, we were most concerned about conveying probable outcomes of harvest on all of the demographic units within the assessment aggregate. Any level of harvest will result in some distribution of female escapements expressed as the proportion of demographic units failing to reach one of four LRPs. The group is still grappling with how to incorporate the more usual concept of risk, which in this context could be simply characterized as the probability distribution of outcomes (escapements) that would result from the choice of any particular exploitation rate. Uncertainty is incorporated in a limited way through the presentation of three "risk" plots prepared with the mean, the 25th percentile and the 10th percentile of the marine survival forecast.

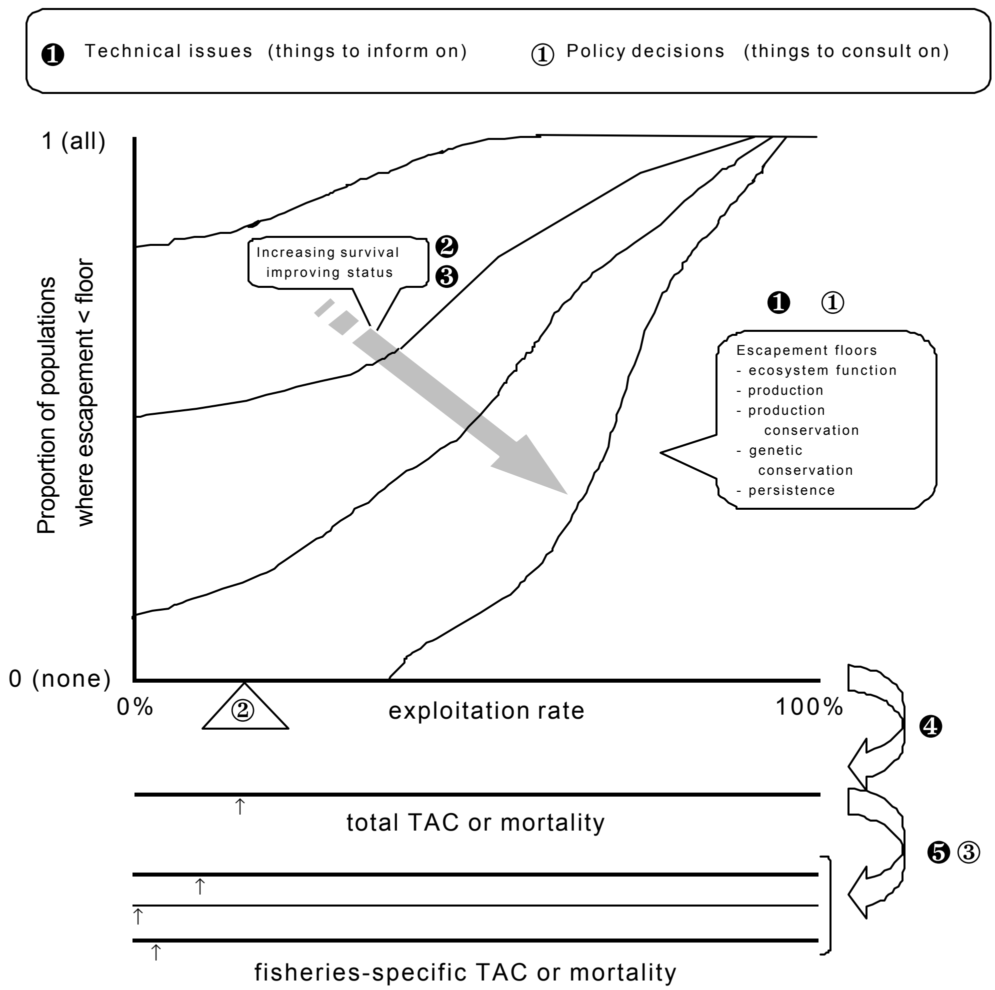

Figure 2. The approach being used to provide advice on the status of coho and the implications of fisheries. Technical and policy issues are identified. This approach summarizes information for an assessment unit or an aggregation of demographic units (colloquially populations). Technical issues requiring further work include delimiting the assessment units, determining what are "safe" or desirable escapement floors or targets to meet specific objectives ❶, measuring status ❸, forecasting adult abundance ❷, translating exploitation rate decisions to total catch or total mortality ❹, and translating total catch to fisheries-specific catches ❺. Policy decisions include setting the objectives (only a subset are

shown) ①, determining the overall exploitation rate ②, and allocating the catch or mortality among the fisheries ③.

Discussion

1. Why use per km instead of m^2? At the time of the census, streams can be dry. Per km is less sensitive to stream conditions.
2. Is the risk analysis focused on the percentile of escapement levels? Yes, but these provisional ones are based on one stream. We are investigating the specificity of risk curves to each assessment unit.
3. But is risk in the curves obscured? Yes, one could produce different curves for different levels of uncertainty. The curves don't show the full uncertainty in the analysis.
4. Look at risk associated with escapements falling as low as observed. The high capacity for density compensation makes it almost impossible for model coho to go extinct. One would have to present other levels of uncertainty with other CFD plots. Also need to track individual rivers within the distribution.
5. Is there any in-season assessment capability? No, however this is not necessarily bad because the in-season indicators are unreliable. In the Alaska situation, facultative switching between coho and chinook confounds CPUE interpretation. There is enormous resistance by industry to regulation.
6. Is risk and uncertainty represented in these curves? No. Need to clarify this as there is a difference from east coast implications.

2.5. The managers' needs

2.5.1. East coast perspective (Vienneau)

1. Handout provided.
2. Gave Atlantic context: dynamics, history, national backdrop, essential requirements (need broader view including economics), hierarchical objectives (need to be prioritized - this might not as elusive as it once was), clear policy direction from NHQ on adoption of PA (no reference to this in any correspondence in DFO management thus far), external consultation (need comprehensive communication plan).
3. Need consistent application of the PA across regions and fisheries. Promotion of multispecies approach is in the policy framework now.
4. Important recent developments: definition of core fishers, capacity target reduction (Cashin report, 1993)
5. Current context may now allow adoption of prioritized objectives.
6. Potential scenario for objectives (i) conservation, (ii) economics, and (iii) social issues.
7. Focus on the future: needs, priorities, realities.

Discussion

1. How widely held is view that buyback will only remove 10% rather than 50% of the capacity as planned? Widely held. Money is not there. Could money be better spent? A lot of money is involved.
2. In some cases a fishery may be biologically viable but should not be opened until economically viable.
3. How would the small openings fit with a multispecies fishery approach? There is some

precedent for the economic limit to be higher than the biological limit (e.g., snow crab).

4. Regarding economic consideration, fishers have a large role in making the decisions. In Northern Gulf, potential quotas were very low but fishers decided to go fishing using hook and line. Will more of these decisions be made outside the Department? Response is that DFO has to be confident of its controls on fishing. Manager should evaluate risk of an opening under stringent constraints not working and there being enforcement problems. In such cases managers should perhaps step in.
5. What about incorporating PA in existing IFMPs? On the management side, there has been no dialogue or information circulated on PA. A necessary component of IFMPs is putting in all the elements of a PA (objectives, etc.) into the IFMP. The IFMP review is a perfect opportunity for managers to undertake this dialogue. There is an essential need to update the current inadequate IFMP template to incorporate the PA.

2.5.2. The Central and Arctic perspective (Richard)

Co-management is a renewed relationship between government, the fishing industry and aboriginal fishers. It involves a shared responsibility for the management of fisheries, including marine mammal hunts. In the DFO Central and Arctic Region, most co-management is legislated within Land Claims Agreements. The agreements provide beneficiaries with preferential rights to harvest wildlife subject to the principles of conservation as well as rights to participate in decision-making concerning wildlife harvesting.

Wildlife Management Boards (or Committees) with membership consisting of beneficiaries and those appointed by Government, recognizing that Government retains the ultimate responsibility for wildlife management, are the main instrument of wildlife management in each of the Claims areas. Wildlife Management Boards establish “basic need” levels of beneficiaries and recommend Total Allowable Harvest (TAH) levels to the Minister. The Minister can accept, reject or vary such recommendations. The Boards are also responsible for allocating from the TAH. Boards also have a role in wildlife research and its direction.

The formal link between the Wildlife Management Boards (or Committees) and DFO is the DFO Area Manager. The Area Manager facilitates the process of co-management. The Wildlife Management Boards rely on DFO to provide the best scientific advice available to assist them in their decision-making processes.

In relation to a recommended harvest level, the Boards would like an element of choice based on a high, medium and low risk scenarios. The output should be given in easily understood terms. The Management Boards expect that the scientific advisors respect the observations of their clients (resource users) and wherever possible consider them when examining assumptions. The Management Boards expect that the scientific advisors make very clear the assumptions and limitations of the data before they make their recommendations. Scientific advisors must be very careful not to “oversell” what their analyses are capable of providing. In this way, the co-managers become involved in the process from the beginning, including model building, data input, analysis and result presentation. In this way, they are much more likely to accept scientific recommendations.

The Regional Fishery Management Secretariat and Fishery Management Biologists based in Area Offices help to facilitate the process. Board members with a scientific background and biological staff hired by the Management Boards have a responsibility to assist their colleagues in understanding the analytical methods involved in the application of the precautionary approach. DFO has some responsibility to sell the principle and process for developing models to the Boards.

Discussion

1. How big are the Boards? For example, the Nunavut Wildlife Management Board has 3 Inuit and 3 government (1 DFO, 1 CWS and 1 territorial) representatives and an Inuit chairperson. DFO and EU ministers appoint their members and the chair is chosen jointly.
2. How long have the boards been in place? Great Slave Lake Board has been working for two decades. The Inuvialuit FJMC has been working for 10 years and the Nunavut Board is 5-6 years old. Overall, Boards have facilitated cooperation between DFO, fishers and hunters.
3. Comment made that we should be recording the success of the Boards. This is to be reported in the case study.
4. Are the Boards receptive to a PA? Yes, and their thinking is evolving.
5. How is the research funded? Recommendations are set jointly. Many fisheries operate as subsistence harvests, so there are no fees or profits to support research. The land claim agreements came with money, and the research is supported by the profits of the investments. Also, there is a DFO implementation fund to support some research.

2.5.3. The Pacific perspective (Joyce)

1. We need a clear articulation of what the PA means to managers and industry, and how it relates to the Oceans Act.
2. We need good advice and a transparent review process.
3. Make points as clear as possible.
4. Define what science does and does not know.
5. We need communication of concepts and advice that is clear to industry and managers.
6. Managers need to interpret policy and advice from science on a regular basis. We need to understand the uncertainties to explain them to stakeholders and the media.
7. Managers are now considering what is meant by the precautionary approach.

Discussion

1. When reviewing assessments, is Science really quantifying uncertainty and recommending low-risk alternatives, or does it make conservative decisions simply because Science is not confident about its evaluation of the status of a stock? The differences should be made clear when advice is provided.
2. Assumptions and limitations of science were also made in the Central and Arctic presentation. Do not oversell science. Stakeholders want to be involved at the beginning. In the Pacific, science, managers and industry are cooperating from the beginning.
3. Science Branch is seeing cooperation with industry in RAP but there is less dialogue with managers in the Maritimes. In the Laurentian region, the opposite is happening. However, in the Maritimes, more cooperation occurs in the Fisheries Management Subcommittee outside of RAP assessment subcommittees.
4. It is the reversal of burden of proof that is going to change the type and amount of participation by industry in DFO meetings, RAP or otherwise.

5. In the Pacific, the Fisheries Research and Conservation Society has facilitated participation of stakeholders in fisheries management.
6. Burden of proof should not be on the stakeholders, but jointly agreed to.

2.6. General discussion of opening session topics (O'Boyle)

1. It would be useful to have a more general non-technical meeting with managers, scientists and industry to discuss the PA. Response was that all regions have to push for this in order for it to happen. Perhaps we could have regional meetings to brief everyone on what is happening regarding the PA. This need will be raised in the upcoming strategic planning at NHQ.
2. Scientists need to understand what they are talking about as well. This workshop is a first step towards this.
3. There was no mention in any manager presentation of reference points. For instance, the shift from F_{CRASH} to F_{MSY} as called for by the UNFA is a shift to sustainability.
4. The hope was that participants could discuss what is feasible regarding practical management at this meeting. It would be good to have managers at this discussion to judge implementation problems.
5. Regarding the PA, a lot of costs are involved (Pacific herring used as example). There was a suggestion that the increased costs fell largely on management, not science. Resolution of disagreements over costs – and risks – will necessitate cooperative arrangements. A comment was made that addressing uncertainty costs more than ignoring it, but perhaps only in the short term. However, this should not stop us from adopting a PA.
6. What are these management costs? Most are associated with assessment. However, the Department should not differentiate among these costs. The expenditure allows the management of a more precautionary approach to fishing. Thus, the Pacific herring arrangement worked.
7. Participants and the Department need to address institutional uncertainty as part of the PA. Simply saying that a PA is wanted does not address this fundamental problem.
8. The concern is that science will produce tools that no one wants. However, the discussion at this workshop indicates that this will not occur. There were differing opinions on this.
9. It is not obvious that DFO will embrace prioritized objectives among the biological, social, and economic objectives for a fishery.
10. What Science must do is focus on the conservation needs of the PA. However, in some instances like snow crab, Science must consider the economics.
11. We should accept the biology and the PA statements in the agreements, and continue identifying the things that our jobs require us to investigate.
12. It was suggested that by the end of the week, a plan be defined on where we are going with the PA as a Department, and not just as a science branch.
13. There must be communication in layman's terms on this project. Perhaps, as part of this project, a science communicator should be hired to facilitate communication between managers and stakeholders. A response was that good communication depends upon good understanding of the issue. Scientists are good communicators as long as they understand the issues. There were differing opinions, particularly with regard to scientists' abilities to separate detail of interest only to other scientists from information stakeholders want to know about. All **agreed** that communication is important. However, the issue is to communicate to whom. Some felt that it is essential that scientists effectively

communicate with managers. The latter are the ones that communicate with stakeholders.

14. A pamphlet describing the PA in layman's terms is needed immediately. This was seen as very important by some of the group. However, there was disagreement by those who believed the Department needs an official PA policy first. Otherwise, a pamphlet might cause confusion.
15. If the PA is perceived as a policy forced on clients from the top down, it will fail. If it is perceived as being developed collaboratively to improve their lives, it can succeed.
16. The FRCC is on the side of science here. Science is the group that defines a healthy stock, a collapsed stock, etc. What FRCC provides is a vehicle for translating the science into operational form.
17. What Science needs to do is translate science into tools that can be used operationally. A reference was made to a paper by Mace and Gabriel.
18. Project members must develop a proposal for how DFO is to proceed on the PA.

3. Basic Approaches

3.1. NAFO's approach to 3NO American plaice (Atkinson)

A summary of the work done by NAFO to date in development of a Precautionary Framework for 3LNO American plaice was presented. During their Workshop held in March 1998, Scientific Council considered it useful to examine a couple of specific examples and 3LNO American plaice was selected as one of these. It was selected because of the long time series of data available, and in the context of the Scientific Council work was considered to be "data rich".

Canada has taken the lion's share of catches historically although there were two periods of increased foreign activity; the first beginning in the mid-1960s to the time of jurisdiction extension, and the second after the mid-1980s. During this more recent period, catches exceeded TACs due to foreign catches being greater than their NAFO allocations. In addition during this period, although the regulated mesh size was 130 mm, there were indications that in many instances the effective mesh size was probably as small as 60 mm. Therefore, the non-Canadian catch in numbers most likely exceeded the Canadian catch during most of this period. Catches and TACs declined from the mid 1980s, and the fishery was closed beginning in 1995. It remains closed today and will do so for 1999.

Canadian research survey estimates of biomass have shown a steady decline from the mid-1980s to 1997.

To set the stage for the analyses carried out, a number of points were noted as follows:

- Catch/weight-at-age not well estimated 1960-64;
- No plus group used in catch-at-age and this may result in an underestimate of SSB particularly in the earlier years;
- Catch-at-age and catches poorly estimated from 1986-1993 due to misreporting, use of small mesh and non-reported catches;
- Reference Fs calculated as mean F from ages 8-12 which covers substantial portion of catch but also includes some partially recruited ages;
- May have been substantial discarding during several periods but no estimates available;
- SPAs in early 1990s rejected by SC because of poor fit;

- Severe retrospective pattern observed;
- Catch/population-at-age data not available by sex in early years. Therefore 9+ used as proxy for SSB. Reasonable during current period but based on maturity ogives may result in overestimate in early years.

It was also noted that:

- 2 changes in Canadian research vessel surveys during 1971-1997 (1983,1995).
- Russian survey data might be available for 1972-1991.
- SSB from research vessels (females only, 1975-1995) shows slight increase to mid-1980s followed by a precipitous decline after 1988. This is similar to result from SPA data, used in most analyses, due to longer time series.
- Standardized CPUE available from Canadian fleet. Data from other fleets spotty and therefore not used.
- Natural mortality assumed to be 0.2 but may have increased in more recent period (indications of an increase in adjacent, more northern, stock).

Overall, there has been a dramatic decline in maturity-at-age from age 10+ in earlier times to about age 7 today. In summary, there have been substantial changes in maturity-at-age and mean weight-at-age over time, there have been substantial changes in the stock/recruitment relationship over time, and the stock appears to be continuing to decline (or at least is not showing any improvement) after the cessation of fishing.

A number of changes have taken place over time, and consideration of these was felt to be important in the determination of reference points. As no clear biological breaks in the various time series could be agreed upon, analyses were conducted for two time periods, 1960-1977 and 1980-1995. These were considered to represent periods of very different fisheries, i.e., before and after declaration of the 200-mile limit.

Scientific Council explored three perspectives of the PA for American plaice: (i) methods for determination of reference points, (ii) evaluation of uncertainty, and (iii) decision or harvest control rules. Four methods for determination of reference points were explored: (i) yield per recruit, (ii) SSB per recruit, (iii) production-based methods, and (iv) other primarily qualitative approaches. The methods were chosen without any specific priority or preference.

Sissenwine/Shepherd plots were developed applying an age-based production model for the two time periods as well as for the entire time period combined. The spawner-recruit data were evaluated to determine a Beverton-Holt relationship based on the best fit to the Evans-Rice median. For the earlier period, MSY yield was in the range of about 40,000 t, whereas for the more recent period it was estimated to be only about 10% of this. It was not resolved as to whether the differences were due to a real change in stock productivity or only a reflection of the dynamic range of available data during the two selected periods.

Overall, $F_{0.1}$ appeared to be fairly stable, but the other reference points of F_{MAX}, F_{MSY}, F_{CRASH}, B_{MSY}, and MSY change dramatically between the two periods. With regard to any estimation of B_{TARGET}, because both F_{MSY} and B_{MSY} showed low stability, it was decided not to relate B_{TARGET} to B_{MSY}. No agreement could be reached regarding limit reference points for F.

A number of analyses (Evans and Rice, visual examination) suggested a limit SSB (B_{LIM}) in the range of about 150,000 t. B_{BUF} was then calculated as twice standard deviation greater than B_{LIM} (about 220,000 t) using a 95% confidence interval and noting that VPA CVs were in the order of 20-30%. Based on these SSB reference points, the SSB has been below B_{BUF} since about 1970.

For fishing mortality (F), 0.25 appeared to be too high for F_{LIM}. Although the stock was stable for many years at Fs of about 0.25-0.3, it declined rapidly afterwards. A value of 0.21 was finally selected, but strictly for illustrative purposes, and F_{BUF} of 0.15 was also used since it appeared to allow the SSB to move away from 150,000 t.

Based on all of these biomass and F reference points, the stock was in what might be called a low risk situation only in the 1960s. During most of the 1970s-1980s the biomass was above B_{LIM}, but fishing mortality was greater than F_{BUF}. During the late 1980s –1993 the stock was really in trouble with Fs above the buffer and SSBs well below the limit.

Scientific Council also examined the determination of uncertainty; however, this was primarily limited to a general discussion, and there were no actual risk analyses conducted. It was noted that a variety of methods are available, but that there are no general guidelines for quantifying uncertainty. Managers and management issues were also raised here and it was noted links to management and dialogue with managers is essential at this point.

