Proceedings of 4X5 Pollock Management Strategy Evaluation Workshop – 2010

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PROCEEDINGS OF 4X5 POLLOCK MANAGEMENT STRATEGY EVALUATION WORKSHOP – 2010

Co-Chaired by

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ABSTRACT

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The 4X5 Pollock Management Strategy Evaluation (MSE) Workshop was held 9-10 December 2010, at the St. Andrews Biological Station, St. Andrews, New Brunswick. Participants included DFO staff (Science, and Fisheries and Aquaculture Management branches), Industry, and external experts. The objectives of the workshop were to gain a better understanding of the MSE process and to progress towards development of a structure on which recommendations will be based for risk management of 4X5 pollock. A set of 12 Operating Models was agreed upon. Industry and Fisheries Management participants agreed to several management objectives to be evaluated in the MSE. A 5-month workplan was established to advance the process in completing the 4X5 pollock MSE and to identify where to focus future research efforts to provide the greatest improvements to management advice.

RÉSUMÉ

Porter, J.M., and Docherty, V., Chairpersons. 2011. Proceedings of 4X5 Pollock Management Strategy Evaluation Workshop – 2010. Can. Manuscr. Rep. Fish. Aquat. Sci. 2945: iv + 158 p.

L’atelier sur le processus d’évaluation de la stratégie de gestion (ESG) de la goberge de 4X5 a eu lieu les 9 et 10 décembre 2010 à la Station biologique de St. Andrews, à St. Andrews, au Nouveau Brunswick. Les participants comprenaient des employés du MPO (Sciences et Gestion des pêches et de l’aquaculture), des représentants de l’industrie ainsi que des spécialistes de l’extérieur. Cet atelier avait pour objectifs de favoriser une meilleure compréhension du processus d’ESG et de poursuivre l’élaboration d’une structure sur laquelle on se basera pour formuler des recommandations aux fins de la gestion des risques liés à la goberge de 4X5. Les participants à l’atelier se sont entendus sur douze modèles opératoires. Les représentants de l’industrie halieutique ainsi que les représentants de la Gestion des pêches ont également approuvé plusieurs objectifs de gestion pour faire l’objet du processus d’ESG. Le groupe a établi un plan de travail de cinq mois afin de faire avancer le processus d’ESG de la goberge de 4X5, et aussi afin d’établir l’orientation des futurs efforts en recherche pour améliorer autant que possible les avis de gestion.

Proceedings of 4X5 Pollock Management Strategy Evaluation Workshop – 2010

1.0 INTRODUCTION

There has been consideration by Fisheries and Aquaculture Management (FAM) and Industry to manage pollock in the Canadian portion of 4X5 using more of a risk management approach. In July 2010, FAM discussed a Management Strategy Evaluation (MSE) approach with Science and Industry, with management objectives and harvest control rules specified up front.

This workshop on 9-10 December 2010, was held to explore the existing assessment model (virtual population analysis - VPA), to understand the sources of uncertainty by running sensitivity analyses for a plausible range of variables for the key areas of uncertainty, and to evaluate their impact on both utilisation and sustainability objectives. The exercise was about exploring MSE and not developing new assessment models. The strength of this process (quite apart from the results) is that it demands integration at a much earlier stage between the Science and Management functions, and has an explicit role for Industry participation.

The meeting was co-chaired by Dr. Julie M. Porter (Science) and Ms. Verna Docherty (FAM, in the absence of Mr. Stefan Leslie who sent his regrets).

The objectives (below) of this December meeting were to gain a better understanding of the MSE process and to progress towards development of a structure on which recommendations will be based for risk management of 4X5 pollock.

- Review data inputs from research vessel (RV) surveys and the commercial fishery for Western Component pollock (4Xopqrs5), including changes in geographic distribution, size and age composition, and trends in relative abundance.
- Update the current assessment for the Western Component using the latest information from fisheries and research surveys, and the best model formulation and assumptions.
- Examine sources of uncertainty in the current pollock assessment including:
  - variability in survey indices/relative abundance;
  - changes in selectivity of older ages; and
  - changes in natural mortality.
- Illustrate MSE application to 4X5 pollock with the existing VPA model as the baseline Operating Model.
- Make recommendations on how to proceed in updating the approach for developing Science input to inform management decisions, and on how to proceed towards developing a risk-management approach.

The Terms of Reference, meeting Agenda, and List of Participants can be found in Appendices 1-3, respectively. This report is meant to serve as a consensus summary of the workshop's principle discussions and conclusions and is not intended to be a chronological transcript.

2.0 SUMMARY OF PRESENTATIONS

2.1 2010 POLLOCK ASSESSMENT UPDATE FOR THE WESTERN COMPONENT (4Xopqrs5) INCLUDING EXAMINATION OF SOURCES OF UNCERTAINTY

Heath Stone presented a Working Paper (Appendix 4a) on the current assessment model used (VPA) including 2010 updates and sensitivity runs to explore major uncertainties.

As a first step in examining a Management Strategy Evaluation process for Western Component (4Xopqrs+5Yb+5Zc) pollock, the data inputs for the assessment of this stock were reviewed and the analytical assessment was updated using the latest information from fisheries and research vessel (RV) surveys to determine current resource status. In addition, sensitivity analyses were conducted to examine sources of uncertainty in the assessment, including variability in survey indices, changes in selectivity of older ages, and changes in the values of natural mortality (with age and/or over time).

The DFO summer survey has shown a general decline in the geographic distribution of pollock catches, which have declined in NAFO Divisions 4V and eastern 4W and now occur mainly in 4Xpq and 4Xmn/western 4W. The proportion of pollock > 70 cm fork length (FL) (age 7+) in the fishery and survey catch at size (CAS) declined sharply in the early 1990s and remained low to the mid-2000s. During this time, exploitation levels were high (average = 66% for 1991-2005). Since 2005, the proportion of fish > 70 cm FL has shown modest improvement, but it is still much lower than the pre-1990s, despite reductions in fishing effort.

Assessment results were based on VPA model formulations which incorporated indices of abundance from both the summer RV survey (1984-2010) and standardised catch per unit effort (CPUE) from the commercial fishery, excluding the most recent six years (1982-2004; DFO 2006). To bracket the uncertainty associated with the 2010 RV age-specific indices of abundance (which appear to be unusually low), two base model approaches were used, one which included the 2010 RV index and one which did not. Including the 2010 RV indices in the VPA model analyses resulted in lower estimates of recruitment (back to 2001), age 4+ (considered spawning stock) biomass (9,000 t *vs.* 23,000 t in 2010), and higher estimates of age 6-9 fishing mortality rate (F) (0.78 *vs.* 0.29 in 2010). Heath Stone suggested that the MSE framework will need to include results from both model runs in the Reference Set of candidate VPA models for defining the current population state.

When the VPA model was allowed to estimate natural mortality rate (M) on older ages (7+) from the mid-1990s onward, M increased to a fairly high level (0.62-0.68). This increase could be related to the movement of pollock outside of the management area (*i.e.,* to U.S.A. waters), increased predation, or changes in environmental conditions, which lead to reduced survival. A VPA model formulation with domed-shaped selectivity generated more biomass and lower estimates of fishing mortality rate (F) compared to a model with the standard (flat-topped) selectivity pattern. There is concern that the domed partial recruitment (PR) model generates cryptic biomass since fish aged 8 and older have not been captured in large amounts in either the summer RV survey or the Canadian fishery since the early 1990s. The MSE Operating Models will need to capture the uncertainty associated with higher levels of M and changes in selectivity on older ages.

Discussion following the presentation highlighted the following points:

- There has been a slight improvement in catch proportions at age, which had declined in the older ages since the early 1990s, but there is a small improvement since 2006.
- The proportion of age 3 fish in the catch in the 2009 fishing season increased, mostly from the redfish fishery. Industry noted that market conditions have changed to favour these fish.
- There is no CPUE index for the gillnet fishery; given that the gear is so selective, only a few ages are caught, and this does not provide much contrast to other gears. Mobile gear CPUE is more useful because of the spread of ages in the catch. It also was noted that there is not a good measure of effort for gillnets (*e.g.,*number of panels).
- There is an absence of samples of pollock caught in the Bay of Fundy from both port sampling and at-sea observers. Although sampling was somewhat improved in 2010, there are only two port samplers, and often trips in the Bay of Fundy or in the east are not sampled.
- There was a discussion on whether the year effects based on the semi-pelagic schooling behaviour of the fish also could be linked to abundance (*i.e.,* the probability of having a positive year effect increased with increasing abundance). This could be complicated by environmental factors as well (*e.g.,* temperature).
- The value of including *versus* excluding the 2010 RV survey result was discussed, as well as the process for making that decision. Heath Stone noted that it has been accepted in other assessments to initially exclude a very high survey catch, allow a few years to pass, and then include such a result only when it has less effect on the model results. It further was noted that the 2010 result does not match the trend over the past few years of the survey results, which have shown a steady increase.
- Industry commented on the disappearance of the larger vessels, which were active in the 1990s; these vessels towed at a faster speed and had the ability to catch faster and, therefore, larger pollock. Although the larger vessels are no longer in operation, for the earlier part of the time series, the catch at age (CAA) calculations were/are calculated separately for Small Mobile (TC 1-3) and Large Mobile (TC 4+) gear sectors, provided that either port or observer samples were available. This also was assessed during the 2004 Framework (Stephenson 2004), and it was determined that there was no change in the age of fish caught because of changes to the fishery, including vessels, but that all ages were caught by all sized vessels; the CAA age composition from both sources is similar.
- The recent CPUE information (since 2004) has not been used since a decision to exclude it was made at the 2006 assessment meeting (DFO 2006). With quota

reductions, it was concluded that the CPUE indices would no longer be comparable with earlier values.

- On the topic of survey variability, it was noted that it is possible that changes in fish behaviour from one year to the next could influence catchability. This change in behaviour could be affected by environmental conditions; the current practice is to capture only temperature information but perhaps more collected variables are required.
- The retrospective patterns for age 2 recruits, age 4+ biomass and age 6-9 fishing mortality rate (F) were examined for both VPA model formulations (*i.e.*, with and without the 2010 RV indices). Including the 2010 RV indices in the VPA resulted in a stronger tendency to underestimate F, overestimate 4+ biomass and age 2 recruits compared to the model formulation which excluded the 2010 RV indices. This occurs because the 2010 index values are so low that they have a negative impact extending back for several years. Although the model which excludes the 2010 index still has a tendency to underestimate F and overestimate biomass and recruitment, the results are more comparable to those observed during the 2008 assessment.
- The representativeness of the research surveys as an index of relative abundance was discussed. It was noted that although the survey is noisy, it follows the VPA. A research recommendation for the future was to improve or develop new indices of relative abundance for this assessment.

The group accepted the current updated pollock assessment based on the 2004 Framework methodology (Stephenson 2004) and noted that this exercise was not about reviewing the VPA in detail or making improvements, but rather the goal was to identify major sources of uncertainty. The group agreed to use the current data. The reference case for the proposed set of Operating Models (see Section 3.0) included the 2010 survey point, but, as recommended by Heath Stone in his presentation, the MSE framework includes results from both model runs (with and without the 2010 survey result).

2.2 PROPOSED VPA REFERENCE SET OF OPERATING MODELS FOR CANADIAN POLLOCK IN THE WESTERN COMPONENT (4Xopqrs5) TO BE USED IN MANAGEMENT PROCEDURE TESTING (OR MSE)

Doug Butterworth provided an overview of the working paper in Appendix 4b. He emphasised that the models presented were meant to be illustrative.

A key feature that distinguishes the Management Strategy Evaluation (MSE; also termed the Management Procedure Approach) from conventional “best assessments” is the importance of selecting not the (“best”) one assessment, but rather of ensuring that future resource trends will be satisfactory no matter which of a number of plausible assessments most closely reflects the actual (but unknown) underlying situation of the resource.

Frequent convention is to select a small number of such "Operating Models" (OMs), spanning the most important aspects of uncertainty in the assessment, for use as a Reference Set (RS), which provides the initial basis to develop and to tune a Management Procedure.

This paper developed an illustrative set of four VPA-based OMs and suggested that these provide a RS to serve as a basis for subsequent testing of Candidate Management Procedures (see Appendix 4c&d). Two Statistical Catch-at-Age (SCAA) models were also developed to provide robustness tests for Management Procedures developed using the VPA-based RS.

This exercise demonstrated that Rademeyer and Butterworth were able to reproduce the Stone VPA (Appendix 4a), and that the SCAA produced similar results to the VPA though it was not intended to be used in the RS.

2.3 MSE APPLICATION TO 4X5 POLLOCK, WITH THE PROPOSED VPA REFERENCE SET OF OPERATING MODELS

Doug Butterworth provided an overview of the working paper in Appendix 4c. Again, he emphasised that the information presented is meant to be illustrative not definitive. The PowerPoint presentation (Appendix 4d) is presented in addition to the paper as it provides a more detailed explanation.

Four alternative VPA-based assessments of the Western Component of the Canadian pollock resource were used to provide a Reference Set of Operating Models for an illustrative application of Management Strategy Evaluation (MSE) approach to the associated fishery. Results for future total allowable catches (TACs) and resource trends were shown for a variety of Candidate Management Procedures (feedback catch control rules), which are all based on the direct use of an annual survey-based index of abundance. These results were compared to anticipated outcomes under a constant TAC approach. Suggestions were made regarding aspects that need discussion and further refinement if this approach is to be taken further.

It was explained that Management Strategy Evaluation (MSE) is simply an evaluation of a Management Procedure, which is a formula that informs what the TAC or other management response should be. Through the MSE approach, the inputs are agreed-upon in the early stages and then the formula (Management Procedure) is tested. After acceptance and implementation, the Management Procedure can subsequently be revised and refined over time.

Following the presentation by Doug Butterworth on a proposed set of Operating Models, the discussion from the group focussed on the following points:

- In the generation of future RV survey results, variance (cv = 60%) in the index was assumed with no bias. If it is reasonable to expect changes in catchability, then some of the Operating Models should simulate these changes. However, given that there is so much variability, it likely would be difficult to detect changes in catchability.

- It was noted that, despite all of the uncertainties, it was surprising that all of the projections in this paper were positive. Doug Butterworth noted that the majority of projections used for illustration used a possibly optimistic stock recruitment relationship. Although there will be some poor recruitment events, they will not necessarily all be poor. Using only the past five years of information for generating future recruitment, results in projections with the lower probability interval bound for biomass relative to the 2011 biomass to be below 1 (*i.e.,* biomass will decline from 2011). In projections where the next eight years have the lowest recruitment observed in the past, projections show a low probability of biomass increase. However, there needs to be consideration of whether this is a plausible hypothesis before too much weight might be placed on such results.
- It was noted that nearly all the earlier observations of recruitment (prior to 2000) were above the line that was fit through the data in the stock recruitment model used. It was suggested that with higher spawning stock biomass (SSB), the stock would experience better recruitment not captured by the curve. Doug Butterworth explained that only the last ten years were used as a conservative approach more closely aligned to recent resource behaviour, so the curve is not meant to be representative of all the data. The previous data provides an indication that, once the population attains a certain SSB level, recruitment would improve.
- Participants noted the time series for recruitment only goes as far back as 1984, and there is no idea of recruitment from an unexploited biomass. Other stock recruitment relationships can be considered in the Operating Models that allow higher recruitment, but Doug Butterworth believed that it is most important to reflect what happens at low levels, especially when SSB is low.
- Liz Brooks suggested weighting survey points with high variability. Doug Butterworth suggested that one could incorporate a rule that particularly large values in the survey would be capped at a maximum value; however, it is important to understand what causes the index variability.
- Doug Butterworth outlined a stock (South African hake) with which he was involved in implementing a MSE approach and provisions that were created to address “exceptional circumstances.” He described these provisions as something that only would be invoked to override the TAC recommendation provided by a Management Procedure if there was compelling evidence that the procedure was not working as intended or if observations fall outside the range that was tested.

3.0 RECOMMENDATIONS ON HOW TO PROCEED IN UPDATING THE APPROACH FOR DEVELOPING SCIENCE INPUT TO INFORM MANAGEMENT DECISIONS, AND ON HOW TO PROCEED TOWARDS DEVELOPING A RISK MANAGEMENT APPROACH

It was agreed that it would be productive to proceed with a MSE approach using existing data. A traditional Framework Assessment, as conducted in 2004 (Stephenson 2004), likely would yield no better assessment as little has changed in the sources or quality of data. The MSE approach can take a range of models (assessments) that encompass the uncertainty – there is no need to establish a *best* model. The MSE approach also can focus future research efforts on areas that will provide the greatest improvement to management advice (*e.g.,* determining the fate of the older pollock).

Doug Butterworth outlined that different Operating Models (OMs) correspond to different assumptions and different assessments. Four models were presented for illustration in Section 2.3. But other models (or assessment runs) can be added to that set. When a set of OMs are established, a subset of those can be selected for a Reference Set (RS). Rather than testing on just one model or fifty, the goal is to take a few illustrative models, which are considered to be among the more plausible and span the major uncertainties, and to run the Management Procedure simulation tests on those. In MSE, projections into the future are required, and therefore, assumptions must be made about what will happen in the future as well as the data to be used (CAA data, CPUE, *etc.*).

For high plausibility OMs, it is important to satisfy even low risks; while for medium plausibility, higher risk can be tolerated. The RS should include the most believable OMs. The major testing (simulations) will be conducted on the RS. Then the number of rules can be reduced (to approximately 4). Those rules then can be validated on all high and medium plausibility OMs (not just the RS).

Doug Butterworth summarised the next steps required to implement a MSE approach (Slide 43 in Appendix 4d), and subsequent discussion was focussed by this slide:

1. Refine medium-term management objectives:
   - What would ideal catch levels be?
   - What risk of unintended stock depletion is acceptable?
   - What restrictions might be placed on annual TAC changes and a maximum TAC?
2. What are the most appropriate assumptions for projections (*i.e.,* stock recruitment (S/R) relationships)?
3. What further alternative Operating Models (robustness tests) need be considered to span uncertainties?
4. How might the Management Procedures shown be improved? Further potential data inputs (beyond surveys) available perhaps?

3.1 MAJOR SOURCES OF UNCERTAINTY AND SELECTION OF OPERATING MODELS

Through the presentations and subsequent discussions, the major sources of uncertainty in the pollock assessment model were identified. Discussion determined how these would be considered in the Operating Models (Table 1), and whether they were high, medium, or low plausibility. Those sources of uncertainty discussed included:

- Variability of surveys and the relationship between survey abundance and population abundance;
- Changes in natural mortality;
- Utility of the catch per unit effort series;
- Partial recruitment (PR) on older ages; and
- Stock recruitment relationship.

Table 1. Set of Operating Models (OMs) and Reference Set (RS) agreed to for the MSE application to 4X5 pollock.

Uncertainty	Proposed Operating Model (OM)	In Reference Set (RS)?
Reference Case	1. RAD 1 (no bias correction, with 2010), M = 0.2, S/R last 10 reliable years, survey proportional	√
2010	2. Stone with 2010 proportional, bias correction, M = 0.2	√
	3. Stone without 2010 proportional, bias correction, M = 0.2	√
Survey Abundance	4. square root	
	5. power (square?)	
	6. mixture distribution for future (inferred from RAD1 fit to past data)	
M Strategies	7. 0.2 age 6 or less, age 7-13 high M (Stone estimates of higher M) – no change in future	
	8. 0.2 age 4 or less, age 5-13 high M (Stone estimates of higher M) - no change (= stays high) in future	√
	9. 0.2 age 6 or less, age 7-13 high M – all back to 0.2 after 5 years	
	10. 0.2 age 4 or less, age 5-13 high – all back to 0.2 after 5 years	
CPUE	11. CPUE future (based on Stone (Appendix 4a) 2005-2010),	
Partial Recruitment (on older ages)	12. Dome–shaped survey PR on older (9+? – maybe to no less than 0.5 of maximum)	
Stock Recruitment Relationship	13. Last 5 reliable years	√
	14. Field hockey stick – B-H fit up to a maximum value corresponding to average of values for spawning stock biomass above 20,000 t	√

The reference case (Table 1, OM-1) was established as RAD 1 (from Appendix 4b) (no bias correction, including 2010 survey result, M = 0.2, S/R last 10 reliable years, survey proportional to abundance). It was noted that the "reference case" should not be considered as the "base case," which is generally the outcome reported in most stock assessments. Where the base case would be the best possible assessment, the reference case is only intended as a convenient set of specifications, which are varied to run the sensitivity analyses. Given the RAD 1 formulation, it is convenient first to change only one specification at a time to examine sensitivity.

Survey abundance

An area of uncertainty that participants felt should be explored in this approach was the variability in the RV survey. Pollock is a semi-pelagic schooling species and is not well sampled by the gear. Alain d'Entremont proposed that there may be density-dependent aggregation, and distribution in the water column could be affected by abundance (*i.e.,* when pollock are less abundant, they will appear higher in the water column). He further noted that large fish occur higher in the water column when water temperature is low.

It was agreed that the two VPAs, that both include and exclude the 2010 RV survey results (presented by Heath Stone in Appendix 4a), should be included as Operating Models as a robustness test, since these would bracket the abundance range (OM-2, 3).

The following suite of assumptions was put forward to address this uncertainty in the Operating Models:

- Survey result is proportional to the population abundance (as is the case in OM-1 (RAD 1), 2, 3);
- Survey result is proportional to the square root of the abundance (OM-4);
- Survey result is proportional to a power function of the abundance (could be squared) (OM-5); and
- Some mixture distribution where catchability is high only part of the time (*i.e.,* a low catchability usually applies, but occasionally jumps to a period of high catchability) (OM-6).

Natural mortality (M) possibilities

Stocks in the same geographic area as this pollock stock have experienced changes in natural mortality since the mid-1990s. Pollock may be experiencing a similar effect and this could explain the absence of the older fish in the survey and the commercial catch.

Heath Stone ran the current VPA model with differing assumptions of natural mortality (M):

- M = 0.2 on all ages for the duration of the time series;
- M = 0.2 for ages 2-6 for the years 1982-2010 and ages 7-13 for 1982-1995; allow the model to estimate M for ages 7-13 from 1996-2010; and

- M = 0.2 for ages 2-4 for 1982-2010 and ages 5-13 for 1982-1995; allow the model to estimate M for ages 5-6 and 7-13 as two M-blocks for the period from 1996-2010.

It was noted that the time series (1982-2010) is very short and that there was substantial exploitation on this stock before the 1980s. Heath Stone noted that poor sampling prior to 1982 is one reason for the truncated time series, as well as the difficulty in distinguishing between the Canadian and U.S.A. landings information prior to the implementation of the Hague Line. Notwithstanding this limitation, it was proposed that a review of Canadian landings from the Western Component prior to 1982 may provide an indication of stock productivity particularly if landings were higher than the period used in the current stock assessment (*i.e.,* 1982-2010), and this review would be useful in providing some insight on an upper stock reference point. These early landings also could be included in a SCAA model to take account of total catches made before the more recent period for which reliable catch at age information is available.

Incorporating differing assumptions of natural mortality into the Operating Models examines several possible scenarios:

- Natural mortality remains high through the period of the projections for either ages 7-13 (OM-7) or ages 5-13 (OM-8), using the Stone (Appendix 4a) estimates of higher M. Given that biomass has not improved over the past decade, possibly as a result of high natural mortality, it may be overly optimistic to assume that natural mortality will revert to a lower level; and
- Natural mortality on the older M-blocks (as estimated by the VPA in Appendix 4a) would remain high for a period of five years and then revert to M = 0.2 (OM-9, 10). Five years was selected to allow for some time for this to occur, but also to have an effect on the 20 year projections.

Catch per unit effort (CPUE)

A decision was made at a 2006 pollock assessment meeting (DFO 2006) that the CPUE information since 2004 is no longer comparable to the earlier time series given that there were changes in the fishery which include reductions in TAC that limit Industry's ability to direct for pollock.

Participants felt that CPUE information may still be important although recent information may not be comparable to the CPUE index that ends in 2004. Suggestions were made to incorporate two new indices of CPUE: a 2005-2010 CPUE index for mobile gear, and a CPUE index for the gillnet fishery.

The information from 2005-2010 could be considered as a new mobile gear index, given that it is not considered to be comparable to the earlier time series. There was some discussion on how to address what trips should be included, including an option to use a few selected vessels as a reference. However, it was agreed that trips that caught 50% or more pollock would be used in the new 2005-2010 CPUE index. This new mobile gear CPUE index would be used for the projections in the future but not used to tune the VPA (OM-11).

Although a gillnet CPUE index could be useful, considering that there is a portion of the fixed gear fishery that targets pollock using gillnets, this index is not possible to construct because of the lack of effort data for gillnets. The current monitoring document does not allow for adequate information on a set basis to determine a CPUE for gillnets. It also was noted that gillnets are selective for very few sizes (ages).

Partial recruitment (PR) on older ages

There has been an absence of larger (older) fish observed in both the RV survey and the commercial catch. There are three possible assumptions that can be made for this absence of older fish:

- The older fish have been fished out (as is the assumption in OM-1 to 11);
- There is a dome-shaped selectivity curve with the older fish in a cryptic biomass unavailable to the fishery or survey (OM-12); or
- Natural mortality is high, and the fish die before reaching older ages (OM-7, 8).

Stock recruitment relationship

In exploring stock recruitment relationships, it had been noted previously that the majority of projections used for illustration employed a possibly optimistic stock recruitment relationship. Biomass declines relative to 2011 biomass using the past five years of information on recruitment projections. Earlier observations of recruitment (*i.e.,* prior to 2000) were above the line that was fit through the data in the model. It was suggested that with higher spawning stock biomass (SSB), the stock would experience better recruitment not captured by the curve.

Participants discussed assumptions that would bracket the range of plausible scenarios for stock recruitment relationships. Maintaining the two assumptions that were used in the models presented by Rademeyer (Appendix 4b) would use the last 10 years (OM-1) and the last 5 years of information (OM-13). A third assumption proposed using a Beverton-Holt fit that is constrained to the average over the previous observations; this would result in a flat-top relationship, but it would become flat at a much higher recruitment level, providing a more optimistic view of recruitment (OM-14).

Alain d’Entremont commented on the assumption using the last five years, noting that these are the most uncertain points. The final two points are not precisely estimated, and Alain suggested that the 2004-2008 period be used instead. The participants discussed the value of adjusting the time period, and, although having two imprecise points in five could be worrisome, the result of changing the time period only would be to remove a high and low point. Heath Stone and Rebecca Rademeyer will discuss the series of points to use for which there are reliable estimates.

3.2 SELECTION OF REFERENCE SET OF MODELS

After agreeing to the OMs in Table 1, the next step was to select a RS from within the existing set of OMs. The RS is used to run the initial tests on the likelihood of achieving the management objectives and a Candidate Management Procedure. Ideally a limited number of models for the RS is selected rather than running simulations on all 14 OMs.

Following discussion, six OMs were selected for inclusion in the RS (Table 1):

- OM-1 = RAD1 with no bias correction, M = 0.2, stock-recruit last 10 years, survey proportional;
- OM-2 = Stone with 2010 RV survey point, survey proportional, bias correction, M = 0.2;
- OM-3 = Stone without 2010 RV survey point, survey proportional, bias correction, M = 0.2;
- OM-8 = M strategies applied to RAD1 “reference case” using Stone estimates of M where M = 0.2 on ages 4 or less, ages 5-6, ages 7-13 high M as estimated in Appendix 4a, with no change to M in future (*i.e.,* M stays high);
- OM-13 = stock recruitment relationship applied to OM-1 using the last five reliable years of recruitment information; and
- OM-14 = stock recruitment relationship applied to OM-1 using a Beverton-Holt model constrained fit up to a maximum value corresponding to average values for SSB above 20,000 t.

Participants agreed that this RS covers the plausible range of current abundance and stock recruitment relationships, as well as addressing a continued concern over possible recent higher natural mortality. The projection period for the Reference Set will be 20 years. It was felt that this RS was more appropriate for 4X5 pollock than the illustrative example in Appendix 4c&d.

It was noted that the Management Procedure selected is not required to “pass” the RS or all OMs; instead the selection of the RS is meant to provide information for Fisheries Management to determine its risk tolerance in making management decisions.

There was a discussion held on the differences in providing projections based on either SSB or exploitable biomass. Although SSB is the conservation metric, there was concern about any model that projects cryptic biomass that is not available to the fishery. It also was agreed to use exploitable biomass for projections so as to remove the build-up of cryptic older biomass that results from all models with the exception of one with high M on older ages. If there are reasons to believe that the older fish are not there in the future (*i.e.,* continued absence in the RV survey or commercial catch), the Management Procedure may need to be overridden. A second option might be to explicitly include an adjustment for the lack of older fish inside the Management Procedure (*i.e.,* the TAC formula). Appendix 5 contains Performance Statistics to assess Candidate Management Procedures for the Canadian pollock in the Western Component (4Xopqrs+5Zc).

3.3 REFINING MEDIUM TERM MANAGEMENT OBJECTIVES

Following the steps in Slide 43 of Appendix 4d, Industry and Fisheries Management participants at the meeting suggested several management objectives to be evaluated in the MSE, as follows:

Ideal catch levels

- Catch of up to 10,000 t within a 3-5 year period and 15,000 t within 10 years;

Acceptable risk of unintended stock depletion

- Maintain a low (no more thant 10%) risk of dropping below the 2000 biomass levels (calculated for each run) (the use of the 2000 SSB was decided as a reference given that this is a more precisely estimated value than those for more recent years); and

Restrictions that might be placed on annual TAC changes and maximum TAC

- Maximum change of 20% for all TAC levels,
- Possible two-year TAC setting.

Although 20-year projections were used for the illustrative runs presented at this meeting (Appendix 4c&d), the focus in the MSE will be on the first 10 years. However, it is important to remain aware of the second decade. The initial MSE will be a first cut, and the management objectives are likely to be refined. It is also possible that all management objectives will not be achievable, and Industry and Fisheries Managers may need to re-assess the objectives.

3.4 WORKPLAN

A workplan for the upcoming months was established to advance the process in completing the 4X5 Pollock Management Strategy Evaluation.

Proceedings

- Julie Porter and Verna Docherty will collaborate on the proceedings over the following two to three week period with an aim of circulating them in early January. The proceedings will be published as part of the series of Canadian Manuscript Reports of Fisheries and Aquatic Sciences.
- It was agreed that the working papers and the PowerPoint presentation made by Doug Butterworth will accompany the proceedings document (see Appendix 4). DFO Science will coordinate the review of the full proceedings document including the working papers (following minor adjustments by the authors). The review of the Manuscript Report is editorial in nature.

MSE runs and initial review

- Heath Stone and Rebecca Rademeyer will make contact to resolve outstanding data issues.
- Doug Butterworth and Rebecca Rademeyer will complete the requested runs (see Table 1) for the Reference Set by mid-February and distribute them to this group.

- A conference call will be scheduled tentatively for late-February. This will allow an opportunity to review the results from the anticipated runs and allow for feedback and further refinement of the management objectives.

Next face-to-face meeting

- It was agreed that the next face-to-face meeting will be scheduled tentatively for 2 days during the period of 9-11 May 2011, to coincide with Doug Butterworth's presence in Woods Hole during the previous week.
- The venue possibly will be the St. Andrews Biological Station again, to be confirmed.
- Participation will be by invitation and based on the participants list (Appendix 3).
- Given other commitments early in 2011 and the required effort for the next stage of the Pollock MSE, DFO Science is not available to meet again until May. It was acknowledged that this would be a disappointment to Industry who would prefer to see the establishment of an MSE proceed at a much faster pace. Julie Porter noted that there was an excellent and enthusiastic group of individuals in attendance and she would like to see continuity of this group.
- It was agreed that the next meeting will occur under the auspices of the Regional Advisory Process (RAP); a process often used by DFO Science to provide advice to Fisheries Managers. No reviewers external to DFO are required.

Management of 4X5 pollock in 2011-12

- With respect to planning for the 2011-12 fishing season, Industry noted that they still would like to use information that may be available in February/March to assist in development of a TAC recommendation. Fisheries Management indicated that this was a discussion that would occur between Industry and Fisheries Management early in 2011.
- Individuals noted that this is a new process to many people and that this requires engagement from a large number of people: Science, Fisheries Management, and Industry. It was suggested that there should be a briefing on this issue at the January 2011 Scotia-Fundy Groundfish Advisory Committee meeting.

4.0 CONCLUDING REMARKS

The Co-Chairs thanked the participants for an extremely productive meeting. The authors/presenters were thanked for their excellent efforts and clarity of presentation. In particular the group benefited from the knowledge, skill, and expertise of Doug Butterworth and his clear and patient explanations. It was noted that Bruce Chapman inspired the exploration of a MSE for pollock and facilitated it with substantial funds from the Groundfish Enterprise Allocation Council (GEAC). GEAC's level of commitment was commended. The Co-Chairs expressed enthusiasm for the next steps, including the completion of the 4X5 Pollock Management Strategy Evaluation and identification of where to focus future research efforts to provide the greatest improvements to management advice.

5.0 REFERENCES

DFO. 2006. Proceedings of the Maritimes Regional Advisory Process on the Assessments of Scotia–Fundy Groundfish Stocks, 23 October 2006 and 16-17 November 2006. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2006/035: 16 p.

Stephenson, R.L., Chairperson. 2004. Proceedings of the Pollock Framework Assessment: 1 May 2003; 16-18 June 2003; and 6-8 April 2004. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2004/030: 44 p.

APPENDIX 1. TERMS OF REFERENCE

4X5 Pollock Management Strategy Evaluation

9-10 December 2010 (0830-1700)

Hachey Conference Centre
St. Andrews Biological Station
531 Brandy Cove Road
St. Andrews NB
http://www.mar.dfo-mpo.gc.ca/sabs/

TERMS OF REFERENCE

Context

There has been consideration by Fisheries and Aquaculture Management (FAM) and Industry to manage pollock in the Canadian portion of 4X5 using more of a risk management approach. In July 2010, FAM discussed a Management Strategy Evaluation (MSE) approach with Science and Industry, with management objectives and harvest control rules specified up front. The approach will start with a process to explore the existing assessment model (virtual population analysis - VPA), to understand the sources of uncertainty by running sensitivity analyses for a plausible range of variables for the key areas of uncertainty, and to evaluate their impact on both utilisation and sustainability objectives. The exercise is about exploring MSE and not developing new assessment models (that would have to take place in a Regional Advisory Process (RAP) framework); therefore, Science advice to the management process will not be produced for review at the December meeting. The strength of this process (quite apart from the results) is that it demands integration at a much earlier stage between the Science and Management functions and has an explicit role for Industry participation.

This workshop will focus on the MSE component, beginning with Science agenda items (survey update and review of updated VPA and associated sensitivity analyses).

Objectives

The objectives of the meeting are to gain a better understanding of the MSE process, and to progress towards development of a structure on which recommendations will be based for risk management of 4X5 pollock.

- Review data inputs from research vessel surveys and the commercial fishery for Western Component pollock (4Xopqrs5) including changes in geographic distribution, size and age composition, and trends in relative abundance.

- Update the current assessment for the Western Component using the latest information from fisheries and research surveys, and the best model formulation and assumptions.

- Examine sources of uncertainty in the current pollock assessment including:
    - variability in survey indices/relative abundance;
    - changes in selectivity of older ages; and
    - changes in natural mortality.

- Illustrate MSE application to 4X5 pollock, with the existing VPA model as the baseline Operating Model.

- Make recommendations on how to proceed in updating the approach for developing Science input to inform management decisions, and on how to proceed towards developing a risk management approach.

Outputs

Workshop report and working papers published as DFO Canadian Manuscript Reports of Fisheries and Aquatic Sciences
(http://www.dfo-mpo.gc.ca/libraries-bibliotheques/manu-eng.htm).

Participation

Stefan Leslie* (FAM) and Julie Porter (Science): Co-Chairs
DFO Science, Maritimes
DFO FAM, Maritimes
Industry Representatives/Experts
International MSE Experts

* Replaced by Verna Docherty

APPENDIX 2. AGENDA

4X5 Pollock Management Strategy Evaluation Workshop

9-10 December 2010

Hachey Conference Centre
St. Andrews Biological Station
531 Brandy Cove Road, St. Andrews NB

AGENDA

Thursday 9 December 2010

0830-0845	Welcome and Introductions (Co-Chairs: Julie Porter and Verna Docherty)
0845-1000	2010 Pollock Assessment Update for the Western Component (4Xopqrs5) including examination of sources of uncertainty. (Heath Stone)
1000-1015	Break
1015-1115	Proposed VPA Reference Set of Operating Models for Canadian Pollock in the Western Component (4Xopqrs5) to be used in Management Procedure Testing (or MSE). (Rebecca Rademeyer & Doug Butterworth)
1115-1200	MSE Application to 4X5 Pollock, with the Proposed VPA Reference Set of Operating Models. (Doug Butterworth)
1200-1300	Lunch (provided)
1300-1500	MSE Application to 4X5 Pollock, with the Proposed VPA Reference Set of Operating Models. (Doug Butterworth)
1500-1515	Break
1515-1700[1]	MSE Application to 4X5 Pollock, with the Proposed VPA Reference Set of Operating Models. (Doug Butterworth)

Friday 10 December 2010

0830-1000	Recommendations on how to proceed in updating the approach for developing Science input to inform management decisions, and on how to proceed towards developing a risk management approach.
1000-1015	Coffee Break
1015-1130	Recommendations on how to proceed in updating the approach for developing Science input to inform management decisions, and on how to proceed towards developing a risk management approach, continued.
1130-1200	Summary and Closing

[1] Note to participants: At 1700 the Co-Chairs will assess progress and determine if an evening session is required to complete the work by noon on Friday. Participants should be prepared to work past 1700 and/or attend an evening session.

APPENDIX 3. LIST OF PARTICIPANTS 4X5 POLLOCK MANAGEMENT STRATEGY EVALUATION WORKSHOP

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* Participated by WebEx.

** Unable to attend workshop, but key to planning and follow-up.

APPENDIX 4. CONTRIBUTED PAPERS

APPENDIX 4a. 2010 POLLOCK ASSESSMENT UPDATE FOR THE WESTERN COMPONENT (4Xopqrs5)

Heath H. Stone

ABSTRACT

As a first step in examining a Management Strategy Evaluation (MSE) process for Western Component (4Xopqrs+5Yb+5Zc) pollock, the data inputs for the assessment of this stock were reviewed and the analytical assessment was updated using the latest information from fisheries and research vessel (RV) surveys to determine current resource status. In addition, sensitivity analyses were conducted to examine sources of uncertainty in the assessment, including variability in survey indices, changes in selectivity of older ages, and changes in natural mortality.

The DFO summer survey has shown a general decline in the geographic distribution of pollock catches, which have declined in NAFO Divisions 4V and eastern 4W and now occur mainly in 4Xpq and 4Xmn/western 4W. The proportion of pollock > 70 cm fork length (FL) (age 7+) in the fishery and survey catch at size (CAS) declined sharply in the early 1990s and remained low to the mid-2000s. During this time, exploitation levels were high (average = 66% for 1991-2005). Since 2005, the proportion of fish > 70 cm FL has shown modest improvement, but it is still much lower than the pre-1990s, despite reductions in fishing effort.

Assessment results were based on virtual population analysis (VPA) model formulations which incorporated indices of abundance from both the summer RV survey (1984-2010) and standardised catch per unit effort (CPUE) from the commercial fishery, excluding the most recent six years (1982-2004). In order to bracket the uncertainty associated with the 2010 RV age-specific indices of abundance (which appear to be unusually low), two base model approaches were used, one which included the 2010 RV index and one which did not. Including the 2010 RV indices in the VPA analyses resulted in lower estimates of recruitment (back to 2001), age 4+ (considered spawning stock) biomass (9,000 t *vs.* 23,000 t in 2010), and higher estimates of age 6-9 fishing mortality rate (F) (0.78 *vs.* 0.29 in 2010). The MSE framework will need to include results from both model runs in the reference set of candidate VPA models for defining the current population state.

When the VPA model was allowed to estimate the natural mortality rate (M) on older ages (7+) from the mid-1990s onward, M increased to a fairly high level (0.62-0.68). This increase could be related to movements outside of management area (*i.e.*, to USA waters), increased predation, or changes in environmental conditions, which lead to poorer survival. A VPA model formulation with domed-shaped selectivity generated more biomass and lower estimates of F compared to a model with the standard (flat-topped) selectivity pattern. There is concern that the domed partial recruitment (PR) model generates cryptic biomass since fish aged 8 and older have not been captured in large amounts in either the summer RV survey or the Canadian fishery since the early 1990s. The MSE Operating Models will need to capture the uncertainty associated with higher levels of M and changes in selectivity on older ages.

INTRODUCTION

Pollock in the management unit 4VWX5 are assessed as a Western (4Xopqrs5) and an Eastern Component (4VW+4Xmn) as a result of the recommendations of the Framework Assessment completed in 2004 (Neilson *et al.* 2004) (Fig. 1). This paper updates the last stock assessment for pollock in the Western Component completed by Stone *et al.* (2009) and includes updated information for 2008 (fishery data: Trimester 3), 2009 (survey and fishery data: Trimesters 1-3) and 2010 (survey and fishery data: Trimesters 1&2).

There has been consideration by Fisheries Management and Industry to manage 4Xopqrs5 pollock using a Management Strategy Evaluation (MSE) approach. Since this is the first time a MSE has been applied to a Maritimes Region groundfish stock, it was decided that the approach should be kept simple and involve a process of exploring the Canadian virtual population analysis (VPA), understanding the sources of uncertainty by running sensitivity analyses, and evaluating their impact on both utilization and sustainability objectives. The exercise will explore a MSE to test the decision rules, not the model. The following analyses were undertaken to provide updated candidate VPA runs for the MSE process.

The *Terms of Reference* for this assessment update include the following elements:

- Review data inputs from research vessel (RV) surveys and the commercial fishery for Western Component pollock (4Xopqrs5), including: changes in geographic distribution, size and age composition, and trends in relative abundance.
- Update the current assessment for the Western Component using the latest information from fisheries and research surveys, and the best model formulation and assumptions.
- Examine sources of uncertainty in the current pollock assessment, including:
    - Variability in survey indices/relative abundance,
    - Changes in selectivity of older ages, and
    - Changes in natural mortality.

THE FISHERY

Landings of pollock for the Western Component of the management unit in fishing years ending March 31, 2009, and March 31, 2010, were 3921 t and 3911 t, respectively, against annual quotas of 5000 t (Fig. 2). Fishing year landings from the Western Component for 2010-2011 are currently at 3049 t (April-October; quota = 5000 t). Calendar year landings were used for the analytical assessment. For 2008, 2009, and 2010, they were 4115 t, 3819 t, and 3218 t (to August 31), respectively (Table 1). During the 1980s, landings from the Eastern Component (4VW+4Xmn) represented over half the catch, but they have declined significantly since 1990 and in 2003 dropped to a record low of 243 t. Fishing year landings from the Eastern Component were 1543 t and 1114 t for 2008/2009 and 2009/2010, respectively, and 408 t for the current year (April-October, 2010). Calendar year landings for the east were 1032 t, 1354 t, and 756 t for 2008, 2009, and 2010 (to August 31), respectively (Table 2). The total allowable catch (TAC) has rarely been restrictive except for a five year period in the late 1980s and more recently since 2004 (Fig. 2).

The pollock fishery has had significant changes in both area fished and in dominant gear type. The Western Component of the management unit usually contributes the largest proportion of the total landings (> 80% since 2000) (Fig. 2, Table 1). Landings from the Eastern Component traditionally came from the tonnage class (TC) 4+ sector and have followed a declining trend since 1990 (Fig. 2, Table 2). During the 1980s and early 1990s, there was a significant Canadian fishery for pollock on the eastern and western Scotian Shelf (Fig. 3; left panel). In 1993, the eastern Scotian Shelf was closed to cod- and haddock-directed fishing, which reduced pollock landings from that area. The Canadian fishery in the 1990s was mostly on the central and western Scotian Shelf up to international boundary (Fig. 3; right panel).

Canadian bottom trawl catches now occur mainly in Crowell and Jordan Basins (4Xpq), the eastern Bay of Fundy, northeastern Georges Bank (5Zc), along the shelf slope (4Xn), and east of La Have Bank (4Xn) (Fig. 4; left panel). During the fall of 2007, 2008, and 2009, there was a test fishery in 4W, which occurred in Emerald Basin and along the shelf slope south of Emerald Bank. Gillnet catches are mainly in the Jordan Basin area (4Xq), northeastern Georges Bank (5Zc), around the edges of LaHave (4Xm) and Emerald (4Wk) Basins, and on Baccaro and LaHave Banks (4Xn) (Fig. 4; right panel). Catches extend up to the international boundary in the Gulf of Maine and on Georges Bank for mobile gear but less so for gillnet.

Landings from the Western Component are now mostly from unit areas 4Xpq, and have declined substantially from the Bay of Fundy (4Xrs+5Yb) and Georges Bank (5Zc) since 2003 and 2004, respectively, and off southwest Nova Scotia (4Xo) since the mid-1990s (Fig. 5; Table 1). The seasonal pattern of the fishery over the past three years for the west was similar to previous years, with most pollock catches occurring from May through September (Table 3). Occasionally, winter fisheries have occurred with high landings in January and February (*i.e.*, 1986-1988, 1991, 1993, and 2005).

Since the early 1980s, the small mobile gear component (otter trawl bottom,OTB, 1-3) has accounted for most of the total landings, followed by gillnet (Fig. 6; Table 4). The percentage of total landings taken by gillnet has declined since 2000 whereas the small mobile share has increased. Currently, the gillnet share is 27% and small mobile is 62%. However, both gear sectors are also limited by their respective quotas. The contribution of larger trawlers to total landings (OTB 4+) has been steadily declining since the mid-1990s but showed a modest increase from 2% in 2005 to 8% in 2010. The offshore sector was using smaller vessels (TC 1-3, under the Temporary Vessel Replacement Program (TVRP)) to catch their allocation. The TVRP category is no longer in existence as a quota group for pollock (as of the 2008/2009 fishing year), and there have been few TC 4+ vessels involved in the fishery since 2002. The contribution by the longline/handline sector has also declined since the mid-1990s, but there has been a modest increase (3% of total landings) over the past few years.

SAMPLING AND CATCH/WEIGHT AT AGE

Port (shore) and observer (at-sea) sample collections contributed to several thousand pollock length measurements annually from 2008-2010 (Table 5). Sampling was considered adequate to characterise the catch at size and catch at age for the Western Component, with 1,358 and 1,082 ages available for the 2008 and 2009 fisheries, respectively, and 1,062 ages available to the end of the second trimester in 2010.

Comparisons of 2009 and 2010 port and observer length measurements of pollock from the directed fishery were made for months, areas, and gear types where both types of samples were available. For the most part, these comparisons showed similar pollock catch size frequencies. An exception was 5Zj mobile gear in 2010, but observer sampling for this area was low (Fig. 7). Pollock are also captured in the small mesh (cod end mesh < 130 mm) 4Xpq redfish fishery. Comparisons of 2009 and 2010 port and observer length measurements generally indicated similar size compositions of pollock at sea and at dockside in both years (Fig. 8). This indicates that discarding does not appear to be a problem. There were concerns during the 2008 assessment about pollock discards in the redfish fishery, but increased observer coverage over the past two years appears to have helped resolve this issue.

The level of commercial fishery sampling was relatively low in the 1970s in NAFO Division 4X. Thus, the assessment presented here starts in 1982 when the level of sampling improved to reflect the fishery more accurately. To construct the catch at age (CAA) for 2010 (Trimesters 1 & 2), 2009 (Trimesters 1-3), and update the CAA for 2008 (with data from Trimester 3), data for the Western Component was aggregated to the trimester level by gear type and tonnage class. Area 4Xu was prorated over the Western Component by allocating the proportion of landings attributed to 4Xmn *versus* the remaining unit areas in 4X. Samples were aggregated on a trimester basis for all gear sectors (OTB 1-3 large mesh (cod end mesh ≥ 130 mm), OTB 1-3 small mesh (cod end mesh < 130mm), gillnet, OTB 4+, and longline/handline gear). Small pollock are caught in the small mesh mobile gear used in the 4Xpq redfish fishery, so this gear type was kept separate in the CAA. Length-weight parameters were calculated from data pooled over the last ten years from the summer research vessel (RV) survey for strata 474, 476, and 480-495 (the Western Component). Since no surveys were conducted in the spring or fall, the summer value is used for all three trimesters.

To evaluate the consistency of age determinations, the primary ager for the 4VWX+5 pollock stock re-aged otolith sections used during a Canada/US Ageing Workshop in 2004. Agreement with prior Canada/US consensus ages was 90% (Fig. 9) and was consistent with a previous test performed in 2008 (92%). Although testing for age interpretations were limited this year (since the primary ager retired in September 2010), it was concluded that the current age interpretations were consistent with the reference collection and had no appreciable bias.

Larger pollock were captured by gillnet and handline/longline (average: 67-69 cm fork length (FL)) compared to large mesh (average: 60 cm FL) and small mesh (average: 50-53 cm FL) mobile gear (Fig. 10; upper panel). The small mesh mobile gear (used in the 4Xpq redfish fishery) captured a greater proportion of pollock < 45 cm FL, especially in 2009. The age composition of the catch differed among gear types, ranging from 5-8 for gillnet and handline/longline, 3-8 for large mesh mobile, and 2-7 for small mesh mobile gear (Fig. 10; lower panel).

Strong and weak year-classes are apparent in the age structure and some cohorts are readily tracked (Fig. 11; Table 6). Diminished numbers at age for older ages, a feature which first appeared in the 1990s, continues to the present. The 2010 fishery is dominated by ages 4-7; the 2006, 2005, 2004, and 2003 year-classes, respectively. The most recent strong year-classes apparent in the fishery are the 1999 year-class (Fig. 11; white circles) and the 2001 year-class (Fig. 11; yellow circles). Both have made significant contributions to the Western Component fishery over the past 6 years but diminish rapidly after age 7.

Fishery weights at age (WAA) declined from the early 1980s to the early 1990s and then increased to the early 2000s (Fig. 12; Table 7). Since then, they declined to 2005 but appear to be increasing again. Fishery weights at age are currently within the range of observed values over the time series.

INDICES OF ABUNDANCE

COMMERCIAL FISHERY CATCH RATES

Commercial fishery catch rates (catch per unit effort, CPUE) for small mobile gear (TC 1-3) are used as tuning indices in this assessment and are based on individual standardised catch rates from four areas in the Western Component: NAFO Unit Areas 4Xq, 4Xp/5Zc, Bay of Fundy (4Xrs+5Yb) and 4Xo. The main criteria for trips included in catch rate analyses is that they must be pollock-directed (> 50% of total catch is pollock) and the vessel must have five or more consecutive years in the fishery. The number of qualifying trips has dropped off since the 1990s, and in 2010 there were only 65 trips, compared to the average of 289 per year for the entire series. A multiplicative model (Gavaris 1980, 1988a) with main effects of year (1982-2010), Canadian fishing vessel number, month, and cod end mesh type (diamond or square) was solved using standard linear regression techniques after *ln* transformation of nominal CPUE (t/hr) data:

$$ln(CPUE_{ijkl}) = \mu + Year_i + Month_j + Vessel_k + Mesh\ Type_l + e_{ijkl}$$

Analysis of variance results indicated that for each area, the overall regression and individual main effects were significant ($P < 0.5$) and that the model explained between 37-49% (multiple r^2) of the variability in the data. A weighting factor was applied to the standardised catch rates for each of the four areas to account for changes in the spatial distribution of fishing activity (after Walters 2003). Then they were averaged together to generate a single index for the Western Component. The weighting factor for each area was calculated as the number of productive 10 minute squares in that area in 1992 (a year of high landings) divided by the total number of productive 10 minute squares in all areas in 1992.

There has been a general declining trend in standardised catch rates for all areas since the early 1980s, followed by an increase after 2001 (Fig. 13; upper panel). Area 4Xp/5Zc has had the highest catch rates since 2001, followed by 4Xq. Catch rates for both areas have been variable over the past few years but declined in 2010. In the Bay of Fundy (BOF), catch rates have been declining since 2003. Area 4Xo has had very few trips since 1997 so this series has been set to “0” in the CPUE index from 1998 to present. The area-weighted CPUE for all areas combined reached the second lowest level in the time series in 2006, with the lowest occurring in 1998 (Fig. 13; lower panel). Since 2006, catch rates have been higher but variable. Catch rates from 2005 to 2010 were constrained by reduced quotas and changes in fishing practices and are not comparable to those earlier in the time series. The current view is that since 2004, this series may no longer reflect trends in relative abundance.

The age-specific indices of abundance from the mobile gear sector of the fishery indicate a reduction in the abundance of older (ages 7+) fish since 1996 with modest signs of improvement in age structure beginning in 2006 (Fig. 14; Table 8). Since 2004 is the last year in this series used for tuning, the age-specific indices now have minimal influence on VPA model results.

DFO RESEARCH VESSEL (RV) SURVEY

Indices from the summer DFO research vessel (RV) survey, based on 4X strata 474, 476, and 480-495, are used in the assessment of the Western Stock Component. The time series begins in 1984, the first year that the *RV Alfred Needler* was used for the summer survey program. There has been a general declining trend in the biomass index since the late 1980s, followed by a period of low biomass from the mid-1990s to early 2000s and a trend of increasing biomass from 2003 to 2009 (Fig. 15). This is followed by a very sharp decline in 2010 which appears to be inconsistent with the trend of increasing biomass since 2003 and may be a negative year effect. Strong year-effects are present throughout the time series (*i.e.*, 1988, 1990, 1996, and 2006) and reflect the semi-pelagic schooling behaviour of pollock and changes in *q*.

Plots of summer survey biomass distribution (5-year average kg/tow aggregated by 10 minute squares; Fig.16) show an increase in the relative abundance of pollock and an expansion in their distribution from the 1970s to the 1980s, spreading east into NAFO Division 4V. This increase may reflect the influence of the extremely large 1979 year-class and also the change in survey vessel and net which occurred from 1982-1983 (*i.e.*, the *Alfred Needler* became the lead survey vessel in 1983 and the net was changed from a Yankee 36 to Western IIA in 1982). The summer survey shows a contraction in pollock distribution on the eastern Scotian Shelf from the 1990s through to the 2000s. Since 2005, the main areas of concentration are in 4X5 and western 4W with what appears to be a geographic separation between the Western and Eastern Component areas. In 2009 and 2010, most of the large catches were in eastern 4X and western 4W with very little catch occurring in 4V and eastern 4W (Fig. 17). Catches in western 4X were lower than usual for both years.

Consistent with the catch rate information, the DFO RV age-disaggregated indices for the Western Component show that the 1999 and 2001 year-classes appear strong but that not many are left by the time they reach age 8 (Fig. 18; Table 9). Strong year effects are apparent with high abundance at age in 2006 and very low abundance at age in 2010 (near lowest in time series). The 2010 indices should be interpreted with caution since they are inconsistent with values seen previously for these year-classes.

RV survey weights at age (equivalent to mid-year population WAA) follow a declining trend from the early 1980s to late 1990s (Fig. 19). Since then, the WAA has been increasing for ages 2-5, declining for ages 6 and 7 up to 2007, followed by an increase over the past two years.

OTHER SURVEY INDICATORS

The DFO Georges Bank winter survey is not used as a tuning index for the VPA model, but it does provide information on pollock abundance trends and size composition in 5Zjm (*i.e.*, part of the Western component). This survey has been conducted since 1986 and shows a decline in the extent of pollock catches in USA waters below Wilkinson Basin from the 1980s to present (Fig. 20). A persistent feature throughout the time series is the concentration of pollock in Canadian waters on the northeastern part of the bank. While trends in pollock biomass (kg/tow) from the Georges Bank survey tend to be quite variable (Fig. 21), they show a pattern similar to the DFO summer survey for western 4X, with period of high abundance during 1980s, low abundance in the 1990s, followed by an increase in the 2000s. This suggests a linkage between these two areas. A comparison of size frequency distributions for the 1990s and 2000s shows that pollock captured during the Georges Bank survey in late winter are similar in size to pollock from the summer survey in western 4X (Fig. 22).

Although there is no survey coverage of 5Z during the summer survey, it appears as though pollock relative abundance and size composition exhibit trends which do not differ from western 4X, indicating some connectivity between these two areas. In the past, Industry has expressed concern over the lack of coverage of northeastern Georges Bank during the summer survey despite the fact that landings from this region are included in the fishery CAA. Although this is still the case, it would appear that these areas are not showing trends which differ from each other; indicating that the summer survey, which is used as a tuning index for the VPA model, is representative of both areas.

The National Marine Fisheries Service (NMFS) has conducted stratified random surveys during spring and fall in the Gulf of Maine since the 1960s. Both series show a widespread distribution of pollock across the Gulf of Maine in USA and Canadian waters during the 1970s (Fig. 23). While pollock catches in these surveys were somewhat lower in the 1980s, they were still fairly widespread across the Gulf of Maine. During the 1990s, the NMFS surveys show a continued decline in catches in the Gulf of Maine, with some rebuilding in the 2000s in the western region around Wilkinson Basin, but the geographic distribution of pollock is no longer as widespread. The fall surveys during the 2000s indicate that a large portion of the pollock biomass occurs in Canadian waters (4Xq + 5Zjm). These tows are included in the age disaggregated abundance indices used to calculate population estimates in Subareas (SA) 5&6 but are actually outside of the USA management area (which extends up to international boundary).

A comparison of trends in pollock biomass (kg/tow) from the NMFS spring, NMFS fall, and DFO summer (Western Component) surveys shows strong year-effects in all three series (Fig. 24). There appears to be some synchrony among the three series in the recent period but not in the past. There was a general decline in biomass through the 1990s and a subsequent increase in the 2000s, followed by strong declines for all three series over the past year or so. It is too early to tell if these recent declines are simply effects or reflect an actual drop in relative abundance.

Since 2002, USA landings in SA 5&6 (Gulf of Maine) have been increasing and in 2008 they were 10,000 t, more than double the Canadian landings for the Western Component that year (4,100 t) (Fig. 25). The most recent NMFS assessment for this stock based on Statistical Catch at Age Model results (Northeast Fisheries Science Center 2010) reported that the pollock stock in SA 5&6 is not overfished and that overfishing is not occurring.

CHANGES IN SIZE COMPOSITION

An analysis of catch at size (CAS) frequencies from the commercial fishery and the summer survey was carried out to confirm the contraction in the age structure observed in both data series (see Figs. 11 and 18). Plots of the average CAS frequency for 5-year periods indicate a progressive decline in the proportion of pollock > 70 cm FL (proxy for age 7+) in the commercial fishery CAS from the 1980s to 1990s (Fig. 26). This pattern continues through to the mid-2000s and then the proportion of fish > 70 cm FL shows modest signs of improvement in 2005-2010.

The summer survey average CAS also shows a decline in the proportion of pollock > 70 cm beginning in the 1990s which continues through to the mid-2000s, with modest improvement after 2005 (Fig. 27). Analysis of the 5-yr average proportion at length for pollock ≥ 70 cm FL (age 7+) and ≥ 75 cm FL (age 8+) shows a rapid drop in the proportion of larger/older fish in both the survey and the fishery beginning in early the 1990s and extending to the mid-2000s (Fig. 28). This decline is coincident with a period of high exploitation levels (range: 53-78%) on the stock. Despite recent reductions in fishing effort since 2005, there has been only a modest increase in the proportion of larger/older fish.

ESTIMATION OF CURRENT POPULATION STATE

Two VPA model approaches were used based on the framework assessment formulation of Neilson *et al.* (2004) with a few modifications. The first approach was the Base Model formulation accepted for the 2006 and 2008 assessments, and used CAA for ages 2-13 (1982-2010), RV indices for ages 3-8 (1984-2010, proportional fit), truncated CPUE indices for ages 3-8 (1982-2004, power fit) and natural mortality of 0.2. The truncated CPUE series excluded 2005-2010, years which had more restrictive quota, fewer pollock-directed trips, and considered by Industry to be unrepresentative of abundance trends. During the 2004 Framework Assessment, it was concluded that it is useful to have the catch rate series as a tuning index to dampen the year effects apparent in the RV series. Currently the CPUE series now has very little influence on the model results and tuning is based largely on the RV indices.

The second approach was the Base Model excluding the 2010 RV age-specific indices. The assumption for this model was that the 2010 RV age-specific indices are not consistent with values seen previously for these year-classes.

The adaptive framework, ADAPT (Gavaris 1988b), was used to calibrate the sequential population analysis with the CPUE and RV survey age-specific abundance trend results. For the Base Model in the terminal year (2010), population size (N) was assigned a value for age 2 (geometric mean for past 10 years) and for ages 11-13, N was estimated for ages 3-8, fishing mortality rate (F) was calculated for age 9 (2009 and 2010) and was assumed to be equal to the population number weighted average fishing mortality on ages 7 and 8. For the oldest age (13), N was assigned a small value (= 1) from 1995-2009 (a period of very low catch), and then F was calculated on age 12 for 1982-1993 (a period of moderate catch) based on the weighed average F on ages 9-11.

For the Base Model excluding the 2010 RV, the only difference in model setup was for the terminal year. N was assigned a value for age 2 (for 2009 and 2010) and ages 11-13 (2010), and estimated for ages 4-8 (2010). The rest of the model setup was the same as the Base VPA.

DIAGNOSTICS

Results for population abundance, F, and biomass are given in Tables 10-12, respectively, for the Base VPA and in Tables 13-15, respectively, for the Base VPA excluding the 2010 RV indices. The 2010 RV indices have a strong negative influence on current estimates of recruitment, 4+ biomass, and age 6-9 F (Fig. 29). Including the 2010 RV indices in the Base VPA results in lower recruitment (back to the 2001 year-class), lower estimates of 4+ biomass (9,000 t *vs.* 23,000 t in 2010), and higher estimates of age 6-9 F (0.78 *vs.* 0.29 in 2010). Both models give results that are less optimistic than the 2008 assessment, especially the model which includes the 2010 RV.

Age-specific residuals for the Base VPA formulations including and excluding the 2010 RV indices are shown in Figs. 30 and 31, respectively. The residual pattern for the CPUE series shows a band of positive residuals for ages 4-6 from 1994 to 2004 and is the same in both models. The models predict higher abundance than indicated by the CPUE series for ages 3, 4, 7, and 8 in 2004. Since this series only extends to 2004, it has little influence on the results of both VPA formulations. Residuals for the RV series are large and positive for most ages in 2006, which was a strong year effect (high indices for all ages). For both model formulations, the model predicts lower abundance for these age groups than indicated by the survey indices in 2006. For the Base Model including the 2010 RV indices, large negative residuals occur for most ages in 2010, especially ages 7 and 8. The model predicts higher abundance than indicated by the survey indices, which were extremely low in 2010. For the model which excludes the 2010 RV indices, the residuals get smaller for the last few years of the series but are still large and negative for age 8 in 2009. Overall, the model fit is better when the 2010 RV indices are excluded as indicated by the mean square of the residual values, *i.e.*, mean square residuals (MSR) = 0.779 (including 2010 RV) *vs.* 0.733 (excluding 2010 RV).

The relative errors for population abundance estimates from both the Base VPA and the VPA excluding the 2010 RV tend to be quite high, and they reflect the high variability in the RV survey age-specific indices used for tuning the respective models (Tables 16 and 17). A correction factor is applied to the age-specific population estimates in the terminal year to correct for bias from the minimisation routine and log-log transformations used within the model. The relative bias is very high for both model formulations (*i.e.*, the average relative bias on the estimate of N for all ages is 0.28 *vs.* 0.22 for the Base VPA and the VPA excluding the 2010 RV indices, respectively). Compared to other stocks and species, the bias correction for Western Component pollock is quite high. For example, the average bias correction is 6.6% for 5Z haddock (Van Eeckhaute *et al.* 2009), 6.1% for 5Z cod (Wang *et al.* 2009), 6.1% for 4X/5Y cod (Clark and Emberley 2009), and 4.3% for 5Zjm yellowtail flounder (Legault *et al.* 2010) (Table 18). This contrasts with an average of 22-25% for Western Component pollock. The bias correction affects terminal year estimates of N, especially ages 3 and 5 in the Base VPA, and age 4 in the VPA excluding the 2010 RV. Consequently, the bias correction will have a strong influence on trends in age 4+ biomass for the recent period.

The survey calibration constants (*q*'s) for both models increase with age up to age 7 and then decline at age 8 (Tables 16 and 17). The values are slightly higher for the Base VPA as is the relative error. CPUE calibration coefficients are essentially the same for both model formulations and increase from ages 3-6 and then decline for ages 7 and 8. Relative bias on the CPUE calibration constants is high for both model formulations.

While the age-specific estimates of population numbers and calibration constants are sometimes associated with high variance, they are comparable to those reported in the assessments of pollock in 2006 and 2008. The CPUE calibration coefficients show high relative error at ages 3 and 4, but these indices are fit to the model using a power function and the coefficients appear to be poorly estimated.

Retrospective analysis for the Base VPA indicates a strong tendency to underestimate fishing mortality on ages 6-9 and to overestimate 4+ stock biomass and age 2 recruits (Fig. 32). This pattern is largely due to the influence of the 2010 RV indices, which are so low that they have a negative impact extending back several years, and result in a retrospective pattern that is much stronger than observed in the 2008 assessment. When the 2010 RV indices are not included for tuning, the retrospective pattern improves (Fig. 33). Although this model still has a tendency to underestimate F and overestimate biomass and recruitment, the results are more acceptable compared to Base VPA (with the 2010 RV included).

A comparison of age 3+ population biomass from the Base VPA and *q*-adjusted age 3-8 total biomass from the RV survey indicates that the biomass from the population model does not match the *q*-adjusted biomass from the survey in the recent period since the 2010 index is pulling it down (Fig. 34; upper panel). When the 2010 RV indices are excluded, age 3+ biomass from the population model has a better match to the recent increasing trends in the *q*-adjusted age 3-8 biomass from the survey (Fig. 34; lower panel). The VPA excluding the 2010 RV indices was selected for updating the current population trends.

STOCK TRENDS AND CURRENT STATUS

The updated assessment results were based on the age-structured population model for the Western Component that incorporated indices of abundance from both the DFO summer research vessel survey (1984-2009), excluding the 2010 indices, and standardised CPUE from the commercial fishery excluding the most recent six years (1982-2004). The model set up for the terminal year involves assigning abundance for age 2 (in 2009 and 2010), estimating abundance for ages 3-8 (2010), calculating a weighted F for age 9 (using the population weighted average for ages 7 and 8 in 2009 and 2010), and assigning a small value for the abundance of ages 11-13 (2010).

While age 2 recruitment is estimated to be below average (~ 5 million) for the 2004 and 2005 year-classes at 2.4 and 3.7 million recruits, respectively, this is an improvement over the estimates of 1.3 and 1.5 million, respectively, from the 2008 assessment (Fig. 35). In contrast, the strong 2001 year-class, estimated at 12.4 million recruits during the 2008 assessment, is currently estimated at 6 million. A positive sign may be the 2006 year-class, which is currently estimated at 7 million recruits.

Estimates of age 4+ (considered spawning stock) biomass declined from about 66,000 t in 1984 to about 7,500 t in 2000. Biomass has been rebuilding since 2000. It has increased steadily to about 23,000 t in 2010 (Fig. 35). During the 2008 assessment, age 4+ biomass was estimated at 27,000 t for 2008. The current estimate for 2008 based on the VPA excluding the 2010 RV indices is only 17,000 t, which is considerably lower than indicated from the 2008 assessment. During the benchmark review, it was concluded that the probability of good recruitment is higher when adult biomass is > B_{ref} = 30,000 t. This conclusion was based on the relationship between age 4+ biomass and age 2 recruits, which, when examined visually, gives an indication that recruitment may be higher when age 4+ biomass exceeds 30,000 t (Fig. 36). If this is the case, then the current level of age 4+ biomass (23,000 t) is below the reference level for improved recruitment.

Fishing mortality rates steadily increased from the early 1980s to above 1.0 by the early 1990s and remained high until the early 2000s. Subsequent reduced quotas and harvests as well as increasing population biomass have contributed to a decline in the fishing mortality rate on ages 6-9, which was below the F_{ref} of 0.2 in 2009 but increased to 0.29 in 2010 (Fig. 37). The overall prognosis is not as optimistic as indicated from the 2008 assessment, but it is better than when the 2010 RV indices are included.

SUMMARY OF UPDATED ASSESSMENT RESULTS FOR THE WESTERN COMPONENT

- The DFO summer survey indicates a general decline in the geographic distribution of pollock catches, which now occur mainly in 4Xpq and 4Xmn/western 4W.

- The proportion of pollock > 70 cm FL in the fishery and survey CAS declined sharply in the early 1990s and remained low to the mid-2000s. During this time, exploitation levels were high (average = 66% for 1991-2005). Since 2005, the proportion of pollock > 70 cm FL has shown modest improvement, but it is still much lower than the pre-1990s.

- The 2010 RV age-specific indices appear to be unusually low and are inconsistent with values seen previously for these year-classes.

- Using the Base Model formulation, which excludes the 2010 RV indices (best assessment but problems with bias), age 4+ population biomass for the Western Component in 2010 is ~ 23,000 t. At this level, the probability of good recruitment is not as good.

- Fishing mortality on fully recruited ages 6-9 declined sharply after 2005 following a reduction in quota for the Western Component and fell below F_{ref} (= 0.2) in 2009, but has increased to 0.29 in 2010.

- Since 2005, there has been only a modest improvement in the age structure despite reductions in F. However, after age 8, pollock seem to disappear in the survey and fishery CAA. The overall prognosis is less optimistic than indicated by the 2008 assessment.

- The MSE framework will include results from both model runs in the reference set of candidate VPA models for defining the current population state.

SENSITIVITY ANALYSES FOR SOURCES OF UNCERTAINTY

CHANGES IN NATURAL MORTALITY

The VPA model excluding the 2010 RV indices was used for exploring changes in the natural mortality rate (M) and used CAA for ages 2-13 (1982-2010), RV indices for ages 3-8 (1984-2009, proportional fit), and a truncated CPUE indices for ages 3-8 (1982-2004, power fit). For the terminal year, N was assigned a value for age 2 (for 2009 and 2010) and ages 11-13 (2010) and was estimated for ages 4-8 (2010). For the oldest age (13), the setup was the same as the Base VPA (p. 8).

Two approaches were used for exploring changes in M. The first involved estimating M on ages 7-13 from 1996-2010, a period when there was a contraction in the age structure. In the model setup, M was assigned a value of 0.2 for ages 2-6 for 1982-2010 and ages 7-13 for 1982-1996, and then the model to estimate M for ages 7-13 from 1996-2010. The second approach involved the estimation of M separately for two age groups: ages 5-6 and ages 7-13. In this case, M was assigned a value of 0.2 for ages 2-4 from 1982-2010 and ages 5-13 from 1982-1995, and then the model was allowed to estimate M for ages 5-6 and 7-13 separately from 1996-2010, the period when age structure was contracted. Trends in recruitment, 4+ biomass, and age 6-9 F were compared between models with M assigned (*i.e.,* 0.2 throughout the time series as per standard formulation) *vs.* models where M was estimated (*i.e.,* approach 1: ages 7-13, and approach 2: ages 5-6 and 7-13).

Results for population abundance, F, and biomass are given in Tables 19-21 for the VPA which estimates M on ages 7-13, and in Tables 22-24 for the VPA which estimates M on ages 5-6 and 7-13 separately. When M is estimated, age 2 recruitment is higher after 1993 (Fig. 38). Age 4+ biomass is higher from 1993 onwards but drops off after 2007 to the same level in 2010 (~ 23,000 t) as estimated by the model when M is assigned to all ages and years. The model which estimates M for 2 age groups has the highest biomass from 1995-2007.

Fishing mortality on ages 6-9 is lower from 1995-2008 when M is estimated compared to when it is assigned because natural mortality is contributing more to total mortality (F + M) during this period. When M is estimated for ages 7-13 from 1996 onwards, the model estimates high natural mortality for these ages (M = 0.68). Similarly, when M is estimated for ages 5-6 and 7-13 separately, natural mortality remains high on both age groups (0.58 and 0.62 for ages 5-6 and 7-13, respectively). Model fit, in terms MSR, actually improves slightly when M is estimated (*i.e.*, MSR = 0.70 and .69 for approaches 1 and 2, respectively) compared to the case when M is assigned (MSR = 0.73).

The higher value of M could be one reason why fish aged 7 and older seem to disappear so rapidly, especially since the mid-1990s. Although the reasons for this are unknown, it could be related to:

- A decline in forage with high energy content (*i.e.*, herring, euphausiids). There is some evidence for this hypothesis based on a proxy for “condition” (predicted weight at length based on linear regression analyses) which has shown 0.5 kg decline over the survey time series (Fig. 39).

- Movement outside the area (*i.e.*, emigration to USA waters?)

- Increased predation (seals?).

CHANGES IN SELECTIVITY ON OLDER AGES

The Base VPA is somewhat complicated in terms of model set up for the terminal year and the oldest age (13) due to low catches of older fish (ages 10+) since the mid-1990s. Therefore, a simpler approach was used to illustrate the effects of different selectivity patterns for Western Component pollock by using a CAA matrix out to age 9 (truncated CAA). The model with truncated CAA has similar trends in age 2 recruits, slightly higher 4+ biomass, and slightly lower age 6-9 F after 2006 compared to model with a full CAA (Fig. 40; Tables 25-27). Since these differences are relatively minor, the truncated CAA model, which is easier to set up, was used to explore the effects of different selectivity patterns.

The VPA models used for exploring the effects of different selectivity patterns (*i.e.*, standard model formulation *vs.* dome-shaped) used truncated CAA (ages 2-9, 1982-2010), CPUE from 1982-2004 (ages 3-8), RV indices from 1984-2009 (ages 3-8, excluding 2010) and M = 0.2. The VPA model setup to simulate a dome-shaped selectivity on older ages involved calculating F on age 9 (1982-2010) based on 0.5 of population weighted average F on ages 7 and 8. Trends in age 2 recruits, age 4+ biomass, and age 6-9 F were compared between the standard *vs.* the domed model formulations.

Results for population abundance, F, and biomass are given in Tables 28-30, respectively, for the VPA which has the dome-shaped selectivity. Recruitment is estimated to be slightly higher in the 1980s and 2000s when selectivity is dome-shaped (Fig. 41). Similarly, age 4+ biomass is higher through the 1980s and 1990s and again after 2005. Age 4+ biomass in 2010 is estimated at 30,000 t for the domed model *vs*. 25,000 t using the standard (flat-topped) formulation. F on ages 6-9 is considerably lower over the time series for the domed partial recruitment (PR) model up to 2008 and then is similar to the standard PR model. Overall, the model fit was not as good for the dome-shaped formulation compared to the standard formulation (MSR = 0.77 *vs.* 0.74).

The model with domed PR assumes that more older fish are alive but are not available to the fishery or the survey (Fig. 42). Similar selectivity patterns and assumptions are used in statistical catch at age models such as the one used recently in the NMFS assessment for pollock in SA 5&6. For Western Component pollock, there is currently no empirical evidence available to indicate that older fish are actually present.

SUMMARY FOR SENSITIVITY ANALYSES

- When the VPA model is allowed to estimate M on older ages (7+) from the mid-1990s onward, M increases to a fairly high level (0.62-0.68).

- This increase could be related to movements outside of the management area (to USA waters?), increased predation, or changes in environmental conditions, which lead to poorer survival. Tagging studies on harbour pollock could be used to investigate transboundary movements but would require several years before tagged fish recruit to the fishery.

- The model formulation with domed-shaped selectivity generates more biomass and lower estimates of F compared to the model with the standard (~flat-topped) selectivity pattern. The concern with this approach is that the domed PR model generates cryptic biomass since fish aged 8 and older have not been captured in large amounts in either the summer survey or the Canadian fishery since the early 1990s.

- The MSE Operating Models will need to capture the uncertainty associated with higher levels of M and changes in selectivity on older ages.

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Table 1. Pollock landings (t) by area in the Western Component, (4Xopqrs5). The landings for 2010 represent a partial year (Jan. 1 to Aug. 31).

	4Xo	**4Xp**	**4Xq**	**4Xr**	**4Xs**	**4Xu**	**5Y**	**5Zc**	**Total**
1982	4781	1499	2675	2508	1345	183	925	4430	18347
1983	4337	1146	3635	1170	461	1319	1079	3301	16448
1984	3536	1189	4541	716	163	1933	2015	1199	15291
1985	6179	595	5718	1284	696	3275	853	911	19511
1986	7326	1073	2531	1046	1287	2066	654	1538	17520
1987	4734	2329	1893	508	1209	2571	1120	2096	16460
1988	3194	3417	3333	307	790	4110	345	2403	17899
1989	3619	3373	2334	332	374	1777	531	1385	13724
1990	3668	2523	2953	1042	693	2629	346	1740	15595
1991	4621	3745	2665	2465	2105	831	456	1715	18602
1992	4174	1528	2626	2175	1793	865	443	3036	16639
1993	2754	1985	2226	1605	941	337	368	4193	14410
1994	1860	1097	1213	1453	866	784	236	3327	10836
1995	429	1158	2552	676	393	683	250	1004	7144
1996	419	1478	1811	686	412	179	256	1200	6441
1997	446	1574	4030	1112	607	447	311	1231	9759
1998	437	3495	3134	564	469	153	425	1857	10534
1999	313	879	1372	648	380	37	135	996	4760
2000	257	1086	1531	264	249	47	136	1197	4768
2001	207	1191	1774	301	186	68	104	1569	5400
2002	201	1482	2628	189	159	52	157	1616	6485
2003	114	1823	2578	403	665	316	594	1347	7839
2004	58	2404	2342	321	557	147	137	2047	8012
2005	126	3397	970	221	324	43	108	1740	6928
2006	99	1187	781	95	290	42	128	848	3469
2007	109	2004	1562	168	133	56	95	552	4679
2008	131	1712	1609	42	75	53	104	389	4115
2009	128	1088	1781	15	39	212	96	458	3819
2010	93	988	1431	11	10	111	36	537	3218

Table 2. Pollock landings (t) by area in the Eastern Component, (4VW+4Xmn). The landings for 2010 represent a partial year (Jan. 1 to Aug. 31).