The Council also explored the use of decision or harvest control rules (HCR). For American plaice it was agreed that special consideration would be necessary because the fishery is currently closed and re-opening criteria are therefore most important, although this does not appear to be the case in the short term or at least until the stock begins to show some signs of surplus production.

It appears that productivity may be lower now and there is a question as to whether the stock would reach the currently chosen B_{LIM} at this lower productivity level. If this will not occur, then reference points based on the historical data are not appropriate and will have to be recalculated.

To examine harvest Control rules, a number of trial simulations were done although at this point the results are only considered illustrative because of the concern noted above as well as the other uncertainties regarding the reference points. For the simulations, the following decision rules were adopted:

- B_{LIM}, B_{BUF}, F_{LIM} and F_{BUF} used as defined earlier;
- Four levels of inter-annual quota change were permitted: unlimited to maximum of 25%;
- A re-opening strategy of 15,000 t TAC when B_{LIM} reached was imposed;
- When re-opened, the HCR allowed F to change linearly between F_{BUF} and F_{LIM}.

The illustrative results were not very optimistic. They showed that the re-opening would not occur until 2013 or later, and that after re-opening, the amount of time fishing in a precautionary manner (i.e., between buffer and limits) would be in the order of about 85%. After re-opening, the mean yield was estimated to be only about 40% of MSY with the trial HCR.

The intent of Scientific Council is to explore these simulations further, and the Fisheries Commission – Scientific Council Working Group that met in May 1998, recommended this. These types of simulation should also be able to provide information on the number of possible closures after re-opening, etc.

More generally, Scientific Council considered that there are a number of other aspects that must be taken into consideration for American plaice as well as other stocks when applying the Precautionary Approach. These include:

- the exploitation pattern;
- the age/length distribution in the population (this has particular relevance to SSB as evidence mounts that all SSBs are not necessarily equal depending upon age structure);
- growth and maturity;
- non-fishing mortality;
- various species interactions;
- technical interactions;
- possible regime shifts for various reasons, including environmental, which may affect overall stock productivity

In conclusion, for American plaice, Scientific Council could not easily base limits and buffers on analytical results. Instead, limits on SSB and F were agreed upon from inspection of historical data although there was agreement between visual examination and the semi-parametric approach in estimating B_{LIM}. So far there is no agreement on use of B_{TARGET}, nor on what to do when buffers and limits are reached. These need to be developed in concert with managers. Also, harvest control rules must be developed in consultation with managers. For American plaice a number of research requirement have been identified:

- evaluate the sensitivity of reference point calculations to various assumptions;
- improve data quality so as to once again be able to do VPAs;
- understand links between reference points from surveys and VPA;
- carry out simulations with changes in productivity to test framework under various decision rules.

Scientific Council also discussed the current situation for other stocks. With the exception of 3NO cod and possibly 3M cod, other NAFO stocks represent either “data poor” or “data moderate” situations. In “data poor” situations, provisional reference points must be developed, and it was considered inappropriate to simply take lowest observed biomass since for the NAFO stocks these are considered too low for reasonable limits. Scientific Council will also examine possible non-parametric precautionary frameworks. This would allow development of a set of rules to adjust catch levels, but some of these techniques require sufficiently long time series of data. In “data moderate” situations, it is hoped that frameworks can be developed based on indices. It is also within the mandate of Scientific Council to make recommendations on the activities required to improve the databases for these data moderate or data poor stocks so they become more “data rich”.

Scientific Council also concluded that for developing fisheries (e.g., skates and roughhead grenadiers) there needs to be the application of conservative caps on fishing mortality and effort. These present special difficulties since time series of information may not be available.

For the many fisheries that are currently closed, there needs to be careful consideration of harvest levels during the re-opened but rebuilding phase and constraints should be imposed on catches to guarantee a precautionary approach.

Lastly, bycatches of species still under moratorium need to be considered. This is particularly important for American plaice in 3NO where its distribution overlaps significantly with that of yellowtail flounder. The latter fishery was opened for the first time this year since 1995, and the bycatch of American plaice is a real problem.

Discussion

1. The plaice example included the calculation of a separate equilibrium stock production for different time periods where the authors detected different patterns of stock and recruitment. Decisions about which regime applies to the rebuilding phase has large impacts on the rebuilding trajectories under various harvest scenarios.
2. Further discussion is warranted on the criteria for selecting input data for production analysis and the interpretation of possible discontinuities in stock production. Such analyses should proceed by examining the influence of the different inputs on the estimated curves (i.e., stock/recruitment, weight-at-age, partial recruitment, maturity).
3. In this case, the stock production reference points (e.g., F_{MSY}) were sensitive to the input data while the yield per recruit estimates of $F_{0.1}$ were not. $F_{0.1}$ was above F_{CRASH} for the latter time period, indicating that the former is not a universally conservative proxy for the latter.
4. Retrospective patterns were not dealt with explicitly in these analyses.
5. B_{LIM} based on non-parametric stock/recruitment curves (à la Evans and Rice) and "squinty" visual analysis were around 110,000 t.
6. Rebuilding projections indicate a very long period of closed fishing until reopening. It was suggested that this type of message would not be well received by managers nor by the industry and may lead to rejection of PA as being too conservative.
7. Other aspects that should be considered in a PA include age and length composition of the stock, natural mortality, species interactions, technical interactions, regime shifts. It would be possible to have reference points for spatial distribution, size of first capture, and other biological characteristics.
8. The simulations included fishing when B was below B_{BUF} because NAFO has not adopted any specific harvest control rules yet. Until scientists are confident that the harvest control rules will be implemented successfully, scenarios used in projections should include consideration of fishing when the stock is low, if it is likely to occur.
9. Multi-national fisheries management brings along with it a series of political problems not necessarily seen in national fisheries.
10. It was not possible to use analytical models to select reference points but some success was found using qualitative examination of indicators.
11. We should think about ways of incorporating costs of foregone catch when doing risk analysis.
12. Managers feel strongly that it is their prerogative to choose among alternative reference points.
13. Given that the $F_{0.1}$ management strategy was adopted because it was considered to be somewhat more conservative than F_{MSY} and to have economic advantages to F_{MSY}, a PA management strategy should be at least as conservative as $F_{0.1}$.
14. While it may be that there are some cases where $F_{0.1}$ may be higher than F_{MSY} and indeed F_{CRASH}, there are few cases where the benefits of an F_{MSY} management strategy can be achieved with a target $F > F_{0.1}$.

3.2. Risk analysis for short term catch projections

3.2.1. Part A. (Gavaris)

To operationalize the PA we need to explicitly define what we want to avoid, to go beyond estimation of mean and variance. We must characterize the frequency distributions of management quantities to make probabilistic statements and consider potential actions in the decision process. This operational definition of the PA is captured in the mathematical form:

$$\Pr\left(X_t < X_{LIM} \mid \{Z_s\}_{s=1}^{t}\right)$$

This is a general approach which can be useful for any of the PA objectives. We have used it for the conservation objectives.

Short term projections are a special case of the general approach. Here we are interested in the immediate consequences of decisions about the next fishing management season.

$$\Pr\left(X_t < X_{LIM} \mid \{Z_1\}\right)$$

Note that this analysis is not a way to examine the relative merits of alternative harvest strategies. It is assumed that these are established.

Fisheries management in Atlantic Canada involves a variety of measures including gear regulations, area/season closures and fish size limits and quotas. Most of the measures are relatively permanent but quotas are set each year. Consequently, the decision making process boils down to a decision on what the catch quota should be in the coming fishery season. We focused on translating the uncertainties from the stock assessment into the risks of setting alternate quotas.

$$\Pr\left(X_t < X_{LIM} \mid \{Quota_1\}\right)$$

Harvest strategy in Atlantic Canada is based on Y/R considerations, largely a strategy to prevent growth over-fishing. We capitalized on the acceptance of the $F_{0.1}$ reference and incorporated it as a management reference.

$$\Pr\left(F_t < F_{0.1} \mid \{Quota_1\}\right)$$

Recruitment over-fishing concerns may be paramount for depleted stocks. Then the strategy aims to rebuild the biomass. We promoted biomass increase as a reference.

$$\Pr\left(\Delta B_t > 0 \mid \{Quota_1\}\right)$$

Finally, there may be a biomass threshold which there is a desire to exceed. We included such references as well.

$$\Pr\left(B_t > B_{thresh} \mid \{Quota_1\}\right)$$

There may be a tendency to think of X_{LIM} as coming out of an assessment. This is only 1 of 3 practical cases which may arise. First, a reference may be absolutely prescribed as some fixed constant for which there is consensus. Second, a reference may depend on data and population characteristics which are external to an assessment. Finally, a reference may be estimated from parameters within an assessment. We need to consider the nature of X_{LIM} when evaluating uncertainty and risk.

Various methods may be used to quantify uncertainty. I am familiar with three approaches which have been used in Atlantic Canada. The standard approach employs calculated statistics of management quantities with an assumed Gaussian distribution to make probability statements. The parametric Monte Carlo approach uses the estimated mean, standard error and bias of the terminal year population abundance and an assumed lognormal distribution to simulate replicates and project these. Probability statements are based on the empirical frequency distribution. The Bootstrap (model-conditioned, non-parametric) approach generates bootstrap samples by re-sampling index residuals. Bootstrap replicates of management quantities are derived by conducting an assessment and projecting for each bootstrap sample. Of these 3 approaches, the bootstrap method does not require assumptions about distribution of data or distribution of parameters, so it is now more favoured.

There are several ways to do a bootstrap. I am aware of assessments where the percentile method and the Bias Corrected percentile method have been used. I tend to favour the Bias Corrected percentile because it adjusts the cumulative frequency distribution when the percentile median does not correspond to the estimate with the original data. A further refinement, the Bias Corrected-Accelerated percentile method also adjusts for differences in standard error with respect to the parameter. Theory indicates that the Bias Corrected-Accelerated percentile method should perform better than the percentile or the Bias Corrected percentile methods.

Comparison of results with a real example, 5Zjm haddock using only the DFO survey (bias is reduced when 2 NMFS surveys are included), suggest that the standard approach results in a longer lower tail (Figure 3). Probabilistic statements may be too pessimistic. The percentile method results are shifted to the right over most of the range and may result in optimistic probabilistic statements.

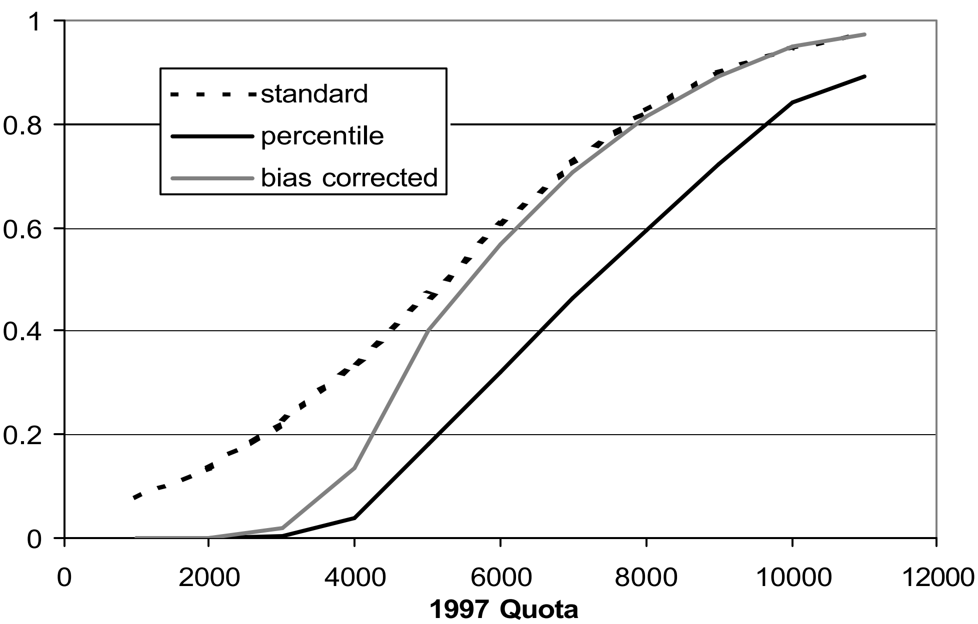

Figure 3. Probability of biomass decline between beginning of year 1997 and 1998 for alternative catch quotas in 1997 (5Zjm haddock fishery), determined by three bootstrap methods: (i)standard, (ii) percentile, and (iii) bias-corrected percentile.

Discussion

1. Of the three methods used (analytical, Monte Carlo and Bootstrap) to quantify risk, the author stated that the Bootstrap method is the preferred in Atlantic Canada because of the less rigid distribution assumptions. It was noted during the discussion that while this is indeed the case, the model framework still assumes that the residuals are independently and identically distributed.
2. Of the Bootstrap methods considered (Percentile, Bias-Corrected, Bootstrap-t, Bootstrap-accelerated) the theory suggests that the Bias Corrected-accelerated method has superior properties. Bootstrap-t methods have good accuracy but are not transformation invariant and have performed erratically in practice. The Bias Corrected method adjusts the percentile for median bias but both are accurate to the same order. It was acknowledged that there has been work to evaluate performance of the various methods but this was not reported. More work needs to be done to assess performance of these methods. Some of this will take place at the January 1999 ICES ComFiE meeting.
3. The particular quantile of a probability distribution used to quantify risk needs to be carefully considered when providing advise. The 20-80% quantile region of distributions is likely better estimated and thus should be the basis of risk statements. Based on the US experience, the acceptable level of risk chosen by managers and stakeholders is not rigid and has varied in particular instances.
4. What has been the reception to the probability plots? Several individual experiences were reported, all indicating that risk plots have been generally well understood by both managers and industry. However, there frequently has been a reluctance to adopt risk averse positions on the risk probability plots, because industry sees substantial loss of quota in order to have a low probability of exceeding a limit.

3.2.2. Part B. (Cadigan)

Stock projections based on SPA are essentially just functions of the unknown SPA parameters. The probabilistic description of a stock projection can be thought of as a standard inference problem for a function of unknown parameters. Within the likelihood framework for statistical inference, the most recommended statistic for inferences about a function of parameters is the profile likelihood. In this paper I discuss how to use this "standard" statistic to determine the probability that a projected stock size is less than some reference level.

The situation considered is when we have data Y, and an assumed probability model $P(Y;q)$, where q is a fixed but unknown parameter vector. This framework for stochastic inference usually underlies most statistical procedures we use. For the VPA-type analyses performed for groundfish stocks off the east coast of Canada q usually consists of survivors, survey catchabilities, and a variance parameter. Our concern is to make inferences about $g(q)$; for example,

$$g(q) = \frac{Next\,year\,stock\,size\,remaining\,after\,some TAC\,option}{reference}$$

$$g(q) = Next\,years\,stock\,size - reference$$

We are usually interested in whether $g(q)$ exceeds some target c. In this situation we should do the composite test

$$H_o : g(q) \le c \;\; vs. \;\; H_a : g(q) > c \, .$$

For some suitable statistic T that gives information about $g(q)$ we can measure the "strength" of evidence our data supplies against the null hypothesis using the p-value,

$$p - value = \Pr\ (T > T^{obs}) \, .$$

The p-value is not the probability that the stock will increase.

For multi-parameter models the "best" statistics, T, available are the maximum likelihood ratio statistic and the score statistic. Hypothesis tests based on these statistics are asymptotically most powerful, invariant to (at least) onto transformations of q, and unbiased. These properties hold for hypotheses like $H_o : q = q_o \; vs. H_a : q - q_a$ is small. For composite hypotheses like ours the optimality may not hold. The most recommended statistic for two-sided confidence intervals (Cox and Hinkley, Barndorff-Nielsen and Cox, Snell and Hinkley, and many others) is the profile likelihood:

$$T_{pl} = 2\left\{ \, l(\hat{q}) - l(\hat{q}_o) \, \right\},$$

where $l(\cdot) = \log\left\{P(\cdot)\right\}$, $\hat{q}$ maximizes $P(q; y)$, and $\hat{q}_o$ maximizes $P(q; y)$ subject to the constraint $g(q) = c$; that is, $\hat{q}_o$ is a constrained maximum likelihood estimate. This constrained estimate is the value of µ that must exist to achieve the target c, given the data we have observed. For example, if a TAC of 5000 tonnes is considered, then $\hat{q}_o$ is the current stock size (and catchabilities) that must exist so that next years stock size will equal some reference level after 5000 tonnes have been removed by a fishery. The difference between $\hat{q}$ and $\hat{q}_o$ indicates how plausible it is that the stock will achieve the target c. If $\hat{q}_o$ is very different from $\hat{q}$; our "best" estimate of current stock status, then we conclude that our data suggests it is unlikely the target will be achieved next year. We measure this likelihood using T_{pl}.

For one-sided intervals (our interest) the recommended statistic is the directed likelihood

$$R_{pl} = sign\left\{ \, g(q) - c \, \right\}\sqrt{T_{pl}}$$

Other common and asymptotically equivalent statistics are

$$T_w = \frac{g(\hat{q}) - c}{\sqrt{s^2}}$$

where

$s^2 = \quad \dot{g}(\hat{q}_o)' I^{-1}(\hat{q}_o)\, \dot{g}(\hat{q}_o)$, or

$\qquad \dot{g}(\hat{q})' I^{-1}(\hat{q})\, \dot{g}(\hat{q})$, or

$\qquad$ equivalent s^2 based on observed information.

Here $\dot{g}(q) = dg(q) / dq$ and $I(q) = E\left[-d^2 l(q) / dq^2 \right]$ is the expected information matrix. Statistics such as T_w are not invariant to the parameterization of q, whereas R_{pl} is. For small sample sizes this invariance often translates into more reliable probabilities.

For distributional robustness I offer the quasi-likelihood, which is based only on the assumed means and variances for the random data. Adjustments may be required when there are many "nuisance" parameters. Inferences about $g(q)$ almost surely get worse for models with higher dimensional q.

Discussion

1. It was noted that a good overview of the problem was presented.
2. How does one differentiate probabilities of different changes in biomass (or other reference points)? Separate plots, like alternative methods. Generally the limiting case is the plot of greatest interest.
3. How would one show the "weight of evidence" for a particular interpretation of stock status? It would look just like the plots produced at present.
4. Can a medium-term rebuilding strategy be evaluated in this framework? Yes, in principle, but the strategy needs to be spelled out very specifically.
5. Science needs a unified vocabulary and set of algorithms for these tasks

3.3. Population projection models and risk assessment (Richard)

These methods are useful for precautionary approach analyses for populations with little information. When data on catch composition and population size are scarce, one cannot model production changes with stock size. An alternative is to use models of population projection coupled with re-sampling methods to simulate the variability and uncertainty of projection parameters. In these models, life history parameters (fecundity and natural mortality) and fishing or hunting mortality are variables whose values are chosen at random from a probability density function (PDF) that encompasses the range of ignorance and natural variation about their values. Repeated runs yield a number of population sizes at a time horizon. This provides a PDF of population sizes and consequently a cumulative probability distribution function of population sizes which can be used to determine a risk probability of exceeding an undesirable population size threshold.

Advantages to the use of this modelling approach are (i) models explicitly define all aspects of a problem and its uncertainty, and they foster discussion; (ii) all parties can examine the problem, facilitating co-management; and (iii) improvements to the model can be made with changes in thinking and information load. Problems with the modelling approach are (i) obtaining data to parameterize the model may be a problem and modellers may have to rely on similarities to other stocks or species depending on life history or expert opinion, (ii) spatially-explicit models and models with habitat changes can be built but information requirements can be burdensome; (iii) models cannot be validated so that they are always open to question, supporting the contention that they should be re-evaluated regularly as new information accumulates and used experimentally in management to distinguish between competing models; and (iv) models must be understandable and simple to use but also complex enough to address the problem.

3.4. State space models as general framework (Schnute)

In this talk, I describe a general framework that could potentially be used as a template against which to compare our various analyses. I draw on ideas from relatively recent developments in the statistical literature, trying to find those most applicable to problems associated with the precautionary approach. I begin by examining a resource system, in which human controls determine outputs, subject to a hidden population dynamics determined by nature. Available data must be used to infer the system dynamics and to evaluate the risk of future control policies.