	4Vn	4Vs	4Vu	4Wd	4We	4Wf	4Wg	4Wh	4Wj	4Wk	4Wl	4Wm	4Wu	4Xm	4Xn	Total
1982	149	2216	162	4	89	8	230	904	3181	1987	2469	25	69	4341	3154	18987
1983	104	5214	13	7	189	24	621	1577	235	1725	702	7	191	2713	2532	15855
1984	351	4598	101	5	60	9	207	1699	252	2061	1406		106	2251	3805	16912
1985	839	9375	7	79	80	6	1002	198	32	1156	247		43	4803	3014	20882
1986	1379	11639	138	202	30	2	658	289	454	986	239		220	4124	2448	22808
1987	915	9680	303	70	26	0	416	92	659	2302	29		154	4947	5987	25583
1988	1448	9307	224	128	85	10	746	124	44	934	841		165	5020	2599	21674
1989	4465	7542		253	79	30	313	253	272	1394	931	6	309	4239	5689	25774
1990	2124	6065		90	20	80	769	160	300	1172	1093	46	350	3078	3886	19233
1991	1043	3009		193	42	7	2146	132	477	1329	2229	106	72	2824	5172	18779
1992	284	2129		149	98	13	990	101	162	1064	2695	44	387	1594	5357	15066
1993	86	743		81	470	1	114	6	5	588	272	1	63	739	2563	5731
1994	437	329		19	434	0	69	11	4	787	60		6	878	1128	4161
1995	397	665		36	3	0	108	31	1	130	188	6	135	220	592	2513
1996	30	432		35	0	0	19	44	0	747	67	1	81	305	898	2660
1997	10	135		7	1	0	1	94	0	606	66	1	73	305	770	2071
1998	155	171		11	16	0	36	63	2	149	1160	1	20	257	1767	3806
1999	29	422		0	0		80	61	1	1067	248	0	3	247	803	2963
2000	6	234		0	0		20	2	0	145	85	0	7	153	239	891
2001	0	94		0	0		7	2	0	128	151	2	15	146	336	882
2002	0	39			0		0	2	0	37	39	0	1	77	317	513
2003	0	4		0	0		1	5	0	15	37	0	4	24	152	243
2004	0	9						2	0	25	135		1	25	144	340
2005	8	4			0		0	1	0	81	75		7	44	379	599
2006	0	15	0	0			0	5	0	67	98		0	42	269	496
2007	0	3	1			10	0	0	1	462	234		8	67	333	1120
2008	0	0					0	5		317	192		5	55	458	1032
2009	2	1			0			2	1	80	106	0	18	85	1059	1354
2010	0	5			0	0	0	2	0	114	223	0	5	28	379	756

Table 3. Pollock landings (t) by month in the Western Component (4Xopqrs, 5Yb, and 5Zc). The landings for 2010 represent a partial year (Jan. 1 to Aug. 31).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1982	766	667	258	196	1555	2789	3413	2510	2317	2085	1140	620	18317
1983	1147	805	477	495	1814	4650	3272	1659	1207	568	172	77	16344
1984	167	170	362	753	1413	3922	3818	1619	1325	1090	346	91	15076
1985	114	681	841	1892	981	4503	5243	1885	1556	1048	357	222	19323
1986	1023	682	758	452	2221	3015	3678	2649	2069	664	169	23	17404
1987	1428	648	643	34	2212	3686	2797	1905	1431	490	114	836	16224
1988	1043	563	140	375	912	4213	4534	1241	1159	409	151	2561	17301
1989	645	1473	329	459	712	3740	1682	1230	1140	561	1317	320	13607
1990	244	233	44	132	1039	3199	3465	2944	2002	1182	465	923	15874
1991	1091	884	433	1235	1884	3435	3189	2136	1750	1335	729	681	18783
1992	432	625	222	783	1744	2916	3073	2414	1813	1572	817	232	16644
1993	1089	654	633	385	1202	2725	2741	1684	1172	550	900	629	14363
1994	36	244	228	517	801	1931	2950	1350	1061	903	473	489	10981
1995	106	217	206	472	319	2013	1406	255	1472	255	300	180	7200
1996	277	199	222	223	470	786	1226	914	544	606	387	604	6457
1997	56	458	508	681	597	1482	1917	1392	1209	661	560	282	9802
1998	285	624	807	711	953	1872	2193	1109	986	789	165	51	10544
1999	64	59	174	236	348	781	1112	825	666	215	180	111	4771
2000	135	272	301	98	318	738	850	684	553	506	184	140	4778
2001	231	46	417	224	418	775	1180	566	610	534	261	146	5410
2002	139	268	328	415	947	1346	1266	599	505	345	221	121	6501
2003	39	235	941	643	893	1171	1205	901	877	450	374	116	7845
2004	48	514	871	527	676	1806	1547	764	560	367	245	85	8012
2005	398	1065	547	448	536	1460	835	543	371	302	404	19	6928
2006	220	143	344	161	251	533	426	440	283	301	310	57	3469
2007	61	289	654	472	876	502	643	581	367	152	58	19	4675
2008	98	251	388	452	709	577	623	524	294	108	53	39	4115
2009	34	260	249	217	395	595	932	473	303	196	150	14	3819
2010	72	158	403	596	675	353	505	455					3217

Table 4. Pollock landings (t) by gear in the Western Component (4Xopqrs, 5Yb, and 5Zc). The landings for 2010 represent a partial year (Jan. 1 to Aug. 31).

	Gillnet	OTB 4+	Longline	Misc	OTB 1-3	Total
1982	2574	6782	2315	241	6435	18347
1983	2416	4307	1618	25	8081	16448
1984	1809	1623	1615	39	10204	15291
1985	3045	1246	2443	52	12725	19511
1986	4378	1928	4447	55	6712	17519
1987	4003	3465	2934	26	6032	16460
1988	3021	5904	1704	93	7177	17899
1989	4217	3558	1391	78	4480	13724
1990	4810	3027	2252	95	5411	15595
1991	3572	3884	2387	132	8627	18602
1992	3784	3135	2789	3	6928	16639
1993	3159	3983	2199	1	5067	14410
1994	2760	1703	2019	44	4310	10836
1995	2620	951	506	4	3062	7144
1996	1301	1733	605	3	2799	6441
1997	2312	1648	978	1	4820	9759
1998	3076	1323	621	21	5492	10534
1999	1431	546	494	5	2286	4761
2000	1796	516	278	5	2172	4768
2001	1776	564	291	1	2765	5398
2002	1621	559	229	1	4074	6484
2003	1902	11	217	9	5699	7839
2004	2017	90	121	1	5782	8012
2005	1356	80	125	0	5365	6926
2006	929	354	87	0	2095	3465
2007	1027	149	180	0	3313	4668
2008	980	0	133	0	2992	4105
2009	1103	0	119	0	2560	3782
2010	890	247	79	0	1994	3210

Table 5. Summary of pollock sampling in 2008, 2009, and 2010 (Trimesters 1&2) from port (dockside) and observer (at sea) collections. "Ages" refers to the number of ages used in catch at age calculations. Values in parentheses indicate number of port samples or number of observed trips.

Year	Number measured/aged			Landings (t)
	Port Samples	Observer Samples	Ages	
2008 (West)	9,845 (47)	3,795 (27)	1,358	4,115
2009 (West)	10,919 (47)	3,975 (25)	1,082	3,819
2010 (West)	8,498 (37)	13,885 (37)	1,062	3,218

Table 6. Total catch at age (000s) for pollock in the Western Component (4Xopqrs, 5Yb, and 5Zc). The catch at age for 2010 includes January 1 to August 31.

	2	3	4	5	6	7	8	9	10	11	12	13
1982	95	1618	1352	371	1031	838	425	145	45	33	13	0
1983	45	1283	3966	854	179	314	291	138	59	17	19	0
1984	4	370	1832	2751	465	85	148	114	41	19	2	0
1985	5	195	621	1806	2142	328	38	100	99	62	30	0
1986	1	162	1410	1136	1329	876	88	37	37	41	15	0
1987	5	104	628	1622	883	786	490	68	17	15	28	0
1988	19	425	990	1126	1281	519	424	242	22	14	20	0
1989	93	386	1533	1129	576	463	147	129	65	6	7	0
1990	47	776	1102	1621	873	429	174	138	49	23	10	0
1991	58	1013	1900	1506	1395	347	157	56	49	25	10	0
1992	46	1250	2678	1651	675	314	124	96	61	14	12	0
1993	4	551	1989	2125	1143	318	92	27	10	7	6	0
1994	51	259	675	1327	1151	494	166	59	14	8	2	0
1995	24	263	537	949	676	294	63	17	4	1	1	0
1996	14	202	949	710	473	256	55	15	0	0	1	0
1997	6	151	900	1654	780	217	54	4	0	1	0	0
1998	7	228	829	1368	1262	307	47	16	2	1	0	0
1999	13	89	496	621	426	173	22	4	1	2	0	0
2000	86	581	404	592	319	139	27	6	1	0	0	0
2001	15	335	814	571	314	91	14	5	2	1	1	0
2002	7	191	787	1073	416	127	20	6	1	0	0	0
2003	2	111	1302	1331	513	120	18	5	1	1	0	0
2004	2	173	542	1876	696	118	13	4	2	1	0	0
2005	0	37	842	759	1160	170	13	5	1	0	0	0
2006	1	30	154	534	353	218	18	3	0	0	0	0
2007	5	69	370	453	619	223	28	3	1	0	0	0
2008	20	97	175	390	429	260	52	11	1	0	0	0
2009	25	336	296	291	357	157	51	7	2	0	0	0
2010	10	119	266	293	209	213	62	29	6	1	0	0

Table 7. Mean weights at age (kg) for pollock from the commercial landings in the Western Component (4Xopqrs5), 1982-2010. Weights at age for 2010 represent a partial year (Jan. 1 to Aug. 31).

	Age1	**Age2**	**Age3**	**Age4**	**Age5**	**Age6**	**Age7**	**Age8**	**Age9**	**Age10**	**Age11**	**Age12**
1982	0.000	0.943	1.427	2.529	3.462	4.211	4.772	5.681	6.239	7.687	8.622	10.621
1983	0.000	0.881	1.349	1.983	3.373	4.367	5.105	5.651	6.624	7.220	8.381	8.886
1984	0.000	0.914	1.635	2.331	3.005	4.078	5.401	6.062	6.208	6.661	7.230	9.725
1985	0.000	0.974	1.615	2.462	3.169	3.695	4.296	6.022	7.315	7.185	7.968	9.343
1986	0.000	0.738	1.554	2.306	3.095	3.929	4.530	5.791	6.651	7.161	7.322	8.698
1987	0.000	0.943	1.475	2.266	3.046	3.564	4.315	4.907	5.300	6.794	7.482	7.909
1988	0.000	1.195	1.549	2.240	3.096	3.807	4.191	4.979	5.886	7.073	8.169	8.454
1989	0.000	0.880	1.313	2.095	3.068	3.885	4.491	4.869	6.012	6.334	8.911	7.133
1990	0.000	0.571	1.263	2.055	2.894	3.657	4.766	5.818	6.371	6.966	7.625	9.770
1991	0.000	0.906	1.344	2.153	2.866	3.736	4.730	5.711	6.460	6.815	8.060	9.030
1992	0.000	1.033	1.271	1.831	2.615	3.509	4.614	5.466	6.141	6.864	8.164	9.189
1993	0.000	0.761	1.110	1.666	2.312	3.143	3.754	4.723	5.492	6.704	7.704	8.131
1994	0.000	0.805	1.250	1.586	2.163	3.058	3.765	4.219	4.854	6.268	6.082	7.846
1995	0.000	0.671	1.132	1.806	2.296	3.038	3.941	4.796	5.389	7.348	8.573	8.781
1996	0.000	0.896	1.336	1.795	2.353	3.057	3.665	5.205	6.296	8.502	9.561	11.422
1997	0.000	0.915	1.388	1.938	2.446	3.288	3.976	5.101	7.763	10.058	6.737	11.915
1998	0.000	0.867	1.103	1.720	2.361	3.144	4.219	5.159	5.640	8.615	8.833	12.063
1999	0.000	0.806	1.193	1.682	2.419	3.245	4.288	5.659	7.057	9.939	9.943	10.000
2000	0.000	0.757	1.247	1.796	2.478	3.166	4.168	5.412	5.745	9.003	9.821	10.000
2001	0.105	0.453	1.039	1.987	2.929	3.734	4.775	6.532	8.118	8.539	9.026	10.788
2002	0.062	0.280	0.931	1.592	2.528	3.714	4.829	6.328	6.936	8.663	10.872	11.081
2003	0.000	0.590	0.977	1.536	2.376	3.528	4.780	6.289	7.427	9.281	10.090	8.875
2004	0.000	0.475	0.873	1.621	2.210	3.125	4.290	6.509	7.369	8.699	9.077	12.027
2005	0.000	0.391	0.955	1.439	2.152	2.801	4.087	5.479	5.956	9.216	14.277	14.277
2006	0.309	0.654	0.931	1.722	2.180	3.101	3.715	4.680	5.186	9.121	9.906	10.851
2007	0.242	0.660	0.948	1.573	2.525	2.973	3.944	4.567	6.229	7.352	10.195	13.091
2008	0.000	0.758	1.202	1.681	2.299	3.191	3.819	4.907	5.552	5.985	8.832	11.824
2009	0.000	0.585	1.137	1.884	2.451	3.318	4.153	4.558	5.074	5.324	11.959	12.974
2010	0.000	0.683	1.026	1.754	2.456	3.091	3.804	4.358	4.471	4.969	6.365	10.252

Table 8. Small mobile gear (TC 1-3) age-disaggregated catch rates (t/hr x 100) for the Western Component (4Xopqrs5), 1982-2010, calculated using the area-weighting factor. Catch rates for 2010 represent a partial year (Jan. 1 to Aug. 31).

	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8
1982	1.72938	1.05245	0.24912	0.71304	0.63583	0.34554
1983	1.60946	4.73163	0.82651	0.11850	0.18753	0.18914
1984	0.39052	2.16937	3.51716	0.62828	0.11347	0.18606
1985	0.16434	0.58922	1.86852	2.14667	0.30732	0.02596
1986	0.21374	1.58021	1.28235	1.49302	0.96322	0.08194
1987	0.14692	0.87875	1.90677	0.93956	0.82743	0.50634
1988	0.19990	0.57002	0.92743	1.12395	0.41787	0.35228
1989	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
1990	0.83710	1.10470	1.38769	0.61173	0.22972	0.07564
1991	0.59083	1.64805	1.27981	1.01420	0.24596	0.11814
1992	1.04516	2.45511	1.24453	0.32822	0.09064	0.02762
1993	0.47916	1.87449	1.60375	0.59880	0.13115	0.03965
1994	0.27508	0.65757	1.19513	0.95213	0.37038	0.12570
1995	0.71029	1.08922	1.66522	0.96576	0.34242	0.07393
1996	0.51120	2.61749	1.79702	0.89548	0.39310	0.06128
1997	0.21695	1.29466	2.21772	0.78079	0.18180	0.03081
1998	0.15335	0.72932	1.15268	0.90624	0.16419	0.02507
1999	0.08325	0.69101	0.83014	0.46119	0.12145	0.01149
2000	0.97861	0.65701	0.82286	0.34360	0.11191	0.02023
2001	0.58155	1.32254	0.68046	0.31101	0.07027	0.01203
2002	0.23517	1.45273	2.00070	0.60868	0.15388	0.02424
2003	0.17203	2.10437	1.94293	0.54794	0.08988	0.01162
2004	0.24792	0.73501	2.38138	0.66680	0.07686	0.00667
2005	0.04098	1.23965	1.15597	1.47656	0.10470	0.00569
2006	0.04341	0.36553	1.19809	0.53766	0.27739	0.02297
2007	0.17976	1.03326	1.13867	1.48947	0.44634	0.05803
2008	0.14869	0.32917	0.74728	0.70471	0.39833	0.06832
2009	0.28049	0.59080	0.61187	0.61891	0.27164	0.09487
2010	0.10285	0.52922	0.62841	0.33508	0.28532	0.07176

Table 9. DFO summer research vessel survey age-disaggregated numbers per tow for the Western Component, 1984-2010.

	Age3	Age4	Age5	Age6	Age7	Age8
1984	0.545	0.951	3.308	0.913	0.097	0.284
1985	0.101	0.498	2.844	3.613	0.747	0.000
1986	1.468	1.929	1.599	3.027	1.821	0.072
1987	0.064	0.633	1.851	1.119	2.268	1.159
1988	1.651	2.277	6.218	5.278	4.043	1.984
1989	0.098	0.488	1.358	1.957	1.868	0.568
1990	15.197	6.864	10.383	2.456	0.619	0.755
1991	1.872	1.656	2.877	2.862	0.890	0.800
1992	0.364	0.989	1.341	1.061	0.223	0.143
1993	11.941	8.135	4.141	1.815	0.514	0.016
1994	0.301	1.086	2.306	1.980	0.784	0.219
1995	1.501	1.216	1.957	0.986	0.297	0.050
1996	1.142	12.519	10.772	3.475	1.531	0.133
1997	0.351	0.477	1.616	0.763	0.081	0.090
1998	0.126	0.306	0.616	0.609	0.143	0.000
1999	0.538	0.849	0.492	0.378	0.271	0.000
2000	0.480	0.439	0.795	0.216	0.000	0.029
2001	6.976	1.824	0.652	0.177	0.093	0.022
2002	1.583	0.731	0.580	0.200	0.106	0.024
2003	0.904	6.055	2.146	0.491	0.021	0.024
2004	2.462	1.438	3.659	1.347	0.313	0.000
2005	0.082	1.228	1.349	2.412	0.419	0.000
2006	0.896	10.378	22.111	8.642	3.219	0.201
2007	0.068	0.751	3.244	3.763	0.668	0.108
2008	0.210	0.489	4.298	5.222	2.008	0.134
2009	1.087	2.056	3.570	4.877	2.614	0.024
2010	0.124	0.561	0.107	0.428	0.427	0.036

Table 10. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the Base VPA model formulation with the 2010 RV included, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13
1982	16664	20867	4653	1119	2248	1991	947	404	87	102	34	1
1983	9119	13557	15625	2597	583	920	881	396	200	31	54	16
1984	11558	7425	9943	9230	1361	317	472	460	200	111	10	27
1985	7287	9459	5745	6492	5088	697	183	253	274	127	74	6
1986	7818	5962	7569	4144	3694	2250	278	116	118	136	49	34
1987	11224	6400	4735	4928	2372	1834	1057	149	62	63	74	26
1988	8603	9185	5146	3311	2580	1151	799	428	61	35	38	36
1989	12062	7027	7137	3323	1702	970	479	276	135	30	16	13
1990	13888	9791	5404	4465	1708	877	381	260	111	52	19	7
1991	10304	11328	7316	3433	2204	620	335	157	90	47	22	7
1992	5769	8384	8361	4283	1465	568	199	134	78	30	16	9
1993	5556	4682	5738	4444	2029	597	186	54	25	11	12	3
1994	8927	4545	3337	2915	1742	644	206	70	20	11	3	4
1995	6010	7263	3487	2125	1201	407	93	23	6	3	2	1
1996	3958	4899	5709	2371	892	381	75	20	4	2	2	1
1997	3530	3228	3829	3819	1305	309	86	13	3	3	1	1
1998	3356	2884	2506	2326	1648	375	62	23	7	2	1	1
1999	5908	2742	2156	1309	689	240	39	9	4	4	1	1
2000	6732	4825	2165	1319	517	186	44	13	4	2	1	1
2001	9729	5434	3427	1409	551	140	30	12	5	3	2	1
2002	4340	7951	4147	2074	643	172	34	12	6	2	1	1
2003	5489	3547	6338	2687	742	157	29	10	5	4	1	1
2004	3363	4492	2804	4018	1013	154	24	8	4	3	2	1
2005	3993	2752	3521	1807	1615	214	22	8	2	2	1	1
2006	1966	3269	2220	2126	801	299	27	7	2	2	1	1
2007	1353	1609	2650	1679	1261	340	53	6	3	2	1	1
2008	3949	1103	1255	1836	968	480	81	18	2	2	1	1
2009	786	3215	815	870	1152	409	161	21	4	1	1	1
2010		621	2329	402	451	624	195	87	10	2	1	1

Table 11. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the Base VPA model formulation with the 2010 RV included.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	4-9 F	6-9 F	6-9 u
1982	0.006	0.089	0.383	0.452	0.694	0.616	0.673	0.501	0.834	0.440	0.539	0.000	0.521	0.648	0.437
1983	0.005	0.110	0.326	0.446	0.410	0.468	0.449	0.482	0.391	0.942	0.476	0.000	0.358	0.452	0.332
1984	0.000	0.057	0.226	0.396	0.469	0.351	0.422	0.318	0.253	0.203	0.285	0.000	0.321	0.419	0.313
1985	0.001	0.023	0.127	0.364	0.616	0.718	0.256	0.566	0.504	0.763	0.578	0.000	0.375	0.615	0.420
1986	0.000	0.030	0.229	0.358	0.500	0.555	0.423	0.426	0.418	0.408	0.417	0.000	0.359	0.515	0.368
1987	0.000	0.018	0.158	0.447	0.523	0.631	0.704	0.693	0.357	0.311	0.529	0.000	0.411	0.600	0.413
1988	0.002	0.052	0.237	0.466	0.778	0.676	0.861	0.954	0.501	0.581	0.876	0.000	0.495	0.783	0.498
1989	0.009	0.063	0.269	0.465	0.463	0.734	0.410	0.712	0.745	0.249	0.690	0.000	0.386	0.553	0.388
1990	0.004	0.091	0.254	0.506	0.813	0.762	0.689	0.863	0.659	0.665	0.785	0.000	0.472	0.789	0.501
1991	0.006	0.104	0.335	0.652	1.157	0.935	0.718	0.492	0.888	0.877	0.675	0.000	0.579	1.039	0.596
1992	0.009	0.179	0.432	0.547	0.698	0.918	1.113	1.494	1.775	0.737	1.490	0.000	0.528	0.831	0.518
1993	0.001	0.139	0.477	0.736	0.947	0.865	0.781	0.799	0.624	1.082	0.786	0.000	0.662	0.916	0.552
1994	0.006	0.065	0.251	0.687	1.253	1.734	1.992	2.275	1.530	1.571	0.905	0.000	0.753	1.453	0.711
1995	0.004	0.041	0.186	0.668	0.947	1.498	1.323	1.647	1.077	0.415	0.407	0.000	0.542	1.107	0.618
1996	0.004	0.046	0.202	0.398	0.859	1.292	1.565	1.604	0.104	0.042	0.438	0.000	0.371	1.029	0.592
1997	0.002	0.053	0.298	0.640	1.047	1.412	1.128	0.462	0.132	0.478	0.049	0.000	0.587	1.112	0.619
1998	0.002	0.091	0.450	1.017	1.726	2.068	1.674	1.458	0.403	0.475	0.107	0.000	1.045	1.783	0.775
1999	0.002	0.036	0.291	0.729	1.109	1.489	0.923	0.647	0.354	0.882	0.000	0.000	0.618	1.190	0.643
2000	0.014	0.142	0.229	0.673	1.107	1.623	1.097	0.772	0.285	0.086	0.000	0.000	0.546	1.227	0.654
2001	0.002	0.070	0.302	0.585	0.964	1.209	0.692	0.531	0.513	0.331	0.427	0.000	0.464	0.993	0.580
2002	0.002	0.027	0.234	0.828	1.207	1.577	0.986	0.730	0.271	0.253	0.185	0.000	0.533	1.265	0.664
2003	0.000	0.035	0.256	0.776	1.371	1.699	1.133	0.850	0.305	0.541	0.198	0.000	0.505	1.412	0.701
2004	0.001	0.043	0.239	0.711	1.353	1.729	0.890	0.937	0.687	0.669	0.352	0.014	0.648	1.390	0.696
2005	0.000	0.015	0.305	0.613	1.486	1.879	1.020	0.992	0.263	0.006	0.007	0.000	0.698	1.523	0.726
2006	0.000	0.010	0.079	0.322	0.657	1.536	1.315	0.653	0.090	0.029	0.002	0.000	0.344	0.904	0.547
2007	0.004	0.048	0.167	0.351	0.765	1.234	0.883	0.707	0.261	0.188	0.007	0.000	0.412	0.865	0.532
2008	0.006	0.102	0.167	0.266	0.661	0.891	1.172	1.192	0.286	0.034	0.000	0.000	0.406	0.765	0.491
2009	0.036	0.122	0.506	0.456	0.414	0.544	0.420	0.509	0.768	0.008	0.008	0.010	0.463	0.446	0.329
2010	0.003	0.341	0.194	2.179	1.008	0.674	0.619	0.661	1.594	0.579	0.058	0.000	0.583	0.777	0.496

Table 12. Beginning of year biomass (t) for pollock in the Western Component from the Base VPA formulation with the 2010 RV included, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	2+	3+	4+
1982	4728	16923	7877	3344	8585	8926	4930	2405	602	831	325	11	59487	54758	37835
1983	2765	16745	25936	7659	2268	4265	4574	2426	1345	248	471	175	68878	66113	49368
1984	4163	7010	25999	25196	5046	1539	2625	2725	1328	802	89	271	76793	72630	65620
1985	2353	7630	13219	18824	16953	2918	1042	1686	1830	926	610	63	68054	65701	58071
1986	3308	5364	12167	12995	13035	9204	1389	733	852	983	404	345	60780	57472	52108
1987	2079	4106	8918	12585	7878	7551	4985	827	416	465	562	256	50628	48549	44443
1988	4921	6392	7019	8953	8786	4448	3702	2301	374	264	303	332	47795	42875	36483
1989	4413	5271	13565	8931	5901	4013	2164	1513	824	241	124	125	47084	42672	37401
1990	3524	6426	7148	12430	5722	3773	1949	1450	718	365	180	59	43744	40220	33794
1991	3773	6686	8443	8295	7247	2579	1748	961	593	352	183	75	40935	37162	30476
1992	1907	6503	11489	8525	4646	2357	1014	792	522	226	138	92	38211	36304	29801
1993	2468	2620	6704	9787	5816	2167	867	294	158	79	97	30	31085	28617	25997
1994	2762	3151	3696	4714	4632	2216	819	333	116	69	23	42	22573	19811	16660
1995	1277	3498	4126	4179	3078	1414	396	110	35	26	13	9	18162	16885	13387
1996	792	3005	5949	4626	2363	1273	338	112	25	14	19	10	18524	17732	14727
1997	720	3144	5129	8030	3629	1079	371	81	27	20	14	11	22254	21534	18390
1998	1258	1743	2434	4691	4571	1397	279	122	54	23	12	11	16594	15337	13594
1999	1309	1665	2567	2392	1907	882	190	57	32	33	11	12	11056	9748	8083
2000	1774	3364	2617	2423	1431	684	214	72	32	25	12	10	12659	10885	7520
2001	3045	2853	5069	3315	1675	544	157	80	33	23	19	10	16825	13780	10927
2002	1117	4807	4864	4387	2120	730	188	83	49	23	15	11	18393	17275	12469
2003	1208	2512	7448	5644	2216	663	160	72	39	34	15	11	20022	18814	16302
2004	690	2543	4009	7659	2760	600	131	52	29	27	19	10	18530	17840	15297
2005	906	1642	4376	3417	3981	759	106	49	20	17	14	12	15298	14392	12750
2006	689	2294	3091	4094	2022	956	116	34	17	15	15	13	13356	12668	10374
2007	302	1126	3817	3677	3205	1187	217	32	17	17	14	11	13624	13322	12196
2008	1461	851	1685	3611	2744	1616	356	90	15	14	13	12	12470	11008	10157
2009	358	2793	1358	1838	3183	1490	673	103	24	12	15	11	11858	11501	8708
2010	365	465	3610	877	1242	2216	828	392	51	10	13	14	10082	9716	9251

Table 13. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the Base VPA model formulation with the 2010 RV excluded, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13
1982	16669	20863	4658	1115	2244	1992	945	405	85	103	34	1
1983	9117	13562	15622	2600	580	917	881	394	201	29	55	16
1984	11568	7424	9946	9227	1363	315	469	461	199	112	9	28
1985	7286	9467	5744	6495	5086	699	181	251	275	126	75	5
1986	7821	5961	7575	4143	3696	2248	280	114	116	136	48	34
1987	11229	6402	4734	4933	2372	1835	1057	150	60	62	75	26
1988	8600	9189	5148	3310	2585	1151	800	428	62	34	37	36
1989	12058	7024	7140	3324	1701	974	479	277	135	31	15	13
1990	13890	9788	5402	4467	1709	876	384	260	112	52	20	6
1991	10303	11329	7314	3432	2205	621	335	159	90	48	22	8
1992	5773	8383	8362	4281	1464	569	200	134	80	30	17	9
1993	5552	4685	5737	4445	2027	596	186	54	25	12	12	3
1994	8919	4542	3339	2915	1742	643	205	70	20	11	3	5
1995	6009	7257	3485	2127	1201	408	92	22	6	4	2	1
1996	3958	4898	5704	2370	893	382	74	20	3	1	2	1
1997	3530	3228	3828	3815	1303	310	86	13	3	3	1	1
1998	3357	2885	2506	2325	1645	374	62	23	7	3	1	1
1999	5909	2742	2156	1309	688	238	38	10	5	4	1	1
2000	6738	4826	2165	1320	517	186	42	11	4	3	1	1
2001	9729	5439	3428	1409	551	140	30	11	4	3	2	1
2002	4518	7951	4151	2075	643	172	34	12	4	1	1	1
2003	6125	3693	6338	2690	743	158	29	10	4	3	1	1
2004	6378	5013	2923	4018	1015	155	23	8	4	3	1	1
2005	5631	5220	3948	1905	1615	216	23	8	3	1	1	1
2006	2374	4611	4240	2475	881	299	28	7	2	1	1	1
2007	3741	1943	3748	3333	1546	405	52	7	3	1	1	1
2008	6997	3058	1529	2735	2320	712	133	18	3	2	1	1
2009		5711	2416	1094	1888	1514	350	63	5	1	1	1
2010		4071	4372	1712	634	1224	1098	241	45	2	1	1

Table 14. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the Base VPA model formulation with the 2010 RV excluded.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	4-9 F	6-9 F	6-9 u
1982	0.006	0.089	0.383	0.453	0.695	0.615	0.675	0.498	0.863	0.431	0.538	0.000	0.521	0.649	0.437
1983	0.005	0.110	0.327	0.446	0.413	0.470	0.449	0.484	0.387	0.996	0.477	0.000	0.358	0.453	0.333
1984	0.000	0.057	0.226	0.396	0.467	0.352	0.424	0.317	0.257	0.207	0.285	0.000	0.321	0.419	0.312
1985	0.001	0.023	0.127	0.364	0.616	0.716	0.262	0.571	0.502	0.769	0.580	0.000	0.375	0.615	0.421
1986	0.000	0.030	0.229	0.358	0.500	0.555	0.423	0.439	0.429	0.401	0.421	0.000	0.359	0.515	0.368
1987	0.000	0.018	0.158	0.446	0.523	0.630	0.705	0.682	0.370	0.309	0.528	0.000	0.411	0.599	0.413
1988	0.002	0.052	0.237	0.466	0.776	0.677	0.860	0.954	0.490	0.596	0.875	0.000	0.495	0.782	0.498
1989	0.009	0.062	0.269	0.465	0.463	0.731	0.410	0.708	0.745	0.238	0.686	0.000	0.386	0.552	0.388
1990	0.004	0.091	0.254	0.506	0.812	0.762	0.682	0.860	0.651	0.651	0.779	0.000	0.471	0.787	0.500
1991	0.006	0.104	0.336	0.652	1.155	0.934	0.716	0.488	0.894	0.843	0.668	0.000	0.578	1.038	0.595
1992	0.009	0.179	0.432	0.548	0.699	0.916	1.115	1.481	1.717	0.705	1.462	0.000	0.528	0.831	0.518
1993	0.001	0.139	0.477	0.736	0.948	0.869	0.773	0.793	0.577	1.041	0.766	0.000	0.662	0.917	0.552
1994	0.006	0.065	0.251	0.686	1.253	1.740	2.025	2.238	1.423	1.400	1.021	0.000	0.753	1.456	0.711
1995	0.004	0.041	0.186	0.667	0.945	1.500	1.332	1.746	1.216	0.328	0.639	0.000	0.542	1.107	0.618
1996	0.004	0.047	0.202	0.398	0.858	1.287	1.582	1.645	0.000	0.000	0.639	0.000	0.371	1.029	0.592
1997	0.002	0.053	0.299	0.641	1.048	1.407	1.131	0.430	0.000	0.550	0.000	0.000	0.587	1.112	0.619
1998	0.002	0.091	0.450	1.017	1.734	2.092	1.672	1.412	0.398	0.550	0.000	0.000	1.047	1.792	0.777
1999	0.002	0.036	0.291	0.728	1.111	1.528	0.998	0.610	0.276	0.899	0.000	0.000	0.620	1.203	0.647
2000	0.014	0.142	0.230	0.672	1.104	1.636	1.178	0.848	0.298	0.000	0.000	0.000	0.547	1.235	0.656
2001	0.002	0.070	0.302	0.585	0.963	1.208	0.725	0.717	0.786	0.550	0.639	0.000	0.465	0.997	0.581
2002	0.002	0.027	0.234	0.828	1.206	1.576	1.001	0.814	0.298	0.000	0.000	0.000	0.533	1.266	0.664
2003	0.000	0.034	0.256	0.774	1.369	1.705	1.104	0.749	0.298	0.550	0.000	0.000	0.505	1.410	0.701
2004	0.000	0.039	0.228	0.712	1.348	1.712	0.922	0.799	0.786	0.550	0.000	0.000	0.637	1.383	0.694
2005	0.000	0.008	0.267	0.572	1.488	1.856	0.961	1.233	0.471	0.000	0.000	0.000	0.645	1.523	0.726
2006	0.000	0.007	0.041	0.270	0.576	1.542	1.218	0.612	0.000	0.000	0.000	0.000	0.233	0.829	0.518
2007	0.001	0.040	0.115	0.162	0.575	0.912	0.873	0.672	0.423	0.000	0.000	0.000	0.251	0.651	0.438
2008	0.003	0.036	0.135	0.171	0.227	0.510	0.556	1.099	0.496	0.000	0.000	0.000	0.222	0.309	0.242
2009	0.006	0.067	0.145	0.345	0.233	0.121	0.175	0.131	0.594	0.000	0.000	0.000	0.194	0.182	0.151
2010	0.003	0.047	0.100	0.301	0.644	0.306	0.093	0.205	0.229	0.980	0.000	0.000	0.203	0.292	0.231

Table 15. Beginning of year biomass (t) for pollock in the Western Component from the Base VPA model formulation with the 2010 RV excluded, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	2+	3+	4+
1982	4730	16920	7885	3332	8569	8928	4920	2409	586	840	327	11	59456	54726	37806
1983	2764	16751	25931	7670	2256	4250	4576	2417	1351	235	480	176	68857	66093	49343
1984	4167	7009	26007	25189	5056	1527	2610	2728	1321	808	80	276	76777	72611	65602
1985	2353	7636	13217	18832	16946	2927	1033	1674	1834	917	612	56	68038	65686	58049
1986	3309	5364	12177	12994	13041	9199	1395	722	842	988	398	346	60775	57466	52102
1987	2080	4107	8917	12598	7878	7557	4982	832	405	454	568	251	50629	48550	44442
1988	4919	6395	7021	8952	8801	4449	3708	2298	381	254	297	336	47811	42892	36497
1989	4411	5269	13571	8934	5899	4025	2164	1517	824	248	117	123	47102	42690	37422
1990	3525	6424	7146	12436	5725	3771	1962	1449	724	365	188	56	43770	40245	33822
1991	3773	6686	8440	8292	7251	2584	1746	974	594	358	186	78	40963	37190	30503
1992	1908	6503	11491	8522	4642	2361	1017	793	532	225	145	94	38231	36324	29821
1993	2467	2621	6703	9789	5812	2162	869	294	160	85	100	32	31095	28628	26007
1994	2759	3149	3698	4714	4633	2213	814	337	117	73	26	44	22577	19818	16669
1995	1277	3495	4124	4183	3079	1415	393	105	37	29	17	9	18163	16886	13391
1996	792	3004	5944	4622	2367	1275	337	110	21	13	23	10	18518	17726	14722
1997	720	3144	5128	8021	3624	1081	373	80	25	20	13	11	22240	21520	18377
1998	1258	1743	2434	4688	4563	1394	282	122	55	24	11	11	16585	15328	13585
1999	1309	1665	2567	2392	1905	873	185	58	34	34	11	12	11045	9736	8071
2000	1776	3365	2616	2425	1431	683	203	65	34	28	12	10	12649	10874	7508
2001	3045	2855	5071	3315	1678	546	154	71	28	23	24	10	16820	13775	10919
2002	1163	4807	4869	4388	2119	732	189	79	36	14	12	11	18418	17255	12448
2003	1348	2615	7448	5650	2218	664	161	71	34	24	12	11	20256	18908	16293
2004	1309	2838	4179	7658	2766	602	131	54	32	24	13	10	19617	18308	15470
2005	1278	3116	4907	3602	3979	765	108	47	24	17	14	12	17867	16589	13473
2006	831	3235	5905	4766	2223	954	120	37	13	14	15	13	18127	17295	14060
2007	835	1359	5399	7300	3931	1414	215	36	20	14	14	11	20550	19715	18356
2008	2589	2360	2052	5378	6579	2396	585	90	17	14	13	12	22086	19496	17136
2009	2275	4961	4026	2311	5214	5511	1461	313	27	12	15	11	26136	23861	18900
2010	365	3051	6777	3731	1745	4350	4670	1087	226	13	13	14	26042	25677	22625

Table 16. Bias adjusted statistical properties of estimates for population abundance and survey calibration constants for pollock in the Western Component using the Base VPA model formulation with the 2010 RV included.

		Analytical			
Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
Population Abundance					
3	754	701.765	0.930	322.438	0.427
4	2320	1605.069	0.692	532.146	0.229
5	140	139.339	0.993	58.599	0.418
6	266	212.227	0.799	64.645	0.243
7	410	276.183	0.674	62.845	0.153
8	142	106.263	0.750	29.338	0.207
RV Survey Calibration Constants					
1984-2010 (Ages 3-8)					
3	0.00015	0.00003	0.17549	0.00000	0.00817
4	0.00044	0.00008	0.17281	0.00000	0.00838
5	0.00119	0.00021	0.17388	0.00001	0.01250
6	0.00187	0.00032	0.17322	0.00003	0.01429
7	0.00218	0.00039	0.17705	0.00003	0.01540
8	0.00148	0.00029	0.19392	0.00003	0.01850
CPUE Calibration Constants					
1982-2004 (Ages 3-8)					
3	0.00000	0.00000	3.24630	0.00000	5.26317
4	0.00001	0.00004	3.19676	0.00006	5.10759
5	0.00010	0.00025	2.54186	0.00032	3.23024
6	0.00014	0.00026	1.82554	0.00024	1.66614
7	0.00009	0.00009	1.04060	0.00005	0.54137
8	0.00002	0.00001	0.66264	0.00000	0.21952
CPUE Power Coefficients					
1982-2004 (Ages 3-8)					
3	1.01101	0.37606	0.37197	0.00057	0.00057
4	0.85029	0.38714	0.45530	0.00017	0.00020
5	0.64252	0.33363	0.51925	0.00000	0.00000
6	0.57963	0.27310	0.47116	0.00000	0.00000
7	0.57409	0.18559	0.32328	0.00000	0.00000
8	0.80404	0.14296	0.17781	0.00000	0.00000

Table 17. Bias adjusted statistical properties of estimates for population abundance and survey calibration constants for pollock in the Western Component using the Base VPA model formulation with the 2010 RV excluded.

		Analytical			
Age	Estimate	Standard Error	Relative Error	Bias	Relative Bias
Population Abundance					
4	6043	5612.442	0.929	2467.724	0.408
5	1627	1287.794	0.791	403.562	0.248
6	480	453.611	0.944	120.242	0.250
7	988	634.047	0.642	115.722	0.117
8	981	490.304	0.500	78.753	0.080
RV Survey Calibration Constants					
1984-2009 (Ages 3-8)					
3	0.00013	0.00002	0.17515	0.00000	0.01315
4	0.00040	0.00007	0.17216	0.00001	0.01363
5	0.00114	0.00019	0.17119	0.00002	0.01491
6	0.00174	0.00030	0.17059	0.00003	0.01502
7	0.00205	0.00036	0.17394	0.00003	0.01485
8	0.00150	0.00028	0.18875	0.00002	0.01668
CPUE Calibration Constants					
1982-2004 (Ages 3-8)					
3	0.00000	0.00000	3.18439	0.00000	5.06137
4	0.00001	0.00003	3.11767	0.00005	4.85638
5	0.00010	0.00025	2.46508	0.00030	3.03804
6	0.00014	0.00025	1.77127	0.00022	1.56855
7	0.00009	0.00009	1.00838	0.00005	0.50837
8	0.00002	0.00001	0.63736	0.00000	0.20309
CPUE Power Coefficients					
1982-2004 (Ages 3-8)					
3	1.01597	0.36858	0.36279	0.00085	0.00084
4	0.85340	0.37746	0.44230	0.00034	0.00040
5	0.64294	0.32355	0.50324	0.00000	0.00000
6	0.58071	0.26498	0.45630	0.00000	0.00000
7	0.57388	0.17990	0.31348	0.00000	0.00000
8	0.79830	0.13771	0.17250	0.00000	0.00000

Table 18. Age-specific estimates of relative bias for selected stocks/species for which age-based analytical assessments are conducted using VPA models.

	Relative Bias by Stock/Species (%)				
Age	5Z Had	5Z Cod	4X5Y Cod	5Zjm Ytail	Western Pollock
1	19		19		
2	8	10	7	6	
3	6	8	5	7	
4	4	5	4	3	41
5	4	6	5	1	25
6	1	4	7		25
7	3	6	4		12
8	5	5	3		8
9		5	3		
10			4		
Avg	**6.3**	**6.1**	**6.1**	**4.3**	**22.2**

Table 19. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the VPA model formulation estimating M on ages 7-13 (1996-2010) and excluding the 2010 RV, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13
1982	16669	20864	4659	1115	2244	1992	945	405	85	103	34	1
1983	9119	13562	15622	2601	580	917	881	394	201	29	55	16
1984	11568	7426	9947	9227	1363	315	469	461	199	112	9	28
1985	7286	9467	5746	6495	5086	699	181	251	275	126	75	5
1986	7829	5961	7575	4144	3696	2249	280	114	116	136	48	34
1987	11246	6409	4734	4933	2373	1835	1057	150	60	62	75	26
1988	8641	9203	5153	3310	2585	1152	800	428	62	34	37	36
1989	12150	7057	7151	3328	1701	974	480	277	135	31	15	13
1990	14143	9864	5430	4476	1713	876	384	261	112	52	20	6
1991	11131	11537	7376	3454	2213	624	335	159	91	48	22	8
1992	6366	9061	8532	4332	1482	575	202	134	80	31	17	9
1993	6095	5170	6293	4583	2068	610	191	56	25	12	12	3
1994	9438	4986	3736	3368	1855	676	216	74	21	11	3	5
1995	6460	7681	3849	2452	1570	498	118	31	9	5	2	1
1996	4358	5268	6052	2667	1158	681	146	41	10	4	3	1
1997	3909	3555	4130	4100	1546	525	172	37	10	5	2	1
1998	3700	3195	2775	2572	1877	570	120	50	16	5	2	1
1999	6360	3023	2410	1528	888	420	87	29	14	7	2	1
2000	7101	5195	2394	1527	695	347	97	29	12	7	2	1
2001	10250	5736	3730	1597	720	284	82	30	11	5	3	1
2002	5582	8379	4394	2322	796	309	82	32	12	4	2	1
2003	8255	4564	6687	2889	943	281	71	28	12	5	2	1
2004	7974	6757	3636	4304	1177	315	62	24	11	5	2	1
2005	6327	6527	5376	2489	1847	345	80	22	9	4	2	1
2006	2563	5180	5310	3643	1357	483	62	31	8	4	2	1
2007	4066	2097	4214	4209	2502	794	99	19	14	4	2	1
2008	7734	3324	1655	3117	3037	1492	249	31	8	6	2	1
2009		6314	2634	1197	2200	2100	574	90	8	3	3	1
2010		4071	4866	1890	719	1480	950	254	41	3	2	2

Table 20. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the VPA model formulation estimating M of ages 7-13 (1996-2010) and excluding the 2010 RV.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	4-9 F	6-9 F
1982	0.006	0.089	0.383	0.453	0.695	0.615	0.675	0.498	0.863	0.431	0.538	0.000	0.521	0.649
1983	0.005	0.110	0.327	0.446	0.413	0.470	0.449	0.484	0.387	0.996	0.477	0.000	0.358	0.453
1984	0.000	0.056	0.226	0.396	0.467	0.352	0.424	0.317	0.257	0.207	0.285	0.000	0.321	0.419
1985	0.001	0.023	0.127	0.364	0.616	0.716	0.262	0.571	0.502	0.769	0.580	0.000	0.375	0.615
1986	0.000	0.030	0.229	0.358	0.500	0.555	0.422	0.439	0.429	0.400	0.421	0.000	0.359	0.515
1987	0.000	0.018	0.158	0.446	0.523	0.630	0.705	0.681	0.370	0.309	0.528	0.000	0.411	0.599
1988	0.002	0.052	0.237	0.466	0.776	0.676	0.859	0.953	0.490	0.595	0.875	0.000	0.495	0.782
1989	0.008	0.062	0.268	0.464	0.463	0.731	0.409	0.708	0.744	0.237	0.686	0.000	0.385	0.551
1990	0.004	0.091	0.252	0.505	0.809	0.762	0.682	0.858	0.650	0.650	0.777	0.000	0.469	0.785
1991	0.006	0.102	0.332	0.646	1.148	0.927	0.716	0.488	0.888	0.842	0.667	0.000	0.573	1.032
1992	0.008	0.165	0.421	0.539	0.687	0.901	1.091	1.481	1.717	0.694	1.460	0.000	0.517	0.817
1993	0.001	0.125	0.425	0.704	0.918	0.837	0.744	0.753	0.577	1.041	0.742	0.000	0.616	0.886
1994	0.006	0.059	0.221	0.563	1.116	1.543	1.734	1.893	1.225	1.400	1.021	0.000	0.640	1.286
1995	0.004	0.038	0.167	0.550	0.635	1.024	0.865	0.893	0.646	0.239	0.639	0.000	0.426	0.738
1996	0.004	0.043	0.189	0.345	0.591	0.693	0.692	0.672	0.000	0.000	0.517	0.000	0.312	0.634
1997	0.002	0.048	0.274	0.581	0.797	0.791	0.547	0.160	0.000	0.297	0.000	0.000	0.501	0.767
1998	0.002	0.082	0.397	0.864	1.296	1.193	0.734	0.558	0.189	0.297	0.000	0.000	0.823	1.234
1999	0.002	0.033	0.256	0.587	0.740	0.786	0.416	0.209	0.100	0.520	0.000	0.000	0.475	0.723
2000	0.013	0.131	0.205	0.551	0.694	0.757	0.472	0.329	0.123	0.000	0.000	0.000	0.419	0.686
2001	0.002	0.067	0.274	0.496	0.646	0.560	0.265	0.254	0.299	0.297	0.517	0.000	0.383	0.585
2002	0.001	0.025	0.219	0.701	0.841	0.784	0.400	0.297	0.123	0.000	0.000	0.000	0.447	0.783
2003	0.000	0.027	0.241	0.698	0.895	0.830	0.417	0.282	0.123	0.297	0.000	0.000	0.435	0.843
2004	0.000	0.029	0.179	0.646	1.026	0.688	0.336	0.262	0.299	0.297	0.000	0.000	0.513	0.920
2005	0.000	0.006	0.189	0.407	1.140	1.030	0.251	0.363	0.162	0.000	0.000	0.000	0.445	1.085
2006	0.000	0.006	0.033	0.176	0.336	0.898	0.493	0.141	0.000	0.000	0.000	0.000	0.160	0.479
2007	0.001	0.037	0.102	0.126	0.317	0.475	0.477	0.240	0.105	0.000	0.000	0.000	0.184	0.358
2008	0.003	0.033	0.124	0.148	0.169	0.271	0.333	0.639	0.198	0.000	0.000	0.000	0.176	0.212
2009	0.006	0.060	0.132	0.310	0.197	0.108	0.130	0.113	0.396	0.000	0.000	0.000	0.166	0.150
2010	0.003	0.047	0.090	0.270	0.553	0.293	0.126	0.228	0.302	0.854	0.000	0.000	0.192	0.296

Table 21. Beginning of year biomass (t) for pollock in the Western Component from the VPA model formulation estimating M of ages 7-13 (1996-2010) and excluding the 2010 RV, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	2+	3+	4+
1982	4730	16920	7886	3332	8569	8928	4920	2409	586	840	327	11	59457	54727	37807
1983	2765	16751	25931	7670	2256	4251	4576	2417	1351	235	480	176	68859	66095	49344
1984	4167	7010	26007	25189	5056	1527	2610	2728	1321	808	80	276	76780	72614	65603
1985	2353	7636	13220	18832	16947	2928	1033	1674	1834	918	612	56	68043	65690	58054
1986	3312	5364	12177	12997	13041	9199	1396	722	842	988	398	346	60783	57471	52107
1987	2083	4112	8917	12598	7881	7557	4983	832	405	454	568	251	50641	48558	44447
1988	4942	6405	7029	8952	8801	4452	3708	2299	381	254	297	337	47856	42913	36509
1989	4445	5294	13593	8946	5899	4025	2166	1517	824	248	117	123	47198	42753	37459
1990	3589	6473	7182	12462	5738	3771	1962	1452	724	365	188	56	43962	40373	33900
1991	4077	6809	8511	8346	7276	2596	1746	974	597	358	186	79	41555	37478	30669
1992	2104	7029	11724	8622	4700	2387	1029	793	532	228	145	94	39386	37282	30253
1993	2708	2893	7352	10095	5930	2216	892	305	160	85	102	32	32769	30061	27168
1994	2920	3457	4138	5446	4933	2327	861	356	126	73	26	46	24710	21790	18333
1995	1373	3700	4555	4822	4024	1728	503	149	55	38	17	9	20972	19599	15899
1996	872	3231	6306	5203	3067	2272	663	224	71	33	33	10	21985	21113	17882
1997	797	3463	5533	8620	4301	1829	743	235	84	40	21	11	25676	24878	21416
1998	1386	1930	2695	5187	5205	2125	543	269	130	50	18	11	19548	18162	16232
1999	1409	1835	2870	2792	2457	1543	426	175	108	61	19	12	13707	12298	10463
2000	1872	3622	2894	2807	1924	1275	465	165	95	65	20	10	15214	13342	9720
2001	3209	3012	5518	3757	2191	1105	427	201	74	48	34	10	19586	16378	13366
2002	1437	5065	5154	4910	2624	1313	450	213	100	38	20	11	21335	19898	14834
2003	1817	3233	7859	6069	2816	1183	392	190	95	49	19	11	23733	21916	18684
2004	1636	3825	5199	8203	3207	1227	344	161	85	49	22	10	23968	22332	18507
2005	1436	3896	6681	4706	4552	1223	377	136	74	44	23	12	23159	21723	17827
2006	897	3635	7395	7016	3424	1545	269	163	57	37	25	13	24475	23577	19943
2007	907	1467	6071	9219	6361	2770	409	104	85	38	23	11	27465	26557	25090
2008	2862	2565	2221	6128	8611	5021	1093	156	47	50	22	12	28789	25927	23362
2009	2275	5485	4389	2530	6077	7646	2394	449	45	27	34	11	31361	29086	23601
2010	365	3051	7543	4120	1978	5258	4042	1147	203	16	18	19	27760	27395	24343

Table 22. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the VPA model formulation estimating M of ages 5-6 and 7-13 separately (1996-2010) and excluding the 2010 RV, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13
1982	16669	20864	4659	1115	2244	1992	945	405	85	103	34	1
1983	9119	13562	15622	2601	580	917	881	394	201	29	55	16
1984	11568	7425	9946	9227	1363	315	469	461	199	112	9	28
1985	7286	9467	5745	6495	5086	699	181	251	275	126	75	5
1986	7828	5961	7575	4144	3696	2248	280	114	116	136	48	34
1987	11244	6408	4734	4933	2373	1835	1057	150	60	62	75	26
1988	8633	9201	5152	3310	2585	1152	800	428	62	34	37	36
1989	12131	7051	7150	3328	1701	974	479	277	135	31	15	13
1990	14089	9848	5424	4475	1712	876	384	261	112	52	20	6
1991	10962	11493	7363	3450	2212	624	335	159	91	48	22	8
1992	7073	8922	8496	4321	1479	574	202	134	80	30	17	9
1993	9320	5750	6179	4554	2060	608	190	55	25	12	12	3
1994	13292	7627	4211	3275	1831	670	214	74	21	11	3	5
1995	8590	10836	6011	2840	1494	479	113	30	9	5	2	1
1996	5870	7011	8635	4437	1474	620	131	36	9	4	3	1
1997	5493	4793	5558	6214	1951	481	154	32	9	5	2	1
1998	5372	4492	3788	3740	2263	530	107	44	14	5	2	1
1999	8403	4392	3472	2356	1104	381	76	25	13	6	2	1
2000	9732	6868	3515	2396	862	310	84	25	10	6	2	1
2001	14270	7890	5099	2514	905	252	70	26	9	5	3	1
2002	8116	11670	6157	3442	985	279	71	27	10	4	2	1
2003	11818	6639	9382	4332	1144	253	61	24	10	5	2	1
2004	11863	9674	5335	6508	1453	274	53	20	9	5	2	1
2005	8792	9711	7764	3879	2270	318	65	19	8	4	2	1
2006	3174	7199	7917	5598	1607	450	55	25	7	4	2	1
2007	4949	2598	5867	6343	2722	638	91	17	11	4	2	1
2008	9489	4047	2065	4469	3195	1066	185	29	7	5	2	1
2009		7751	3226	1533	2200	1464	385	62	8	3	3	1
2010		4071	6043	2374	641	963	669	169	28	3	2	2

Table 23. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the VPA model formulation estimating M of ages 5-6 and 7-13 separately (1996-2010) and excluding the 2010 RV.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11	Age12	Age13	4-9 F	6-9 F
1982	0.006	0.089	0.383	0.453	0.695	0.615	0.675	0.498	0.863	0.431	0.538	0.000	0.521	0.649
1983	0.005	0.110	0.327	0.446	0.413	0.470	0.449	0.484	0.387	0.996	0.477	0.000	0.358	0.453
1984	0.000	0.056	0.226	0.396	0.467	0.352	0.424	0.317	0.257	0.207	0.285	0.000	0.321	0.419
1985	0.001	0.023	0.127	0.364	0.616	0.716	0.262	0.571	0.502	0.769	0.580	0.000	0.375	0.615
1986	0.000	0.030	0.229	0.358	0.500	0.555	0.422	0.439	0.429	0.400	0.421	0.000	0.359	0.515
1987	0.000	0.018	0.158	0.446	0.523	0.630	0.705	0.681	0.370	0.309	0.528	0.000	0.411	0.599
1988	0.002	0.052	0.237	0.466	0.776	0.676	0.859	0.953	0.490	0.596	0.875	0.000	0.495	0.782
1989	0.008	0.062	0.269	0.464	0.463	0.731	0.409	0.708	0.744	0.237	0.686	0.000	0.385	0.551
1990	0.004	0.091	0.253	0.505	0.810	0.762	0.682	0.858	0.651	0.651	0.778	0.000	0.470	0.786
1991	0.006	0.102	0.333	0.647	1.149	0.928	0.716	0.488	0.889	0.843	0.667	0.000	0.574	1.033
1992	0.007	0.167	0.424	0.541	0.689	0.904	1.095	1.481	1.717	0.695	1.460	0.000	0.519	0.819
1993	0.000	0.112	0.435	0.711	0.924	0.843	0.748	0.758	0.577	1.041	0.745	0.000	0.625	0.892
1994	0.004	0.038	0.194	0.585	1.142	1.580	1.781	1.942	1.248	1.400	1.021	0.000	0.623	1.317
1995	0.003	0.027	0.104	0.456	0.680	1.096	0.932	0.981	0.701	0.249	0.639	0.000	0.328	0.792
1996	0.003	0.032	0.129	0.235	0.534	0.766	0.784	0.762	0.000	0.000	0.530	0.000	0.231	0.616
1997	0.001	0.035	0.196	0.423	0.715	0.872	0.614	0.183	0.000	0.320	0.000	0.000	0.391	0.732
1998	0.001	0.058	0.275	0.633	1.195	1.312	0.835	0.636	0.209	0.320	0.000	0.000	0.661	1.194
1999	0.002	0.023	0.171	0.418	0.681	0.879	0.477	0.241	0.113	0.557	0.000	0.000	0.365	0.712
2000	0.010	0.098	0.135	0.387	0.643	0.861	0.543	0.377	0.138	0.000	0.000	0.000	0.317	0.684
2001	0.001	0.048	0.193	0.350	0.591	0.636	0.308	0.293	0.338	0.320	0.530	0.000	0.292	0.578
2002	0.001	0.018	0.152	0.514	0.773	0.884	0.461	0.341	0.138	0.000	0.000	0.000	0.342	0.771
2003	0.000	0.019	0.166	0.505	0.843	0.941	0.486	0.324	0.138	0.320	0.000	0.000	0.328	0.836
2004	0.000	0.020	0.119	0.466	0.931	0.814	0.394	0.305	0.338	0.320	0.000	0.000	0.386	0.891
2005	0.000	0.004	0.127	0.294	1.032	1.137	0.310	0.428	0.184	0.000	0.000	0.000	0.340	1.023
2006	0.000	0.005	0.022	0.134	0.337	0.972	0.566	0.172	0.000	0.000	0.000	0.000	0.124	0.474
2007	0.001	0.030	0.072	0.099	0.350	0.610	0.519	0.276	0.125	0.000	0.000	0.000	0.156	0.402
2008	0.002	0.027	0.098	0.122	0.193	0.389	0.462	0.686	0.222	0.000	0.000	0.000	0.171	0.254
2009	0.006	0.049	0.107	0.284	0.238	0.155	0.194	0.163	0.416	0.000	0.000	0.000	0.182	0.203
2010	0.003	0.047	0.072	0.240	0.733	0.466	0.179	0.348	0.446	0.868	0.000	0.000	0.194	0.449

Table 24. Beginning of year biomass (t) for pollock in the Western Component from the VPA model formulation estimating M of ages 5-6 and 7-13 separately (1996-2010) and excluding the 2010 RV, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 13	2+	3+	4+
1982	4730	16920	7886	3332	8569	8928	4920	2409	586	840	327	11	59457	54727	37807
1983	2765	16751	25931	7670	2256	4251	4576	2417	1351	235	480	176	68859	66094	49344
1984	4167	7010	26007	25189	5056	1527	2610	2728	1321	808	80	276	76780	72613	65603
1985	2353	7636	13220	18832	16947	2927	1033	1674	1834	917	612	56	68042	65690	58053
1986	3312	5364	12177	12997	13041	9199	1396	722	842	988	398	346	60782	57470	52106
1987	2082	4111	8917	12598	7881	7557	4983	832	405	454	568	251	50639	48557	44446
1988	4938	6403	7028	8952	8801	4452	3708	2299	381	254	297	337	47848	42910	36507
1989	4438	5289	13589	8945	5899	4025	2166	1517	824	248	117	123	47180	42742	37453
1990	3576	6463	7175	12458	5736	3771	1962	1452	724	365	188	56	43925	40349	33886
1991	4014	6783	8497	8336	7272	2595	1746	974	596	358	186	79	41435	37421	30638
1992	2338	6921	11675	8601	4689	2382	1027	793	532	227	145	94	39424	37086	30165
1993	4141	3217	7219	10029	5906	2205	888	303	160	85	101	32	34288	30147	26930
1994	4112	5288	4664	5296	4869	2303	852	353	125	73	26	46	28007	23895	18607
1995	1825	5219	7113	5585	3830	1661	480	141	52	37	17	9	25970	24144	18925
1996	1174	4300	8998	8655	3905	2067	593	200	61	29	32	10	30025	28851	24551
1997	1120	4669	7445	13064	5425	1676	664	203	72	37	20	11	34405	33285	28616
1998	2013	2714	3679	7541	6276	1975	486	238	116	46	17	11	25111	23098	20384
1999	1861	2667	4134	4306	3055	1399	372	150	94	57	18	12	18124	16262	13595
2000	2565	4789	4249	4403	2386	1142	406	144	83	59	19	10	20256	17691	12902
2001	4467	4142	7543	5915	2752	980	365	173	65	44	33	10	26490	22023	17881
2002	2089	7054	7223	7279	3248	1183	391	185	87	34	19	11	28803	26714	19660
2003	2601	4702	11025	9100	3417	1065	338	164	83	45	18	11	32570	29969	25267
2004	2435	5477	7628	12405	3960	1065	294	137	74	44	21	10	33550	31116	25639
2005	1995	5797	9649	7334	5595	1128	306	116	64	39	21	12	32054	30059	24263
2006	1112	5051	11026	10779	4055	1437	236	132	48	33	23	13	33943	32832	27780
2007	1104	1818	8452	13895	6920	2226	374	90	70	34	21	11	35015	33910	32093
2008	3512	3123	2772	8789	9058	3586	812	145	41	43	21	12	31913	28401	25278
2009	2275	6734	5376	3239	6075	5328	1608	310	42	24	31	11	31053	28778	22044
2010	365	3051	9366	5176	1765	3423	2846	764	142	16	17	18	26949	26584	23532

Table 25. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the VPA model formulation with standard partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9
1982	16725	21153	4688	1089	2218	1849	926	319
1983	9223	13607	15859	2625	559	896	765	379
1984	11361	7511	9984	9421	1383	297	452	366
1985	7434	9298	5815	6525	5244	715	167	237
1986	7814	6082	7437	4201	3721	2377	293	102
1987	11253	6396	4833	4820	2420	1856	1162	161
1988	8605	9209	5143	3391	2492	1190	817	513
1989	12063	7028	7156	3320	1767	899	511	291
1990	13858	9792	5406	4480	1706	930	323	286
1991	10287	11303	7317	3435	2216	619	378	110
1992	5754	8370	8341	4284	1466	577	198	169
1993	5536	4670	5727	4427	2029	598	193	52
1994	8905	4529	3327	2906	1728	645	206	76
1995	5993	7245	3474	2116	1194	396	94	23
1996	3941	4885	5694	2361	885	376	66	21
1997	3518	3214	3817	3808	1296	303	82	6
1998	3351	2875	2495	2316	1639	368	57	19
1999	5897	2737	2148	1300	681	233	33	5
2000	6734	4816	2161	1313	510	180	38	8
2001	9796	5436	3420	1406	546	134	25	8
2002	4573	8007	4148	2068	640	168	30	8
2003	6336	3737	6383	2688	737	156	26	7
2004	7271	5185	2960	4055	1014	150	22	5
2005	6236	5951	4089	1935	1644	215	19	6
2006	2396	5106	4839	2591	905	322	27	4
2007	3780	1961	4153	3823	1641	425	71	6
2008	7066	3090	1543	3067	2721	789	149	33
2009		5767	2443	1106	2159	1842	413	76
2010		4071	4418	1733	644	1446	1366	292

Table 26. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the VPA model formulation with standard partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	4-9 F	6-9 F
1982	0.006	0.088	0.380	0.467	0.707	0.682	0.694	0.686	0.539	0.695
1983	0.005	0.110	0.321	0.441	0.432	0.484	0.538	0.509	0.357	0.492
1984	0.000	0.056	0.225	0.386	0.459	0.377	0.444	0.417	0.319	0.441
1985	0.001	0.023	0.125	0.362	0.591	0.693	0.288	0.617	0.368	0.596
1986	0.000	0.030	0.234	0.352	0.496	0.516	0.400	0.503	0.356	0.499
1987	0.000	0.018	0.154	0.460	0.510	0.621	0.617	0.620	0.404	0.572
1988	0.002	0.052	0.238	0.452	0.820	0.646	0.833	0.722	0.489	0.771
1989	0.009	0.062	0.268	0.466	0.442	0.823	0.379	0.662	0.385	0.550
1990	0.004	0.091	0.254	0.504	0.814	0.699	0.881	0.746	0.470	0.782
1991	0.006	0.104	0.335	0.651	1.145	0.940	0.604	0.813	0.577	1.034
1992	0.009	0.179	0.433	0.547	0.697	0.895	1.136	0.957	0.524	0.799
1993	0.001	0.139	0.478	0.741	0.946	0.865	0.733	0.832	0.663	0.913
1994	0.006	0.065	0.252	0.689	1.273	1.728	1.980	1.789	0.754	1.453
1995	0.004	0.041	0.186	0.672	0.954	1.599	1.294	1.541	0.548	1.131
1996	0.004	0.047	0.202	0.400	0.871	1.326	2.247	1.462	0.377	1.074
1997	0.002	0.053	0.300	0.643	1.058	1.474	1.249	1.427	0.593	1.143
1998	0.002	0.091	0.452	1.024	1.751	2.200	2.144	2.193	1.065	1.845
1999	0.002	0.037	0.292	0.736	1.132	1.604	1.246	1.559	0.631	1.254
2000	0.014	0.142	0.230	0.677	1.133	1.771	1.423	1.710	0.558	1.310
2001	0.002	0.070	0.303	0.587	0.979	1.313	0.935	1.254	0.470	1.043
2002	0.002	0.027	0.234	0.832	1.215	1.674	1.308	1.619	0.538	1.313
2003	0.000	0.033	0.254	0.775	1.390	1.761	1.399	1.709	0.505	1.455
2004	0.000	0.037	0.225	0.702	1.352	1.844	1.033	1.741	0.633	1.410
2005	0.000	0.007	0.256	0.560	1.430	1.886	1.279	1.836	0.623	1.482
2006	0.000	0.007	0.036	0.257	0.556	1.312	1.307	1.312	0.208	0.768
2007	0.001	0.040	0.103	0.140	0.532	0.846	0.564	0.805	0.221	0.596
2008	0.003	0.035	0.133	0.151	0.190	0.448	0.479	0.453	0.196	0.259
2009	0.006	0.066	0.143	0.341	0.201	0.099	0.146	0.107	0.175	0.152
2010	0.003	0.047	0.099	0.297	0.632	0.255	0.074	0.167	0.190	0.247

Table 27. Beginning of year biomass (t) for pollock in the Western Component from the Base VPA model formulation with standard partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	2+	3+	4+
1982	4746	17155	7936	3253	8470	8288	4822	1897	56566	51820	34665
1983	2796	16807	26325	7741	2172	4153	3974	2323	66291	63495	46688
1984	4092	7091	26105	25718	5129	1442	2514	2168	74260	70167	63077
1985	2400	7500	13381	18921	17474	2995	951	1580	65202	62802	55302
1986	3306	5472	11955	13177	13130	9726	1461	648	58873	55568	50096
1987	2084	4104	9103	12309	8036	7641	5477	891	49644	47560	43457
1988	4922	6409	7015	9170	8486	4599	3785	2757	47143	42221	35812
1989	4413	5272	13601	8924	6128	3716	2306	1590	45950	41537	36265
1990	3517	6426	7151	12472	5715	4002	1652	1593	42527	39011	32584
1991	3767	6671	8444	8299	7286	2573	1974	672	39686	35919	29248
1992	1902	6493	11461	8527	4650	2397	1006	1003	37438	35536	29043
1993	2460	2613	6691	9750	5818	2169	901	285	30687	28227	25615
1994	2755	3140	3684	4700	4595	2219	820	364	22276	19521	16382
1995	1273	3489	4111	4163	3061	1376	398	111	17983	16710	13220
1996	788	2996	5934	4605	2344	1256	297	116	18336	17548	14552
1997	717	3131	5113	8005	3604	1057	354	36	22017	21300	18169
1998	1256	1737	2423	4670	4545	1372	257	103	16364	15108	13371
1999	1306	1662	2558	2375	1885	855	163	33	10838	9532	7869
2000	1775	3358	2612	2413	1411	661	185	45	12459	10684	7326
2001	3066	2854	5058	3307	1661	523	131	50	16651	13584	10731
2002	1177	4840	4866	4373	2111	713	163	54	18297	17120	12280
2003	1394	2647	7501	5646	2201	655	142	45	20232	18838	16190
2004	1492	2936	4232	7729	2762	585	122	35	19892	18400	15465
2005	1415	3552	5082	3659	4053	760	92	39	18653	17238	13686
2006	839	3583	6738	4989	2285	1030	116	23	19602	18763	15180
2007	844	1372	5983	8374	4171	1484	292	32	22552	21709	20337
2008	2615	2385	2072	6030	7716	2655	656	167	24295	21680	19295
2009	2275	5010	4070	2337	5964	6705	1722	378	28461	26186	21176
2010	365	3051	6848	3778	1772	5139	5813	1318	28086	27720	24669

Table 28. Beginning of year population abundance numbers (000's) for pollock in the Western Component from the VPA model formulation with domed partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV, using analytical bias adjusted population abundance.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9
1982	18670	24423	5571	1586	3287	3834	2680	1410
1983	10815	15200	18536	3346	965	1766	2386	1811
1984	11898	8814	11287	11610	1972	629	1163	1691
1985	8096	9737	6882	7592	7032	1197	438	819
1986	7998	6624	7796	5075	4592	3836	685	325
1987	11424	6548	5277	5114	3134	2567	2353	482
1988	8663	9349	5267	3755	2732	1773	1396	1486
1989	12119	7075	7271	3421	2064	1093	986	763
1990	13873	9838	5444	4574	1789	1172	481	675
1991	10322	11316	7355	3466	2292	686	576	238
1992	5769	8399	8351	4315	1492	639	252	330
1993	5557	4682	5750	4436	2054	618	243	96
1994	8929	4546	3336	2925	1735	665	223	116
1995	6013	7265	3488	2124	1210	402	109	36
1996	3958	4901	5710	2372	891	389	70	34
1997	3533	3228	3831	3821	1305	309	92	9
1998	3370	2887	2506	2327	1650	376	61	27
1999	5925	2753	2158	1309	690	241	39	9
2000	6787	4839	2173	1321	517	187	45	12
2001	10164	5479	3439	1416	553	140	31	13
2002	5183	8308	4184	2084	648	173	34	13
2003	8122	4237	6629	2717	750	162	30	10
2004	8884	6648	3369	4256	1037	160	27	8
2005	7021	7272	5287	2270	1808	233	27	11
2006	2499	5748	5920	3570	1178	453	41	11
2007	3927	2045	4679	4708	2442	648	176	18
2008	7191	3210	1612	3497	3446	1443	331	119
2009		5869	2541	1162	2512	2435	948	224
2010		4071	4502	1814	690	1735	1852	730

Table 29. Bias adjusted (analytical) fishing mortality rate for pollock in the Western Component from the VPA model formulation with domed partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV.

Year	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	4-9 F	6-9 F
1982	0.006	0.076	0.310	0.297	0.421	0.274	0.192	0.120	0.289	0.278
1983	0.005	0.098	0.268	0.329	0.228	0.217	0.144	0.088	0.249	0.160
1984	0.000	0.047	0.197	0.301	0.300	0.161	0.151	0.077	0.237	0.183
1985	0.001	0.022	0.105	0.303	0.406	0.358	0.100	0.144	0.270	0.363
1986	0.000	0.027	0.222	0.282	0.382	0.289	0.152	0.134	0.276	0.319
1987	0.000	0.018	0.140	0.427	0.370	0.409	0.260	0.169	0.308	0.340
1988	0.002	0.051	0.231	0.399	0.716	0.387	0.405	0.197	0.379	0.474
1989	0.009	0.062	0.263	0.448	0.365	0.621	0.179	0.206	0.334	0.360
1990	0.004	0.091	0.252	0.491	0.759	0.511	0.504	0.255	0.423	0.576
1991	0.006	0.104	0.333	0.643	1.078	0.801	0.356	0.299	0.546	0.869
1992	0.009	0.179	0.433	0.542	0.681	0.767	0.768	0.384	0.506	0.673
1993	0.001	0.139	0.476	0.739	0.928	0.820	0.535	0.370	0.651	0.856
1994	0.006	0.065	0.251	0.683	1.263	1.604	1.614	0.803	0.727	1.355
1995	0.004	0.041	0.186	0.668	0.934	1.549	0.981	0.714	0.536	1.073
1996	0.004	0.046	0.202	0.398	0.861	1.243	1.851	0.668	0.370	1.014
1997	0.002	0.053	0.298	0.640	1.045	1.421	1.014	0.664	0.586	1.109
1998	0.002	0.091	0.450	1.016	1.723	2.065	1.755	1.011	1.043	1.775
1999	0.002	0.036	0.291	0.728	1.106	1.482	0.948	0.704	0.617	1.189
2000	0.014	0.142	0.229	0.672	1.104	1.608	1.056	0.751	0.543	1.219
2001	0.002	0.070	0.301	0.581	0.960	1.209	0.690	0.558	0.463	0.990
2002	0.001	0.026	0.232	0.822	1.186	1.558	1.003	0.733	0.528	1.246
2003	0.000	0.029	0.243	0.763	1.343	1.590	1.062	0.754	0.484	1.370
2004	0.000	0.029	0.195	0.656	1.291	1.573	0.741	0.726	0.572	1.312
2005	0.000	0.006	0.193	0.456	1.185	1.533	0.735	0.725	0.475	1.216
2006	0.000	0.006	0.029	0.180	0.398	0.744	0.647	0.368	0.148	0.497
2007	0.001	0.038	0.091	0.112	0.326	0.473	0.192	0.206	0.165	0.347
2008	0.003	0.034	0.127	0.131	0.147	0.221	0.190	0.107	0.150	0.169
2009	0.006	0.065	0.137	0.321	0.170	0.074	0.061	0.035	0.142	0.110
2010	0.003	0.047	0.097	0.282	0.581	0.210	0.054	0.065	0.164	0.182

Table 30. Beginning of year biomass (t) for pollock in the Western Component from the VPA model formulation with domed partial recruitment, truncated catch at age (2-9), and excluding the 2010 RV, using the analytical bias adjusted population abundance at the beginning of 2010.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	2+	3+	4+
1982	5297	19807	9430	4740	12550	17188	13952	8392	91357	86059	66252
1983	3279	18774	30768	9869	3753	8189	12389	11111	98131	94853	76079
1984	4285	8321	29513	31693	7314	3055	6472	10016	100671	96385	88064
1985	2614	7854	15836	22012	23433	5009	2501	5455	84715	82101	74247
1986	3384	5960	12533	15916	16204	15693	3418	2055	75164	71779	65819
1987	2116	4201	9940	13060	10407	10569	11093	2669	64055	61939	57738
1988	4955	6506	7184	10153	9304	6852	6472	7984	59410	54455	47949
1989	4434	5307	13819	9196	7157	4520	4452	4174	53059	48625	43318
1990	3521	6456	7202	12733	5992	5045	2459	3757	47165	43644	37187
1991	3780	6678	8487	8375	7538	2852	3003	1459	42172	38392	31713
1992	1906	6515	11476	8588	4731	2651	1281	1956	39104	37198	30683
1993	2469	2619	6718	9769	5890	2245	1133	524	31368	28899	26279
1994	2762	3151	3695	4731	4614	2288	887	557	22685	19923	16772
1995	1278	3499	4128	4178	3101	1395	465	173	18218	16940	13441
1996	792	3006	5951	4627	2362	1299	317	185	18537	17746	14740
1997	720	3144	5131	8033	3630	1076	398	57	22188	21468	18324
1998	1263	1744	2434	4693	4575	1400	276	146	16531	15268	13524
1999	1313	1672	2569	2392	1910	886	191	52	10983	9671	7999
2000	1789	3374	2627	2427	1431	687	216	71	12623	10834	7460
2001	3182	2877	5087	3331	1681	546	160	85	16947	13765	10889
2002	1334	5022	4908	4406	2138	735	188	85	18817	17482	12461
2003	1788	3001	7790	5707	2239	683	164	71	21444	19656	16655
2004	1823	3764	4817	8113	2826	623	151	58	22175	20352	16588
2005	1593	4341	6570	4292	4457	827	129	65	22273	20680	16339
2006	875	4033	8245	6875	2974	1446	179	55	24682	23807	19774
2007	876	1431	6741	10313	6209	2261	725	96	28652	27776	26345
2008	2661	2477	2164	6877	9771	4857	1451	598	30856	28195	25718
2009	2275	5099	4234	2455	6937	8864	3954	1117	34935	32660	27561
2010	365	3051	6978	3953	1899	6163	7878	3295	33584	33219	30167

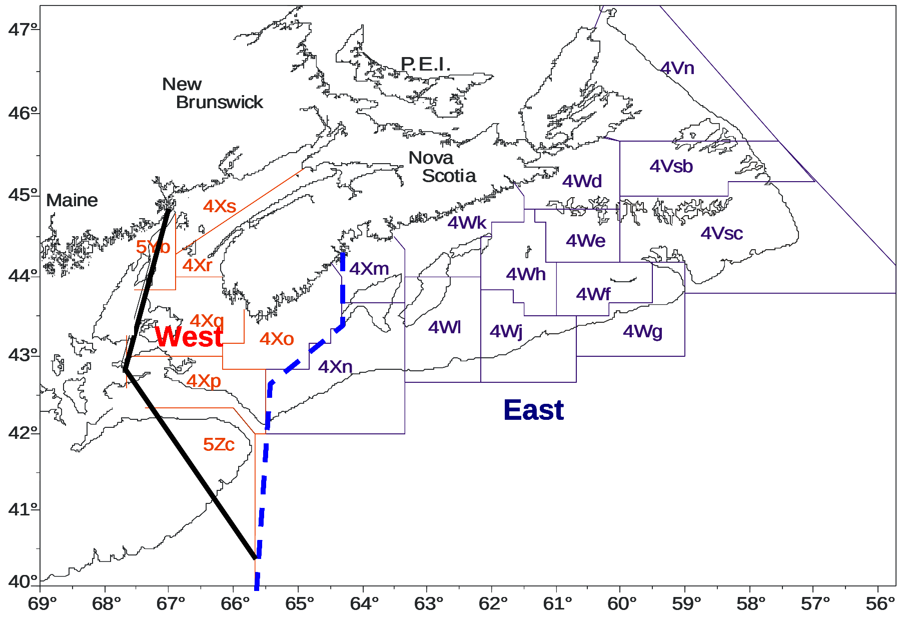


Fig 1. Canadian pollock management unit showing the Western (4Xopqrs5) and Eastern Component (4VW+4Xmn) areas. Dashed line separates Western and Eastern Components; solid line is the Canada/USA international boundary.