Statistical literature defines a state space model in terms of two components:

- process component – a dynamic system that describes the evolution of quantities *X*, called states,
- measurement component – a system for observing certain features of the states *X* to obtain the known data *Y*.

In a fish population model, states *X* might include abundances of fish at various ages. Observations *Y* might include age proportions measured in a sample of the catch. As this example illustrates, states cannot be observed directly, but must be somehow be inferred from available data. Thus, a state space model poses a statistical detective problem: how can unknown states *X*, along with parameters that determine system dynamics, be estimated from the data *Y*?

Mathematically, both the process and measurement components of a state space model are specified by probability distributions. The system itself behaves somewhat randomly (process error) and observations from it are noisy (measurement error). Furthermore, the process component may contain other quantities *Z* that serve as controls. For example, a fishery model might include a harvest rate control or a catch control that explicitly alters the population dynamics. The precautionary approach seeks to measure risk to the population associated with a future control policy *Z*. Unfortunately, this risk assessment must be accomplished using only limited data *Y*, without knowing the actual population *X*. Thus, the estimated risk necessarily reflects two sources of uncertainty:

- What is the current system state (measurement error)?
- How will the system evolve in the future (process error)?

In this talk, I develop the state space model framework completely and investigate how it applies to various stock assessment models currently used in Canada and elsewhere. In particular, I show precisely how the Pacific ocean perch case study depends on a state space model. I then describe associated methods of statistical analysis, from both frequentist and Bayes perspectives, and I highlight some advantages and disadvantages of each approach.

Discussion

1. There was some discussion of Bayesian vs. non-Bayesian approaches to these matters, but neither specific questions nor clear resolution on points of discussion.
2. There was also technical discussion of several aspects of the state-space approach, compared to other approaches currently in use. It was felt that the hands-on session was the best forum to pursue those questions.

3.5. Emerging fisheries (Perry)

A framework is developed for the provision of scientific advice to support the management of new and developing marine invertebrate fisheries. These fisheries often occur on species for which little biological or exploitation information is available. The framework explicitly endorses the precautionary approach to fisheries management and research. Three general management strategies (size/sex limits, regulation by total allowable catch, control of the exploitation rate) and their needs for supporting scientific information are identified. The significance of spatial pattern, and recognizing the need for different approaches to obtain scientific information and to manage sedentary benthic and mobile pelagic species, is a central theme. Three "phases" are proposed to obtain the necessary scientific information: (a) Phase 0 – "collecting existing information", consisting of syntheses of available biological and fisheries information on the target (and similar) species, leading to formulation of potential management strategies; (b) Phase 1 – "collecting new information" to obtain the essential information that is lacking or insufficient from the Phase 0 analysis, and to evaluate alternative management strategies and propose regulatory actions; and (c) Phase 2 – "fishing for commerce" to implement the chosen management actions and to monitor fishing operations to increase the information base available to refine the results from previous phases. Phase 1 activities may consist of surveys, site-specific depletion experiments and studies to obtain biological information, and development of experimental management areas to test different exploitation rates. A strategy which includes establishing reserve areas recognizes the inherent uncertainties associated with developing fisheries and provides a buffer against mistakes or "surprises", and also provides control areas to compare stock productivity in fished and unfished locations. Throughout, strong interaction and collaboration among science, management, and stakeholders is crucial to the provision of scientific advice for precautionary management of new invertebrate fisheries.

Discussion

1. In the sea cucumber case, how was the specific 50% of the coast to be closed chosen? In consultation with industry, and considering historic harvested areas.
2. Most of the serious ecosystem effects have come from applying single species models to situations where multi-species effects were indeed important. Will this be included in the proposed framework? Not at this time.
3. How are the property rights established to the new fisheries once the fishers have invested in management research? A. This is currently under consideration.
4. How strongly are we able to adhere to the principle that if industry doesn't pay for research there will be no fishery? Variable, depending on the strength of support from other levels of government for expansion of fishing opportunities.
5. This is a cautious strategy, but not necessarily *precautionary.* What are the reference points? Some explained in other documents, some don't exist.
6. Of all the things on the long list of factors to be considered, which ones really matter? First are biological constraints, then practicalities of management.
7. Will this work for other Regions and fisheries other than invertebrates? Several reports of similarities with practice in other Regions, and is the regional policy for all new fisheries, not just ones on invertebrates.

3.6. General Discussion (Sinclair)

East Coast assessment approaches using ADAPT, quasi-likelihood, etc., may be cast in the state-space framework. At present, East Coast approaches do not explicitly specify probability distributions for parameters, the Bayesian approach. There may be merit in investigating potential benefits of Bayesian inference. The state-space approach has the important value of making assessment scientists face the question of whether or not the properties they are really interested in can be estimated. The requirement to explicitly specify parameter distributions was considered by some a weakness relative to non-parametric bootstrap techniques.

Some elements of a PA are not included in any of the assessment models, i.e., social and economic considerations, the management structures necessary to implement a PA, and an evaluation of management measures other that catch regulation. Some of these things are qualitative and therefore not amenable to including in an analytical assessment. Other parts could be put into some of these frameworks as explicit terms.

There was discussion about the differences between specifying probability distributions and writing objective functions. There are many technical points here, but it was suggested that there should also be focus on what the outcomes mean for management, as well as on issues of scientific nomenclature on these points.

It was suggested that a useful next step in getting familiar with the different assessment models discussed at the meeting (state space, quasi-likelihood, ADAPT) would be to apply the methods to the same dataset and investigate difference in their estimations. It will be important that at least one set of analyses are structured in a similar manner (i.e., the same range of ages, common parameter sets, assumptions about non-estimated parameters (e.g., M)) to ensure that comparisons of the estimation process are not confounded by differences in model assumptions. Additional model formulations are also encouraged to investigate alternative interpretations of the data (i.e., different objective functions) and seeing which are better supported. However, one must be careful not to jump into alternative models without fully understanding their implications.

It was reported that a project currently underway in the EU, headed by Ken Patterson (Aberdeen), is investigating alternative methods of doing risk analysis and short term projections. Some statistical methods for estimating uncertainty being considered are MCMC, bias corrected bootstrap, bootstrap, and parametric Monte Carlo. Each participant in the project is committed to setting things up with the same objective function. The HPPPA project should keep in touch with this initiative (Action Gavaris).

It was noted that attention must also be given to what materials need to be ported out to other users, and to what comparable objective functions are exactly, if the underlying formulations differ in any way. Also, the criteria for evaluating performance of the alternative approaches needs to be determined. It is not a simple problem, and participants suggested that considerations should include complexity of assumptions, ease of explanation, the shape of confidence space for estimated parameters, as well as just maximum likelihood of the estimates themselves.

There was substantial discussion about the differences between short term projection, where performance is often very similar to the present year's assessment, and medium to long-term projections, where uncertainty may escalate, and how uncertainty is formulated can have big consequences. The linkage of harvest control rules to longer-term projections needs particular consideration, and whether it is possible to consider a policy without considering exactly the control point(s) and method(s). There was difference of opinion about whether or not harvest control rules should allow a non-zero probability of stock collapse in the short term, as long as the rule was risk averse in the longer term. It was noted that even if long-term risk cannot be managed, it should not be ignored, and that to guaranteed no stock collapse in long-term projections would require a huge amount of catch to be foregone. Some thought that harvest control rules might not be able to maintain a consistent "attitude" towards risk aversion over a wide range of stock sizes, but others felt this was exactly the sort of question that the project should be exploring.

Participants need to bear in mind that many assessments are of a class where age-structured VPA assessments are not possible. The HPPPA project should include case studies of this type of assessment. This must include reference points other than in terms of biomass and fishing mortality.

There was substantial discussion of the mandate of the Workshop and the Strategic Research Project. It was **agreed** that at least for this meeting, no proscriptive decisions would be made to endorse specific approaches for universal application. Difference of opinion remained about the degree to which this meeting could map out a department-wide approach to implementing the precautionary approach.

4. The HPPPA Case Studies

4.1. Atlantic cod in 3Ps (Cadigan)

The 3Ps cod stock, commonly referred to as the "St. Pierre Bank" stock, extends from Cape St. Mary's to just west of Burgeo Bank and over St. Pierre Bank and most of the Green Bank in NAFO subdivision 3Ps. The distribution of fish in 3Ps does not conform well to management boundaries, and the stock is considered to be a complex mixture of subcomponents. These may include fish that move seasonally into the area from adjacent stocks as well as fish that undergo migrations within the area. Fish in 3Ps also migrate into other adjacent areas. Fish are caught offshore primarily by mobile gear, and inshore primarily by fixed gear.

The 3Ps stock was heavily exploited in the 1960s and 1970s by foreign fleets, mainly from Spain, with catches peaking at 81,000 tonnes in 1961. Catches declined to between 30,000 and 40,000 tonnes during 1977-1985; however, by 1987 catches increased to 59,000 tonnes. After 1987, catches gradually declined to 36,000 tonnes in 1992. A moratorium on commercial fishing in this area was established in August, 1993 after only 15,000 tonnes had been landed; however, fishing resumed in 1997 with a 10,000 tonne quota. In 1998, the quota was increased to 20,000 tonnes.

The core data available for the assessment of this stock are:

(i) a Canadian research survey during the spring from 1983-1997,
(ii) a French research survey during the winter and spring from 1980-1991, and
(iii) landings from the commercial fishery from 1959-1997.

A variety of ancillary data are also available for the assessment of this stock. Most notable are returns from tagging experiments, a GEAC (Groundfish Economic Alliance Council) survey of abundance, and sentinel catch rates. The GEAC survey and the sentinel catch rates have not been explicitly included in the assessment framework to date, but have been used in assessing SPA validity.

Traditionally this stock has been assessed analytically using SPA, which has provided estimates of stock numbers at age. The inputs to the SPA are estimates of commercial catch numbers at age obtained from the reported landings and age composition samples. Fishing mortality on the oldest age group in the SPA are fixed so that the only unknowns are the current numbers at age. These survivors are estimated using research indices of abundance. Estimation traditionally has involved nonlinear least squares. Estimates of current stock size were then projected forward one year, and the resulting $F_{0.1}$ yield calculated. Many other analyses are also routinely used in the assessment of this stock (e.g., multiplicative models to estimate recruitment, etc.); however, the $F_{0.1}$ yield has been the main input for management strategies.

Discussion

1. The quasi-likelihood approach has an optimality property. It was noted that the model varied mortality by age and year. One participant asked how this was dealt with in the estimation. It was noted that these quantities would be regarded as known and, in practice, would be constant in many cases. In essence, this approach corresponds to an observation error model.
2. A simulation study was conducted to assess bias. The bias estimated through parametric bootstrap seemed reasonable, on the order of 10-15%. There was a pattern in the bias (increase with age) and this was believed to be due to the lack of contrast in the data. The increase in bias with age is possibly particular to this data. One cannot assume this is a general problem for all cases.
3. The simulated percentage CV was quite large: 40 to 80% in recent years. The CVs were small for the first years because of the convergence properties of the VPA. In modeling, this is a strange thing as this type of differential effect over time does not occur often in a model. This might change if an initialization process is included in the estimation.
4. A variety of reference points or criteria for risk analyses were presented. Precautionary plots based on quasi-likelihood were also presented. How these analyses are performed is an important piece of information that needs to be communicated (e.g., algorithms, equations, assumptions, etc.). While these are standard biological reference points, there are issues or assumptions that need to be described. For instance, the shape of underlying “curves” would have an impact on the reference points. It is probably not possible (nor necessary) to have analytical forms of all quantities being estimated.
5. These curves could be dependent upon the current estimates of the parameters and could change in subsequent years. In this case, they were relatively stable through time.
6. The production curve was below the data because an average was used for weights. The project has not come to grips yet with ways to depict reference points for stocks with changing weights. In addition, reference points may be shifting targets in “regime shifts”. It will be necessary to distinguish between random or process variations and temporal shifts in the system.
7. The results of analyses based on QLSPA (SPA with quasi-likelihood estimation), QLSPA_Q (adds seasonal q), and ADAPT were compared, as applied to the offshore data only. The results were quite different (considered to be pathologic case). The results were very sensitive to the QLSPA_Q assumptions. There is concern that the results depend only on the assumption of error structure about which little is known. The CVs may be seen as corresponding to one set of variances, conditional to model and data. The “meta-variance”, however, would also include what would happen if one changed the model. What is the basis to select the final model? This is a recurrent issue and the scientific community needs tools to deal with this.
8. Another generic concern was the trade-off between robustness vs. efficiency of estimators. This is a general issue in parameter estimation, and applying a PA presents no unique problems. Some felt that for PA applications a middle ground would be preferable – estimators which are moderately efficient but have little risk of being badly biased.
9. There was a discussion of the Shepherd – Sissenwine plots, and information they

contained. Although their usefulness was recognized, it was noted that they require stationarity of a number of biological attributes, including weights at age, catchabilities, and stock-recruit parameters.

10. It was noted that team members need to bring the inshore component into the precautionary approach framework. How does the team plan to deal with inshore data? On a more general question, how should the scientific community cope with stock sub-components? A generic discussion is needed on this. There is a need for some way to capture the uncertainty of the inshore estimates and dynamics in the overall picture. In short, the project does not have a precautionary framework for the inshore. Why would the generic framework not be applicable to the inshore? The generic question is to what degree one should disaggregate or aggregate stock components. It was noted that while tagging gives estimates of variability, the bigger variability comes from the between year variability because the time series is short. At present the team has no idea of the between year error. Nevertheless, the framework should apply to all components.
11. Long debate on separating the model from the control system was summarized as "Getting bogged down with a flea's leg when we should be looking at the dog". It was concluded that getting in a big debate on the pros and cons of various conceptual frameworks (bootstrapping, quasi-likelihood or Bayesian) would not be productive at this stage and that we needed to come back to the greater picture.

4.2. Atlantic cod in 2J3KL (Shelton)

Risk analysis was first applied to this stock in 1991 using a bootstrap approach. The most recent assessment (January 1998) used both the standard ADAPT and the new quasi-likelihood SPA (QLSPA). The variance-covariance matrix from the ADAPT was used to carry out a Monte Carlo risk analysis on a one year projection on a range of TAC options for a large variety of reference points (15), including those derived from Sissenwine-Shepherd plots and others such as mean spawner biomass in the 1980s. The most important of these is the probability that the stock would grow under the TAC option and exceed $F_{0.1}$. The profile likelihood approach was applied in the QLSPA to the same set of reference points for the same range of TAC options. The results were presented in the form of a decision table with TAC options as columns and reference points as rows.

None of the SPA approaches applied in recent years have been able to resolve the abrupt decline observed in the survey index in the early 1990s. The change in survey gear in 1995 introduces further uncertainty in the assessment of northern cod. While there is little doubt that the population remains at extremely low abundance with no sign of any recovery, there appears to be no rigorous way of undertaking short term projections from the available data.

The conclusion has been drawn for a number of cod stocks that there has been a recent large increase in natural mortality. The same conclusion has been drawn for northern cod although there is considerable uncertainty in the interpretation of the survey index. One approach to short term projections for the northern cod is to consider only the age composition data and to estimate the level of total mortality that would result in the stock declining rather than growing. This places minimum demands on the data but partitioning the total mortality in a way that will be useful in providing scientific advice becomes problematic.

The framework for northern cod will require either the past trajectory of the population based on survey and catch data to be resolved, or will require using a new

approach that is not dependent on knowing this trajectory. If the past can be resolved then the preferred framework would be risk evaluation relative to standard precautionary reference points using the bias corrected ADAPT bootstrap approach as well as equivalent measures of risk from the QLSPA-profile likelihood approach.
It will also be necessary to examine the uncertainty in the stock-recruit relationship at low stock size, including the possibility of depensation. The role of seal consumption on stock recovery needs to be evaluated, as does the role of traditional ecological knowledge (anecdotal or quantified through survey questionnaires).

Further attempts are needed to resolve the SPA issue at the 1999 zonal cod assessment meeting. If this fails, we will need to develop and apply precautionary approaches that do not require a resolved stock trajectory. The short-term focus will be on estimating the uncertainty regarding stock growth (what is the probability that northern cod is recovering?).

Discussion

1. The VPA model cannot explain the abrupt decline observed in the index in the early 1990s. While the precautionary plots were done, using the decision table would require understanding what is causing the abrupt decline. The average Z, as calculated from survey data, was larger in the early 1990s. Risk analysis is available starting in 1991. There is a retrospective problem and a catch reporting problem. Also, data quality in the surveys and catch monitoring could deteriorate under the current downsizing.
2. If the quality of data deteriorates, uncertainty goes up thus this would translate into a more conservative strategy. However, it is believed that as you put more complexity and details in the models, the wider the estimated uncertainty is and the more conservative you become. Can we demonstrate if the perception is right or wrong? By design, the assessments where we can include this complexity are the ones for which the most is known. The corollary is that we are perceived as being risk prone for the stocks for which we know less and risk averse for stocks where stock dynamics and uncertainty are described in complex models. This perception is wrong in the sense that it is not that we know more but that we know more about our ignorance.
3. We need a paradigm to look at all possible situations (e.g., based only on survey data). Intuitively, there must be a way to look at this or to illustrate through simulations how model complexity and uncertainty affect the risk.

4.3. Atlantic cod in 4TVn (Sinclair)

A considerable database exists for the Southern Gulf of St. Lawrence cod case study. Landings estimates are available back to 1917. Catch at age from commercial fisheries has been estimated since 1950. There has been an annual stratified random abundance survey conducted since 1971, there is an otter trawl CPUE at age index for the period 1971-1993, and sentinel surveys were established in 1994. Additionally, surveys of various designs were conducted in the 1960s, stomach contents have been monitored periodically, and condition has been monitored seasonally since 1992. These data are used in an age-structured assessment, calibrated using the research survey abundance index and the ADAPT methodology. The sentinel survey indices will be added to the assessment in 1999. The main outputs are short term (1-3 y) catch forecasts with risk assessment.

The stock has been managed under a constant fishing mortality strategy since 1977 using $F_{0.1}$ as a target. Catch controls have been the main management tactic and this is complemented by limited entry, hook and mesh size regulations. The fishery was closed in September 1993 due to low abundance. Since then, catches have been limited to by-catches in other fisheries, sentinel and index fisheries, and a limited amount of experimental fishing to examine alternative mesh size regulations. The precipitous decline in stock biomass stopped when he fishery was closed, but stock rebuilding has been limited by low recruitment and low production.

A better understanding of the factors leading to the collapse of the stock may help implement a precautionary approach. In retrospect, the rate of fishing exceeded stock surplus production from the mid-1980s until the closure. Fishing mortality was always well in excess of the $F_{0.1}$ target. Intensive overfishing occurred in the 2-3 years preceding the fishery closure, and catch under-reporting was a major problem. Stock production during the 1980s was depressed by low weights-at-age, possibly as a result of size selective mortality, density-dependent growth, and low temperature. Natural mortality may have increased in the mid-1980s. Stock assessments were over-optimistic in the late 1980s, possibly the result of undetected changes in natural mortality and catch misreporting. The management system allowed $F > F_{0.1}$ by adopting the so-called 50% rule, where annual TACs were adjusted to the $F_{0.1}$ over a number of years instead of all at once. In addition, a multi-year management plan was adopted just prior to the closure, where TACs were set for a 3 year period.

Based on analysis of the UN and FAO documentation describing the precautionary approach, we have assumed that the management objectives for the case study are to prevent over-exploitation of the resource, over-development of harvesting capacity, social and economic dislocations, loss of biodiversity, and major physical disturbances of sensitive biotypes. Much of the work will use simulated fishery management systems. The utility of various biological reference points, based on yield per recruit and stock production models, and alternative harvest control laws will be investigated to prevent over-harvesting. We will investigate linkages between management targets based on fishing mortality and fleet capacity targets. The linkage will be in terms of fleet catchability. An important component of the case study will be to evaluate the feasibility of alternative management measures to achieve these objectives and to monitor system performance. At this time our team is unable to assess ways and means of addressing the social, economic, biodiversity and disturbance components of the objectives.