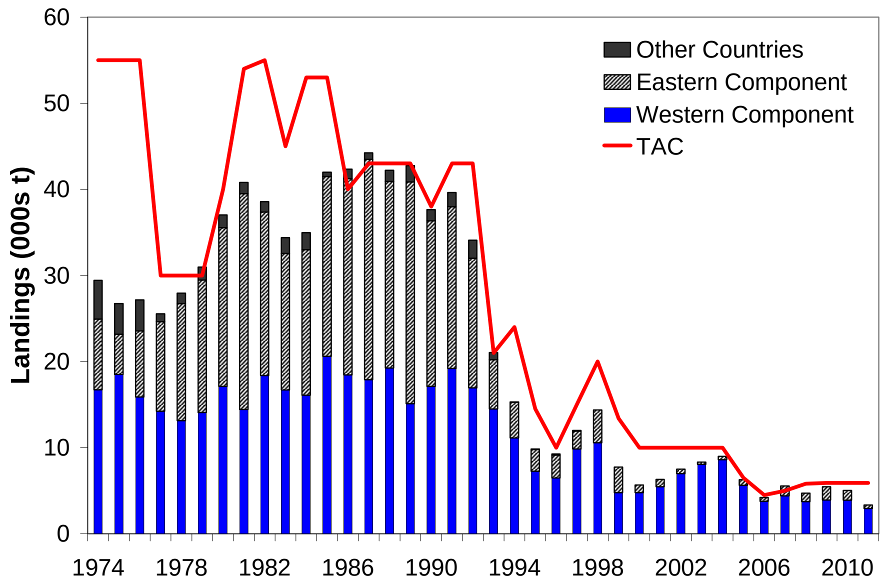


Fig. 2. Landings of 4VWX5 pollock shown with respect to the total allowable catch (TAC). The striped bar in 2010 signifies incomplete landings. Prior to 1999, the quota year was Jan. 1 to Dec. 31. In 1999, the quota year was Jan. 1, 1999, to Mar. 31, 2000. Subsequently, it is Apr. 1 to Mar. 31. All landings are shown for quota years. (2005-2007 TAC is for 4X only).

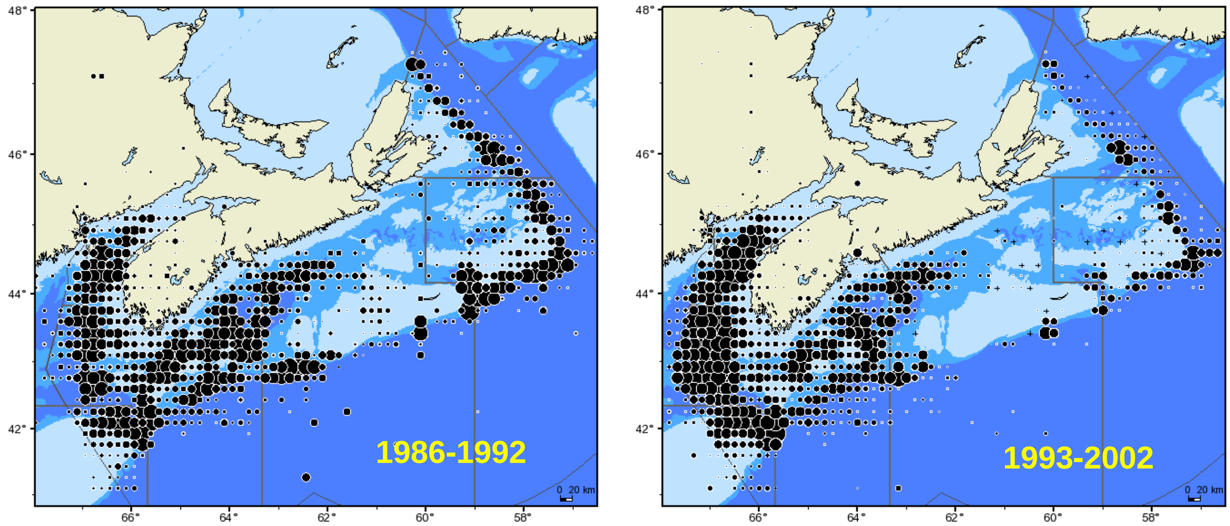


Fig. 3. Distribution of Canadian pollock catches (t) for 1986 to1992 (left panel) and 1993 to 2002 (right panel) aggregated by 10 minute squares for all gear types.

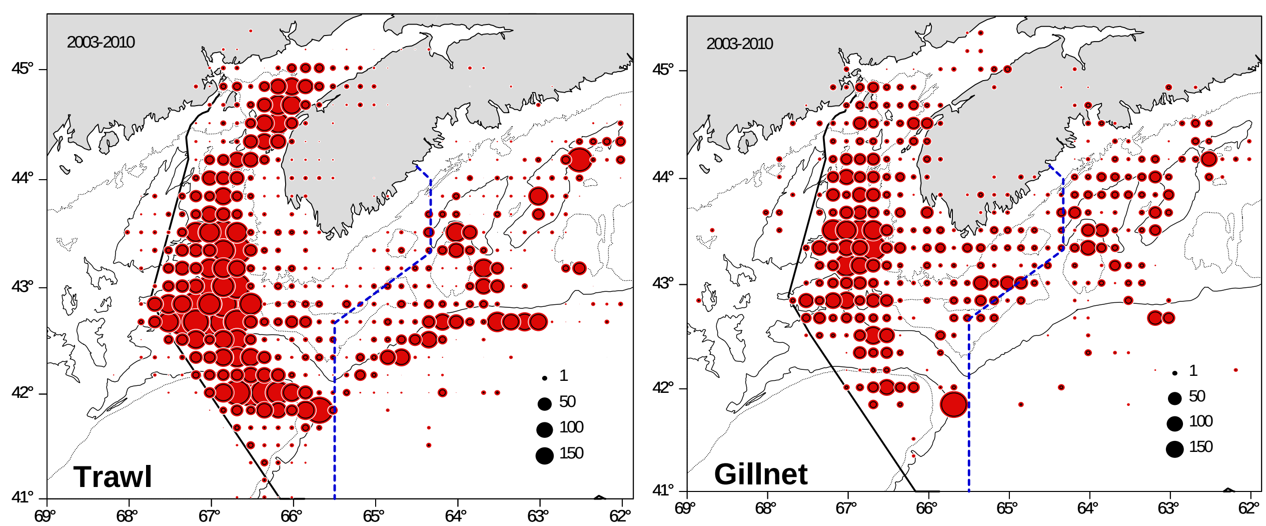


Fig. 4. Distribution of Canadian pollock catches (t) for 2003 to 2010 for bottom trawl (left panel) and gill net (right panel) aggregated by 10 minute squares. The dashed line separates Western and Eastern Components.

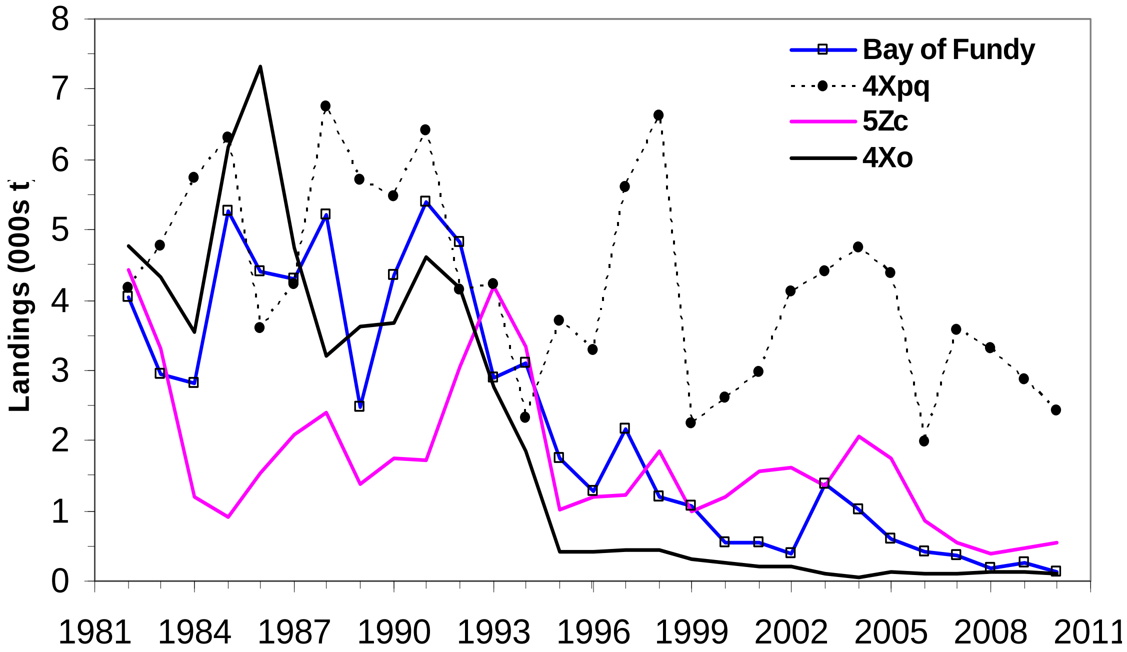


Fig. 5. Calendar year landings of pollock for the Western Component by statistical Unit Area, 1982-2010. Landings for 2010 are from Jan. - Aug.

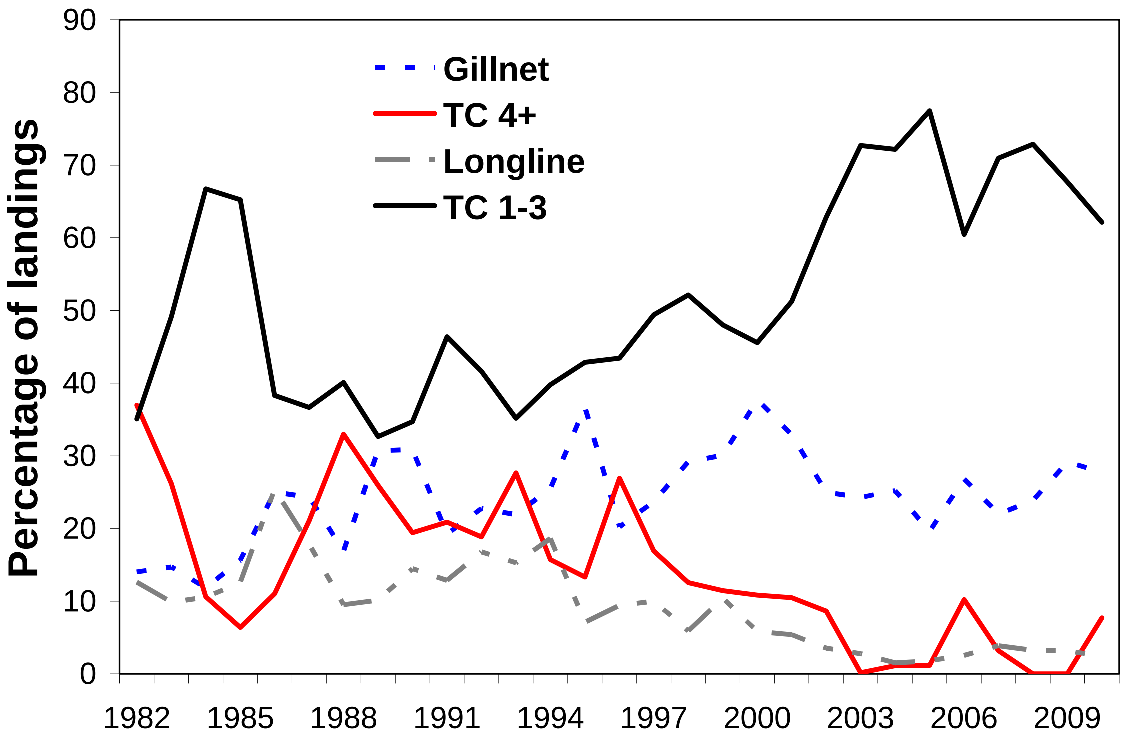


Fig. 6. Percentage of pollock landings by gear type for the Western Component, 1982-2010. Landings for 2010 are from Jan. - Aug.

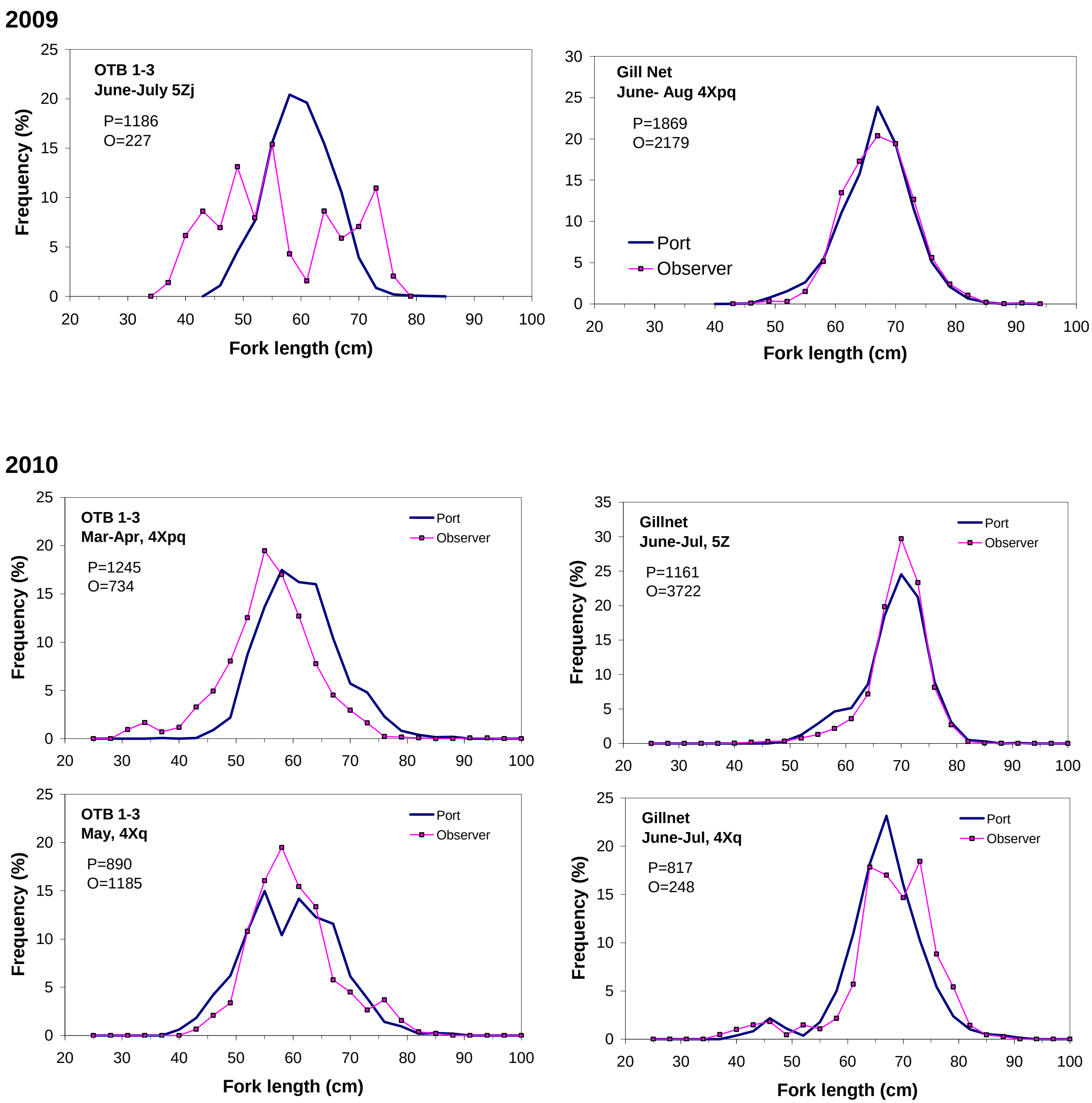
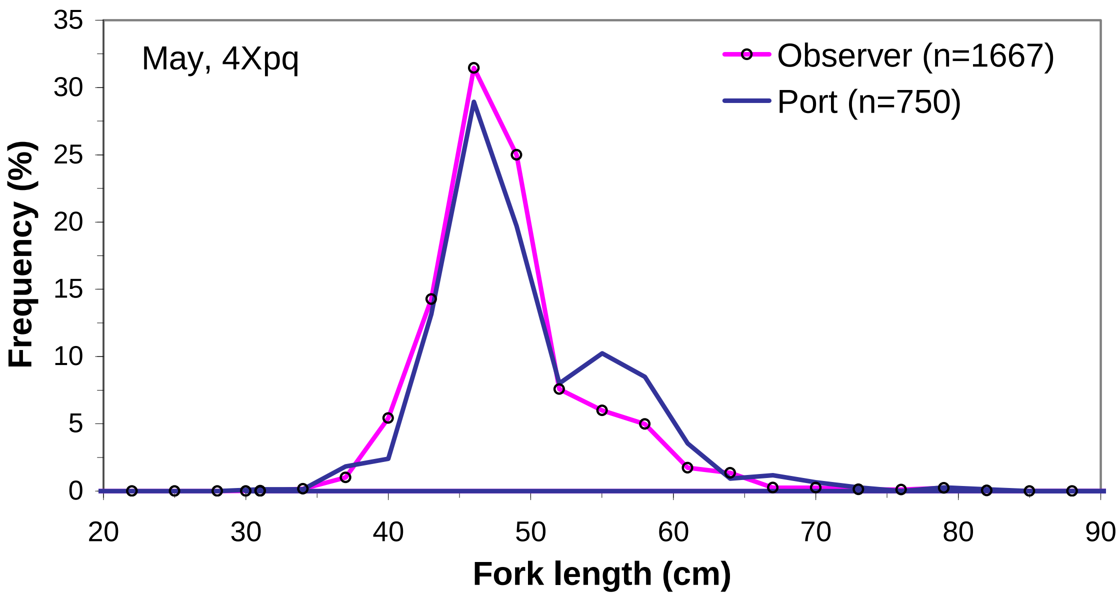


Fig. 7. Comparisons of 2009 and 2010 port (dockside) and observer (at-sea) sample length measurements of pollock from the directed fishery by gear type and month/area. Number of fish measured is shown for port (P) and observer (O) samples.

2009



2010

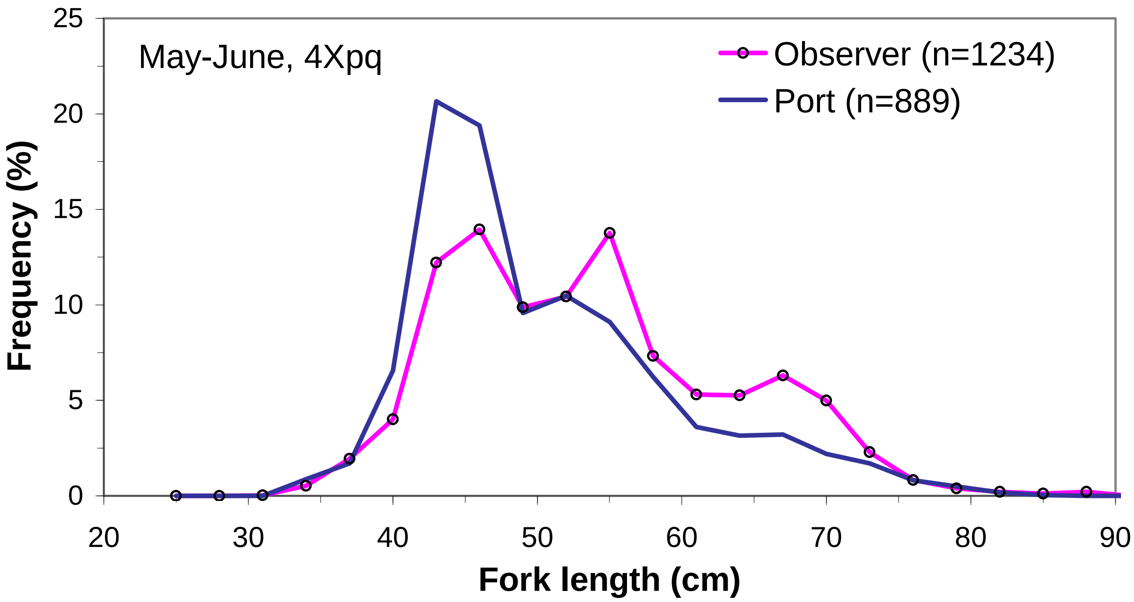


Fig. 8. Comparisons of port (dockside) and observer (at-sea) sample length measurements of pollock bycatch from the 4Xpq redfish fishery in 2009 (upper panel) and 2010 (lower panel). Number of fish measured is shown for port and observer samples.

DFO Primary Ager	Consensus Ages (NMFS/DFO)									
	0	1	2	3	4	5	6	7	8	Total
0	2									2
1		6	1							7
2		1	9							10
3				12						12
4					9					9
5						8	1			9
6						2	9			11
7							1	8	1	10
8									1	1
Total	2	7	10	12	9	10	11	8	2	71

Agreement = 90%

Fig. 9. Age frequency plot comparing pollock age interpretations by the primary ager for the 4VWX+5 pollock stock: comparison of primary ager with NMFS/DFO ages from the 2004 Canada/US Ageing Workshop.

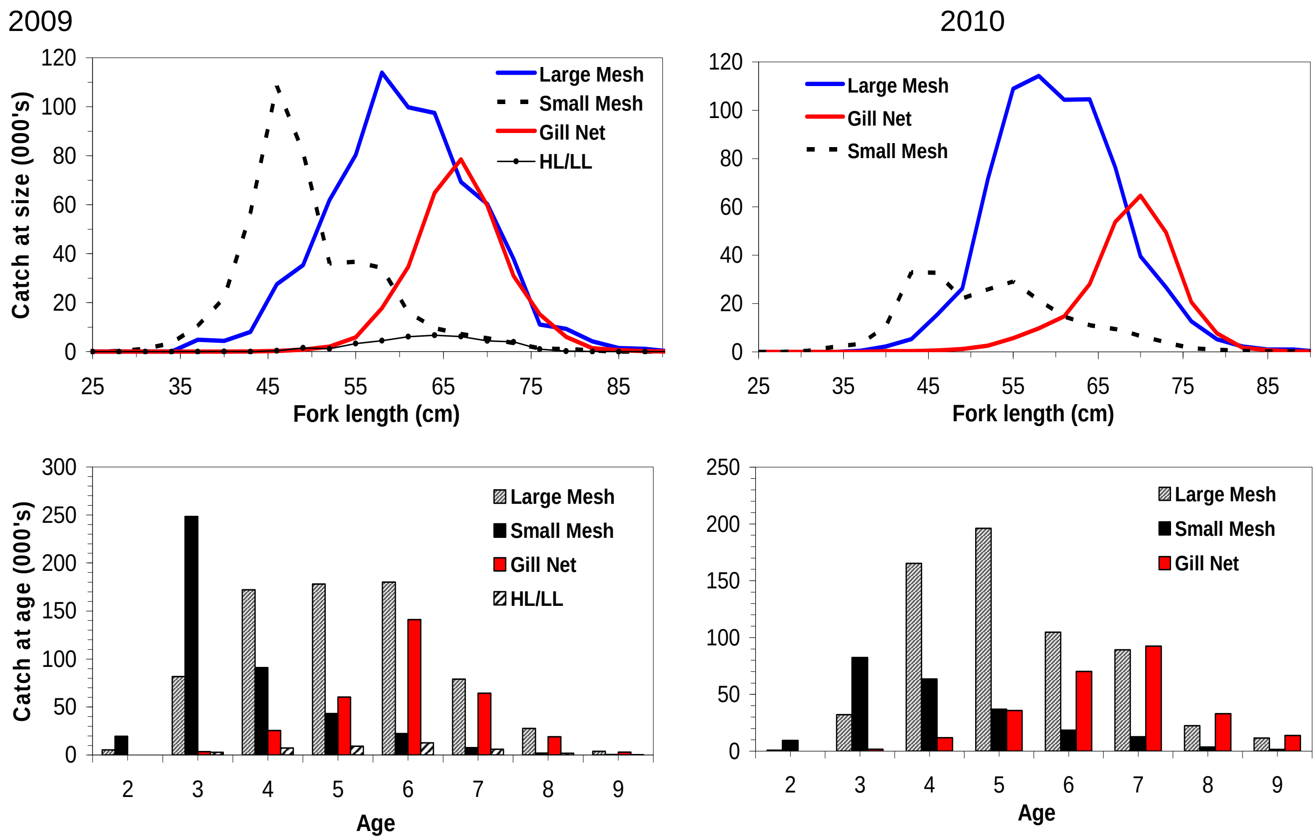


Fig. 10. Catch at size (upper panel) and age (lower panel) of pollock from large mesh otter trawl (cod end mesh ≥ 130 mm), small mesh otter trawl (cod end mesh < 130 mm), gillnet and hand line/longline from the 2009 and 2010 fisheries in the Western Component area. (Data for 2010 is from Jan. - Aug.).

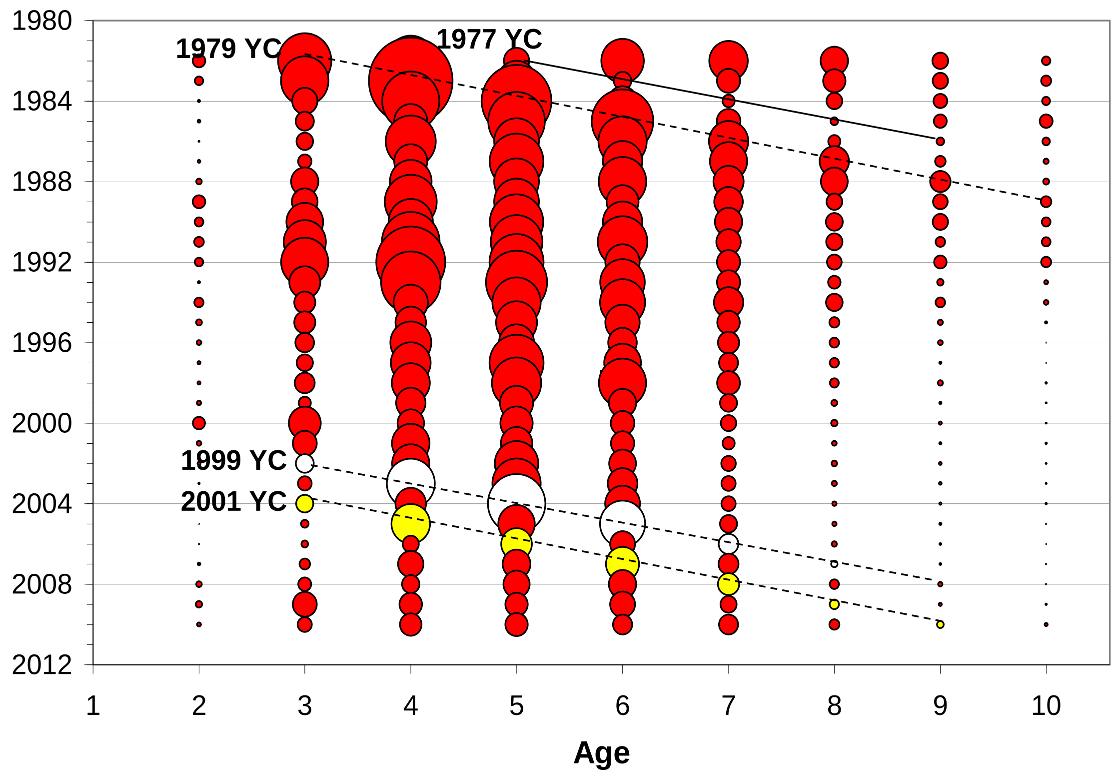


Fig. 11. Catch at age for pollock from the Western Component, 1982-2010. The area of the circle is proportional to the catch at that age and year. Two examples of recent strong cohorts are highlighted. (Data for 2010 is from Jan. - Aug.).

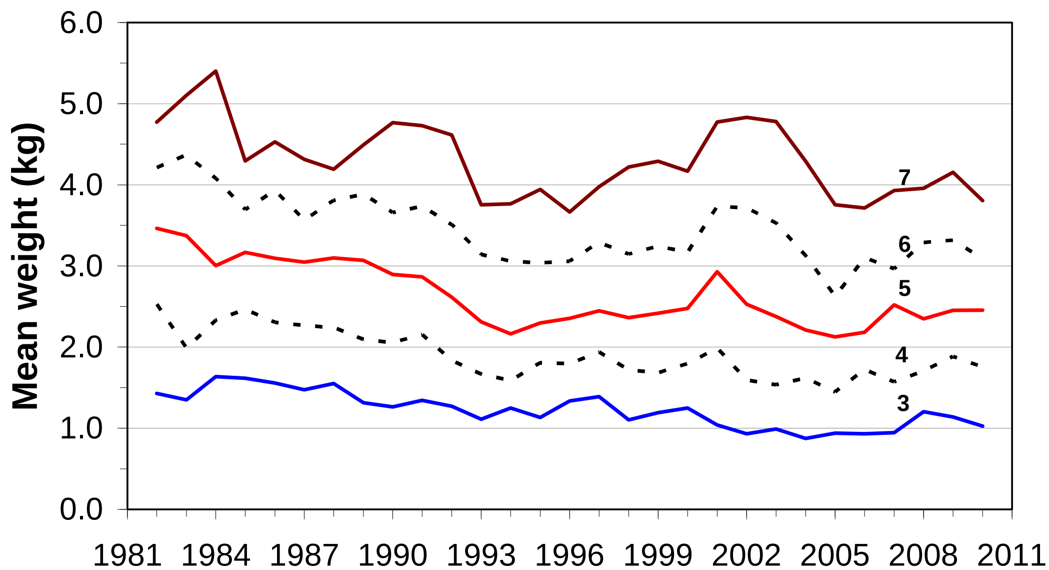


Fig. 12. Trends in fishery weights at age (kg) for pollock aged 3-7 from the Western Component, 1982-2010. (Data for 2010 is from Jan. - Aug.).

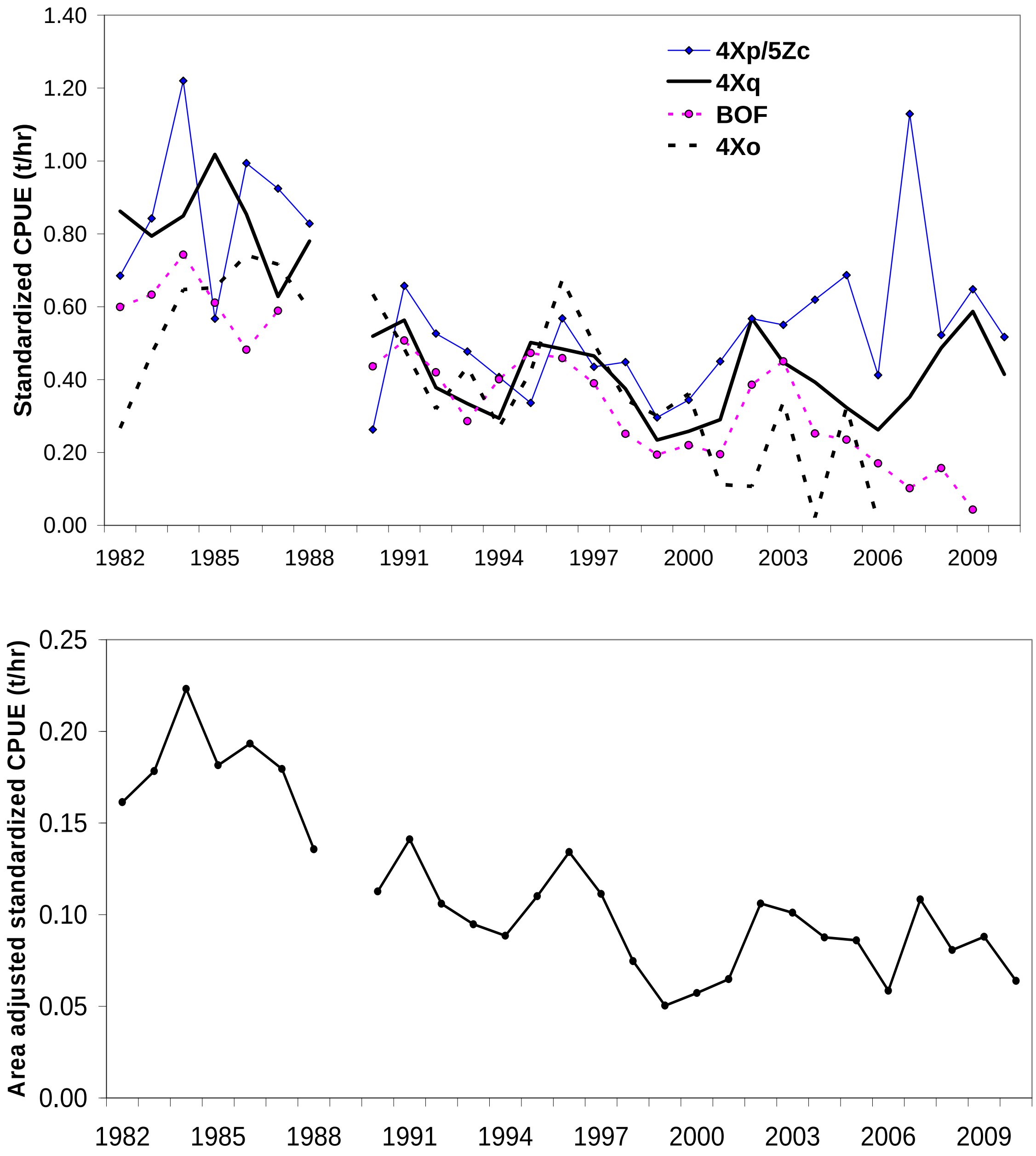


Fig. 13. Standardised mobile gear (OTB 1-3) catch rate series (t/hr) for pollock for the Western Component, 1982-2010. Upper panel: CPUE by area; Lower Panel: area weighted CPUE for combined areas. (Data for 2010 is from Jan. - Aug.).

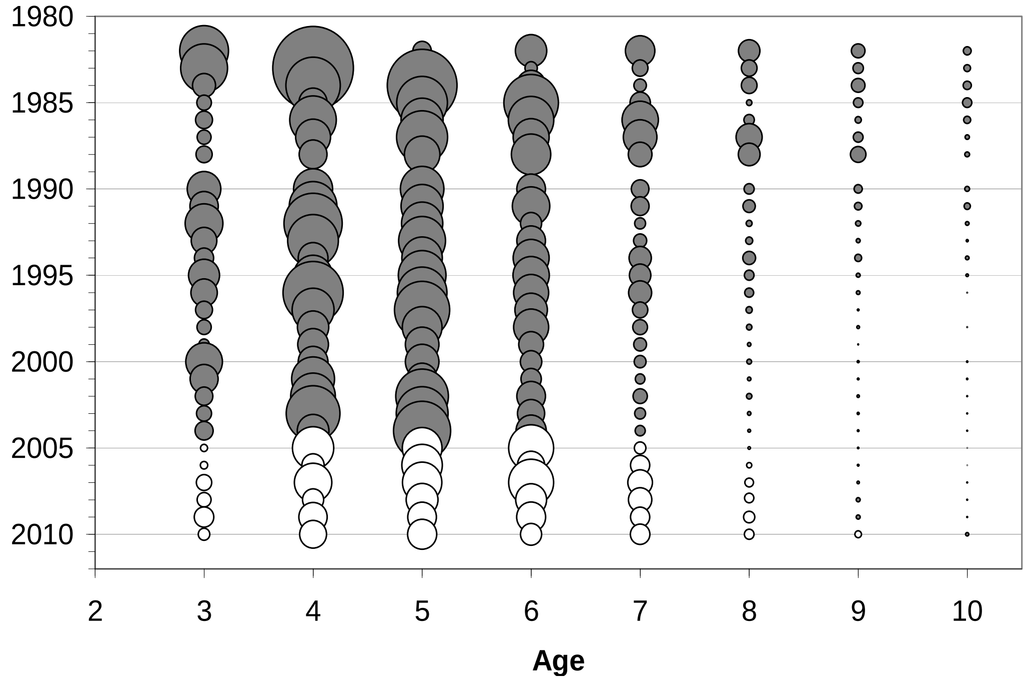


Fig. 14. Age-disaggregated catch rates for small mobile gear (TC 1-3) operating in the Western Component, 1982-2010. White bubbles represent years that were not included in the population model. (Data for 2010 is from Jan. - Aug.).

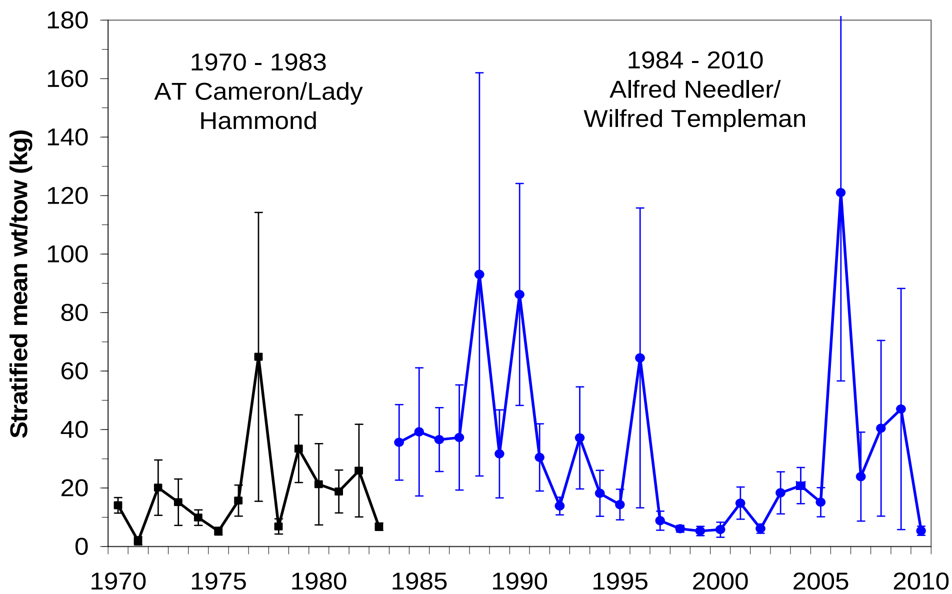


Fig. 15. Stratified mean catch per tow (kg) of pollock from the DFO summer research vessel survey in 4X (strata 474, 476, and 480-495) corresponding to the Western Component, 1970-2010. Data from 1984 to present is used in the VPA.

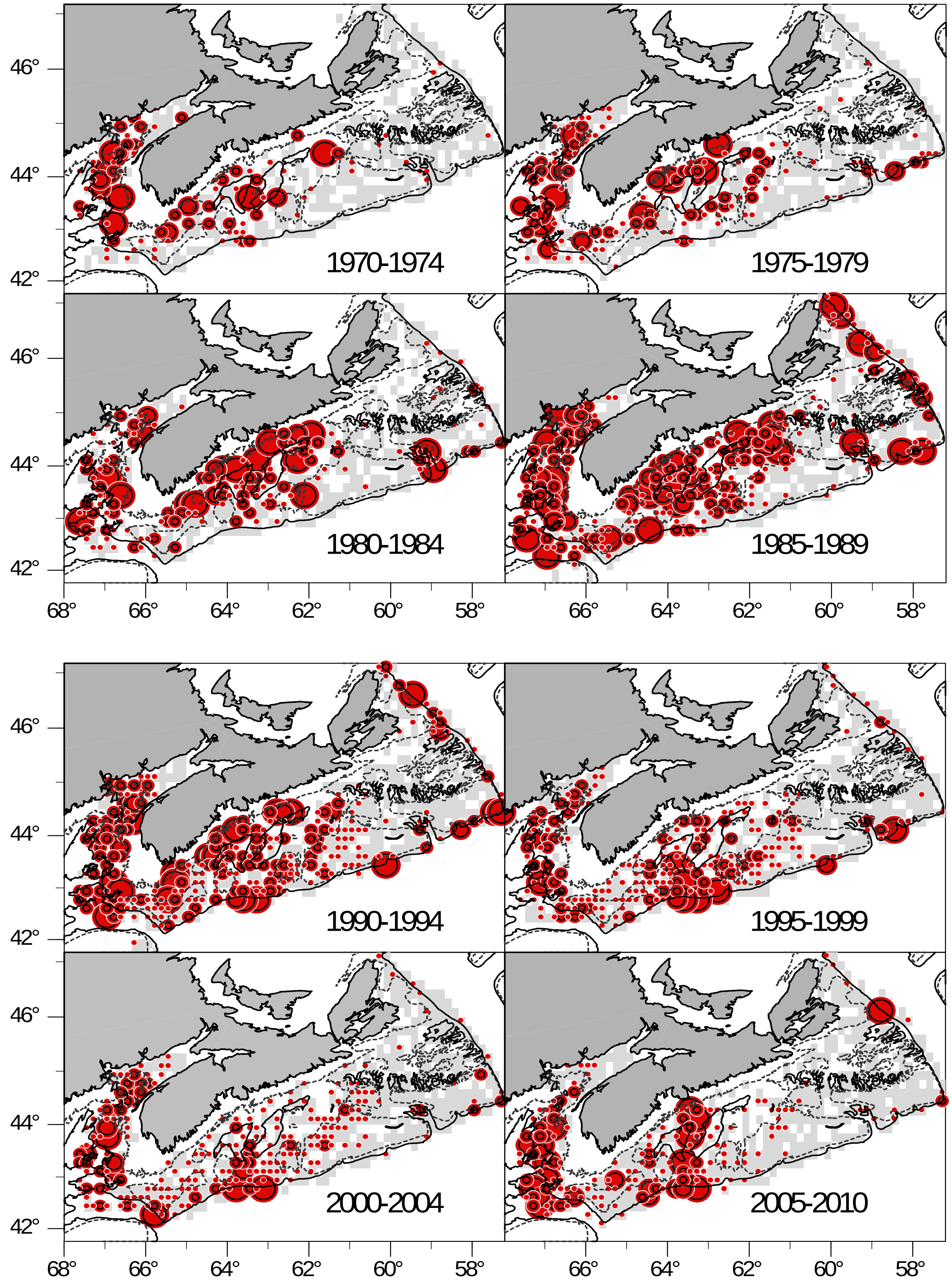
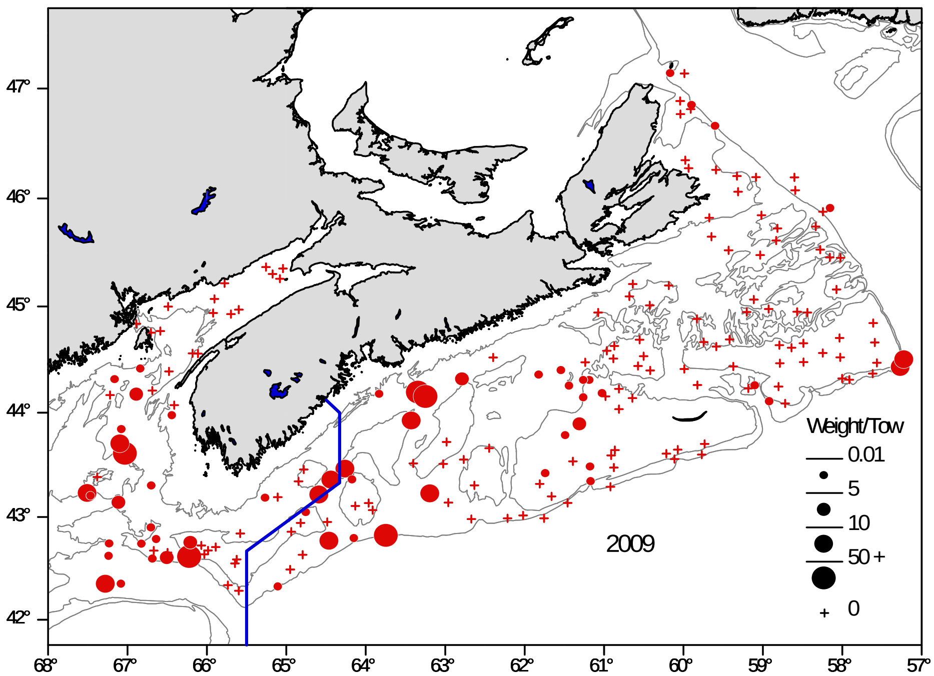


Fig. 16. DFO summer survey biomass distribution (5-yr mean weight (kg)/10 min square) for surveys conducted in the 1970s, 1980s (top panel), 1990s and 2000s (bottom panel). Grey shading indicates areas surveyed with no pollock in the catch.

2009



2010

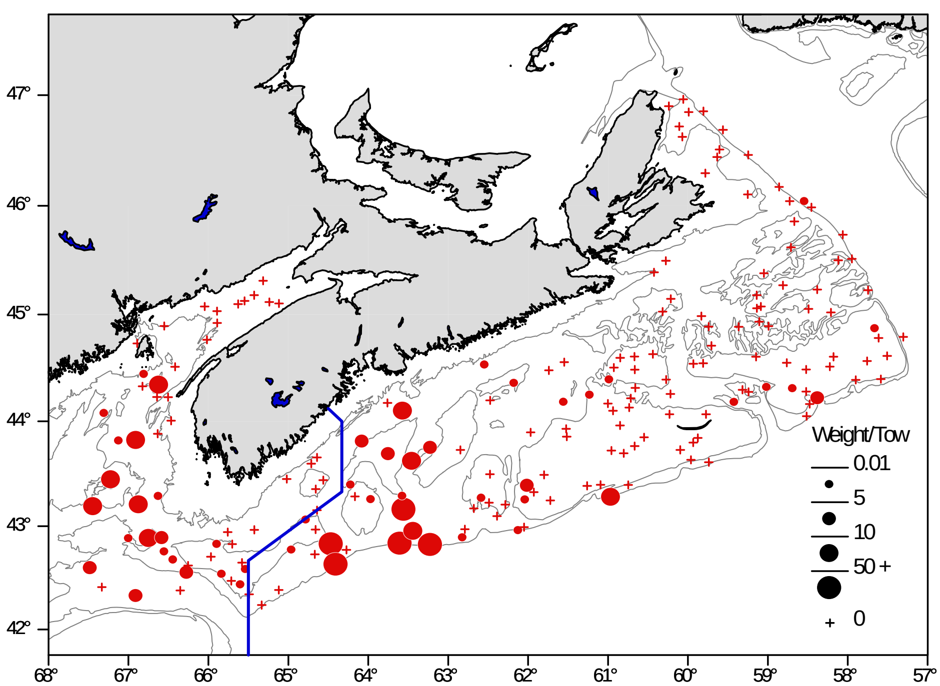


Fig. 17. Pollock biomass distribution (kg/tow) from the 2009 and 2010 DFO summer surveys. The solid line separates the Eastern and Western Components.

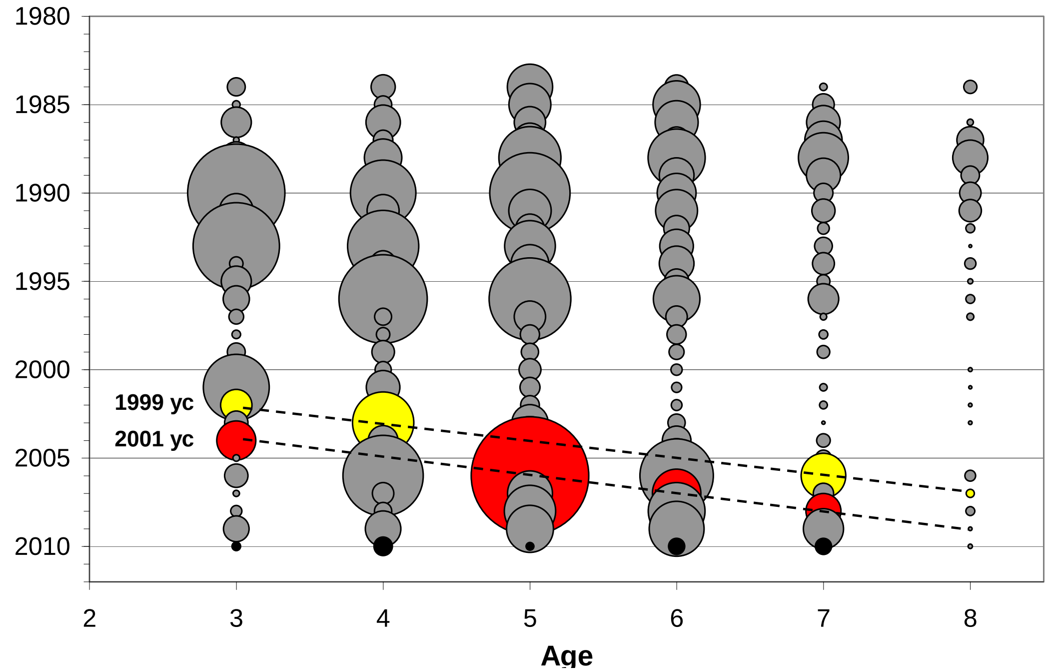


Fig. 18. Stratified mean number per tow at age of pollock from the DFO summer research vessel survey in 4X strata corresponding to the Western Component, 1984-2008. Recent strong year-classes are indicated by yellow (1999) and red (2001) circles. The low index values for the 2010 survey are shown in black.

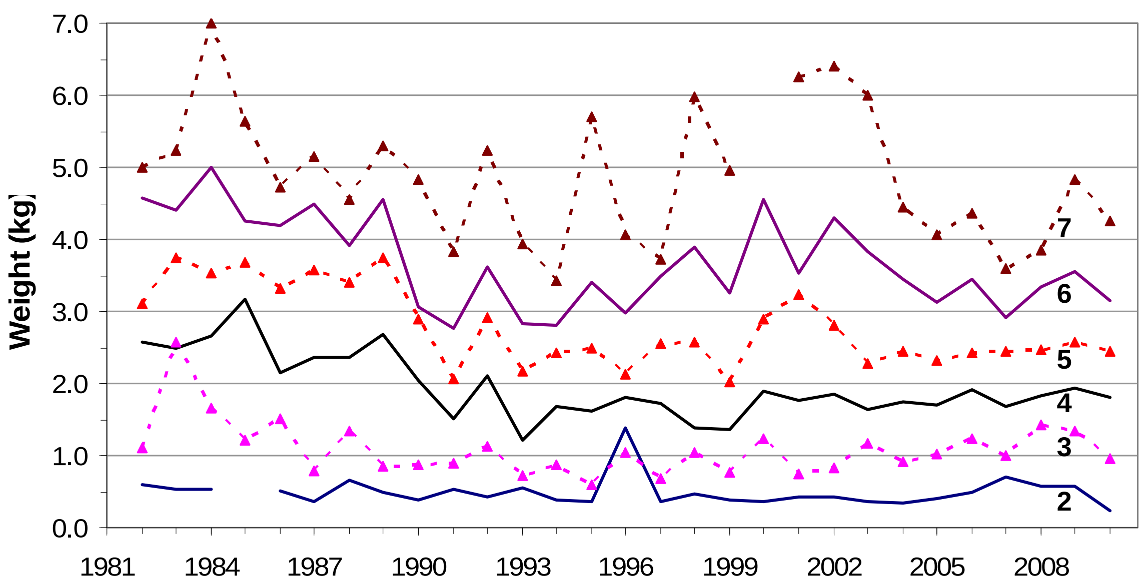


Fig. 19. Weight at age for pollock ages 2-7 from the DFO summer research vessel survey in 4X strata corresponding to the Western Component, 1982-2010.

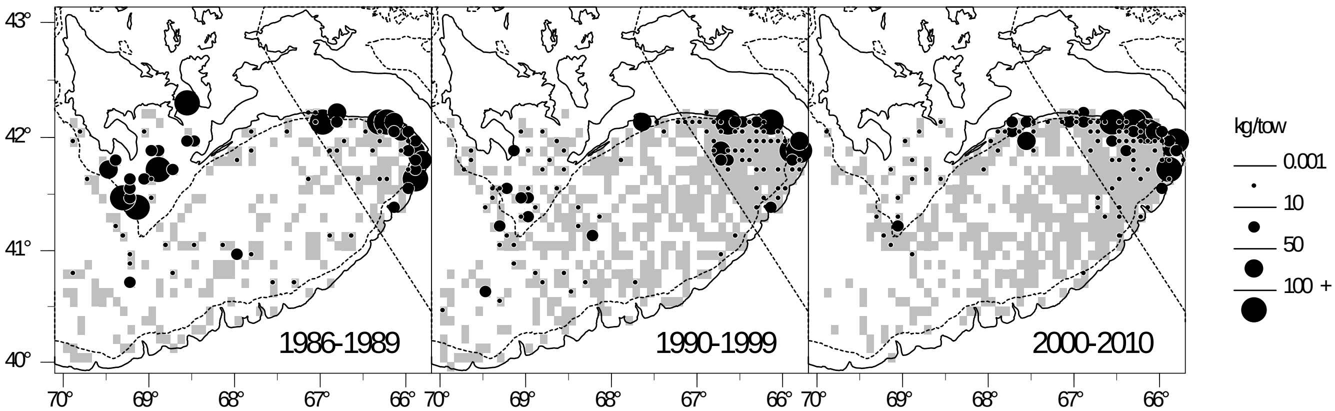


Fig. 20. DFO RV survey biomass distribution (mean weight (kg)/5 minute square) for pollock on Georges Bank for surveys conducted in the 1980s, 1990s, and 2000s. Grey shading indicates areas surveyed with no pollock in the catch.

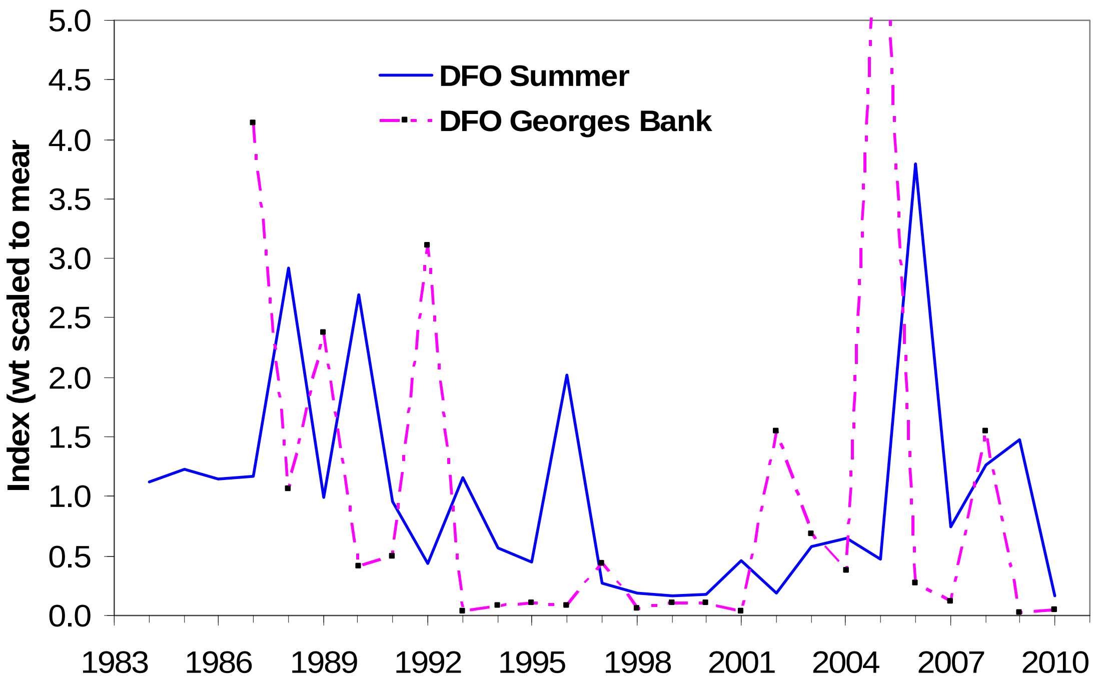


Fig. 21. Comparison of trends in pollock biomass (kg/tow scaled to mean) from the DFO summer survey (1984-2010) and the DFO Georges Bank winter survey (1987-2010).

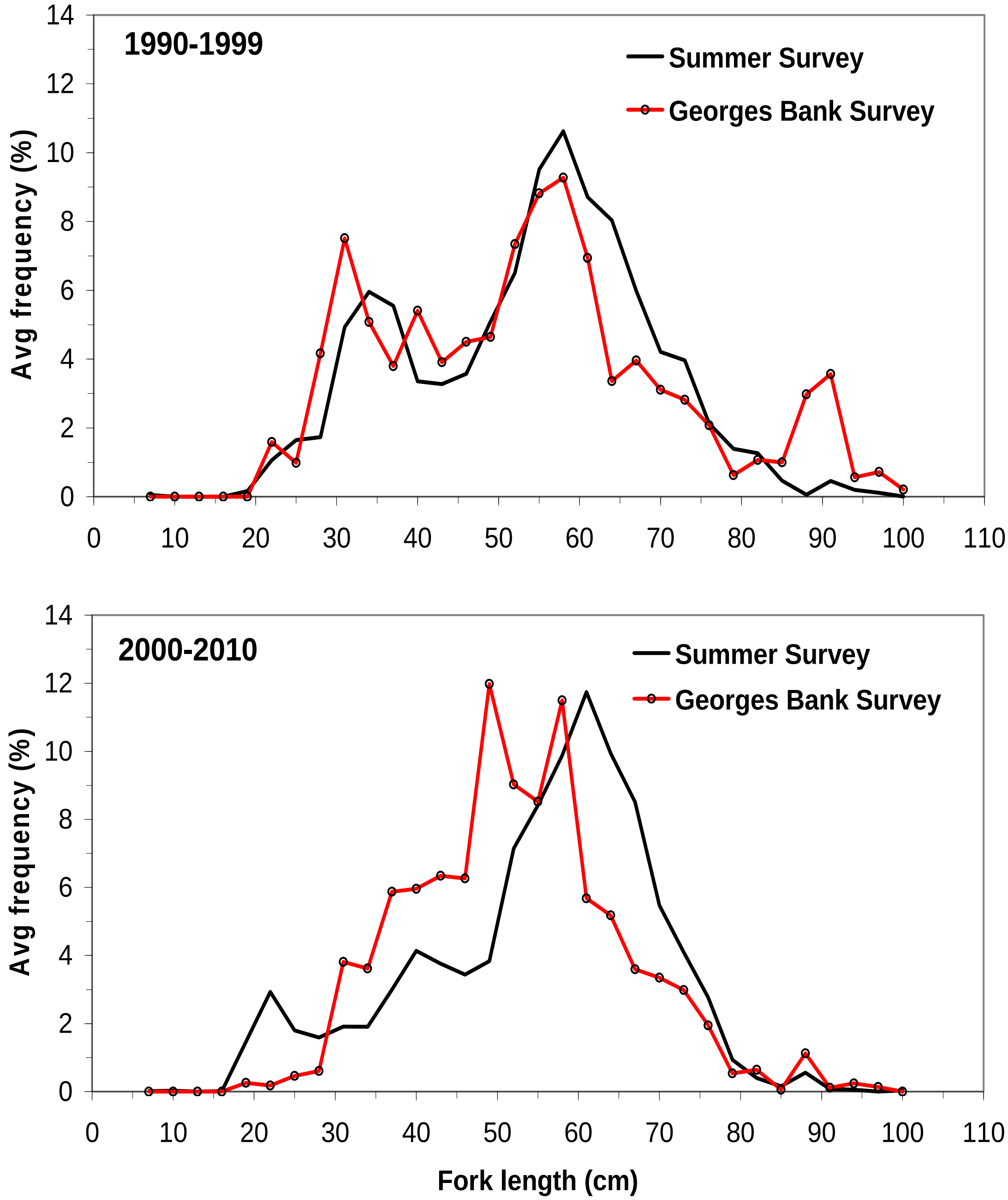


Fig. 22. Average size frequencies (% at length in cm) of pollock captured from DFO surveys of western 4X and Georges Bank during the 1990s (top panel) and 2000s (bottom panel).

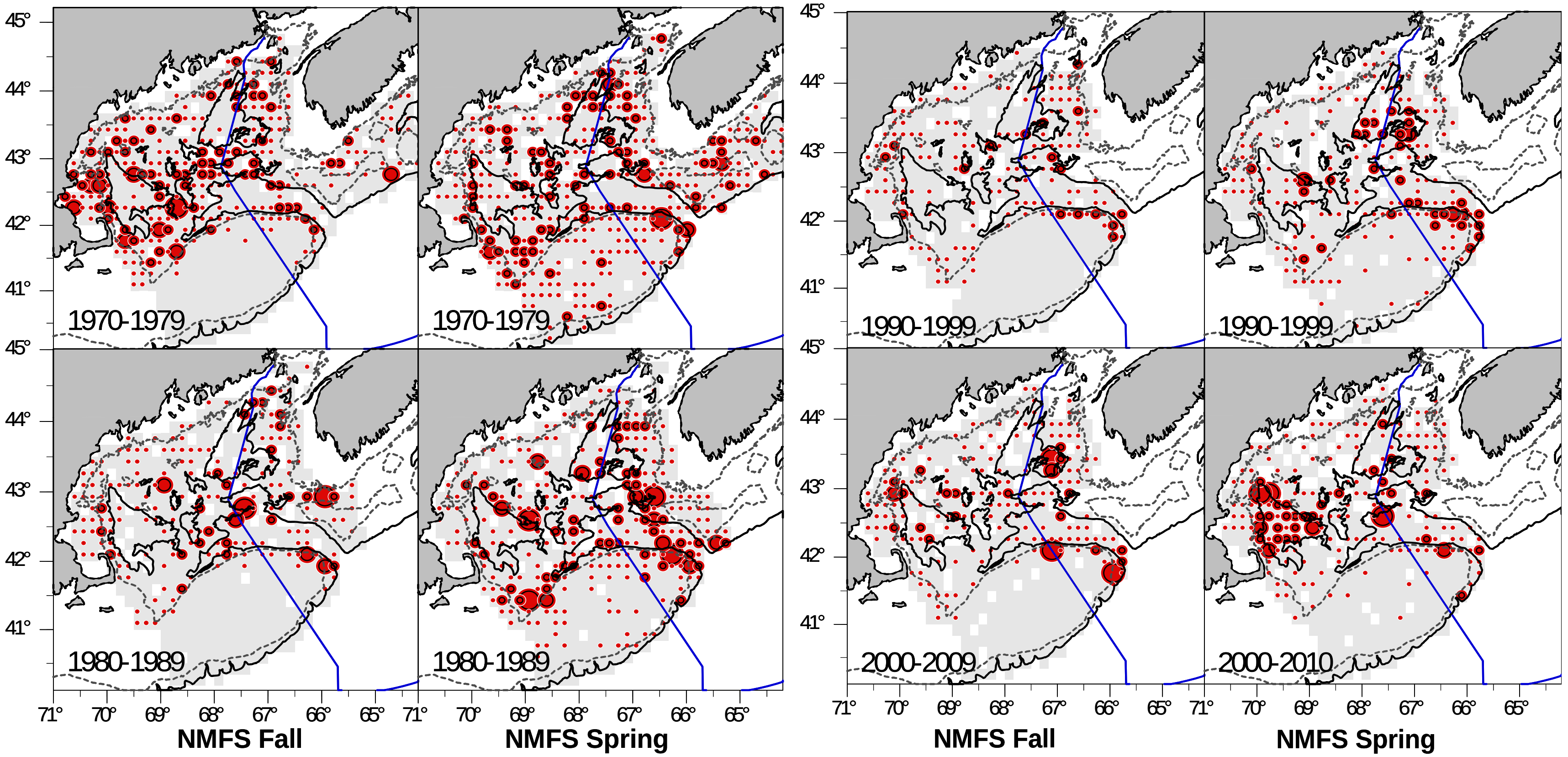


Fig. 23. NMFS Fall and NMFS Spring survey biomass distribution (mean weight (kg)/10 min square) for surveys conducted in the 1970s, 1980s (left panel), 1990s, and 2000s (right panel). Grey shading indicates areas surveyed with no pollock in the catch. The solid line indicates the international boundary.

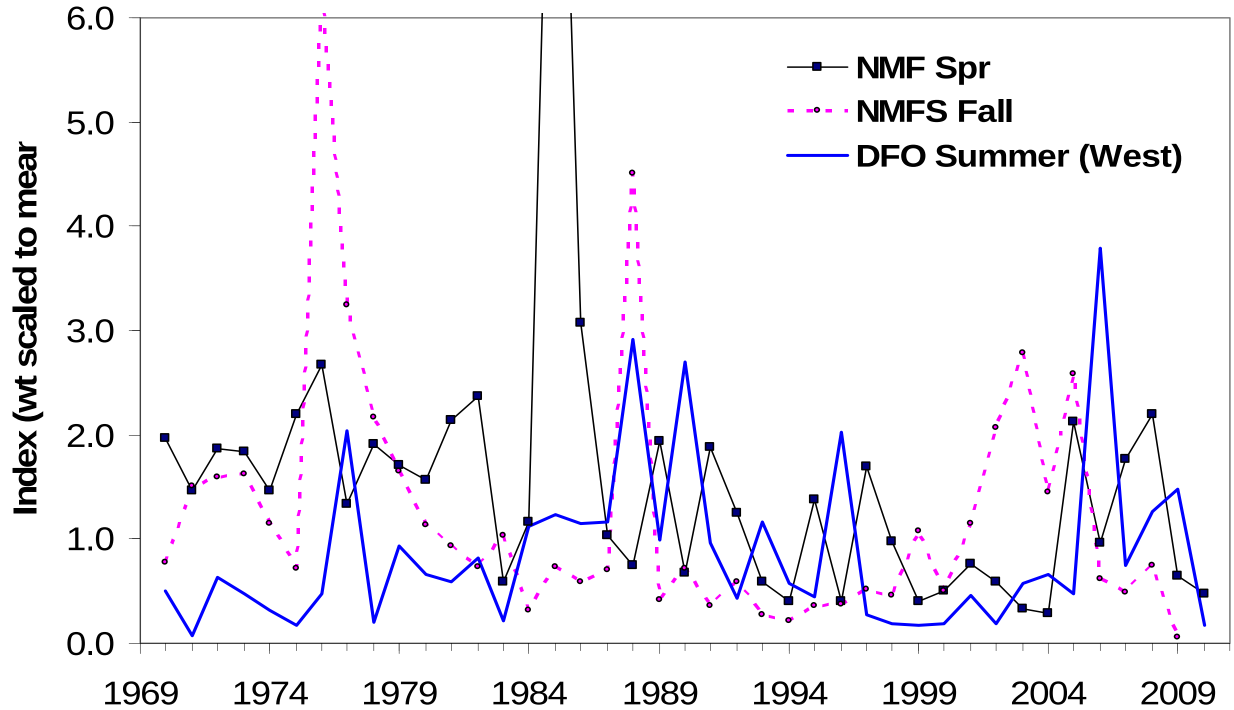


Fig. 24. NMFS spring, NMFS fall, and DFO summer (Western Component) survey biomass (kg/tow scaled to the mean for each series) for 1970 to 2010.

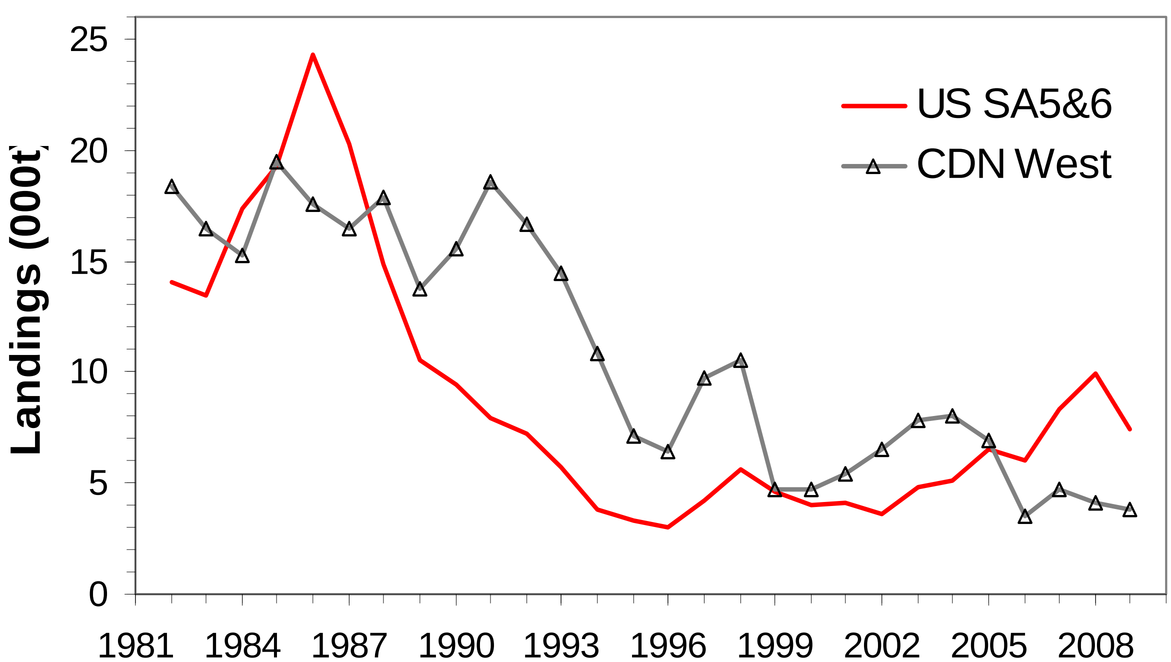


Fig. 25. Pollock landings (t) from Canadian Western (4Xopqrs5) and Eastern (4VWXmn) Components, and USA Subareas 5&6 from 1982 to 2010.

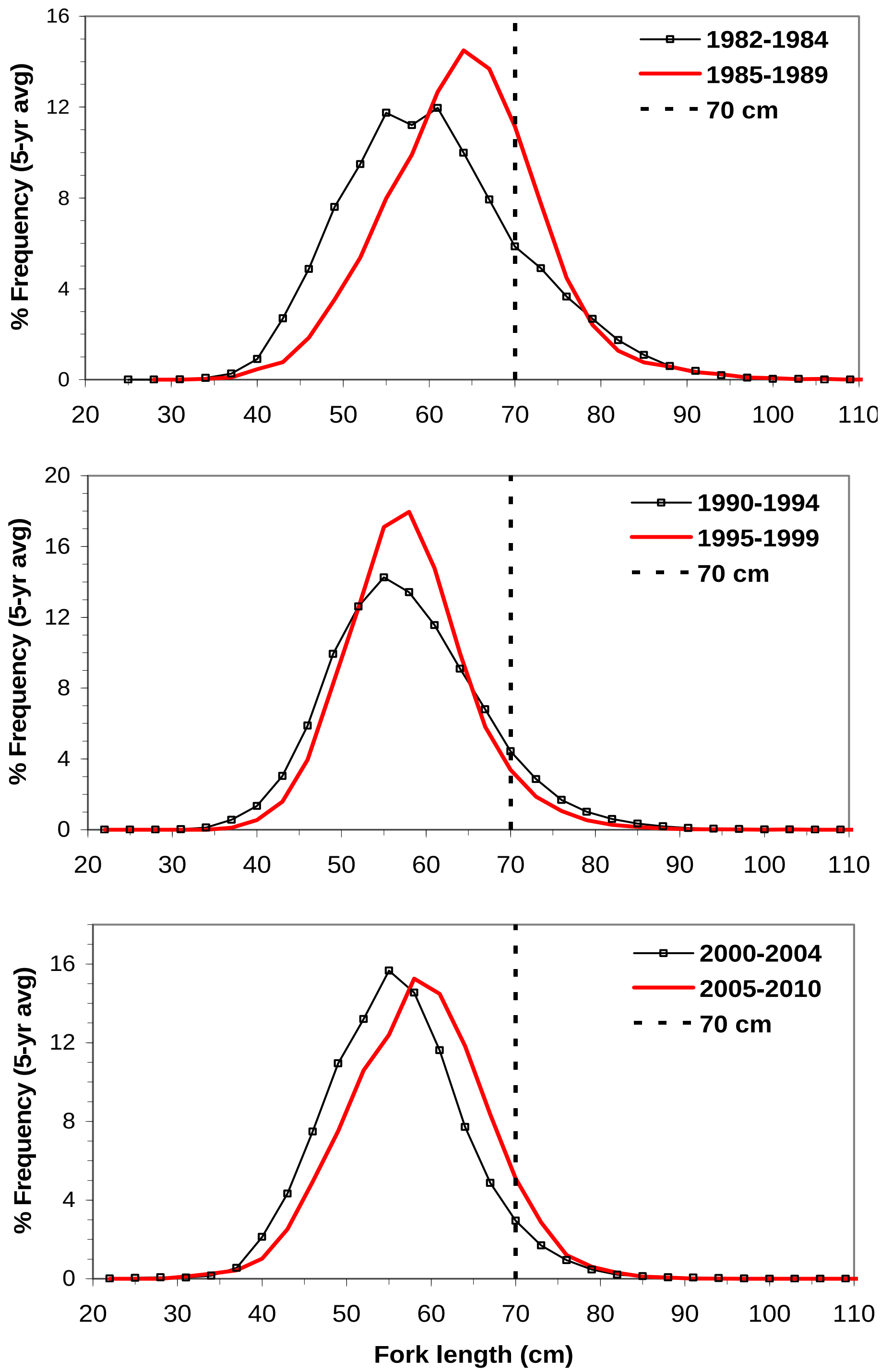


Fig. 26. Five-year average catch at size frequencies for pollock from the commercial fishery in the Western Component, 1982-2010. The dashed line indicates the length at 70 cm, above which fish are considered to be age 7+.

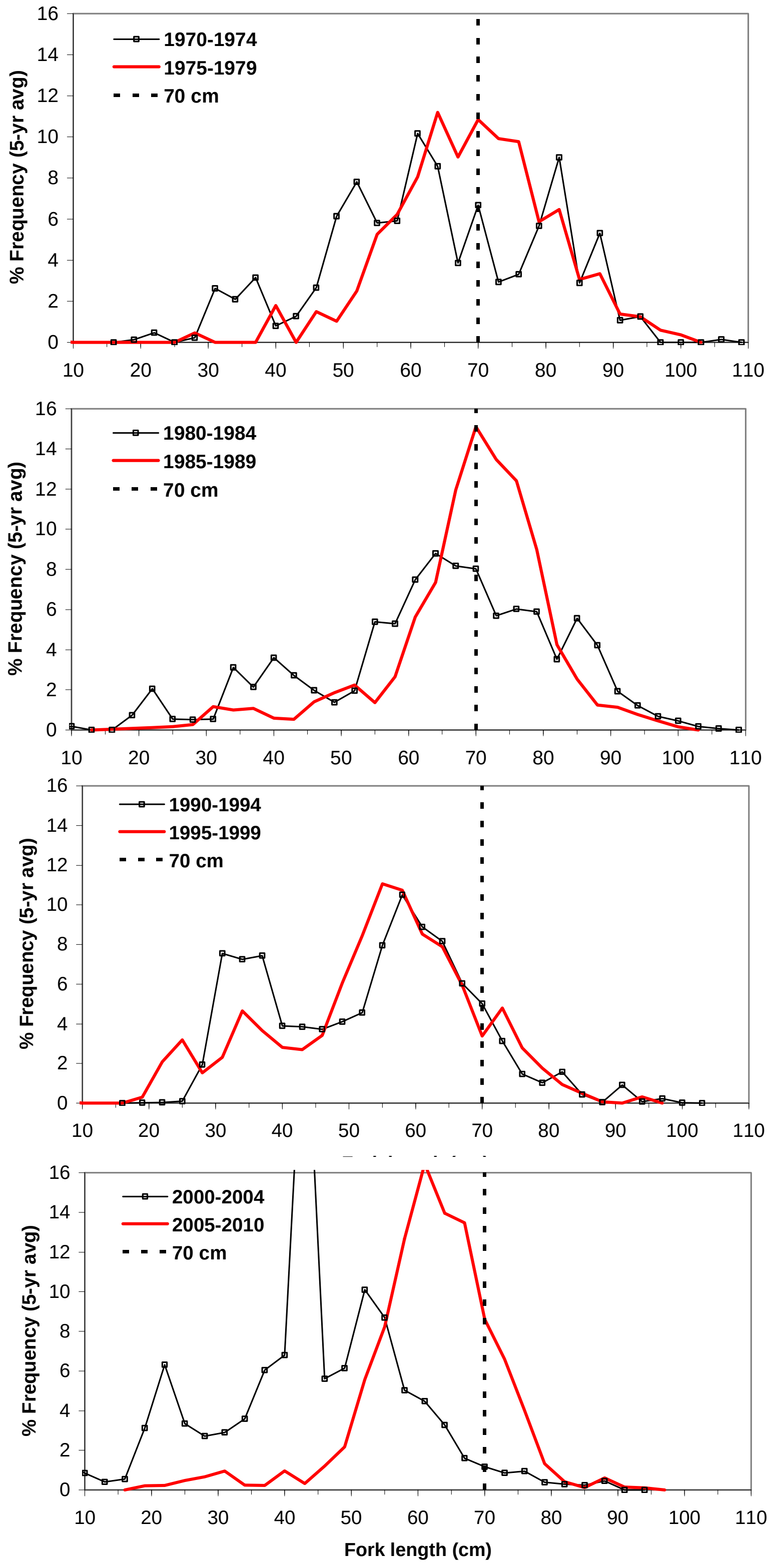


Fig. 27. Five-year average catch at size frequencies for pollock from the DFO summer survey in western 4X, 1970-2010. The dashed line indicates the length at 70 cm, above which fish are considered to be age 7+.