Discussion

1. A description of the stock and fishery was provided. TAC controls are the main control tactic. There is a limited entry policy and ITQs are implemented for some fleet sectors. Mesh size and hook size are regulated. Sentinel surveys are done by fishermen to monitor the stock status.
2. The perceived reasons for the collapse have been related to the following possible causes. Annual Fs have always been higher than target. There has been intensive overfishing 2-3 years preceding the closure. Catches have likely been underreported. Stock production has been depressed by low weights at age (growth) and M may have increased in mid-1980s. Assessments have been optimistic (retrospective effect). The 50% rule and multi-year management plan allowed F to be $> F_{0.1}$. Skepticism was expressed that there would ever be an analytical framework which could say that there was large amounts of unreported catch, at least until some years after the event.
3. Analyses were done in an attempt to pinpoint when M changed. It appears that M changed from 0.2 to 0.4 in the mid-1980s. This was “hard-wired” into the model (ADAPT). The

value of looking at the data (plots) to identify such changes was highlighted: e.g., such drastic changes should be evident (the diagonals would be disappearing sooner than expected).

4. It was noted that there has been a thorough examination of these questions. For instance, Mohn has done some work on the survey catchability in relation to the retrospective problem for a neighboring stock and that this may have application for a more general usage. However, nobody has come out yet with a complete satisfactory answer to the retrospective issue. The first workshop on retrospective problem was in 1984. CAFSAC itself had no formal means for adjusting and moving ahead (in fact, it is still unclear if it is the past or the most recent estimates that need correcting). Our current tools are vulnerable to a repeat of this.
5. It was noted that the process has changed as well. The industry is now involved in the RAP process. This resulted in more transparency in the process. It is always easy in hindsight to claim that something better could have been done.
6. An application of the precautionary approach requires clear objectives. These could be to prevent overexploitation, overcapacity, social and economic dislocations, loss of biodiversity and major disruption of ecosystems. It was argued that the Department needs a reference point for fleet capacity. The precautionary approach refocuses fisheries management on MSY. There is a danger that the limits will become *de facto* targets.
7. In the plaice example, the results showed that two different MSY levels were obtained when the model was applied to a recent and a past time period. The volatility of MSY to the data or to shift in the population dynamics is an issue. For instance, changes in M and weight at age (growth) will affect MSY. In order to capture this dynamic aspect, the framework would also have to be dynamic and the limits would have to change with time. It was agreed that participants have to come back at this point during the meeting and discuss our understanding on what reference points represent. The situation is in fact more complex since surrogate reference points may have to be developed for the majority of the stocks (points based on surveys for example).
8. The Department will have to seek management procedures that are robust to uncertainty, stock identification, stock dynamics (e.g., changes in M), effects of environment and trends, abundance, dynamics of the fleet, etc. The project will also attempt to link target F and fleet capacity. It is unclear, however, if this is part of DFO objectives. Nevertheless, science could describe the technical aspects related to this (i.e., how this could be done in a precautionary approach framework).
9. A simulation framework will be used to evaluate management procedures. The FISHLAB software includes some simulation tools. Does the project need to develop this type of software? The analogy with flight simulators was discussed: for instance, such an approach could be used to “re-play” avoiding crashes or known past situations. The aim of the simulations is to find ways to explore and present alternate options under various situations (e.g., uncertainties). This project will offer an opportunity to deal with this.
10. Regarding HCRs, it is generally recognized that a constant harvest rate strategy performs better than one based on constant catch controls. Some scenarios are now contemplating variable harvest rates. During ComFiE, rebuilding worked better with reduced harvest rates but it was note by one participant that this would result in foregone yield. If economics are ignored, it would not be possible to evaluate control laws against recognized “bad things”. It would be unrealistic to ignore completely the foregone yield. It was noted that from a biological perspective, foregone yield is taken into account as it is

put back in the stock biomass and would thus translate into long term biological benefits.

11. The advantage of sloping rates (phased-in changes in exploitation rates) is to avoid bang-bang controls (i.e., alternating openings and closures). At this point in time, the managers will have to be brought back in the discussion. Confounding sociological and biological reference points should be avoided. In the process that leads to the definition of a framework, it will be necessary to separate these discussions.
12. Regarding the age-structured production modeling, the group noted that (i) the weights at age have declined over time, (ii) M may have changed, and (iii) we are in a situation of moving or shifting equilibrium states. This suggests that the productivity of the resource has been affected by the changes in weights at age (growth). The addition of a change in M for the most recent period led some to question the sustainability of the resource under the present set of conditions. M=0.4 has not been the normal state for the resource but nevertheless this seems to be what the stock is experiencing right now. The overall impact of these changes in stock dynamics on the reference points needs discussion.
13. This example "wipes out" some notions on the reference points. Indications are that B_{MSY} is a very volatile reference point. Some believe that, because of this, it may not be desirable to use such a point for the stock. Others suggest that, to the contrary, reference points need not be fixed in time. Moreover, the differences between limit and precautionary (or "buffer" in the NAFO context) are understood to be a function of the uncertainties, but at some point it will be necessary to specify what is not certain, and how stable the sources of uncertainty are over time.
14. The need for consultations at various levels was recognized between science and management and among DFO, the FRCC and industry. This has not happened yet. Pieces of a precautionary approach framework have been developed, but the approach needs to be fostered in management meetings/consultations/ongoing work.

4.4. Snow crab in the southern Gulf of St. Lawrence (Wade)

Each of the 160 licensed crab fishers completes a logbook for information on catch, effort in number of trap hauls, trap type, depth and position (longitude/ latitude or Loran C, grid number). Compliance is greater than 95% and is, for the most part, accurate.

A major management objective is to avoid the capture of soft-shelled crab. Consequently, observers are deployed on about 20% of fishing trips and make regular reports on the incidence of white crab. At the same time, dockside monitoring programs obtain accurate landing information. Since 1988, a trawl survey has been carried out within the snow crab fishing area.

A geostatistical technique called kriging, which is used by mining and petroleum industries to project total resources in an area, was applied to (i) estimate mean density and (ii) map the population densities.

Snow crab biomass fluctuates every 8-10 years due to cyclic waves of recruitment. The traditional idea of a constant fishable population at a sustained exploitation rate does not appear to be a realistic goal in the management of this fishery. The objective for the precautionary approach study will be to establish a model which will take into account the cyclic nature of this fishery along with probabilities of skip molting and mortality between molts.

One of the most successful aspects of this fishery is the consultation process. During the past year there were 24 public meetings between science staff and the fishing industry. These meetings have included discussions of the survey, sampling, observer programs, and various aspects of snow crab biology.

For snow crab, the management target is a 35% exploitation rate of the estimated biomass of hard-shelled, terminal molt, male crab with a carapace width >95mm. The target is conservative for three reasons. First, female crabs are excluded from the fishery and the target male crabs are sexually and functionally mature. Second, the gear is passive and highly selective, avoiding "undesirable" crabs (females and smaller males). Third, the target protects commercial-sized but newly molted crab that will recruit into the fishery in subsequent years.

A decision rule was formulated and introduced to this fishery in 1989. When the percentage of soft-shelled crab exceeds 20% for two consecutive weeks of fishing, the fishery is closed for the season. The percentage is calculated from the total number of soft-shelled males divided by the total number of males caught per trap regardless their size. There was no biological reason for the threshold of 20%, rather this number was proposed by industry. A 20% level corresponds roughly to an economic threshold for fishers and the processing plants.

The traps used in this fishery are passive and highly selective. There is little by-catch in this industry. Impacts on the ecosystem occur mostly in the event of traps lost at sea, especially by drifting ice. Traps drifting in the ice may dredge the bottom, a process termed "ghost fishing". Between 1966 and 1989 the total number of traps lost at sea was estimated to be 19,110. Ghost fishing occurs until a complete degradation of the trap. Ameliorative measures have been to set opening dates to avoid gear encounters with ice and to introduce the use of mandatory biodegradable escape mechanisms.

Discussion

1. The life history of snow crab was reviewed, together with historical information on the fishery. Catch and effort information after 1990 is considered to be very reliable. An observer program has been completely in place since 1994. There is also dock side monitoring. There are formal decision rules. For instance, if in a particular zone the composition of crabs is 20% soft shells for more than two weeks, the zone is closed (to avoid harvesting the species one year in advance). Traps are designed to avoid fishing small males. Females are not fished. Data on location and percent white crab are analyzed and made available to industry on a weekly basis. Traps are very efficient at avoiding crab smaller than 95 mm (carapace width). Exploitation is roughly 35% of the commercial sized male population and such a level is believed to result in a reasonable accumulation of hard shell animals on the fishing grounds.
2. Geostatistics have been used since 1988 to produce distribution maps and abundance estimates based on kriging. This technique is borrowed from the mining industry. Error maps can be produced to display the geographical distribution of "sampling error". These could be used to indicate where additional samples are needed. The approach has a high "visual value". Trawl surveys seem to provide an index of biodiversity on the fishing grounds. Maps are produced in "near real time" and provide industry with areas to avoid soft shell crabs.
3. Exploitation is on mature individuals (males) only. From a conservation standpoint, the group noted that there is a lot of buffering (security) already built in the management measures.
4. There are still unknowns in the dynamics. For instance, how should the skip molters be

modelled? This would affect forecasts provided to the industry.

5. It was noted that most of the management objectives are industry-based. The controls are quota, 20% soft crab content, license control, and 95 mm CW size limit. As a result, all the reproductive females are left in the water and protected. The current HCR means that the fishery probably does not have an impact on the reproduction of the resource.
6. Why monitor and conduct surveys in such a case? This type of monitoring is an invaluable tool for the efficient management of the fishery by providing, among other things, an indication of the upcoming recruitment. Someone suggested that this is R&D of interest to industry (in fact, industry does cover the cost of R&D), but is not essential for conservation. Not all agreed, and it was pointed out that there is a need to control the quantity of males caught each year and to provide some protection to soft crabs. In essence, managers need to keep the right balance of hard crab on the bottom and soft shell that come in. Industry has already bought into this strategy.
7. In marginal areas (on the edge of key concentrations), crab are often exploited at high rates (60-70%) as these areas are not considered important to recruitment. In terms of the precautionary approach, a key question is what kind of F level would be associated with MSY and how would the current fisheries management regime relate to that?
8. When assessment scientists talk about F_{MSY}, it is assumed to apply to fishing a spectrum of the age groups. Here exploitation is limited to a small portion of ages. The precautionary approach interests are fully covered by the 95 mm CW. The public interest is protected by that rule alone. Therefore, ongoing monitoring is related to industry's interest in composition and abundance. The precautionary approach is also implemented by protecting the females (indirectly by the 95 CW). Consequently, conservation is fully satisfied by the one rule on CW size.
9. There remains some concern regarding the lack of a comprehensive population dynamic model. This project may address that concern. Also, despite the fact that this is a male only fishery, there are other aspects that need to be considered such as the role of older individuals and energy intake during maturation.

4.5. Abalone in Australia (Shepherd)

Three species of abalone have been exploited in four southern Australian States since about 1966. Until the mid 1980s, input controls (mainly size limits and licence limitation) were used to control effort and prevent over-exploitation. These measures were largely successful, except in New South Wales where disastrous open access policies were obstinately pursued, leading to a serious decline of stocks. From about 1985, the four southern States progressively introduced quotas, which successfully controlled technological creep and the tendency to over-exploit. Since that time two problems have emerged.

First, larval dispersal and genetic studies showed that abalone were distributed in many ecologically independent stocks, depending on hydrology and habitat. Long-term catch information showed that smaller populations were gradually declining whereas larger populations remained stable. Egg-per-recruit (EPR) models then established that in general large populations that conserved 40-50% egg production of an unfished stock remained stable whereas those that conserved less declined. More specifically, the models showed that smaller populations needed to conserve up to 80% egg production levels to achieve stability; i.e., the productivity of populations increased with size. In accordance with predictions of this model, many smaller populations of abalone in southern Australia have continued a slow decline. Some studies have also shown that threshold collapse densities are approximately 0.2-0.3

abalone m^{-2}, below which allele effects cause failure of egg fertilization.

The second problem is that fishing is not evolutionarily stable. Harvesting to a size limit over many years causes changes in life history strategy and a tendency to slower growth and higher fecundity (i.e., stunting of abalone). This has led to a decline in productivity of 50% in one population. Research to date suggests that threshold values in EPR models, as well as density of abalone *in situ*, can be used to apply a precautionary approach to management.

All abalone fisheries have approved management plans, and these mandate the precautionary approach. However, this talk has been rhetorical thus far, and more precautionary management has not been achieved. Smaller populations, inadequately protected by current restrictions, continue to decline in all states. Tasmania alone is making tentative moves toward population-specific quotas.

As egg production thresholds and densities of abalone can be readily determined, there is the opportunity and the need to develop target and limit reference points for individual populations in accordance with the precautionary approach. Beyond this, there is a need to develop evolutionarily stable fishing strategies to prevent the long-term decline in productivity of stocks through changes in growth rates and fecundity. One approach being tested in South Australia is to have permanently closed areas that conserve an unfished stock. They are also implementing a “fishing slot”, i.e., an upper and lower size limit.

Discussion

This is a situation where the management unit encompasses many clearly independent population units, each with characteristic and often differing production dynamics. Currently, quotas and size limits are used as harvest control tactics. The common harvest tactics over all population units in the management unit permits comparison of impacts of common action on many independent populations of different sizes. However, the disadvantage is that parameters of dominant units are used to define the harvest strategy. The smaller units display a long gradual decline in abundance. Further, changes in life history characteristics (maturity, fecundity, growth, etc.) have been observed in small populations. It is suspected that evolutionary change via selective fishing from these relatively small populations is the cause. The management desire is to rebuild the abundance and protect the genetic diversity within each population unit. If the fishing mortality has selected for specific biological characteristics, such as slow growth rate, the rebuilding trajectories used in planning for the recovery of these stocks may be incorrect. In general, the genetic selection effects of fishing should be considered in designed precautionary rebuilding strategies.

It was suggested that in addition to the quota and size limit tactics, selective closures of heavily exploited population units might help to limit local exploitation rates. To protect genetic diversity and avoid harvest selection of fast growing animals, it was suggested that protected areas be established within each population. It is expected that establishment of protected areas would reduce yield by perhaps 10-15%. There is a lack of industry support for implementing either selective closures or protected areas. As an alternative to protected areas, limits on upper and lower sizes have been proposed to allow fast growers to survive, but this has not been received well.

4.6. Beluga in eastern Hudson Bay (Richard)

Currently, the beluga whale fishery is co-managed through Nunavik regional and local

Wildlife and Fisheries Committees; this is a consensual process. The hunt is controlled through (i) community quotas throughout Nunavik and (ii) a seasonal area closure of Nastapoka estuary (up to Aug 1).

Historical estimates of abundance (retro-calculation from catch) compared to present day survey estimates suggest an historical stock decline from early 1900. COSEWIC labels the stock status as “threatened”. Population estimates and estimates of intrinsic growth suggest that the catch is too high. Science advises that the catch be reduced.

We investigate biological reference points (e.g., N_0, N_{LIM}, N_{BUF}, F_{LIM}, F_{BUF}) and hunt control rules (e.g., TAC, closures, target sex/age class) appropriate for the precautionary approach of an Arctic beluga stock. Methods of quantifying the uncertainty in reference points, stock discreteness, stock status, and hunting mortality are developed using re-sampling techniques. We also investigate methods of representing uncertainties in reference points, hunting mortality, stock discreteness and size (stock status) to clients. Data are utilized from DFO stock assessments and from hunter knowledge studies on (i) stock distribution and behaviour, (ii) the population dynamics of the stock, (iii) surveyed numbers and survey biases, and (iv) stock discreteness.

We construct stochastic age- or stage-structured projection models and conduct uncertainty analyses using various what-if scenarios. Workshops are organized to involve user groups in modeling and discussion about results.

Discussion

There is somewhat greater uncertainty about beluga whale stock structure. Problems with identification of all catches (hunts outside area, hunt loss) from the population will require evaluation of the robustness of management strategies in relation to violations of assumptions regarding these. Production analyses have indicated that intrinsic growth rate is in the range of 2-4.5%. It was commented that such analyses could possibly provide information on carrying capacity and other important life history parameters. Richard replied that the modelling of density dependence is impossible without information on changes in survivorship and mortality with population size. Nevertheless an attempt could be made with data from biological analogues or theoretical extremes. It was also noted that this may not be all that much of a “data-poor” situation, in that a lot of biological knowledge is required to specify some of the parameters of production models, such as unexploited biomass and population growth rate. There was concern expressed that the peculiar legal environment surrounding aboriginal resource use requires a more co-operative approach in defining reference limits such as B_{LIM}. Aboriginal stakeholders recognize the potential conservation concerns and there is a positive outlook for reaching consensus on conservation reference limits. There was **agreement** that an important step is to explicitly define the undesirable outcomes, and determine what scientific questions it is even possible to ask about those outcomes.

4.7. Pacific ocean perch (Schnute)

The Pacific Canadian groundfish trawl fishery captures more than 50 commercial fish species. Among these, seven slope rockfish species occur primarily along the sloping habitat that marks the edge of the continental shelf. Combinations of seven species within six geographic areas define 42 assessment units for slope rockfish. Only one of these combinations, Pacific ocean perch in area 5AB, receives a thorough assessment based on analysis of catch-at-age data. This stock currently serves as a benchmark for the remaining 41 assessment units.

For the benchmark Pacific ocean perch stock, we define the risk a_t of removing a constant annual catch C until future year t as

$$a_t = P(B_t < B_{LIM} \mid C),$$

where B_t denotes the projected future biomass in year t and B_{LIM} corresponds to a suitably defined limit reference biomass. We choose the estimated biomass in 1977 as our measure of B_{lim}, based on details of the stock history.

Our risk analysis acknowledges that both B_{LIM} and B_t contain statistical error. Figure 4A illustrates these uncertainties. Model errors come from trajectories estimated with past measurement error (related to B_{LIM}) and future process error (related to B_t). Thus, we do not follow the simplistic scheme portrayed in Figure 4B, where the historical trajectory (including B_{LIM}) is presumed known from model estimates and only future process error enters the projection B_t.

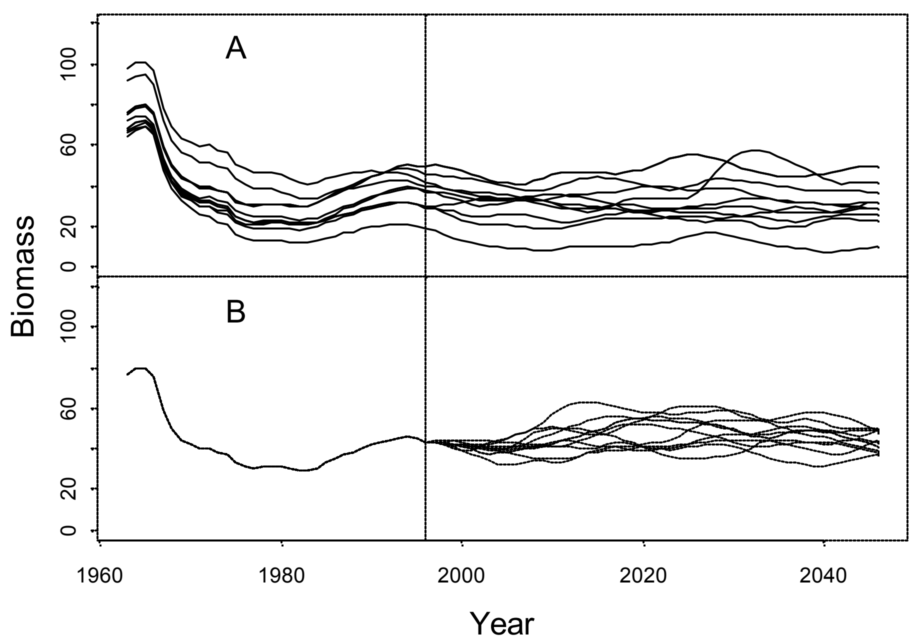

Figure 4. Ten sample trajectories of stock biomass (1000 tonnes) from model reconstructions and forward projections under a catch policy of 2,000 tonnes for (A) the full model error approach and (B) the future process error approach. A vertical line identifies the final year of historical reconstruction, based on a catch-at-age model.

The risk a_t can be quantified in a scatter plot of points (B_{LIM}, B_t) taken from sample trajectories, where a_t corresponds to the proportion of points below the line $B_{LIM} = B_t$. Figure 5 illustrates this analysis for four choices of fixed annual catch C, given a 50 year time horizon. More generally, Figure 6 shows estimates of a_t for varying time horizons.

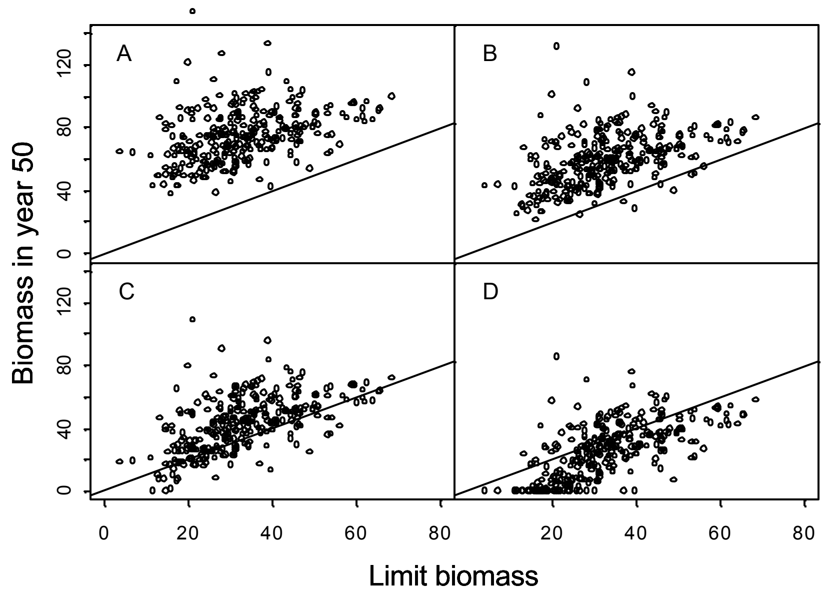

Figure 5. Projected biomass B_{50} (1000 tonnes) in relation to historical estimates of B_{LIM} for the full model error approach under annual catch policies of (A) no fishing, (B) 1,000 tonnes, (C) 2,000 tonnes, and (D) 3,000 tonnes. Points correspond to 300 sample trajectories for each policy. A solid line identifies the condition $B_{50} = B_{\mathrm{LIM}}$.

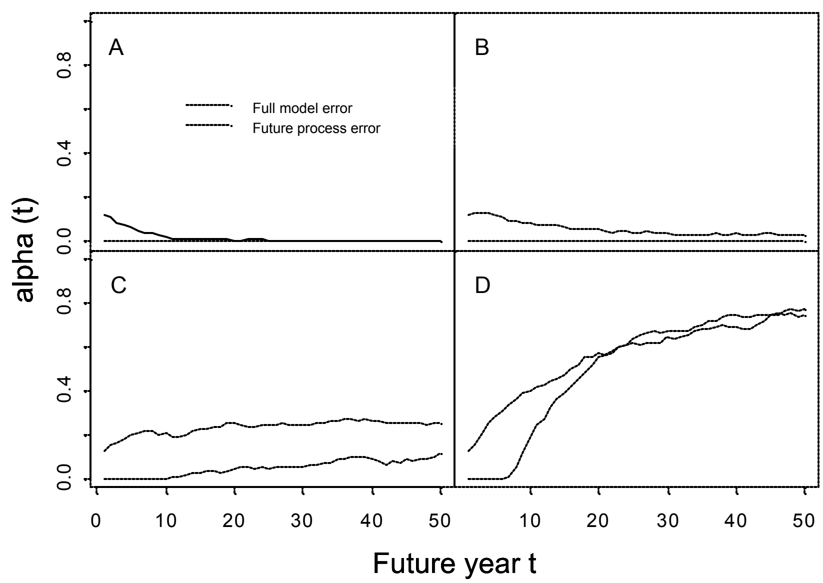

Figure 6. The risk a_t in future year t, corresponding to (a) the two approaches to model error illustrated in Figure 4 and (b) the four catch policies specified in Figure 5.

Discussion

It was demonstrated that this case study presents a complex multi-species fishery with considerable spatial complexity. Undesirable outcomes in the context of spatial patterns may be investigated. Other aspects of the discussion are covered in section 3.4.

4.8. Fraser River sockeye (Cass)

Results presented at the workshop were based on a paper presented at the ICES 1998 Annual Science Conference held in Cascais Portugal. We evaluated consequences of precautionary harvest policies on mixed-stock Fraser sockeye fisheries. In particular, we considered trade-offs between economic and social performance measures, given uncertainty in stock dynamics. Principles of the precautionary approach are incorporated by contemplating effects of alternative harvest policies that impose reduced harvest rates at low stock sizes, including zero harvest below an abundance threshold. We explore effects on fishery performance of various threshold levels and variable harvest rates on surplus fish above the thresholds. The abundance thresholds in our simulations are stock-specific, therefore, the abundance of each stock in the mixed-stock fishery is conserved. For each alternative harvest policy, we reconstruct a sockeye run from initial (historical) spawning escapements that would have occurred using the observed residuals from a best-fit recruitment function. By using the sequence of observed residuals to reconstruct the time series of abundance, the temporal pattern of high and low recruitment is preserved.

Economic and social consequences are evaluated using two performance measures: mean long-term catch and the probability of fishery closures. Mean long-term catch is an obvious economic measure that when maximized over a particular time period is akin to the concept of MSY. Fishery closures, on the other hand, are necessary for conservation and long-term optimal use of the resource. We show that fisheries managers have considerable flexibility in their choice of harvest policies in order to maximize catch. For recovering stocks, such as Fraser sockeye, maximizing long-term catch can result in prolonged periods of fishing closures during rebuilding phases. Resource stakeholders may deem the economic and social costs unacceptable. Therefore, there is a trade-off between policies that maximize catch and minimize closure probability. We also show that there is a conflict between achieving optimal socio-economic objectives and minimizing risk as advocated by the precautionary approach to fisheries management.

Discussion

The analysis explores the implications of various harvest policies on total yield and frequency of closure in the fishery. Harvest policies are categorized in a two dimensional grid based on an escapement threshold and a harvest fraction of surplus escapement. This was a “retrospective” modeling exercise using past data but revising expected recruits as a function of simulated harvest rate. The stock recruitment relationship is the main population dynamic, and residuals are used to capture some of the variation in this process. The existence of an underlying functional parametric S-R model was not challenged, and support for it in the data could be investigated. It was noted that the high fraction of time closed when only 20% of MSY escapement policy was followed could be due to the depressed starting point. Closure was triggered if the run was less than the necessary escapement. Starting with a healthier population might change the conclusions, i.e., results may be dependent on starting values employed in the simulation. Concern was expressed about selecting a specific S-R functional relationship because it is conservative. Concern was expressed that this model was going to be of limited value if the model was driven by a stock-recruit relationship, but uncertainty in the S-R parameters was not included.

4.9. Newfoundland herring (Atkinson)

A summary of herring on the Newfoundland East and Southeast coasts was presented. Herring in these areas are dominated by spring spawners that mature at age 5, and live to about 20. Recruitment survival is largely influenced by the environment, in particular overwintering temperatures and pre-spawning salinities. Good recruitment is sporadic because herring in these areas are at the northern limit of their range. There were large year-classes in the 1960s, after which recruitment was poor until 1982. Since then, only the 1987 year-class has been of moderate strength.

Herring are managed by bay as follows: (i) White Bay - Notre Dame Bay, (ii) Bonavista Bay - Trinity Bay, (iii) Conception Bay - Southern shore, (iv) St. Mary's Bay - Placentia Bay, and (v) Fortune Bay.

Historically, herring supported commercial and bait fisheries. The fishery began in the 1970s with peak catches in the late 1970s due to good markets resulting from the collapse of North Sea herring. Catches are controlled by annual TACs, but recently catches have been largely market driven and the TACs have not been taken.

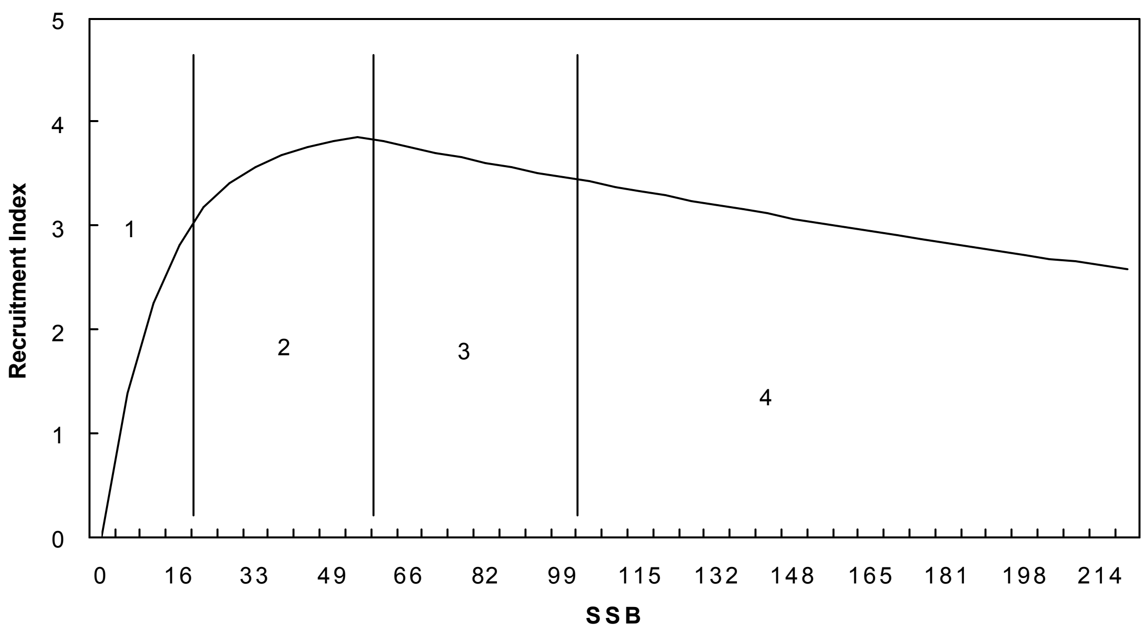

Figure 7. Newfoundland herring stock-recruitment relationship determined by VPA using catchability analyses and research gillnet CPUE.

Assessments use different indices including acoustics, commercial CPUE and results of research gillnet fisheries (CPUE). Also, a commercial gillnet logbook program has recently been initiated. Research gillnet CPUE and acoustic estimates are used in VPA. Standard tuning procedures are not useful because of recent low catches and associated Fs in recent years. Instead, the converged portion of VPA has been used to estimate catchability (q) from the research gillnet CPUE for the same time period. The VPA is then carried out using the results of catchability analysis and the current research gillnet CPUE to set the population size in the terminal year. From this analysis, a time series of SSB and recruits is obtained, and an SSB/Recruit relationship is derived (Figure 7), incorporating temperature and salinity. These Stock/recruit relationships have been questioned by Ottawa and SSSC although more recent analyses have indicated that the addition of temperature and salinity to the model improve the derived relationships.

In 1996, a Stock Classification System based on position along the stock/recruit curve was developed in consultation with industry. This was done for each management unit, and described as a “precautionary approach” although it is, in effect, a set of Harvest Control Rules. The utility of this scheme has yet to be confirmed because of questions regarding the stock/recruit relationships. For the HPPPA, current workloads are such that capelin scientists are not in a position to become involved and carry out the necessary work.

Discussion

This case study is unique in that a harvest control rule has been proposed. This harvest control rule differs somewhat from those being developed in the context of the precautionary approach but is fundamentally similar. No evaluations have been conducted to determine if the established harvest control rule meets the precautionary approach standard, but some participants thought that such an evaluation would be important. It was noted that the reliance of recruitment on temperature and/or salinity could lead to a more reliable harvest control rule using F as a function of biomass and temperature. Having target and limit Fs vary with environmental conditions would present new challenges, however, both with providing annual advice and with keeping industry compliance with moving reference points.

Table 3. Bootstrap results for zones in the Newfoundland herring fishery.

Zone	SSB	F	Type of Fishery
1	Very Poor	0.00-0.05	Scientific
2	Poor-Moderate	0.05-0.10	Restricted
3	Mod.-Good	0.10-0.20	Commercial
4	Good-Very Good	=0.20	Accelerated

4.10. Newfoundland capelin (Atkinson)

A brief summary of capelin in NAFO Subarea 2 + Division 3KL was presented. Capelin is a small, pelagic, schooling species with a short life span and variable recruitment. These characteristics combined result in dramatic changes in SSB over relatively short time periods. The SSB is primarily fish aged 3-4. Capelin is an important prey species for other fish, marine mammals and sea birds. SA2 + 3K were managed separately from 3L until 1992.

There has been a domestic fishery (~25,000 t y^{-1}) for many years along beaches, primarily for food, bait and fertilizer. A foreign offshore fishery developed in the early 1970s and continued in most years up to the early 1990s when it was closed. The Canadian commercial fishery developed in late 1970s as a roe fishery and has continued to the present.

First management in the 1970s was based on surplus production, taking into account spawning as well as predator requirements. Acoustic techniques were employed early on by Canada, Norway and the USSR to estimate stock size. VPA analyses were also employed. More recent indices include aerial survey index, purse seine CPUE index, trap CPUE index, egg deposition index, and offshore groundfish RV indices.

In the 1980s, TACs were established based on estimates of SSB using the harvesting rule that catch should not exceed 10% of SSB. This level was chosen due to the important role of capelin in the food web as an important prey species. The estimates of SSB were based on acoustics as well as VPA projections. Little use was made of the inshore indices. An analysis by Shelton in the late 1980s indicated that even with uncertainties, the probability of harvests exceeding 10% had been low.

Changes occurred in early 1990s with regard to capelin behavior, distribution, growth and time of spawning. Acoustics no longer detected capelin in offshore areas although the reasons for this remain unclear as the various inshore indices and groundfish research surveys did not indicate any dramatic changes in abundance. Researchers stopped using acoustic estimates for assessments, and came to rely on the other indices (inshore).

Current assessments use 7 indices (aerial survey, purse seine CPUE, trap CPUE, egg deposition, fall groundfish 3L, fall groundfish 2J3K, Russian CPUE 1972-91) in a multiplicative model to estimate relative year-class strength. All indices are given equal weight, and there has been no analyses to indicate whether any of the indices actually reflect stock size. An index of recruitment is also obtained from an oceanic 0-group index, sediment larval index, emergent larval index, oceanic age 1 index, all combined in multiplicative model. Again, all indices are given equal weight. We do not analyze uncertainties with the various estimates.

An important part of logbook programs includes receiving narratives from fishermen. A recent problem has arisen in that indices suggest increases in capelin abundance in the 1990s while the narratives suggest declines. This difference has not been resolved.

Due to resource reductions within the Department, the offshore acoustic surveys have been discontinued, and aerial survey coverage and beach coverage (egg deposition, larval emergence) have been reduced. These reductions have all decreased the ability to determine stock status on an ongoing basis.

For the HPPPA, current workloads are such that capelin scientists are not in a position to become involved and carry out the necessary work.

Discussion

This is the only case where we have observations on catch and indices but no accepted process dynamics. This offers an interesting contrast to the other cases and may require a data-based harvest strategy rather than a state-based strategy. It also presents additional dimensions to the question of what is precautionary, because of the role of capelin in the ecosystem. There is currently nobody identified to lead this case study.

4.11. Summary of case studies (Gavaris)

Table 4. Summary of case studies.

Case	Inputs	Process modelled	Derived States	Unacceptable outcomes	Uncertainty calculation	Management actions modified annually
Cod 3Ps	$C_{a,t}$ $I_{a,t}$ Tag returns	SPA Mark/recapture	SSB F	$F>F_{0.1}$ $\Delta B<0$	Profile	Quota
Cod 2J3KL	$C_{a,t}$ $I_{a,t}$	SPA (prior to moratorium)	SSB F	$F>F_{0.1}$ $\Delta B<0$	Profile	Quota
Cod 4TVn	$C_{a,t}$ $I_{a,t}$	SPA	SSB F	$F>F_{MSY\,(short\ term)}$ $\Delta B<0$ $B<B_{reopen}$	Bootstrap	Quota
Crab 4T	C_t $I_{a,t}$ %soft	$B_t=I_t$ $B_{t+1}=B_t-C_t+R_t$	Exp Rate	Exp Rate>35%		Quota Soft shell area closure
Beluga E Hudson Bay	C_t I_t	Leslie type	B Exp Rate	Exp Rate>2-5%; $\Delta B<0$	Monte Carlo	Quota Closure
Pacific Ocean Perch	C_t $p_{a,t}$ $I_{a,t}$	Forward VPA-like	SSB F	$F>F_{ref}$ $B<B_{1977}$	Standard normal Monte Carlo	Quota
Fraser River Sockeye	C_t S_t	R=f(C) S-R model	S	$S<S_{tr}$	Monte Carlo	Effort
Newfoundland Capelin	$C_{a,t}$ $I_{0,t}$ $I_{yc,t}$					Quota
Newfoundland Herring	$C_{a,t}$ $I_{a,t}$ I_t	SPA S-R	SSB F	$F>F_{HCR}$		Quota

5. Limitations and Pitfalls

5.1. Regime shifts and environmental forcing (Rice)

The physical and biological environment in which the stock lives can affect precautionary reference points through four different factors:

- distribution, which affects the unitary interpretation of historic time series, and the future performance of fisheries;
- growth, which affects yield per recruit, and stock fecundity at age;
- natural mortality, which affects yield per recruit and survivorship of spawning biomass;
- recruitment and thereby recruits per spawner and all projections.

The major patterns of environmental change are different between the North Atlantic and the North Pacific. In the North Atlantic, the North Atlantic Oscillation is the major forcing function, and its signal has a typical coherence of several months. In the North Pacific, ENSO events are the major signals, and their typical coherence is measured in years. Major perturbations in the Canadian Atlantic come from the north (boreal or polar waters), whereas major perturbations of the Canadian Pacific coast generally come from the south (temperate or sub-temperate waters).

Several analytical approaches have been used to investigate the patterns in long-term environmental signals. Each approach has value, but can also introduce artifacts. Time series type analyses can produce spurious results, particularly if there are infrequent outliers in the data. When used in diagnostic or forecasting modes, such analyses may fix the timing of a coming phase transition based on historic patterns rather than current information. This can result in serious mismatches of the timing of management actions relative to changes in the state of a stock. Ordination approaches are diverse, and usually methods with alternate assumptions about process structure and variance should be explored in any single application to extract trends from environmental data. Although major multi-year environmental events are extracted by all of the ordination methods, the sequence in which they are concatenated may change, depending on the type of ordination. These changes may have very large consequences for how the environmental factors are associated with biological time series of data. As a generalization, in single investigations of how environmental change influences precautionary management measures or strategies, the environment should not be simply represented by a random variable with mean = 0 and variance drawn from a normal (or log-normal) distribution. However, there is no general form for more complex representations, and several contrasting ones should usually be explored, prior to deciding whether any particular strategy or measure is "precautionary" in a changing environment.

Models in which environmental influences are represented as occasional major perturbations, which have some persistence following their occurrence, appear to have promise as representations of environmental forcing of marine systems. These models nonetheless pose a number of new questions, even if they treat other problems (such as the artificial concatenation of sequences of events through a time series) in a more realistic manner. The new problems include the distribution of intervals between perturbations, the distribution of magnitudes of perturbations, and the form and rate of decay of a perturbation, once it has occurred.