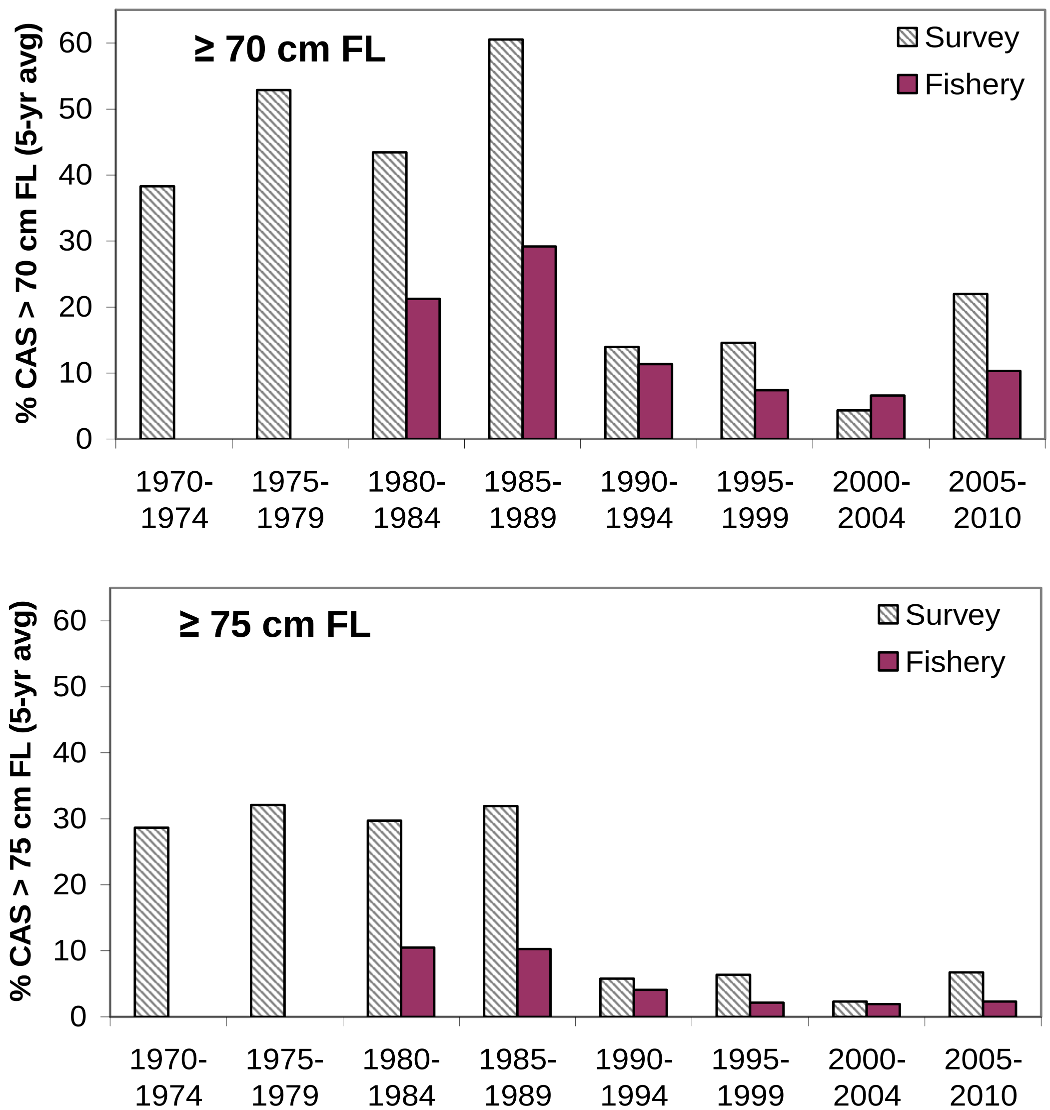


Fig. 28. Five-year average proportion at length for pollock ≥ 70 cm FL (age 7+) (upper panel) and ≥ 75 cm FL (age 8+) (lower panel) from the DFO summer survey in western 4X (1970-2001) and the commercial fishery in the Western Component (1982-2010).

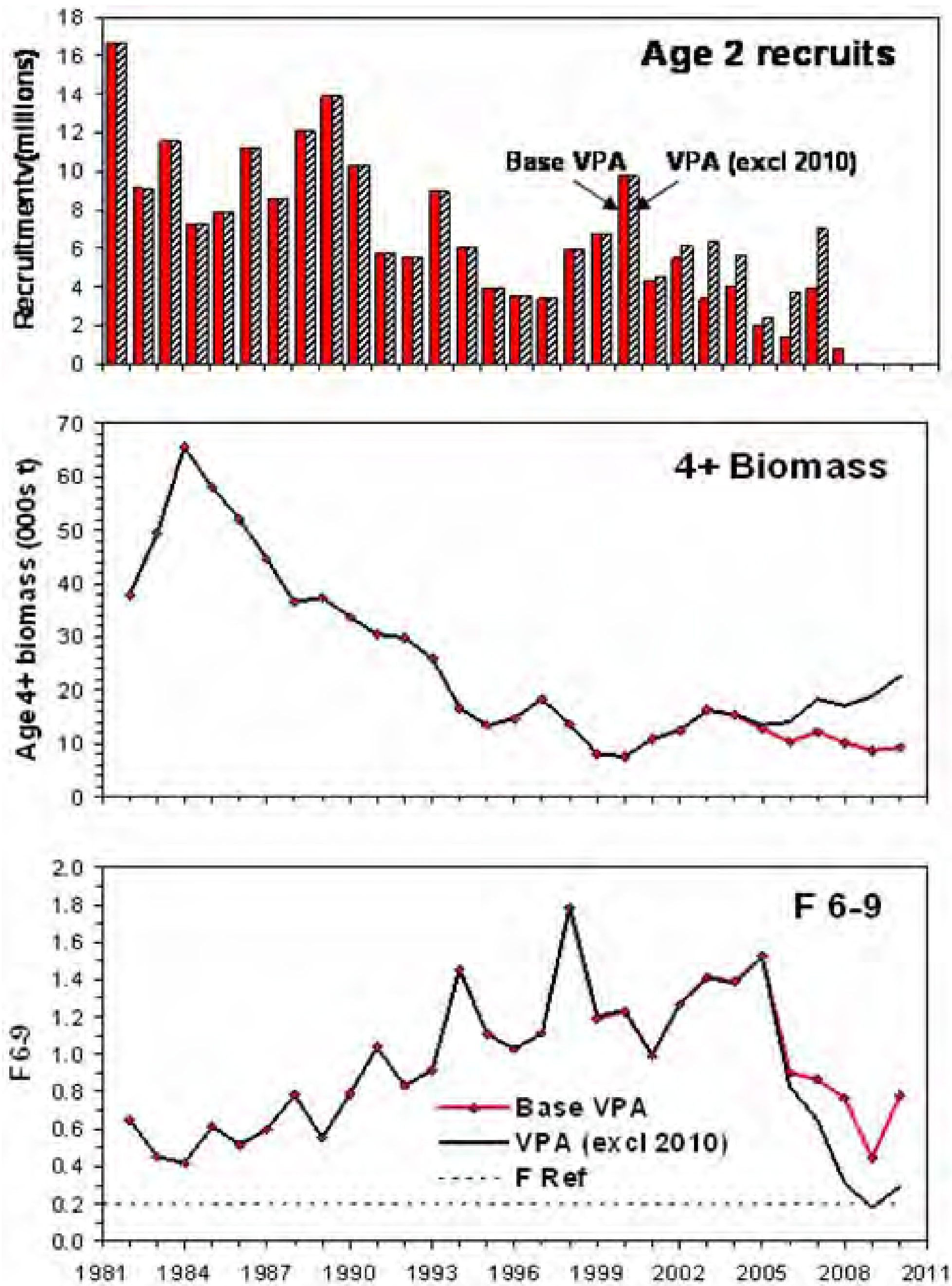


Fig. 29. Comparison of trends in age 2 recruitment, 4+ biomass, and age 6-9 fishing mortality for the Western Component from the Base VPA and the Base VPA excluding the 2010 RV indices.

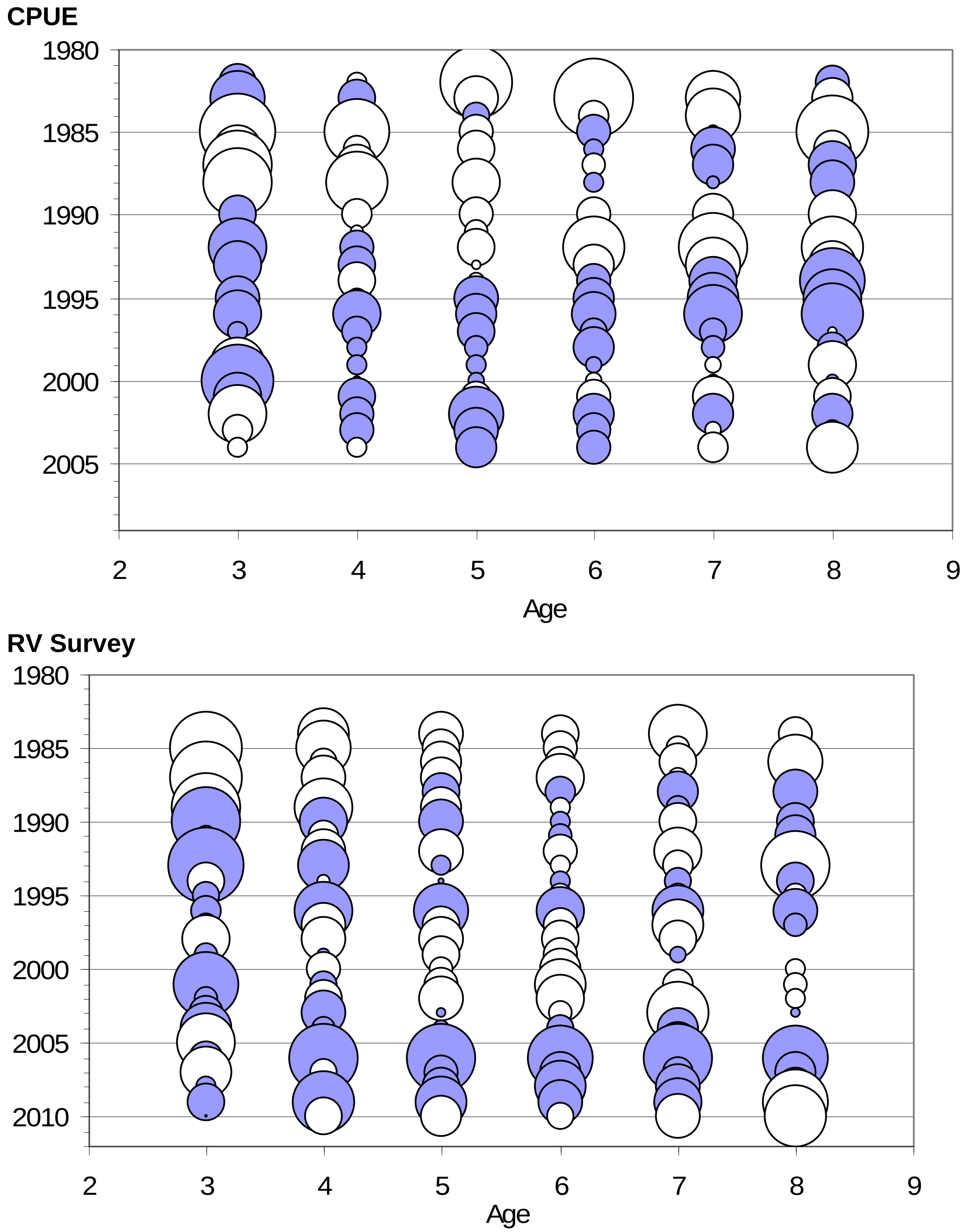


Fig. 30. Age-specific residuals for the Base VPA formulation, Western Component pollock, for the relationships between *ln* abundance index *versus ln* population numbers for the CPUE series (upper panel) and the RV series (lower panel). Closed circles denote positive residuals and open circles denote negative residuals. (Bubble size is proportional to magnitude).

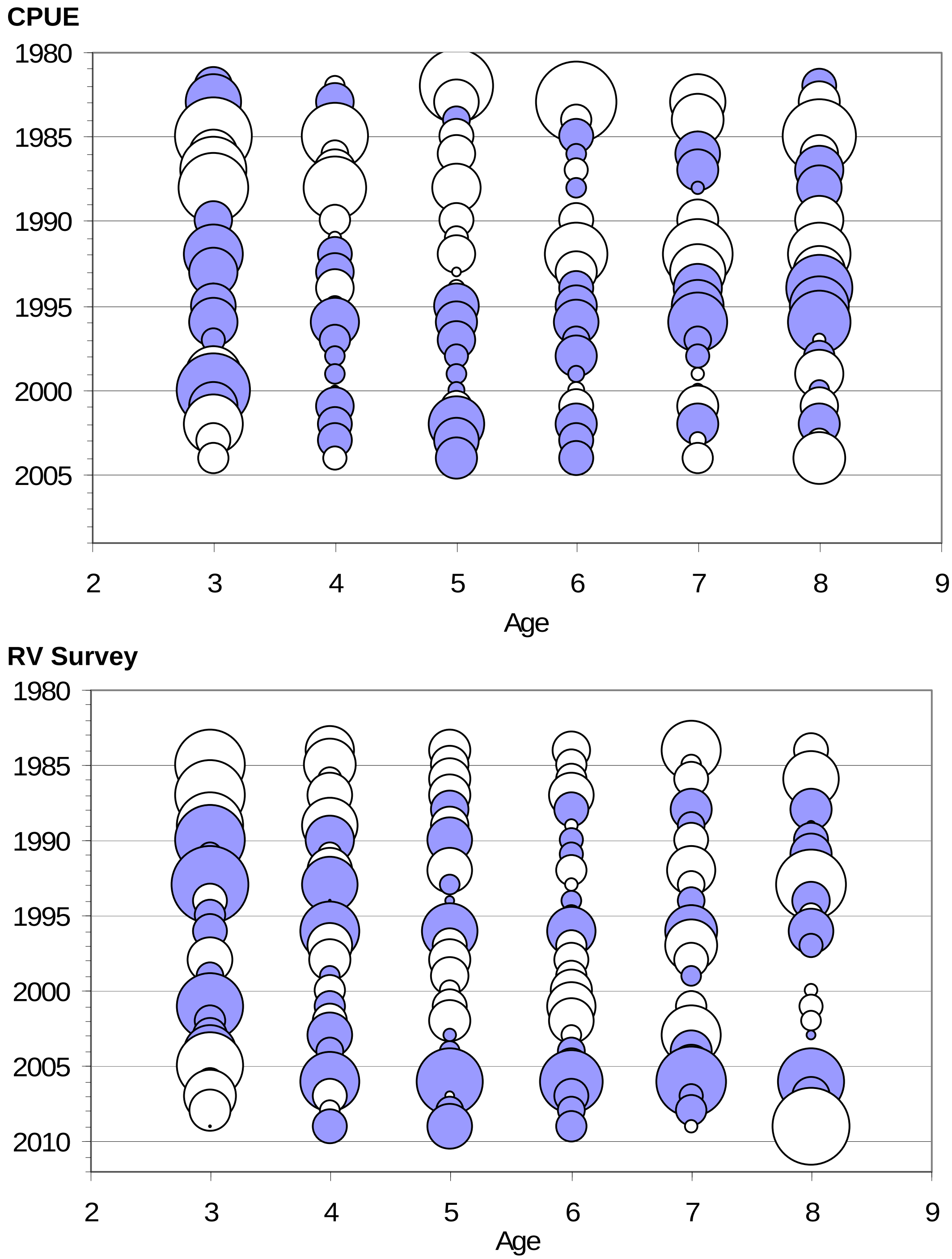


Fig. 31. Age-specific residuals for the Base VPA formulation excluding the 2010 RV indices, Western Component pollock, for the relationships between *ln* abundance index *versus ln* population numbers for the CPUE series (upper panel) and the RV series (lower panel). Closed circles denote positive residuals and open circles denote negative residuals. (Bubble size is proportional to magnitude).

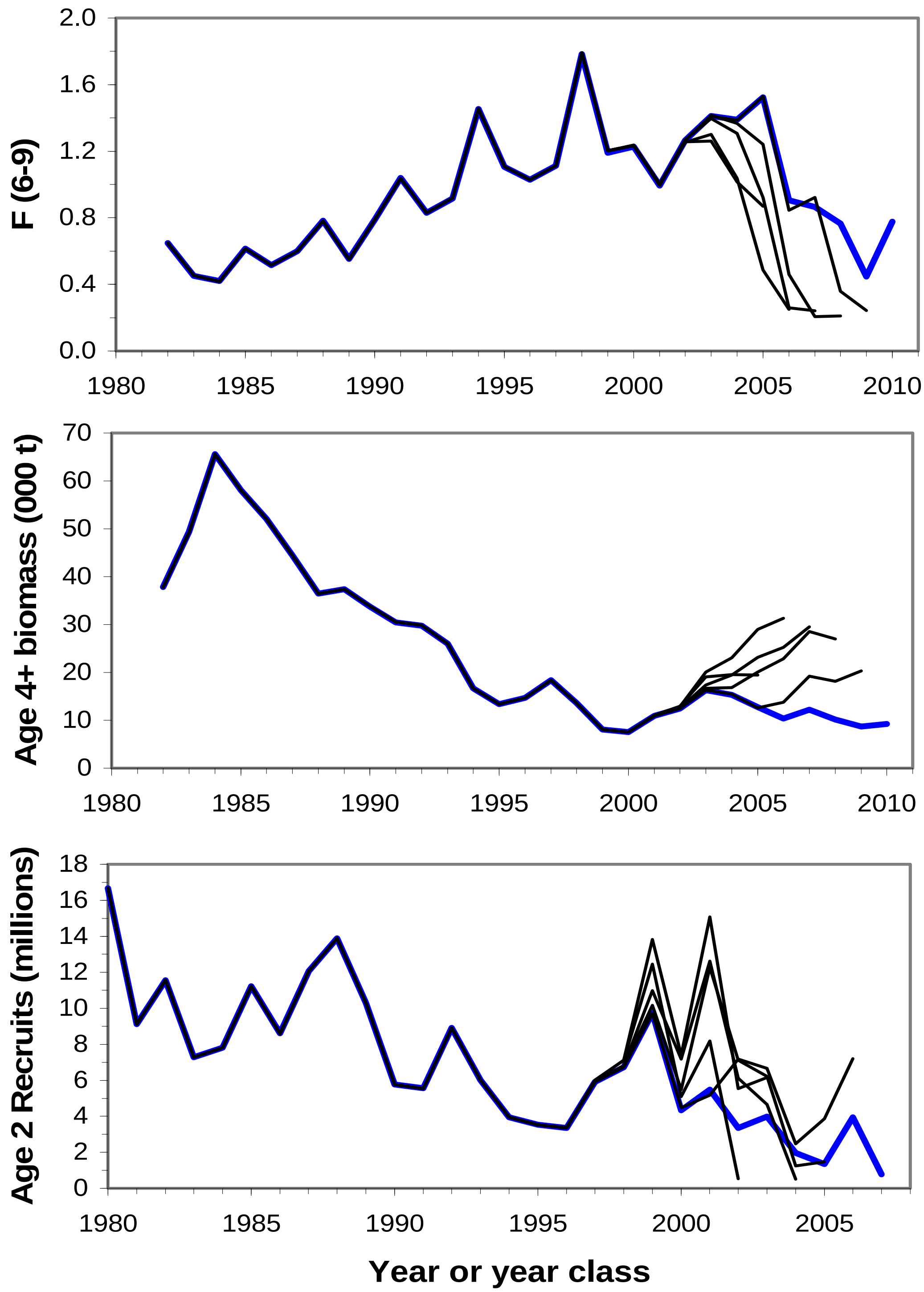


Fig. 32. Retrospective analysis of Western Component pollock from the Base VPA for age 6-9 fishing mortality (top panel), age 4+ biomass (middle panel), and age 2 recruits (lower panel).

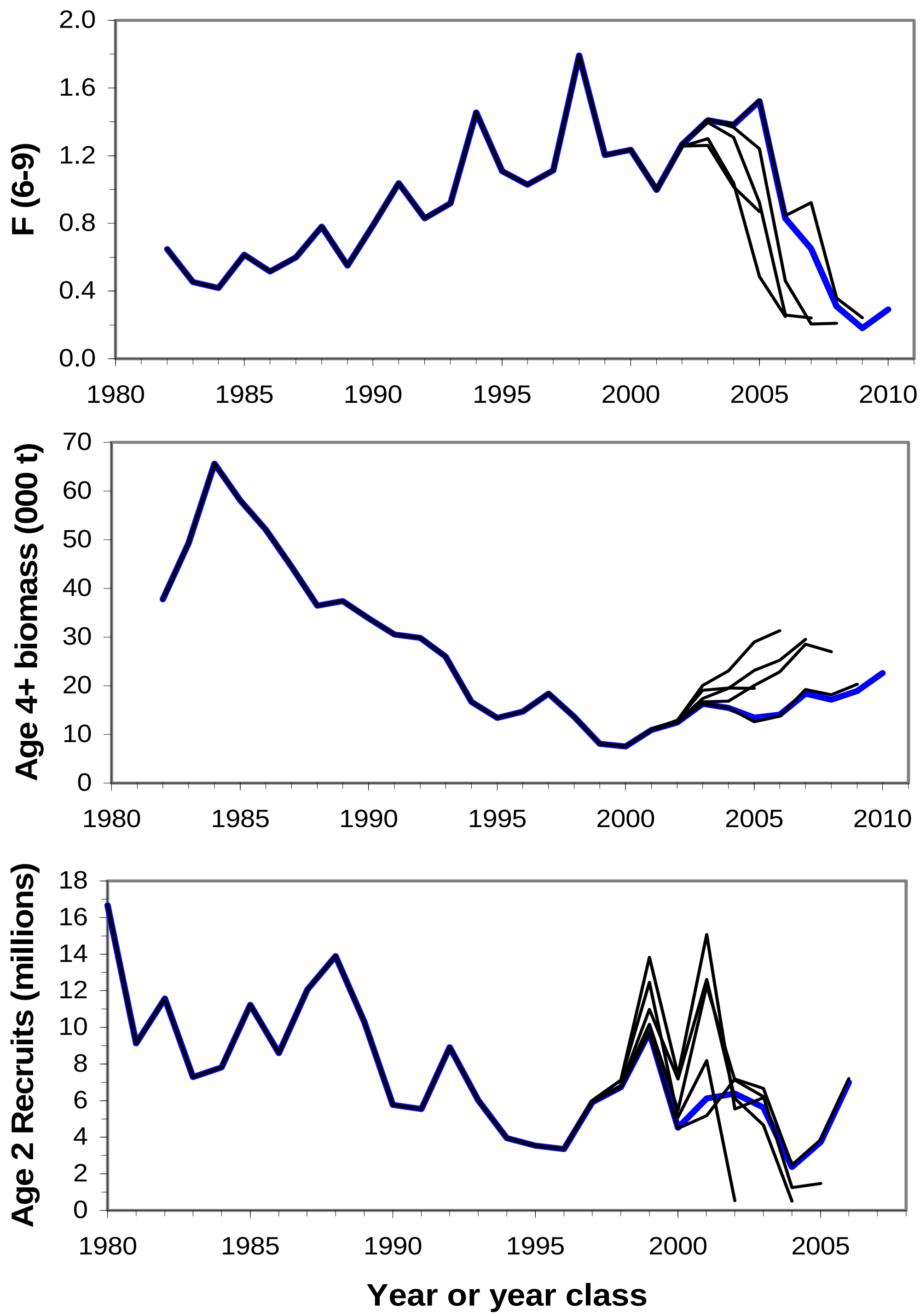


Fig. 33. Retrospective analysis of Western Component pollock for the VPA excluding the 2010 RV indices, for age 6-9 fishing mortality (top panel), age 4+ biomass (middle panel), and age 2 recruits (lower panel).

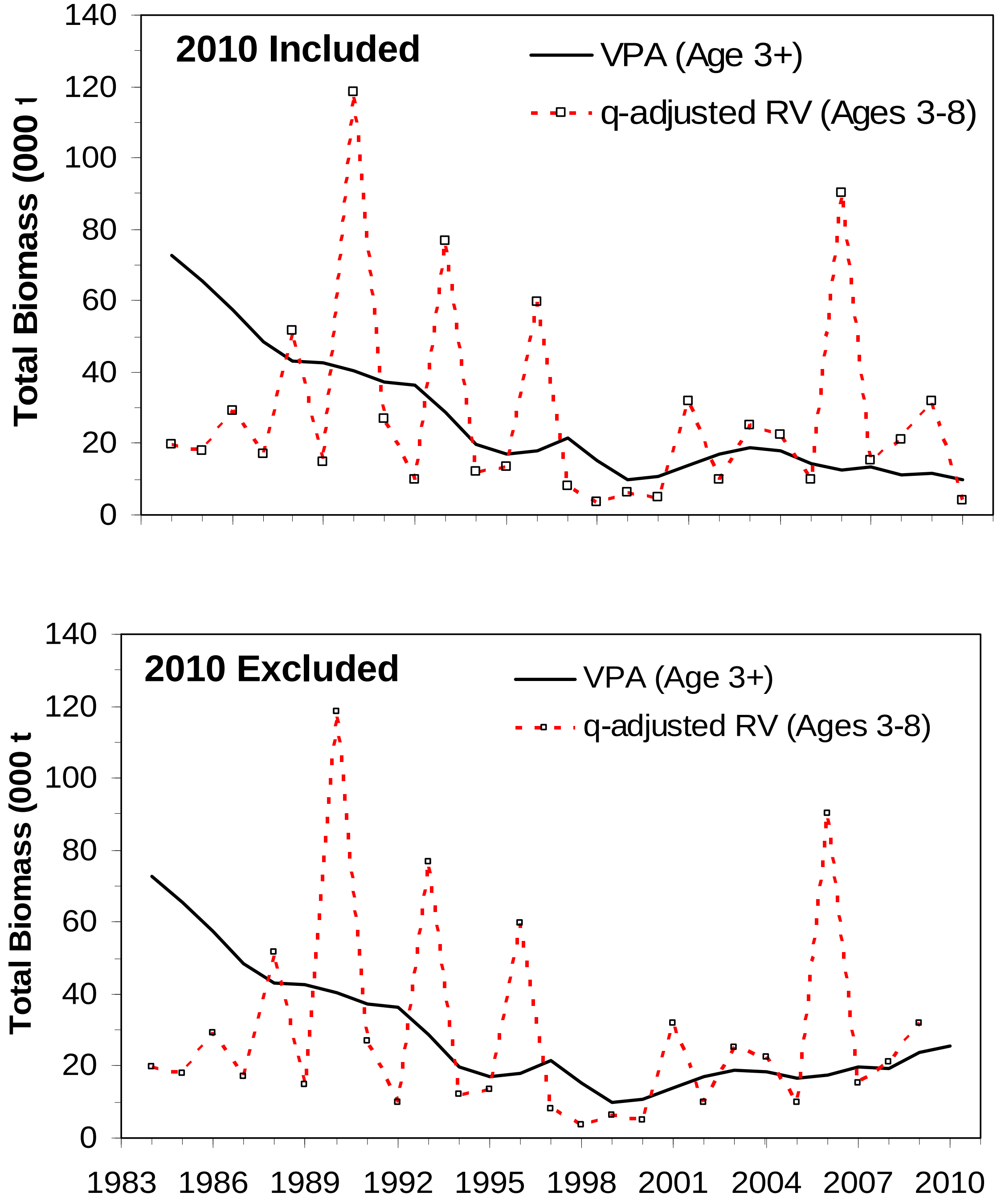


Fig. 34. Base VPA 3+ population biomass compared to the *q*-adjusted survey total biomass for ages 3-8 for the Western Component.

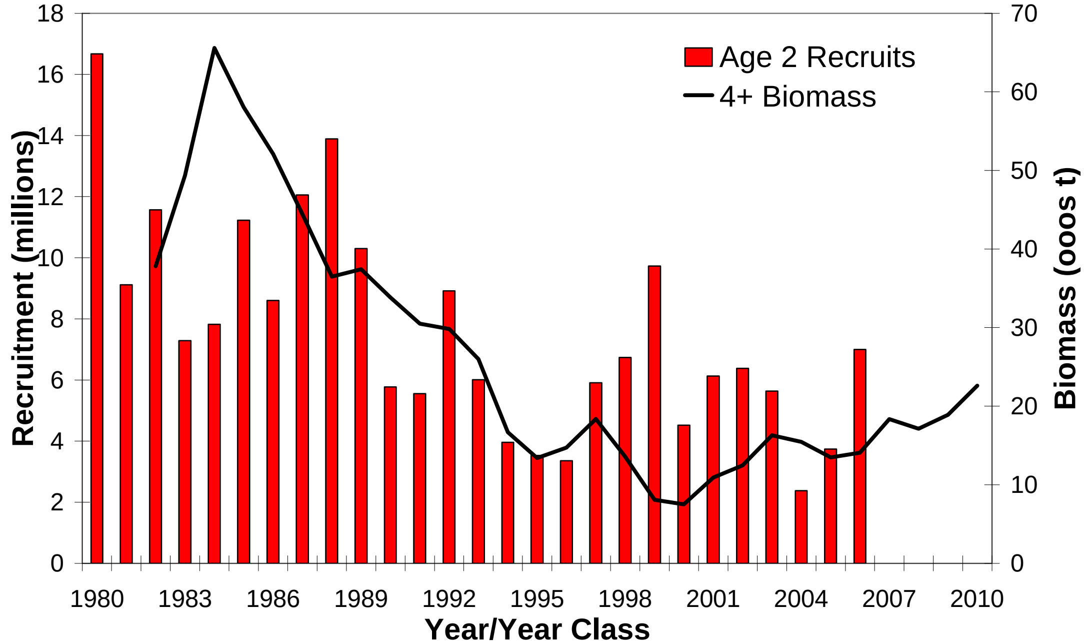


Fig. 35. Trends in age 4+ biomass and age 2 recruitment of pollock in the Western Component from the VPA model excluding the 2010 RV indices.

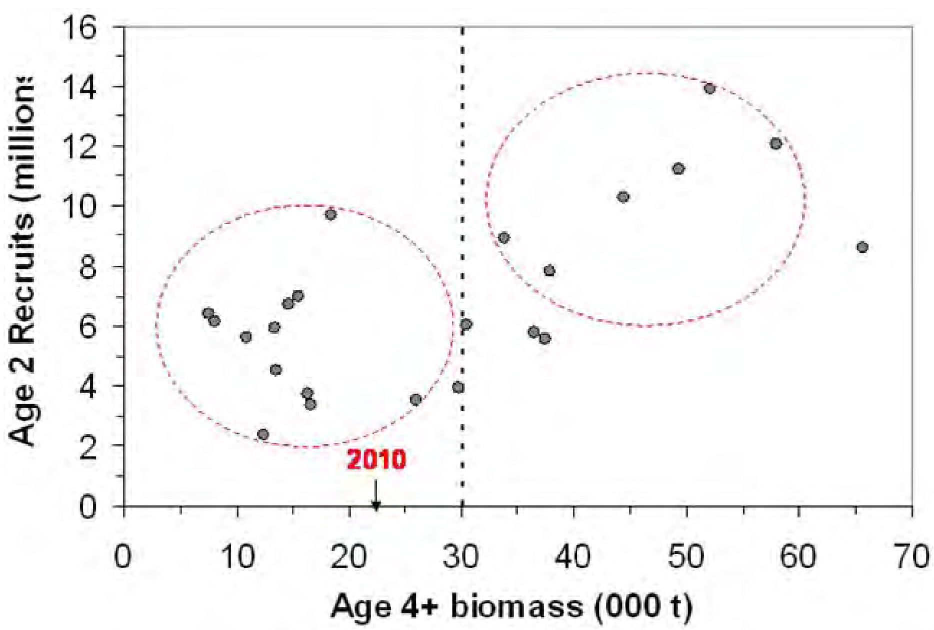


Fig. 36. Age 4+ biomass and age 2 recruitment relationship from the Base VPA model for the Western Component. The beginning of year age 4+ biomass is shown for 2006-2008.

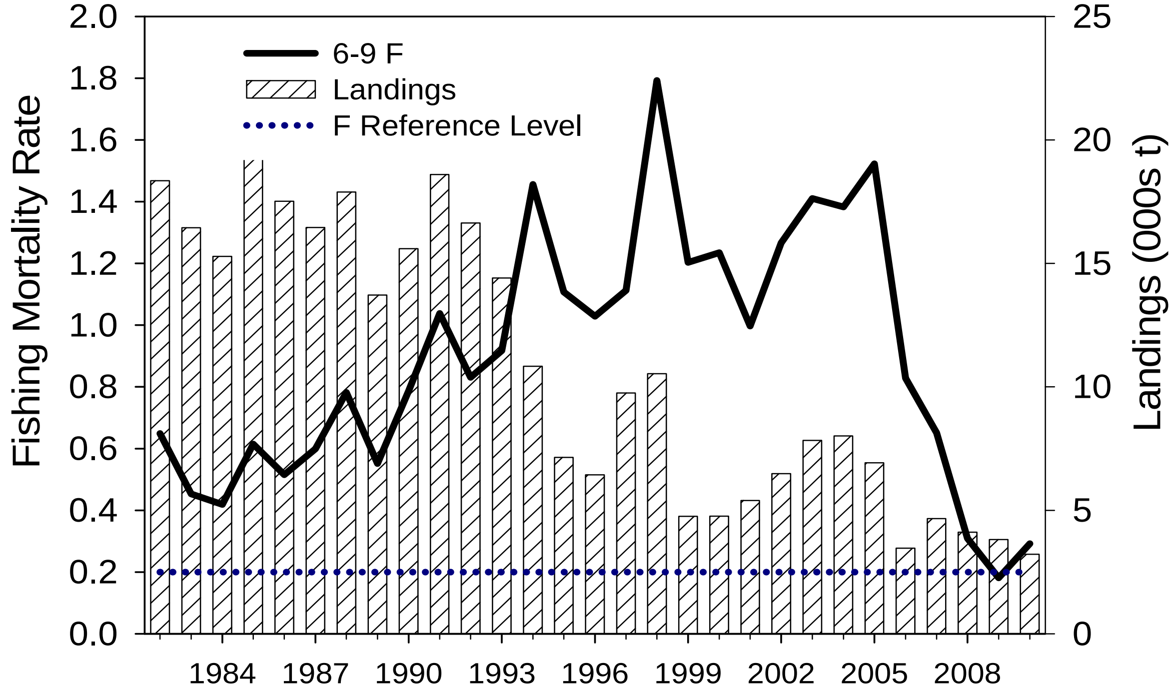


Fig. 37. Trends in fishing mortality and landings of pollock for the Western Component from the VPA model excluding the 2010 RV indices.

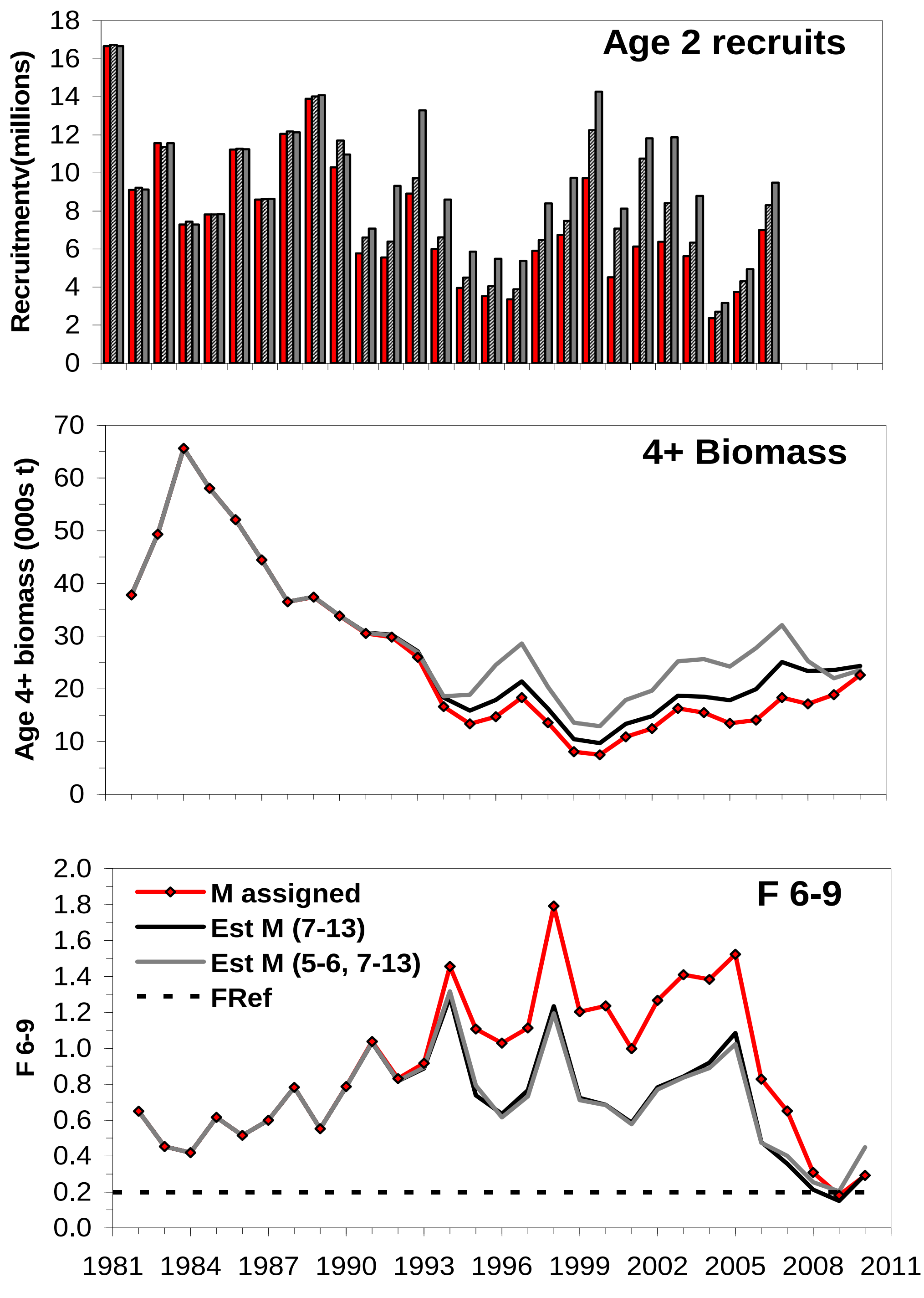


Fig. 38. Comparison of trends in age 2 recruitment, 4+ biomass, and age 6-9 fishing mortality for the Western Component from the VPA excluding the 2010 RV indices with M assigned (0.2) *vs.* M estimated for ages 7-13 and M estimated for ages 5-6 and 7-13 separately.