To include environmental influences on growth in a precautionary approach it is possible to have growth rate or size at age follow some functional form. There are several such models proposed. If these relationships are important for a stock, it is also important to ensure that effects of variable growth on fecundity or reproductive effort surrogates are also included, and that forecast yield reflects expected variation in future sizes at age. This may, in turn, require variable reference points to accommodate changes in yield per recruit and recruits per spawner, as the environment changes.

There is a very large literature on how the environment may affect recruitment, and simulations using variable recruitment are common. Nonetheless, there are few clear guidelines for how an analysis should relate the environmental factors to recruitment strengths, and many functional forms and error structures are possible. Nonparametric methods are also useful, and avoid some of the problems inherent in specifying arbitrary functional forms for these relationship. In a precautionary framework, the key questions are: (i) does a particular excursion of a key environmental indicator represent a short-term event or a longer term change, and (ii) what is the cost of assuming the wrong environmental state when evaluating the consequences of a management action. There has been more work on these questions, than on investigating the processes linking environmental factors to recruitment.

Changes in distribution of a species in response to environmental conditions can influence all the indices of stock status, including survey and commercial CPUE, as well as the performance of fisheries in future at any given effort level. There have been many approaches to analyzing the basic effects of environmental conditions on distribution of species, and all these approaches have the same potential difficulties as analyses linking environment to recruitment. It is generally wise to explore several functional forms and error structures, rather than simply choosing the first formulation which gives “significant” results. Despite the possible influence on the performance of fish harvesting operations, there has been very little work exploring how to accommodate environmental influences on distribution in the forecasting step, or in evaluating management strategies.

With regard to variable natural mortality caused by environmental influences, biotic aspects are treated in the presentation on multi-species effects. Abiotic aspects can be treated as described for environmental influences on growth. However, the problems are more difficult, because there has been much less work on the functional relationships between natural mortality and environmental effects. In fact, there are clear cases where the major effects are rare large die-offs, therefore, the overall functional relationship is neither smooth nor continuous. Such relationships are often problematic to model. Moreover, the difficulty of partitioning changes in m from changes in q in an assessment are well known. Hence, it may prove very difficult to include such affects in a overall precautionary analytical framework. Rather, in this case careful monitoring and swift reaction by decision makers to observed mortality events may be the most appropriate approach.

In many cases, these types of considerations may offer much more opportunity for confusion than for increased clarity. Nonetheless, they have a role in the precautionary approach, and in analyses supporting such an approach. As a generalization, greater environmental variation, and greater impacts of environmental forcing on stock dynamics will mean greater uncertainty in analyses, and therefore greater care in management. This concern should be faced directly, however, through specification of reference points and provision of buffers appropriate for the level of uncertainty expected, and not through intentionally biasing a set of analyses or interpretations, by making consistently pessimistic assumptions about how the environment will affect a stock.

Discussion

1. How does an analysis include environmental effects (physical and biotic), patterns of change (Pacific more coherent than Atlantic)? What should be done may be case specific. However, we should not just use simple random variables. Perhaps make use of cyclic analyses, empirical orthogonal functions (EOF), and Kick-Decay models.
2. Do we use a growth based approach to quantifying SSB, including quality of SSB (SPR)? We should also take into account the quality of eggs. This is done for other fisheries, especially the invertebrate fisheries.
3. How can we put recruitment into short term assessment (rationalizing a long-term property with a recent event)? Depends on how much recruitment comprises total fishable biomass, and the quantity and quality of information on incoming recruitment.
4. If the environment changes, biological reference points are not enough. F must change depending on ecosystem carrying capacities.
5. What about trawl bycatches? Barndoor skate can be protected if the need is demonstrated; we have the tools.
6. Interest was expressed in the use of wavelets (Numerical Recipes, 2nd ed.). Economics has identified regime shifts in the economy for years. It may be useful to define binary states of stock status.

5.2. Multispecies considerations (Rice)

Although all the major agreements and scientific papers on precautionary approach and precautionary reference points include the usual phrases about considering multi-species effects and ecosystem concerns, almost none of the reference points being developed include multi-species interactions directly. Some trophodynamic modellers do propose additional or alternative reference points based on ecosystem properties, but these have not been proposed or evaluated in operational contexts.

One study did introduce variable predation mortality into the standard Shepherd-Sissenwine graphical framework. The study considered predation by con-specifics (i.e., cannibalism), by other predators over the full life-span of the species, and predation primarily occurring prior to recruitment to fisheries. In each case, the study examined the error which would occur in the estimates of F_{MSY}, B_{MSY}, F_{LOSS}, F_{CRASH}, and B_{LOSS}, if the species were truly multi-species, but analyzed as if it were a single species system with constant natural (including predation) mortality.

As generalizations form the results, mis-representing the system as a single-species system leads to underestimation of recruits per spawner and over-estimation of yield per recruit. In the case of cannibalism these appear to cancel, but for other cases they do not appear to cancel. F-based reference points are over-estimated, relative to the true milt-species situation, so F-based reference points are set too high, and B-based reference points are often underestimated, so biomass reference points may be set too low. In both cases the risk of moving into dangerous situations will be higher than expected from single species analyses.

As long as F or B do not change greatly, the multi-species effects noted above do not appear to cause great distortions to risk estimated, even if absolute values for the reference points are wrong. It is when F or B changes substantially that the errors become serious. This was illustrated with simulations of rebuilding for each of the two-species situations described above. In every case the true rebuilding trajectory, when the multi-species effects are included diverged seriously from the trajectory forecast from the single-species treatment of the system. Actual improvements in recruitment, future yield, and spawning biomass were all smaller and slower than forecast in the single-species representation of the system. If the rebuilding approach included harvesting to quotas estimated annually using data from the high mortality – low biomass period, the over-estimation of yield would lead to quotas being set too high. This would result in over-harvesting relative to the intended lower F, and hence failure to reduce F or rebuild biomass.

Another approach to including multi-species interactions in estimating precautionary reference points is to build fisheries models around classic Lotka-Volterra predator-prey models. One implementation of this approach indicated that the area of sustainable fishing for a predator is dependent on the exploitation rate of its prey, and *vice versa*. There was a large area of joint sustainable fishing mortalities for the predator and prey, but in plots of that region the isoclines were not orthogonal to either the predator or prey mortality axes. Hence appropriate fishing mortalities for predators and prey should not be considered independently.

An implementation of MSVPA for cod, herring, and sprat in the Baltic Sea explored the linkage of sustainable fishing for predators and prey as well. The model explored three levels of biological complexity: (i) only predation, (ii) predation plus stock recruit relationships for the three species, and (iii) predation, stock recruit relationships and growth and maturation of cod dependent on prey biomass. All formulations showed again that the domain of sustainable fishing of predators and prey were not independent; the consequences of various fishing mortalities on a predator depended on the exploitation rates of the prey stocks. As biological complexity was added, the slopes of the isoclines became steeper, and the regions of collapse of the system changed considerably. Again, the modelling study indicated that reference points for predators should not be set without consideration of the exploitation rates of prey, and exploitation rates judged sustainable in a single-species context might cause collapse when predation and density dependent factors are considered.

Taken together, these modelling studies all indicate the multi-species interactions are very important to estimates of biological reference points. The studies have focused primarily on interactions among exploitation rates, but biomass reference points will be affected in similar ways. Some results suggest that the species interactions can be considered a secondary concern as long as fishing mortality and spawning biomass varies around a status quo situation. However, the inaccuracies which arise from ignoring these interactions will become important if exploitation either increases or decreases greatly. All results also indicate that not only is it important to consider the magnitude of predation mortality when setting reference points for prey species, but the exploitation rate of important prey stocks must be considered when setting reference points for its predators. If biological processes such as growth and maturation or predators has density dependent functional relations with prey population sizes, the multi-species consequences on reference points are likely to be magnified.

Much of this work is not yet available in the primary literature. However, recent reports of the ICES Multi-species Assessment Working Group, and the ICES Working Group on Ecosystem Effects of Fishing, report methods, results, and provide peer-review commentary, in more detail.

Discussion

1. Cannibalism does not affect yield much but does affect the steepness of the stock-recruitment curve. Cost of errors go up more quickly and cannibalism increases. In a true predator-prey

system a single species analysis will lead to target Fs that are higher than they should be, but they are unlikely to be terribly wrong. This could lead to bifurcations.

2. Theory has been available for a long time but the data are lacking for more complex analyses. However, are data trivial enough that the scientific community can ignore them? At least to explore alternatives, one could overlook data problems, as long as one does not try to implement the results before going back to improve the data.
3. Identify where the project needs further work. How can scientists introduce what they do into control rules? Not obvious, and easiest strategies of just treating all these considerations as uncertainty will make advice very conservative. PA advice may be to forego a lot of yield until adequate knowledge accrues.
4. Some do not believe in the cannibalistic model, but M is now dynamic, and may help to explain observations in many data sets.
5. Do these multispecies models allow explanation of the cod collapse due to seal predation? The models do not explain the collapse, but some formulations are consistent with the failure to rebuild.
6. If scientists do not have the data what do they do? Find "something else", where "something else" may be a distant (and unconvincing) surrogate.
7. What about managing to conserve ecosystem properties? The ICES working group results indicate no ecosystem attribute has been found for which scientists would have to set criteria.
8. It is difficult to preserve the least productive (and potentially uneconomic) species of an ecosystem in compliance with the above.
9. In the krill fishery, Alaska and Washington have protected prey species (as has Canada). Similarly, we need to develop a policy for forage species. Also, this requires formalizing the degree to which values other than commercial values are assigned to species.

5.3. Unrecorded sources of mortality (Fréchet)

The presentation summarized the findings of an ICES Study group on "Unaccounted Fishing Mortalities". As such, it did not address the question of natural mortalities such as changes in predator/prey abundance, changes in fish condition or environmental pressures. It is a rapidly developing area of research in Europe; however, little work is being done in Canada. The FRCC has recently recommended many research priorities in this field (FRCC.97.R.1).

It order to detect any unaccounted fishing mortality, it is important to better understand the whole fishing process. This can explain why most of the research on this topic is done by gear technologists. The estimation and the incorporation of unaccounted fishing mortalities in assessments is in its infancy.

The partitioning of a fishing activity can be given as:

$F =$	F_C	(Landed catch) +
	F_B	(Illegal, misreported and unreported landings) +
	F_D	(Discard mortality) +
	F_E	(Escape mortality) +
	F_G	(Ghost fishing mortality) +
	F_A	(Avoidance mortality) +
	F_P	(Predation mortality) +
	F_O	(Drop out mortality) +
	F_H	(Habitat degradation mortality)

The current practice is to consider that the landings is the sole source of mortality. Clearly, illegal, misreported and unreported landings may be significant in some fisheries but they are seldom known and included in assessments. Moreover, recent research in other, less known, sources of mortality indicate that they may be significant. Selectivity studies focus on the size of the catch, but their usefulness may be seriously hampered if they do not address the survival of non-selected fish. Ghost fishing mortality and habitat degradation mortality may have long term repercussions on many non-targetted species. Findings on most sources of mortality have many implications for management. The overall mortality associated to a particular gear could be used to prioritize its impact on a given stock.

The knowledge of the total fishing related mortality is essential to the assessment process. Hopefully, some of these sub-components of the fishing related mortality may be small but they still remain unknown. Any unaccounted mortality will reflect itself in a large and biased uncertainty in the stock estimation. Under the approach of the Precautionary Principle a better understanding of the overall mortality to a fishing activity has implications for fisheries management. The estimate of overall removals is essential to the assessment and the establishment of a reference catch

Discussion

1. There was a report on unaccounted fishing mortality from an ICES working group that last met in 1997. Robin Cook is trying to partition mortality into identifiable sub-components: landings, misreported species, discards, escapements, ghost fishing, avoidance (and hit by doors), predation (because in wrong environment after release), drop-out (almost landed then accidentally lost), habitat degradation. This would give an estimate of how many fish are killed to land 1 tonne. The scientific community should extend work to other fisheries and try to discriminate the cause of death of escapees. How does this information get used in PA?
2. Proportion of catch may be better known, at least above a certain size, than the amount caught. For some sizes of fish the effects may cancel out – they are put in and killed before they are really relevant to fishable biomass estimates.
3. Incorrect reporting changes the scaling of B in SPA. Some PA effects have compelling effects and some do not, therefore, it is necessary to perform sensitivity analyses.
4. Incorrect scaling is not important unless fishing practices are changed. However, the whole purpose of PA is change practice, otherwise why is it a priority? Scaling is also important in multispecies work where true Bs are needed.
5. Changes in the quality of monitored landing data lead to problems.
6. There were technical questions about the experiments, where it was noted that more work is needed to assess survivorship of fish which escape through gears.
7. The first step in dealing with inappropriate net mesh size is to adopt a mesh size appropriate to catching marketable fish.
8. Because of uncertain effects of exclusion devices, risk might not be reduced as much as expected.
9. There is a link between the quality of data and risk. However, even if management policies do not change, it is preferable to have the proper scale of biomass estimates, even if these estimates do alter management policies.
10. We should clarify the link between inaccuracies in reporting and inaccuracies in estimating stock size. In some instances, fishermen may report deliberately low estimates of catch expecting that these values will imply a low impact of the fishery on the population.

However, reduced catch estimates produce smaller VPA stock size estimates, thus having the opposite of the anticipated effect on management policy.

11. Substantial amounts of starfish are taken as bycatch in the POP fishery. This may be saying something important about impacts of this fishery on other parts of the ecosystem or about the abundance of predatory starfish.
12. Studies have shown that up to 60% of Z is a result of gear effects (incidental mortality).
13. With lobsters, many tagged animals are re-caught often, especially at low stock size. This may bias the estimation of non-fishing mortality.
14. There is a need to research a precautionary gear type.
15. Should the project comment on which of these (non-quota buffer-like) approaches should be emphasized? Silence doe not mean that scientists think it is unimportant.
16. There is a need to model discarding explicitly for some fisheries, and scallops/starfish interactions
17. Density dependent effects on distribution and growth need to be addressed.

5.4. NRC study of assessment quality (O'Boyle)

In 1994, NOAA asked NRC to evaluate the scientific basis of the US management of Atlantic Bluefin tuna. Other requests followed so that by 1997, NOAA and NRC agreed on the strategic review of US assessment approaches, which would be undertaken by NRC's Fish Stock Assessment Committee, formed in 1996. The mandate of the review was to review assessment methods and models and through simulation, test sensitivity and robustness of the models to data type and quality. The Committee was composed of a number of leading scientists familiar with current assessment methodologies. While the report consisted of sections on data collection, assessment methods, harvest strategies, and simulations, the presentation at the workshop focused primarily on the latter. The findings are applicable to the Canadian situation and in particular the lessons learned on uncertainty were of direct relevance to the workshop.

To effect the review, the Committee first created an age-structured population model in EXCEL (a detailed handout was circulated). It used this to generate five data sets which incorporated different population trends, changes in the age of 50% fishing selectivity, underreporting and changes in survey catchability. The Committee selected NMFS analysts to conduct blind evaluations of the five data sets using the major types of assessment methods including Surplus Production, Delay-Difference and several types of age-structured analyses (ADAPT, Stock Synthesis and AD Model Builder). The NMFS analysts were given the simulated catch, age composition, commercial CPUE and survey data, along with the growth and maturity parameters, and aging error probability matrix, but not given any information on the natural mortality, fishery catchability, fishery and survey selectivity, recruitment processes, and the amount of under-reporting (although they were warned of it). The analysts were instructed to conduct the analyses independently, and perform these using three combinations of the abundance indices (CPUE alone, survey alone, and CPUE and survey together). The Committee undertook model runs repeated with the true M, as well as retrospective analyses.

To compare the assessed and true populations, a number of key management variables were defined including the Exploitable Biomass (EB_{30}) in year 30, the ratio EB_{30}/EB_1 indicative of the trend, the TAC_{31} (from $F_{40\%}$ strategy), theTAC_{31}/EB_{31} (recommended harvest rate) ratio, and the average recruitment and spawning biomass (SSB) across all years. The results of each assessment were expressed as a relative error (Estimated-True)/True. The Committee considered that the goal of an assessment should be to obtain estimates of the key management parameters which were within 25% of the true value.

The simulation results exhibited large deviations from the true values, with the 25% criterion not commonly met. Assessments using only the CPUE abundance index yielded the worst results while those using the survey index yielded the best results. Assessments using both indices were in between. Generally, complex models were less affected by the abundance index used, primarily because the formulation could be adjusted to match the data. The SPM performed badly as expected, while ADAPT, SS and ADMB performed reasonably when survey data were used and the underlying dynamics were not complex. SS and ADMB could handle complex dynamics but this depended on accurate model specification. In many cases, assessed abundance trends were neither coincident nor parallel with the true trends. There was no consistent pattern between model and data and no model stood out as the best tracker of abundance.

Regarding the additional analyses, the true M results differed little from the estimated M results as the NMFS analysts had calculated Ms in their assessments similar to the true value. The retrospective analyses were only conducted using the ADAPT, SS and ADMB models. Relative errors were generally much smaller when survey data were used. All methods and data showed a disturbing tendency to overestimate declining biomass and underestimate increasing biomass. There did not appear to be a best assessment method in terms of low bias, although ADAPT performed poorly with the CPUE index.

The Committee concluded that CPUE is not a useful abundance index if not properly standardized and that surveys had the best potential as abundance indices. Indeed, assessments with accurate abundance indices performed twice as well as those with faulty indices. The absence of adequate data was seen as the primary constraint on reliable stock assessment. In addition, auxiliary information on populations dynamics such as natural mortality, growth, selectivity, and catch reporting was required. The Committee encouraged the accounting of environment in assessments and stated that single species assessments, rather than the more complex multi-species versions, are still the way to proceed.

The Committee considered that complex models were needed to quantify uncertainty and recommended consideration of Bayesian approaches. As well, although it felt that new methods could better accommodate data problems, it was thought prudent to analyze the same data with different models. However, while new models offer promise for reducing bias, they do not mitigate poor data quality. Even the best current assessment methods produced exploitable biomass estimates greater than 25% of the true value. Thus, it is essential that the assessment models express the uncertainty and that this uncertainty also be incorporated into the harvest strategies.

The Committee recommended that independent reviews of assessments be conducted every 5-10 years, that a special review of commercial data collection in the US was needed, and that initiatives to foster and encourage education and training of assessment scientists be established.

Discussion

1. NOAA asked NRC for a review of stock assessment methods, and a committee was formed in 1996 to address stock complexity and risk. The committee looked at production, delay difference, and age structured models. Being given the true M did not help much. There was a retrospective lag both in falling and increasing stocks. The study recommended using different models, but single species models are still the way to go. It was not obvious how this conclusion was supported by the analysis. The NRC study used just one data set so

another realization may lead to different results (priors). Project members must question the value of presenting any point estimates.

2. The Department needs to have independent reviews to assess the effectiveness of closed areas and other types of regulation.
3. How did the models in the NRC study estimate uncertainty? Not looked at directly. Might this be done through simulation studies? It is hard to do a simulation study correctly; the NRC study had many unsupported conclusions (e.g., CPUE worse than RV, protected areas are a good strategy). Fuzzy logic is becoming more popular in risk analysis and perhaps the project should consider its application to PA.
4. Even the best assessment models can show considerable variability. It would be wise to give some priority to explaining variability as this is where the users really depend on us.
5. This project seemed to be re-inventing work done elsewhere – for example by the ICES Methods Working Group meeting in Iceland – but doing it less completely.
6. Although the NRC study called them models, ADMB and ADAPT are not models.
7. How does the NRC study help us be precautionary?
8. The study still shows that assessments can be completely wrong and those doing them may not know it. Can this be checked with simulation trials during assessment meetings?
9. How do we separate the shortcomings of models from those of users?
10. We need data sets with known properties for testing our models. This is a big job if it is to be done well.
11. We should incorporate some form of testing (quality control) in routine assessments.
12. Regarding data screening, we should pre-assess our data. If we do that well, many of the worst problems might be avoided.
13. Value must be placed on the ancillary knowledge and experience of the assessment team. Ancillary knowledge is germane to PA as well.
14. A link to the NRC should be established on the PA website and included in the report of this meeting.

5.5. Resource user involvement in science aspects of PA (Richard)

Lack of resource user involvement in analyses leading to PA implementation is a serious limitation to PA analysis. Users have knowledge on the distribution and behaviour of the stock in question. They can give valuable insights on stock status and on catch and hunting loss due to various methods. It is a perennial complaint of resource users that this knowledge is not used by fishery scientists or managers. In the context of PA modeling, users have useful inputs in the data used, in model choice and components, in the choice of reference points (particularly B_{LIM} and B_{TAR}), of hunt control rules and of tolerable risk (related to B_{LIM} and B_{BUF}). Their involvement in various aspects of policy analysis (data gathering, defining the PA model, running the model, interpreting the model results, and formulating a PA policy for a stock) can only lead to greater acceptance of the PA approach and the management policy that results from it.

Discussion

1. User input on choices of data, model, reference points, hunt control rules, and risk tolerance leads to user acceptance.
2. User education is needed to enable wise choices, but education has to work both ways. Users are not merely low grade technical assistants. We need to tap their expert knowledge.

3. Some things which need to be reviewed and discussed are highly technical, and non-experts may not be able to participate in informed discussions.
4. Researchers are eager to improve their knowledge. They just do not know how to incorporate user knowledge.
5. The goal of the beluga case study is not primarily to improve science, but to engender user acceptance. Also, the assessment needs to capture how users view the resource. They know it much better than DFO scientists do.
6. Client knowledge often fails to fit the strict scientific mold. However, clients usually can illuminate data interpretation.
7. The scale at which users can contribute the most may not be the scale at which assessments are often conducted. Users can play a role in management at the local level. They know the fleet dynamics.
8. Industrial risk analysis literature exists on how to capture relevant user knowledge.
9. We are making progress on user involvement, but still lack methods of bringing their knowledge into our stock assessments. We are not sociologists trained in interview techniques.
10. User knowledge may also be confidential, linked to fishing and market strategies.
11. The precautionary approach to fishery management requires buy-in. The Department must have processes to achieve this.
12. Fishermen fish for money, not fish. It is necessary to filter their ecological knowledge from their economic interests. Some argued that when users feel they are actually having an impact, the degree of posturing is reduced greatly.
13. In the U.S., an historical hostility of users toward fishery agencies has been an obstacle.
14. Concern was expressed that users' knowledge often fails to meet the scientific criterion of replicability. Others argued that tools actually do exist for transforming user knowledge into something useful, although these may not have been applied systematically in fisheries contexts. Also, many assessments themselves may not be all that replicable.
15. Fishermen can sometimes pick up things science has overlooked, thus improving our assessments.
16. Scientists can also be subjective.

5.6. Stock and recruit relationships

5.6.1. Part A. (Rice)

Stock-recruitment relationships are fundamental to precautionary reference points. Unless the reduction of spawning stock has detrimental consequences for future recruitments, it is difficult to demonstrate a biological need to keep SSB at any particular distance from the origin (other than a distance somewhat larger than the uncertainty in the estimate of SSB itself). However, if there is a stock-recruit relationship, then the position of a peak or asymptote in the functional form should have great influence on target biomass because it indicates the region of highest productivity. Slope near the origin may have great influence on limit reference points because it relates to the ability of the stock to recover from low SSBs.

The "stock-recruit" problem has been with fisheries science from its earliest years as a scientific discipline, and is still a topic of diverse views. Many analytical approaches, both parametric and non-parametric, have been proposed for expressing the dependence of recruitment on stock. Parametric methods include two-parameter functional forms, most notably the Ricker and Beverton-Holt, and three parameter forms, such as the Shepherd and Schnute-Deriso formulations. Non-parametric methods are also diverse, including narrow-band smoothers (e.g., Cook), full density estimation methods (Evans and Rice), and piece-wise linear methods (Butterworth-Berg).

The productivity of a stock at low SSB has received substantial attention recently because this aspect of a stock's biology is important to biological limits and because many high-profile stocks are in or near that region. Meta-analyses of many S-R data sets, conducted by Myers, Barrowman, and co-authors have shown that although there is little evidence for depensation in S-R relationships, the maximum spawners per recruit produced at low very low SSB seems to be a fairly general property across many species and stocks. In general, no more than about six spawners are produced by each spawner at low B. This factor may be useful when evaluating limit reference points of a stock that appears to remain productive as SSB drops to low values.

Although the equations which justify, and often permit, estimation of several proposed limit reference points include the α parameter of stock-recruit function, there are several arguments against basing limit reference points on this parameter. α is often poorly determined by S-R data, particularly when most observations are far from the origin of the SSB axis. Very low recruitment values have extremely high leverage on the α parameter of Beverton-Holt models, whereas the size of recruitment at the highest SSBs have very high leverage on the α parameter of Ricker models.

Non-parametric methods are less affected by the differential leverage of data far from the region of interest. They can also directly produce the probability distributions required for evaluating the risk associated with various candidate reference points, while preserving the exact distribution properties of the observed recruitments. They are not without their own difficulties, though, particularly when there are few or no observations at low SSB. In such cases a method of extrapolation from the lowest observations to the origin of the S-R plot must be selected, and often must be on grounds different from the basis for how data are treated within the range of observations. Hybrid methods are under development, but not reviewed by the fisheries science community.

5.6.2. Part B. (Schnute)

A risk analysis for the precautionary approach obviously depends fundamentally on some assumption about recruitment. For example, if a future harvest rate reduces stock abundance, how will that influence future recruitment? In the long run, everything depends on the birth of new fish and their recruitment to the population.

Analytical models sometimes offer a route for intuitive thinking about the significance of recruitment parameters. For example, consider a relatively simple age structure model with recruitment R computed from stock S by the Beverton-Holt model:

(A) $$R = \frac{\boldsymbol{a}\, S}{1 + \boldsymbol{b}\, S}.$$

Then it can be shown that the MSY harvest rate h_{MSY} is given exactly by

(B) $$h_{\mathrm{MSY}} = \frac{\sqrt{\boldsymbol{a}\, d} - d}{1 + \sqrt{\boldsymbol{a}\, d} - d},$$

where $d = 1 - e^{-M}$ is the population death rate computed from the natural mortality M. (Note that $d \cong M$ for small M.)

In equation (B), the parameter a appears in both numerator and denominator. Thus, even when a is highly uncertain, this uncertainty may cancel somewhat in the ratio, and h_{MSY} may be somewhat better defined. Rob Kronlund and I have used simulation–estimation techniques to check this in certain cases, and the intuitive argument from (B) appears to have some practical validity. In fact, h_{MSY} can be considered an alternative parameter, one with statistical properties preferable to a .

Discussion

1. Reference points depend on α, which is highly uncertain. Nonparametric estimators offer an attractive alternative.
2. Although reference points depend on α and other parameters, the dependency is nonlinear. Sometimes the variances cancel, leading to improved robustness. The best method is not clear *a priori*.
3. Estimating α is nonsense, because its value is defined by a curve outside the range of the data. It can be reasonably argued that the real curve does not even go through the origin. However, the parameter h_{MSY} depends on the shape of the curve within the range of data. Thus, it makes more sense to estimate this parameter. In fact, this result is independent of parametric or non-parametric estimation. It supports the concept of using some reference points as surrogates for other parameters, and it's consistent with focusing on MSY.
4. If the stock is rebuilding, h_{MSY} may not lie in the range of historical data.

5.7. Retrospective patterns (Mohn)

The retrospective problem is a systematic inconsistency among a series of estimates of population size, or related assessment variables, based on increasing periods of data. In some stocks, this problem is of such magnitude that sequential population analyses (SPA) are deemed inapplicable. The Eastern Scotian Shelf (ESS) cod fishery, which displays the retrospective problem, and simulated data are analyzed to provide insight into the causes and potential solutions to this problem. The retrospective problem is shown to be a result of the traditional analysis techniques and a non-stationarity in the data used in the population analysis. A moving window analysis is developed which allows the non-stationarities to be identified and in some cases rectified. Recommendations are also made for ad hoc investigations of the data. The analysis suggests that failure to correct the retrospective problem for a stock with data like ESS cod could lead to catch level advice that would be twice or more the intended level.

The relevance to precautionary analysis is that one should not proceed with it until the causes of retrospectivity have been identified. Of particular interest was when the cause of the pattern was due to a change in natural mortality. Failure to resolve and account for such a change would bias all aspects of precautionary analysis.

Discussion

1. Retrospective patterns may be characteristic of all time series analysis. When tracking a moving object, one should expect serial correlation of error.
2. Modeling serial correlation might gloss over real underlying problems.

3. This presentation offered two "fixes" to the retrospective problem. Are the fixes generic? They can be made in many applications, but one is left with two versions of reality, and little basis to select one or the other.
4. When faced with a strong retrospective pattern, what is the precautionary choice; decide the problem is so bad the analysis cannot be accepted, or apply a possibly arbitrary fix? Perhaps try to diagnose *when* something changes, and use external information to try to determine *what* changed. Then the fix would not be as arbitrary.
5. History of cod stocks shows this is an important problem. The scientific community would be remiss not to attempt a correction.
6. The department could offer industry the option of accepting higher risk or reducing catch.
7. Can the assessment result in a decision table, including population estimates uncorrected and "corrected" for the retrospective pattern? Retrospective adjustments to the mean must be accompanied by retrospective variance adjustments. This would probably influence the estimate of risk in a manner that would indicate more precautionary management.
8. Retrospective patterns can serve as diagnostics to indicate the need to examine changes in system dynamics. However, some argued that the talks in the morning, on system complexity, had demonstrated that it would be unwise to just stick in some convenient form for the non-stationary process. Time series, correlated-error models can make an analysis appear much better, but be completely wrong.
9. Retrospective problems are endemic, as illustrated by the case studies in the NRC report.
10. An ICES workshop also found retrospective patterns to be common. Some studies found them to be in one direction when the stock was declining, and the other direction when the stock was increasing. Does that pattern match the processes to which the retrospective pattern is being attributed?
11. The problem is obviously important, but the scientific community does not know what to do about it.

5.8. Lack of information or poor quality information (Richard)

Let's not be paralyzed by poor information or a lack of information. More information does not always make things clearer. Without complete information, we can use the precautionary approach to model the uncertainty in relevant data and its effect on possible outcomes of management policies. To model uncertainty, one may have to use analogies with other stocks for which data are more complete or subjective (expert opinion). Here is a place for user knowledge in particular. Use modeling as a thinking tool, not as a black box which gives a solution. Question the model and its assumptions. Use common sense. Update the model regularly as information accrues.

Discussion

1. Originally (at the meeting in Dartmouth, June, 1997), we agreed to look at data-rich situations, and investigate the consequences of removing sources.
2. Some argued that data-rich / data-poor was not a productive conceptual framework in which to work. The objectives of assessments should always be similar – describe system states, process models, derive performance measures, and estimate the likelihood of undesirable outcomes, as best one can whatever the data quality. The issue is to find proxies for biomass and fishing mortality that allow us to set practical limits.
3. This argument suggests that rather than investigating how an assessment degrades when

information sources are dropped, one investigates how the assessment degrades when proxies are substituted for data.

4. Experience of users and scientists must be fully utilized. For example, scientists may be afraid to apply their own qualitative knowledge.
5. More data seem to increase uncertainty, or perhaps data only give scientists a better understanding of the scope of their uncertainty. The buzz saw theory of economics is that, if you cannot see the teeth, the saw will not hurt you. The shape of the knowledge-to-uncertainty curve is not at all clear, nor has the scientific community determined where lie the asymptotes.
6. It might help to explore through simulation a much broader range of model possibilities than those currently contemplated in our estimation methods.
7. Stripping away data from data-rich examples may be too restrictive, because it would still confine us to our current paradigms.
8. Tony Starfield's thoughtful simulation approach offers one attractive avenue.
9. FAO is examining methods applicable to the developing world. The Caddy framework uses biological indicators, such as length of first capture and length at 50% maturity. Red, yellow, and green lights correspond to various simple biological criteria.
10. A concern was expressed that under the FAO approach, uncertainty would not be addressed explicitly when there was little information to work with. This would be going in the wrong direction.
11. Some felt the project participants were already over-burdened, and that these lines of inquiry should not be part of this phase of the project. Others felt that the project would be remiss to ignore providing guidance to assessment scientists for data-poor situations. At the least, one should ensure that an FAO-type approach is at least as conservative as approaches being used for data-rich situations.
12. For beluga whales, this type of approach will be essential and will have to be pursued. The Department needs to use common sense and be alert to alarm bells.
13. When it is foggy, one must drive slowly. However, even when the road seems clear, fog can suddenly roll in. Even data-rich situations can actually turn out to be data-poor, based on the real evidence available.
14. Subjective risk analysis may offer a middle road between the red-yellow-green approach and a fully structured numerical risk analysis.

5.9. Implementation uncertainty

5.9.1. Part A. (Richards)

Implementation error can be defined as the difference between the intended and actual consequence of a management action. For example, actual fishery removals will not precisely match a TAC; a TAC was often considered a lower bound to the targeted catch. In addition, management actions may sometimes lead to unintended consequences, such as highgrading when the TAC is reduced. Most fishery models do not consider implementation error. However, incorporation of implementation error will be important for tests of appropriate harvest control rules, particularly in multi-stock fisheries.

5.9.2. Part B. (Gavaris)

It will probably be necessary to study implementation uncertainty through simulation.

The various simulation frameworks that have been proposed share many common features. Consider the framework proposed by SSSC in 1994 (Figure 8). For implementation uncertainty, we could think of imperfect "tactics" or imperfect "monitor enforce" processes or we could role those aspects into imperfect observation of "landings" and "age structure". It is apparent that many of the "model imperfections" would result in similar model behavior. For example, both unreported catches and a higher M than that assumed by the model could be considered "missing fish". By classifying model mis-specification into generic categories, it may be possible to explore model behavior more efficiently.

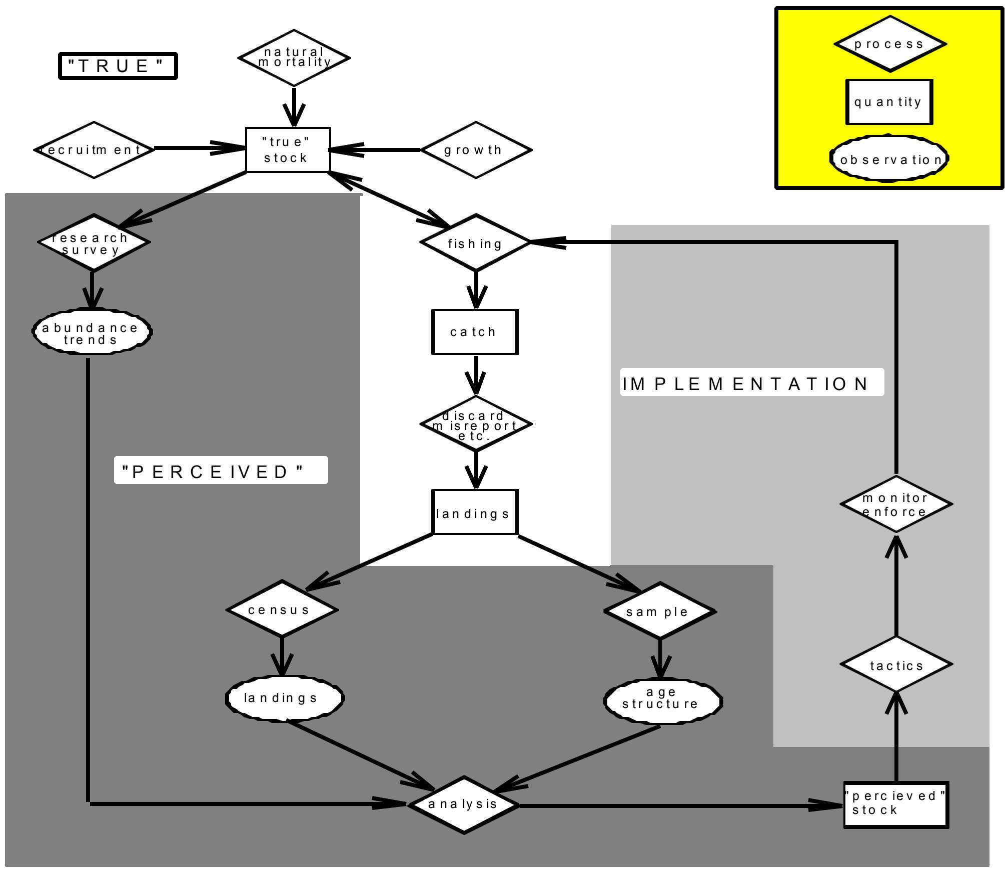

Figure 8. Simulation framework for implementation uncertainty proposed by SSSC in 1994.

<u>Discussion</u>

1. Regulatory change can have unintended consequences.
2. Users' willingness to report discards or previously unreported catch may be counterintuitive. Discards might be exaggerated to discredit regulation, or current estimates of historical underreporting might be exaggerated to increase the current biomass estimate, through raising the scale of estimates of the historic stock.
3. Social psychology has a long history of studying people's reaction to regulation. Thus far, the fisheries science community has not sought help on this problem.
4. Simulations could be used to investigate the performance of inappropriate estimation models. Perhaps one could classify potentially incorrect specifications into categories with similar

consequences.

5. It is necessary to seek at least some overlap in objectives of resource managers and resource uses, if implementation of a PA is to ever be possible.

6. Concluding Discussions

6.1. Review of table of case studies and priorities for future work (Atkinson)

A number of general analytical problems requiring work were discussed. These were summarized as eight issues:

1. Formally incorporate retrospective pattern into risk analyses even if the assessment scientist(s) do not understand the origins of the pattern.
2. Apply simple approaches to complex data sets to evaluate how uncertainty may change with parameter number.
3. Obtain a test dataset generator, and model-specific evaluations on the dataset.
4. Explore and specify properties and behaviour of reference points based on biological attributes other than biomass and fishing mortality (spatial properties, size, genetic diversity).
5. Focus further on stock structure and "unitary stock" concerns. What does the project need to illustrate?
6. Examine if special analytical concerns arise when forecasting outside recent *status quo* conditions (and outside range of observations).
7. Examine time dependency of many "parameters" and processes.
8. Focus more on density dependence in processes; examine evidence and implications.

Table 5 details how these issues will be dealt with in each case study. It was noted that some of the 'simpler' approaches also need examination (non-parametric evaluations, FAO's "red-orange-green" method, etc.). The project also needs to clarify how to evaluate, within a precautionary framework, other possible actions which could be taken with regard to fisheries management, such as changing mesh or gear regulations, closing seasons and/or areas, or creating MPAs.

Table 5. The work planned to address the eight problems for each of the case studies.

Problem	3Ps Cod	2J3KL Cod	4TVn Cod	Crab	PacOcean Perch	Sockeye	Beluga*	Capelin/ Herring
1	Y	Y	Y	Y	Y	N	N	
2	Y	Y	Y	Y	Y	N	Possible	NO
3	Y	Some	Y	Y	Y	N	Possible	Lead
4	N	Some	N	Y	Y	Y	Possible	ID'd
5	Ongoing	Some	N	Y	Y	Y	Possible	
6	N	Y	Y	Y	Y	Y	Possible	
7	N	Y	Y	Y	Y	Possible	Possible	
8	N	Some	Y	Y	Y	N	Possible	

*The beluga case study is different from the others in its focus on co-management. The beluga case will try to address the eight problems; however, the problems are perhaps too technical for a non-technical situation.

Of special note is the current situation for capelin and herring in Newfoundland. The lead researchers here do not have time to become involved in this project; therefore, it is unclear how to proceed. If only one of these fisheries is to be examined, it was **agreed** that it should be capelin because of its unique life history and the current "data-poor" situation, and that the Region should be strongly encouraged to keep this case study going.

It was also **agreed** that the "red-orange-green light" approach of Caddy/FAO should be applied to the various case studies in order to compare results with those of the more analytical approaches. Good agreement would provide more confidence in applying such a technique in more data-poor situations.

Four other "tactic and control" issues were reviewed with regard to the case studies:

A. Explicitly estimating and incorporating implementation uncertainty.
B. Evaluating harvest control rules and understanding how to incorporate "implementability" in the analyses.
C. Evaluating the effectiveness of controls other than direct catch and effort limits (e.g., MPAs).
D. Determining role and reference points for non-target species (e.g., krill, capelin).

Table 6. Tactic and control issues in each case study.

Issue	3Ps Cod	2J3KL Cod	4TVn Cod	Crab	PacOcean Perch	Sockeye	Beluga	Capelin/ Herring
A	N	Y	N	Y	Y	Y	Possible	
B		Y	Y	Y	Y	Y	Possible	NO
C		Y		Y	Y	Y	Possible	Lead
D					Y			ID'd

It was noted that there are ecological issues such as overall ecosystem health, predator-prey interactions, and cohabitation of two commercial species caught in a mixed fishery with different stock status. Work on 2J3KL cod will examine some aspects of the predator-prey issue with regard to seals. The study on Pacific ocean perch and sockeye salmon will examine the mixed fishery issue to some degree. Otherwise, these will not be dealt with as part of the project.

It was noted that in many instances, the uncertainty column in Table 4 was empty. It was **agreed** that as part of the project, project members should examine how the uncertainty calculations should be brought forward (i.e., fill in the column). The proposed worksheet based on Table 4 was reviewed and modified, incorporating comments so as to best reflect the current situation for the various case studies.

The issue of whether other types of case studies would be necessary or useful was discussed. For a data-poor situation, krill might serve as an example (it is also an important forage species). Another invertebrate such as shrimp might be considered in that it represents a resource that is increasing in value. A case study of a developing fishery, such as sea cucumbers in the Pacific, would also be of value. After discussion, it was **concluded** that it was necessary to be pragmatic considering this project. There are only 1½ years remaining and this was considered insufficient to bring other researchers up to speed regarding the project. It was considered more appropriate to delay examination of other invertebrates to phase 2.

It was noted that Pacific region is doing a lot of work on developing fisheries, but this does not have to be part of this project. There are also other activities taking place that will encompass the precautionary approach. There is a joint NAFO/ICES Shrimp Symposium scheduled for September, 1999, in Halifax. The Minister has ask for a policy on fisheries for forage species, and there is a Forage Species Workshop being planned by the Maritimes Region. It was **agreed** that regional Project members should apprise the workshop planning staff of the work related to the Precautionary Approach Project, and request that they include precautionary approach considerations in the initiative regarding forage species. It was also noted that in October, the Minister is meeting with a group of environmentalists who will be saying that Pacific herring should not be fished because it is a forage species.

The question of how one might deal with forage species without an ecosystem model was raised. This issue includes completely different types of problems than those considered by the PA Project to date. It was **agreed** that ecosystem modeling is outside the mandate of the current project, although the assessment and management of forage species could be accommodated within a precautionary framework.

It was suggested that one possibility of accommodating these other issues is to explore ways to get more regional people involved with precautionary frameworks in the various regions. This involvement could include examination of such things as biodiversity, forage species, other multi-species considerations and genetic/ecosystem effects. The group **agreed** that such involvement would be desirable, but would be dependent upon existing resources within the regions, as project resources are fully committed. None of the existing case studies focus specifically on multi-species issues.

The group **agreed** that it is important to promote exchanges of staff at RAPs, ZAPs, and work postings, although implementing such exchanges is outside the mandate of this project. It was **recommended** that regional and zonal RAP coordinators take advantage of all reasonable opportunities to invite project members from other Regions to participate as invited experts at RAPs and ZAPs. The building of project links to other disciplines was also considered valuable as these other disciplines often have valuable alternate tools project members could draw upon for their work. One example cited from sociology was the gathering and analysis of “Traditional Ecological Knowledge”.

It was **agreed** that the overall importance of communicating the activities taking place within this project should be emphasized. There was encouragement for all researchers on various species, whether they are a part of the project or not, to ensure that the precautionary framework itself receives increased consideration in communications products from assessments and research initiatives.

It was **agreed** that a stack of overheads (termed a “deck”) should be prepared, outlining the activities associated with this project and clearly indicating where guidelines and policy decisions are required. This deck should be used as a tool to communicate both within Science and between Science and other Departmental Branches in order to stimulate discussion. This was seen as a necessary first step in the development of any overall Departmental policy on the precautionary approach.

It was felt that presently, management does not have a consistent perspective on the precautionary approach. It was **agreed** that to proceed in a piecemeal fashion in different regions is not satisfactory. The need for consistent application across regions was highlighted.

It was **agreed** that the project leader must be a strong champion and advocate of the precautionary approach. There was some concern that the current project leader may not have the time to communicate the content of the project nor promote the precautionary approach generally. If so, there would be a need to identify someone who is able to take on the responsibility. The lead should come from Ottawa so that the message is heard throughout the Department.

Three levels of communication were summarized:

1. Regionally within Science: This could occur through the RAP process with information disseminated during actual RAP meetings, or with other means of communication determined by the various RAP coordinators. It was considered useful that the Table 4 worksheet serve as one vehicle for this. The worksheet indicates the type of work being done as part of the project. In addition, requesting those involved with various other species to complete the worksheet from the perspective of their own species would help them to better understand and focus on the concept of a precautionary framework. In addition, such a compilation of information on the various species managed by the Department would provide valuable information overall.
2. With Resource Managers: There is an apparent lack of discussion on the precautionary issue by managers, although the situation differs by Region. Ideally, initial discussions should be at the national or zonal level followed by regional discussions. The deck will serve to identify the current lack of policy guidance and should be used to provoke policy decisions, allowing progress. Where possible, the IFMPs appear to be the first place to incorporate a precautionary perspective. It would then follow that CHPs would necessarily be developed within a precautionary framework as well. Managers are on the front line regarding interactions with industry. The latter has expressed grave concerns regarding the precautionary approach, so the role of managers is crucial to successful implementation of a precautionary approach.
3. Industry, FRCC and PFRCC: It is ultimately most important that our various clients accept the concept of a precautionary approach. Therefore, open dialogue with them is vital. The FRCC is currently working on its own perspectives regarding possible precautionary frameworks, and this will bring the issue directly to industry. At present, however, the mandate of the FRCC is restricted to groundfish in the Atlantic zone. None of the case studies, as presently planned, preclude discussions with clients.

   It was **agreed** that parts of the web page should remain password protected while other parts should be open. The details of this will be worked out over the next few months. There should also be links made to CSAS and any other sites considered relevant (e.g., NAFO).

There was some discussion of upcoming activities in other groups. NAFO is planning further work on the precautionary approach during April and May, 1999. The Scientific Council will meet for five days during which there will be hands-on software use and examination of specific case studies. Following this, a three-day meeting of the Scientific Council and the Fisheries Commission will discuss further actions on developing and implementing precautionary frameworks.

In ICES, ACFM developed a list of precautionary reference points for all stocks assessed by ICES, that has been distributed to the various assessment working groups for consideration. The working groups have been asked to review and either approve or suggest more appropriate alternatives. ACFM will review these recommendations next spring and decide if further work is required. ICES has also planned a meeting with external agencies for the spring of 1999 where the ICES interpretation of the precautionary approach will be discussed. Attendance will be through invitation only, although it is currently unclear who will be invited to participate. There are currently no plans for discussions between NAFO and ICES on the PA issue; however, there is considerable cross participation in the various meetings.

The meeting **concluded** that at this time it would be premature to give any explicit interim guidelines to Departmental assessment staff, for analysis methods or approaches to use in preparing assessments and advice. Although the meeting **agreed** that assessments should deal as completely as possible with analytical matters such as quantifying uncertainty, estimating biological reference points, and risk evaluation, it stressed that investigations within this project are in still in progress. The meeting **agreed** explicitly it would not recommend the use nor the avoidance of any of the individual reference points or analytical methods considered during the workshop. Rather, all approaches still remain on the table at this time. Likewise, different approaches in terms of numbers of parameters to estimate within assessment models would continue to be explored.

The final discussion addressed specific direction for the Precautionary Approach Project over the remainder of this phase of the project. After substantial discussion, it was agreed that, aside from the Newfoundland herring case study, all case studies should be continued. It was also **agreed** that Table 5 and Table 6 give the specific guidance necessary from this meeting to lead researchers on each case study. It was noted that the Newfoundland herring case study was being dropped because no DFO Science staff member had the time to take lead responsibility, and not because the case lacked sufficient merit. It was also noted that Newfoundland region should be strongly encouraged to assign an appropriate leader to the case study on Newfoundland capelin.

With regard to the wrap-up activity for this project, some members advocated a major scientific meeting on the Precautionary Approach, with wide participation by the international scientific community. Presentations would showcase results of the project, including but not restricted to, the achievements on each case study. Papers would also be accepted from other participants, and the results would be published together in a Symposium volume. Other members advocated a Workshop type setting, with attendance centered more strongly on DFO staff in Science, Oceans, and Fisheries Management, members of Advisory Councils, and other clients. The workshop would focus on illustrating progress made by the project on implementing the precautionary approach in a DFO context, and on the transfer of tools and approaches from project members to the wider DFO and client communities. A wide discussion addressed many strengths and shortcomings of the two alternative types of final meetings, and various combinations of them. It was finally **agreed** that the wrap-up meeting of the project would be the Workshop format, with a focus on promoting actual application of the results of the project to assessments and advice in DFO. This approach was thought to be more consistent with the objectives of the Strategic Funding Initiative of the Branch and Department. The Workshop would still involve presentation of the advances from each case study, as well as general conclusions and tools that were developed. It was **agreed** that a Workshop schedule which allowed project participants to meet for a couple of days for intensive, technical exchanges in advance of the larger meeting would be preferred, and that some involvement by non-DFO technical experts would still be desirable. Moreover, it was **agreed** that meeting participants should explore the possibility of having scientific publications prepared from as many case studies as possible, for joint submission to an appropriate primary publication outlet. Although there would be many benefits of such a strategy for publishing results of the project, the feasibility of that strategy will hinge of the degree to which all case studies reach stage suitable for primary publication at approximately the same time. This will be monitored over the remainder of the project.

The meeting adjourned at 16:45, with thanks being extended to the local organizers and the session chair.

Appendix I. Agenda

Monday, Oct 5, 1998

Tuesday, Oct 6, 1998

Wednesday, Oct 7, 1998

Thursday, Oct 8, 1998

Friday, Oct 9, 1998

Appendix II. List of participants

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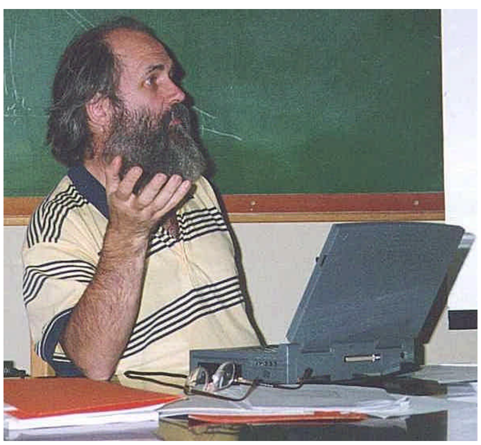
Appendix III. Glossary of Acronyms and Technical Terms

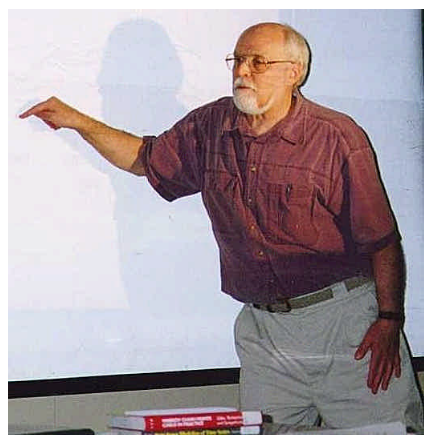
ACFM	Advisory Committee of Fisheries Management
ADAPT	Name of software used for VPA tuned to abundance indices
ADMB	AD Model Builder
B	Stock Biomass
B_{BUF}	Stock Biomass, Buffer: to ensure B_{LIM} is not reached
B_{LIM}	Stock Biomass, Limit: stock should not fall below this level
B_{LOSS}	Lowest observed spawning stock biomass
B_{MSY}	Stock Biomass, Maximum Sustainable Yield
B_{PA}	Stock Biomass, ICES Precautionary Points
B_{TAR}	Stock Biomass, Target: recovery level for stock
CAFSAC	Canadian Atlantic Fisheries Scientific Advisory Committee
CFD	Cumulative Frequency Distribution
CHP	Conservation Harvesting Plan
ComFiE	ICES Comprehensive Fishery Evaluation Working Group
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CPUE	Catch per Unit Effort
CSAS	Canadian Stock Assessment Secretariat
CV	Coefficient of Variation
CW	Carapace Width
CWS	Canadian Wildlife Service
DFO	Department of Fisheries and Oceans
EB	Exploitable Biomass
ENSO	El Niño-Southern Oscillation
EOF	Empirical Orthogonal Function
EPR	Egg per Recruit
ESS	Eastern Scotian Shelf
EU	European Union
Exp Rate	Exploitation Rate
F	Fishing Mortality
$F_{0.1}$	Fishing Mortality, Precautionary level associated with yield per recruit curve
F_{BUF}	Fishing Mortality, Buffer: mortality that ensures F_{LIM} is not reached
F_{CRASH}	Fishing Mortality, Crash: level that causes stock to collapse
F_{LIM}	Fishing Mortality, Limit: mortality that should not be exceeded
F_{MAX}	Fishing Mortality, Max: level that produces maximum yield per recruit
F_{MSY}	Fishing Mortality, Maximum Sustainable Yield
F_{PA}	Fishing Mortality, ICES Precautionary Points
F_{TAR}	Fishing Mortality, Target: $<= F_{BUF}$
FAO	Food and Agriculture Organization
FJMC	Fisheries Joint Management Committee
FRCC	Fisheries Resource Conservation Council for Canada's east coast
FY	Fiscal Year
GEAC	Groundfish Economic Alliance Council
HCR	Harvest Control Rules
HPPPA	High Priority Project on the Precautionary Approach
ICES	International Council for the Exploration of the Sea
IFMP	Integrated Fisheries Management Plan
ITQ	Individual Transferable Quota
LRP	Limit Reference Points
MBAL	Minimum Biologically Acceptable Level for a stock (ICES)
MCMC	Markoff Chain Monte Carlo
MPA	Marine Protected Area
MSVPA	MS Virtual Population Analysis
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
NHQ	National Headquarters
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council
PA	Precautionary Approach
PDF	Probability Density Function
PFRCC	Pacific Fisheries Resource Conservation Council
QLSPA	Quasi-Likelihood Sequential Population Analysis
RAP	Resource Assessment Process
RV	Research Vessel
SPA	Sequential Population Analysis
SPM	Surplus Production Model
S-R	Stock-Recruitment
SPR	Spawner per Recruit
SS	Stock synthesis software used for catch-age analysis
SSB	Spawning Stock Biomass
SSSC	Statistics, Sampling and Surveys Committee
TAC	Total Allowable Catch
TAH	Total Allowable Harvest
UNFA	United Nations Fisheries Agreement
US	United States
VPA	Virtual Population Analysis
ZAP	Zonal Assessment Process

Appendix IV. Images from the Workshop

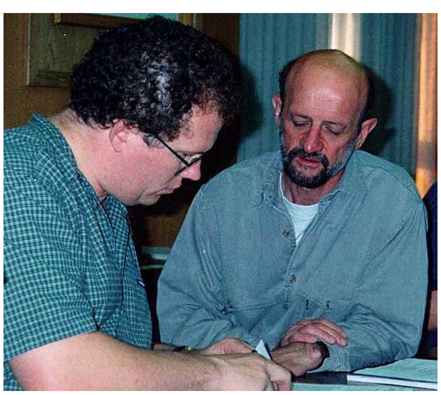
Workshop Participants



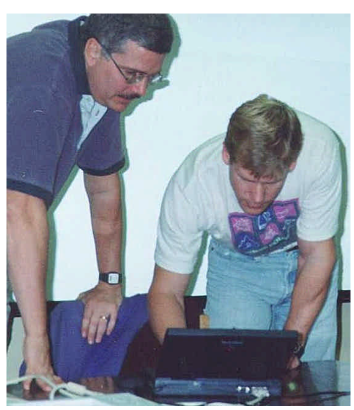
Jake Rice



Jon Schnute



Alain Fréchet, Jean-Claude Brethes

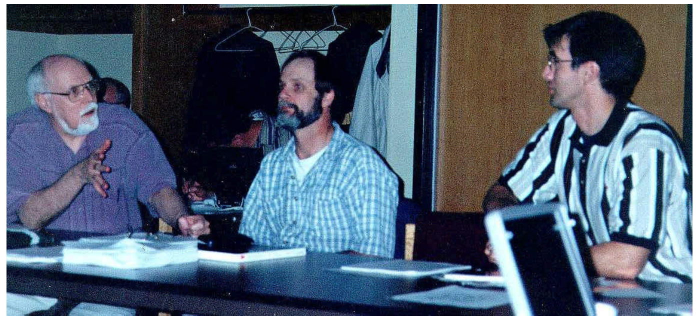


Pierre Richard, Norm Olsen

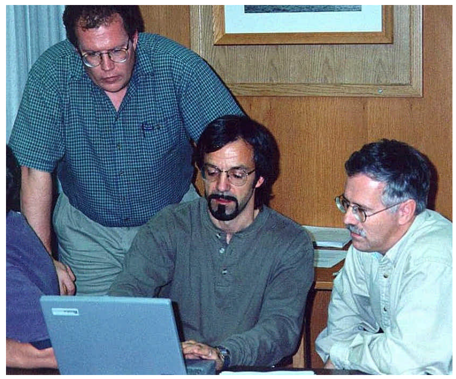
Elmer Wade, Alan Sinclair, Mike Chadwick

Appendix IV cont'd

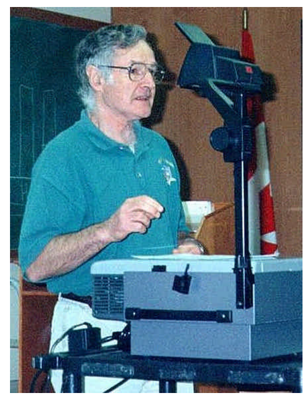
Al Cass



Jon Schnute, Peter Shelton, Elmer Wade



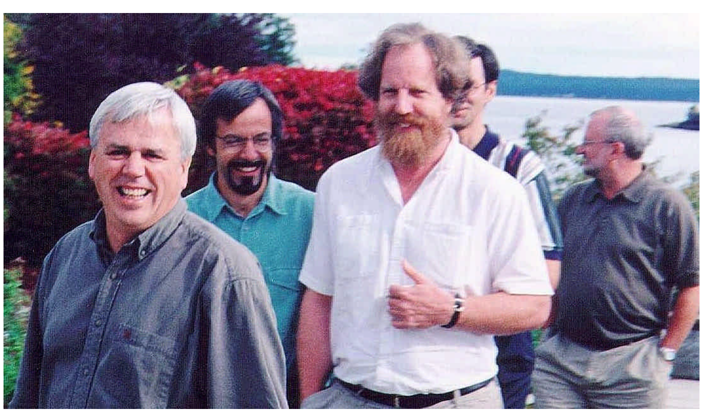
Alain Fréchet, Stratis Gavaris, Denis Rivard



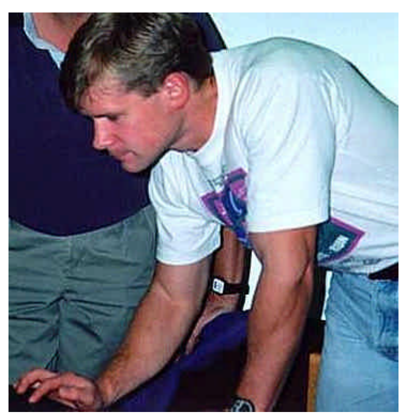
Scoresby Shepherd

Bob O'Boyle

Scoresby Shepherd, Wendy Gabriel



Alan Sinclair, Stratis Gavaris, Robert Mohn, Bruce Atkinson



Norm Olsen