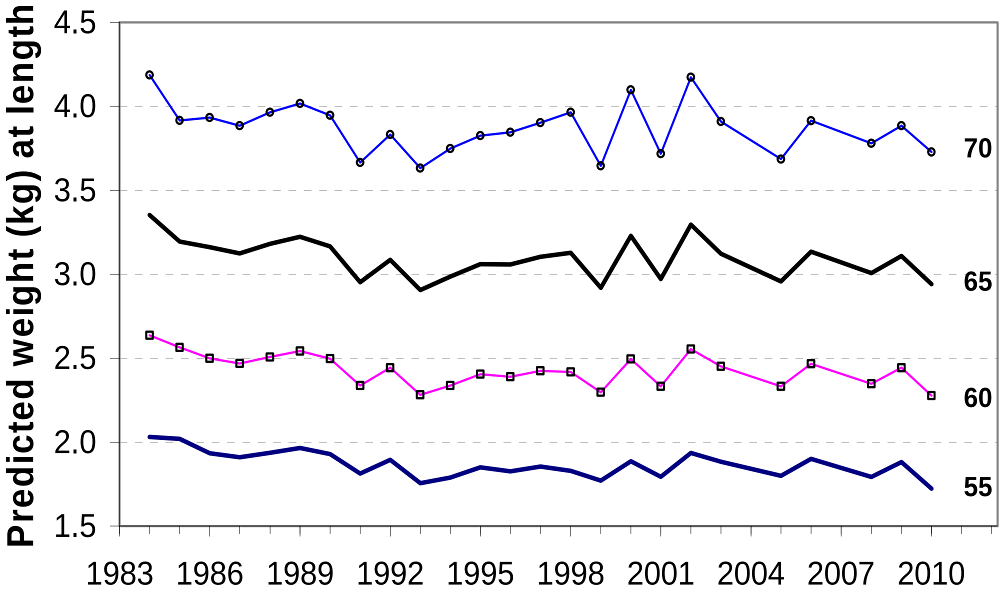


Fig. 39. Predicted weight (kg) of pollock at 55, 60, 65, and 70 cm FL based on length-weight regressions using data collected from DFO Summer RV surveys in western 4X, 1984-2010.

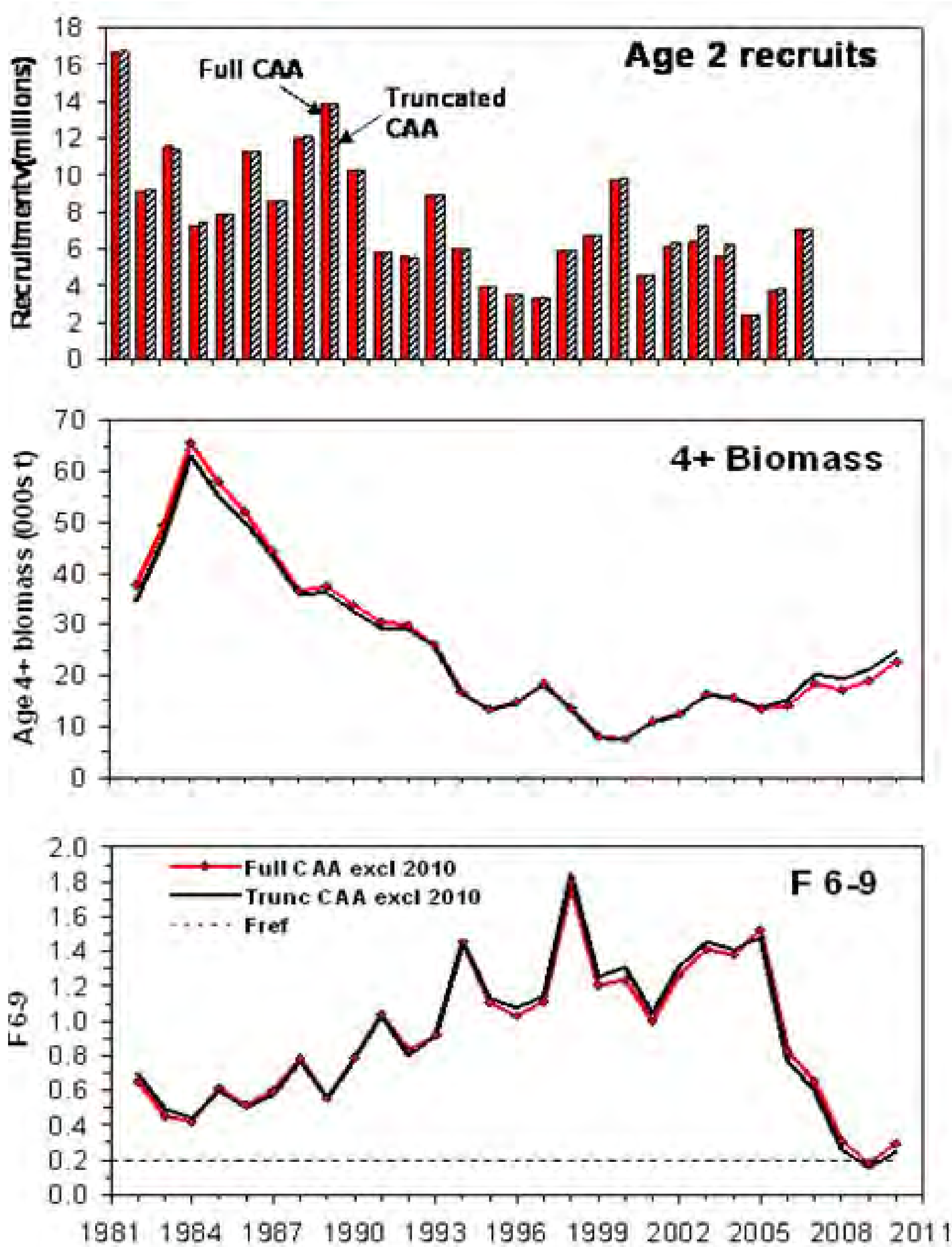


Fig. 40. Comparison of trends in age 2 recruitment, 4+ biomass, and age 6-9 fishing mortality for the Western Component from the VPA excluding the 2010 RV indices and full CAA (ages 2-13) *vs.* the VPA excluding the 2010 RV with a truncated CAA (ages 2-9).

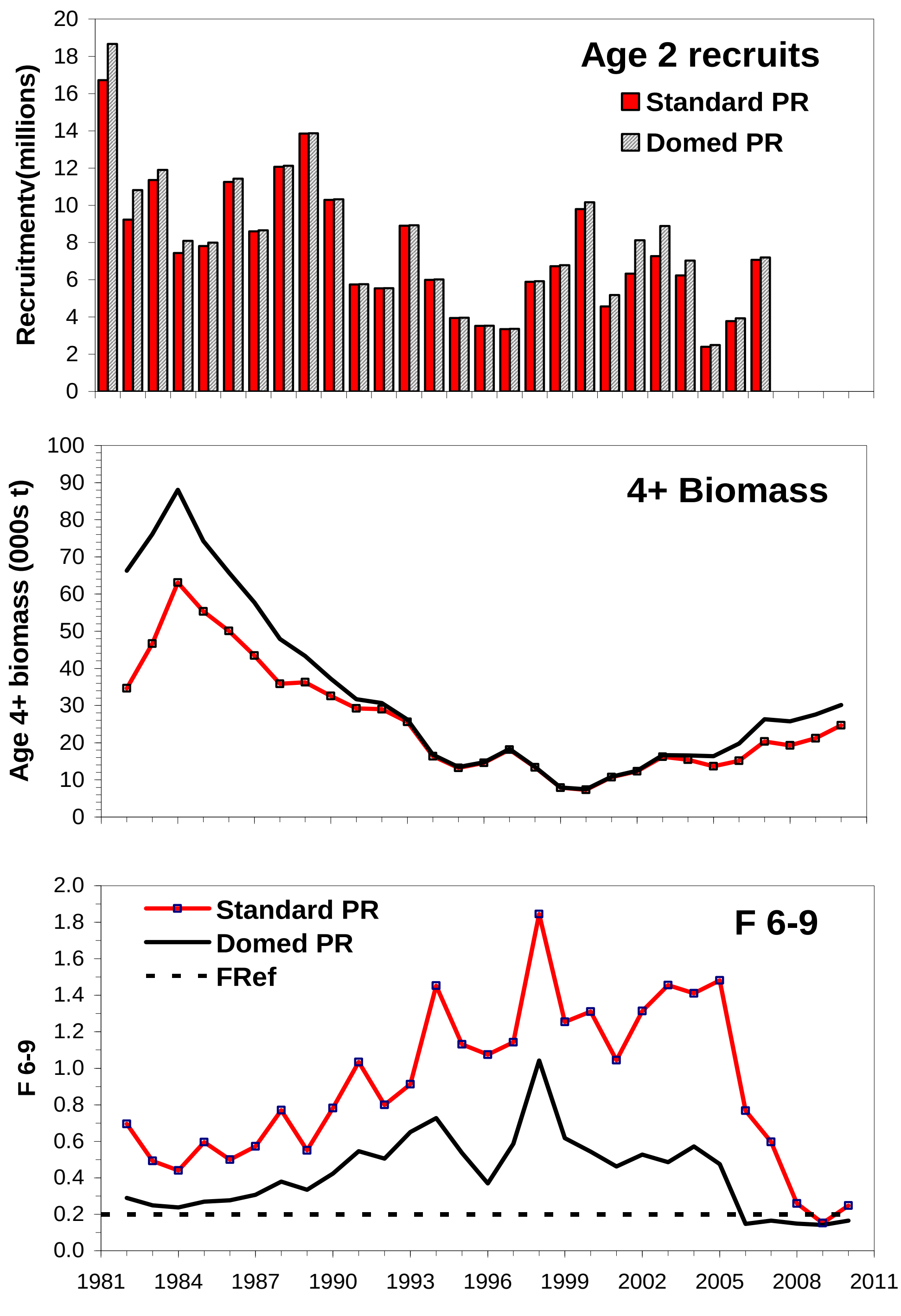


Fig. 41. Comparison of trends in age 2 recruitment, 4+ biomass, and age 6-9 fishing mortality for the Western Component between the truncated VPA (ages 1-9) formulation with the standard selectivity pattern *vs.* the truncated VPA formulation with the dome-shaped selectivity pattern.

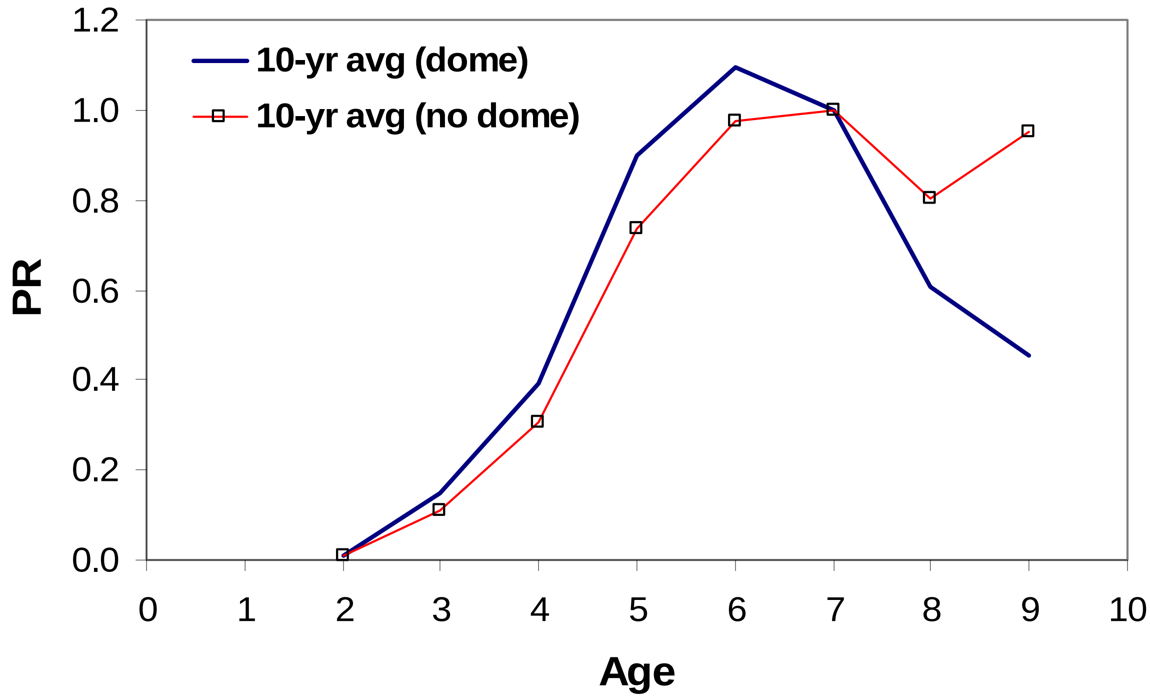


Fig. 42. Ten year average partial recruitment (PR) vector from the VPA model formulations used to examine standard *vs.* dome-shaped selectivity patterns.

APPENDIX 4b. A PROPOSED SET OF OPERATING MODELS FOR CANADIAN POLLOCK IN THE WESTERN COMPONENT (4Xopqrs+5Zc) TO BE USED IN MANAGEMENT PROCEDURE TESTING (OR MSE)

Rebecca A. Rademeyer and Doug S. Butterworth

INTRODUCTION

A key feature that distinguishes the Management Procedure Approach (also termed Management Strategy Evaluation or MSE) from conventional "best assessments" is the importance of selecting not the ("best") one assessment, but rather of ensuring that future resource trends will be satisfactory no matter which of a number plausible assessments most closely reflects the actual (but unknown) underlying situation of the resource.

Frequent convention is to select a small number of such "Operating Models" (OMs), spanning the most important aspects of uncertainty in the assessment, for use as a Reference Set (RS), which provides the initial basis to develop and to tune a Management Procedure (MP).

This paper develops a suggested set of four virtual population analysis (VPA)-based OMs to provide a RS to serve as a basis for subsequent testing of Candidate MPs. Two Statistical Catch-at-Age (SCAA) models are also developed to provide robustness tests for MPs developed using the VPA-based RS.

DATA AND METHODS

The details of the VPA methodology are provided in Appendix 4b-A, while those of the SCAA methodology are provided in Appendix 4b-B. The data used are listed in Appendix 4b-C.

RESULTS

Table 1 summarises the seven OMs presented in this paper, while Table 2 compares the negative log-likelihood values for these.

VPA RESULTS AND COMPARISONS

Stone vs. Rademeyer

Although both are based on VPA, the analysis of Stone (Appendix 4a) uses a slightly different methodology than this paper. Spawning (B4+) and exploitable biomass (B4-8) as well as fishing mortality trajectories for these two cases are compared (Fig. 1). The trajectories are virtually identical except for the most recent years. The recent divergence is due to the use of a bias correction approach in the Stone analysis. These two analyses are subsequently referred to as "Base Cases".

Excluding the 2010 survey estimates

Fig. 2 compares a series of trajectories for two VPAs, which either include or exclude the 2010 survey results. The differences are much greater over recent years than for the "Stone *vs.* Rademeyer" comparison above.

Fishing mortality at older ages

In the Rademeyer Base Case VPA, $\sigma_F = 0.01$, so that the fishing mortality on age 9 is very close to the weighted average of ages 7 and 8 fishing mortalities. Fig. 3 compares the trajectories for this analysis with those for a case when this penalty is relaxed ($\sigma_F = 0.3$). There are differences as in Fig. 2, though not as large, and in particular much less for recruitment.

CHOICE OF A VPA-BASED REFERENCE SET OF OMS

Fig. 4 plots the trajectories for the proposed VPA Reference Set for use in MP testing (MSE). This proposed Reference Set includes the following cases, which are VPA variants selected to attempt to span the range of uncertainties encompassed by key choices for different features of the VPA:

1) St1_BC_withBias: Stone (2010) Base Case;
2) St2_BC_withBias_no2010: Stone (2010), excluding the 2010 survey biomass estimates;
3) Rad1_sig001: Rademeyer Base Case;
4) Rad3_sig03: Rademeyer, with more flexibility on age 9 fishing mortality.

SCAA RESULTS

Fig. 5 compares the Rademeyer Base Case VPA results (Rad1_sig001) with two SCAA implementations: for SCAA1, the survey selectivity is assumed to decline exponentially at older ages; while for SCAA2, the survey selectivity for ages 9 and above is fixed at the age 8 level. These OMs are for use as robustness tests for Management Procedures developed through testing under the VPA-based Reference Set of OMs. Results for the Rademeyer Base Case and SCAA2 are very close, but absolute biomass estimates are generally rather larger for SCAA1.

Table 1. Summary of the Operating Models (OMs) presented.

	Type	2010 survey	bias correction	σ_F	RS	Survey selectivity
St1_withBias	VPA	included	included	-	yes	-
St2_withBias_no2010	VPA	excluded	included	-	yes	-
Rad1_sig001	VPA	included	-	0.01	yes	-
Rad2_sig001_no2010	VPA	excluded	-	0.01	-	-
Rad3_sig03	VPA	included	-	0.3	yes	-
SCAA1	SCAA	included	-	-	-	domed
SCAA2	SCAA	included	-	-	-	flat

Table 2. Components of the negative log-likelihoods for the five VPA- and two SCAA-based OMs.

	St1_ withBias	St2_ withBias_ no2010	Rad1_ sig001	Rad2_ sig001_ no2010	Rad3_ sig03		SCAA1	SCAA2
-lnL:overall	205.6	189.9	209.1	191.0	195.8	-lnL:overall	-14.0	-11.1
-lnL:RV3	50.5	52.6	50.4	53.1	49.8	-lnL:Survey	8.7	9.0
-lnL:RV4	30.7	24.0	30.1	23.5	29.4	-lnL:CPUE	-29.4	-28.9
-lnL:RV5	21.3	17.9	21.9	17.8	21.6	-lnL:CAA	-28.0	-26.7
-lnL:RV6	18.3	14.2	18.1	14.0	14.4	-lnL:CAAsurv	27.2	26.8
-lnL:RV7	26.1	22.2	24.9	20.5	17.7	-lnL:RecRes	7.6	8.7
-lnL:RV8	27.2	27.3	29.0	27.4	26.4			
-lnL:CPUE3	9.1	9.2	10.4	10.4	10.5			
-lnL:CPUE4	3.0	3.0	4.1	4.1	4.0			
-lnL:CPUE5	3.5	3.5	4.4	4.4	4.1			
-lnL:CPUE6	4.3	4.3	4.4	4.4	4.1			
-lnL:CPUE7	4.7	4.7	4.8	4.8	4.7			
-lnL:CPUE8	7.0	7.0	6.5	6.5	6.3			
F penalty	-	-	0.0	0.0	2.7			

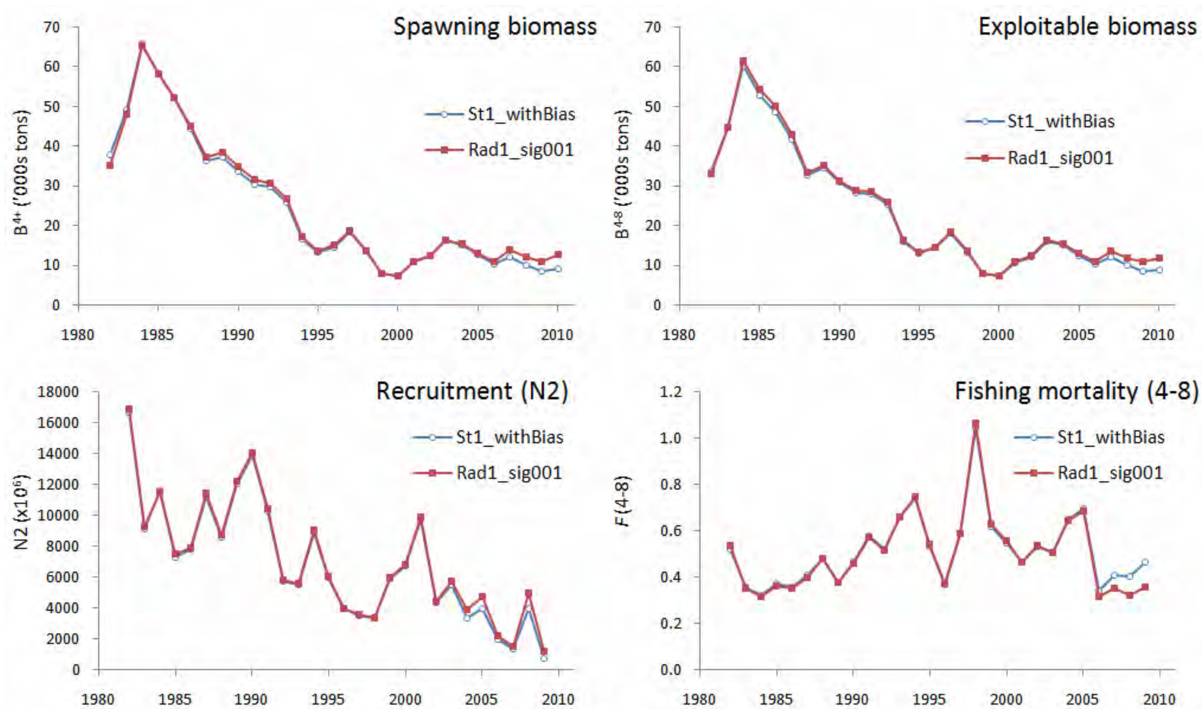


Fig. 1. Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the Stone (St1_withBias) and Rademeyer (Rad1_sig001) VPA Base Cases.

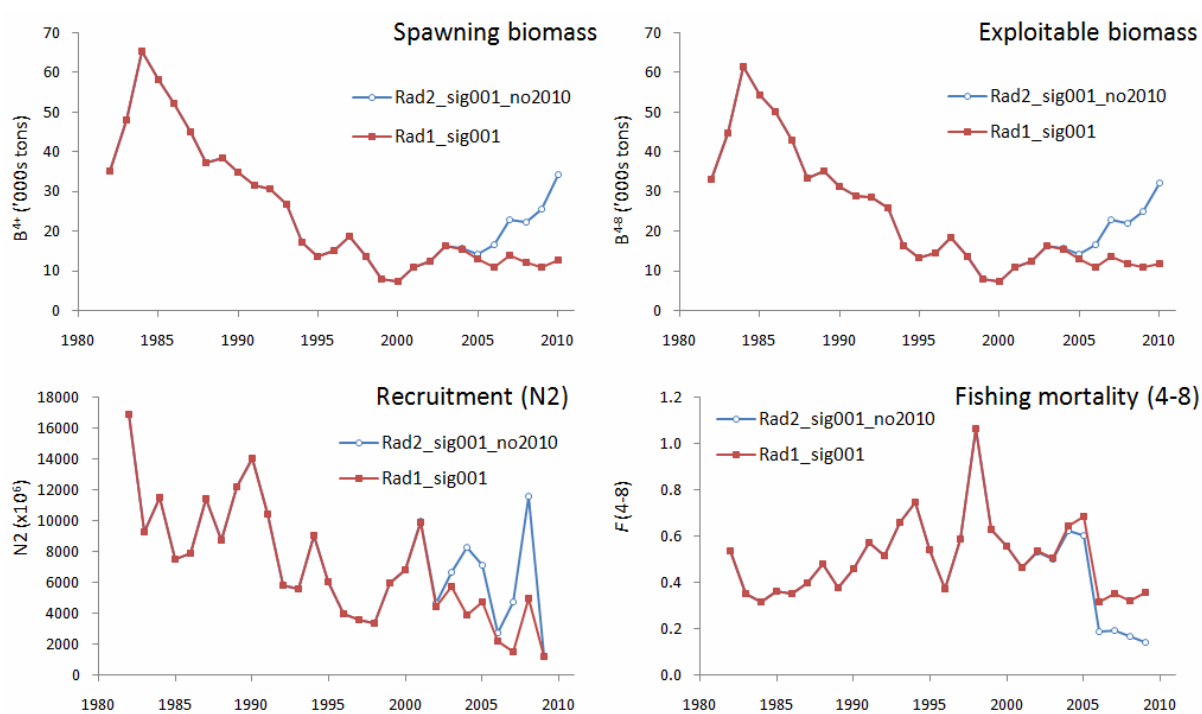


Fig. 2. Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2), and fishing mortality (ages 4-8) for the VPA assessments including (Rad1_sig001) and excluding the 2010 survey results (Rad2_sig001_no2010).

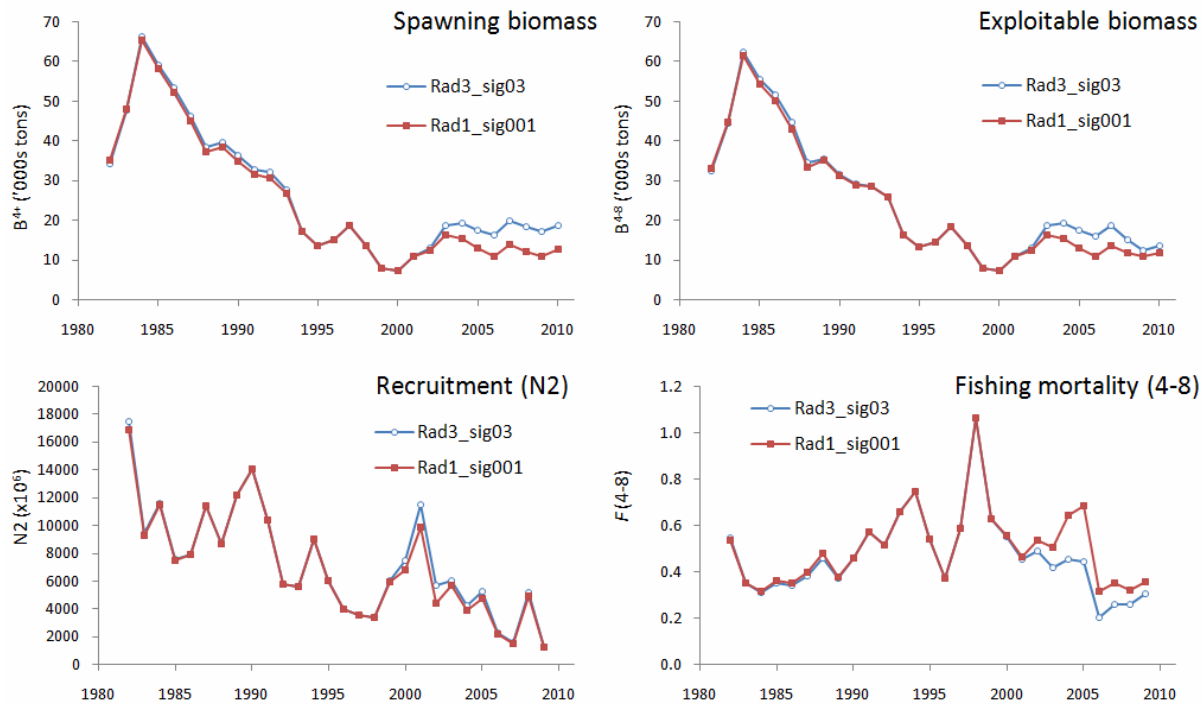


Fig. 3. Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2), and fishing mortality (ages 4-8) for the VPA-based OMs with $\sigma_F = 0.01$ (Rad1_sig001) and $\sigma_F=0.3$ (Rad3_sig03).

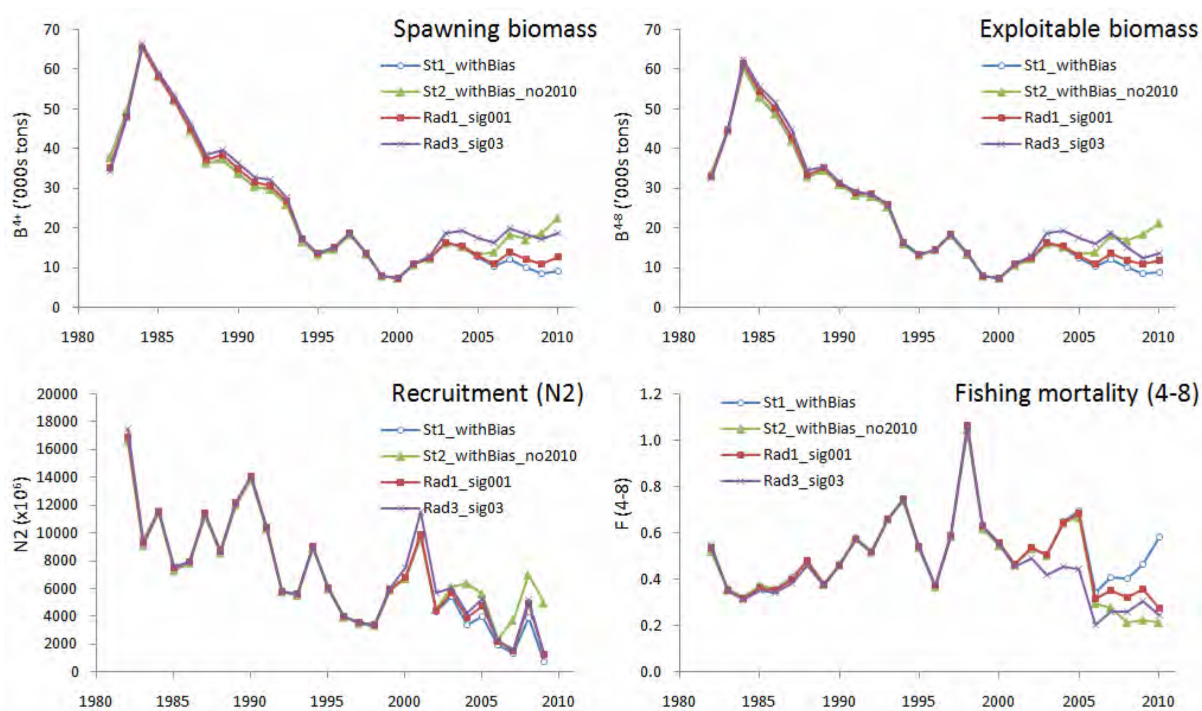


Fig. 4. Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2), and fishing mortality (ages 4-8) for the proposed VPA Reference Set of OMs.

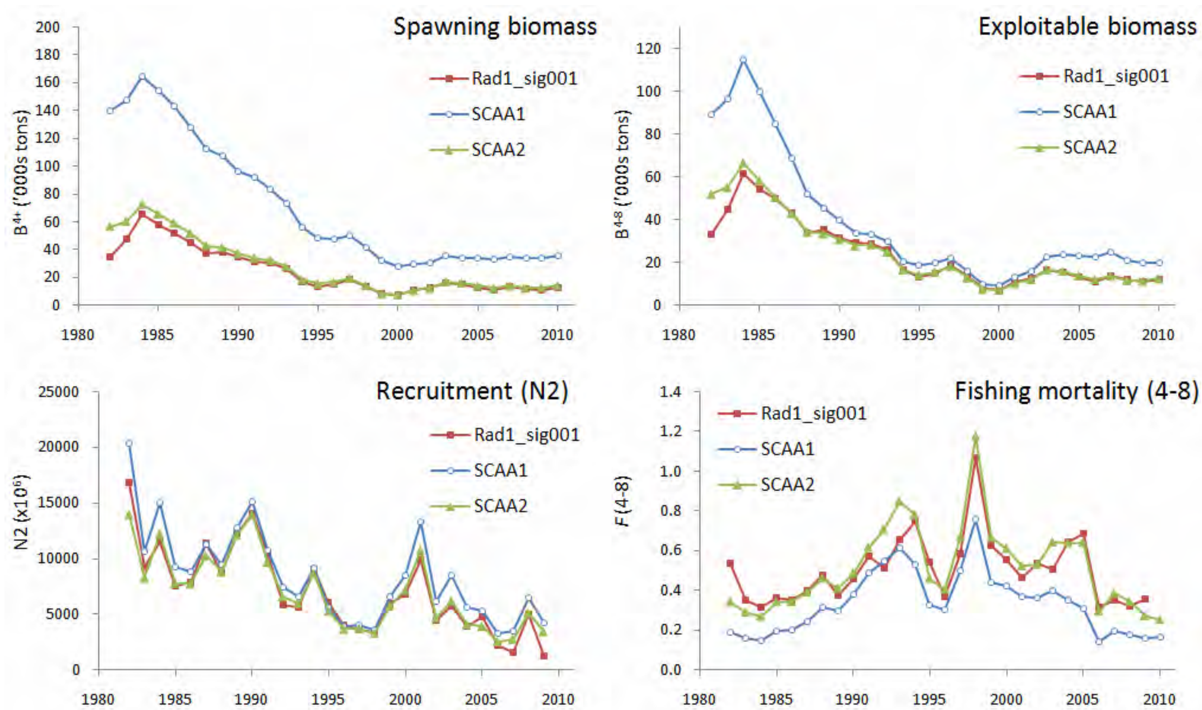


Fig. 5. Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2), and fishing mortality (ages 4-8) for the Base Case VPA and two SCAA OMs, with decreasing (SCAA1) and flat (SCAA2) survey selectivity at older ages.

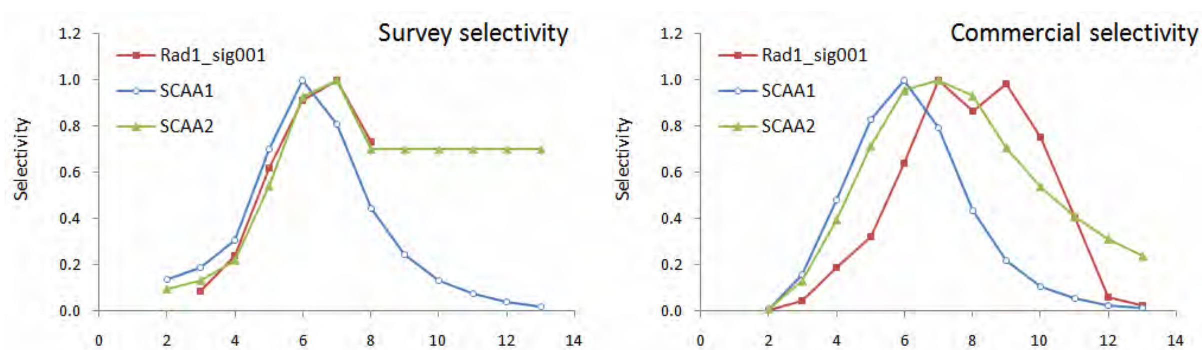


Fig. 6. Survey and commercial selectivities for the VPA Base Case and the two SCAA-based OMs.

APPENDIX 4b-A. THE VPA MODEL

4b-A.1. POPULATION DYNAMICS

The resource dynamics are modelled by the following set of equations:

$$N_{y,a} = N_{y+1,a+1}e^{M_a} + C_{y,a}e^{M_a/2} \qquad \text{for } 2 \le a \le m-1 \qquad \text{(A1)}$$

$$Z_{y,a} = \ell n\left(\frac{N_{y,a}}{N_{y+1,a+1}}\right) \qquad \text{(A2)}$$

$$F_{y,a} = Z_{y,a} - M_a \qquad \text{(A3)}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

M_a denotes the instantaneous rate of natural mortality for fish of age *a* (*M* = 0.2 for all ages),

$C_{y,a}$ is the number of fish of age *a* caught in year *y*,

m is the maximum age for the estimation (age 9),

$Z_{y,a}$ is the instantaneous rate of mortality during year *y* from all causes (total mortality) on fish of age *a*, and

$F_{y,a}$ is the instantaneous rate of fishing mortality on fish of age *a*.

The total and fishing mortality on age *m*:

$$Z_{y,m} = \ell n\left(\frac{N_{y,m}}{\left(N_{y,m}e^{-M_m/2} - C_{y,m}\right)e^{-M_m/2}}\right) \qquad \text{(A4)}$$

$$F_{y,m} = Z_{y,m} - M_m \qquad \text{(A5)}$$

Catch-at-age information is available to age 13, so that the numbers-at-age for ages 10 to 13 (not taken to be a plus-group) can be computed as:

$$N_{y+1,a} = \left(N_{y,a-1}e^{-M_{a-1}/2} - C_{y,a-1}\right)e^{-M_{a-1}/2} \qquad 10 \le a \le 13 \qquad \text{(A6)}$$

4b-A.2. THE OBJECTIVE FUNCTION

The model is fit to survey abundance and catch per unit effort (CPUE) indices. Contributions by each of these to the objective function (maximised in the fit) are computed as follows:

Calculations assume that the observed abundance indices are log-normally distributed about their expected values:

$$I^i_{y,a} = \hat{I}^i_{y,a}\exp\left(\varepsilon^i_{y,a}\right) \quad \text{or} \quad \varepsilon^i_{y,a} = \ell\text{n}\left(I^i_{y,a}\right) - \ell\text{n}\left(\hat{I}^i_{y,a}\right) \qquad \text{(A7)}$$

where

$I^i_{y,a}$ is the observed abundance index for year *y*, age *a* and series *i*,

$\hat{I}^i_{y,a}$ is the corresponding model estimate, where

$$\hat{I}^i_{y,a} = q^i_a N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}}$$ for survey mid-year indices, and (A8)

$$\hat{I}^i_{y,a} = q^i_a \left(N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}} \right)^{\beta^i_a}$$ for CPUE mid-year indices. (A9)

β^i_a are estimable parameters, and

$\hat{q}^i_a$ is the constant of proportionality (catchability) for abundance series *i* and age *a*, estimated by its maximum likelihood value:

$$\ln(\hat{q}^i_a) = \sum_y \left[\ln(I^i_{y,a}) - \ln\left[\left(N_{y,a} \frac{1-e^{-Z_{y,a}}}{Z_{y,a}} \right)^{\beta^i_a} \right] \right] \Big/ \sum_y 1$$ (A10)

The objective function is then given by:

$$SS = \sum_{i,y,a} \left[\ell n(I^i_{y,a}) - \ell n(\hat{I}^i_{y,a}) \right]^2$$

The function is minimised by treating the abundances for ages 3 to 8 in year *T*+1 as estimable parameters, where *T* is the final year. Furthermore, the $N_{y,m}$ are estimated directly for each year to year *T* and a penalty is added to the objective function:

$$P = \sum_y \left[\ln(F_{y,m}) - \ln(\hat{F}_{y,m}) \right]^2 \Big/ 2\sigma^2_F$$ (A11)

where

$$\hat{F}_{y,m} = 0.5(F_{y,m-2} + F_{y,m-1})$$ (*i.e.,* asymptotically flat selectivity) (A12)

σ_F is set small.

APPENDIX 4b-B. THE STATISTICAL CATCH-AT-AGE MODEL

4b-B.1. POPULATION DYNAMICS

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,2} = R_{y+1} \tag{B1}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 2 \le a \le m-2 \tag{B2}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - C_{y,m-1}\right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - C_{y,m}\right) e^{-M_m/2} \tag{B3}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

R_y is the recruitment (number of 2 year-old fish) at the start of year *y*,

M_a denotes the natural mortality rate for fish of age *a*,

$C_{y,a}$ is the predicted number of fish of age *a* caught in year *y*, and

m is the maximum age considered (13, taken to be a plus-group).

The number of recruits (*i.e.*, new 2 year-old fish) at the start of year *y* is assumed to be related to the spawning stock size (*i.e.*, the biomass of mature fish) by a Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B^{sp}_{y-2}}{\beta + B^{sp}_{y-2}}\, e^{(\varsigma_y - (\sigma_R)^2/2)} \tag{B4}$$

where

α and β are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input (0.5) in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B^{sp}_y is the spawning biomass at the start of year *y*, computed as:

$$B^{sp}_y = \sum_{a=2}^{m} f_{y,a} w^{strt}_{y,a} N_{y,a} \tag{B5}$$

where

$w_{y,a}^{strt}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness", *h*, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realised at a spawning biomass level of 20% of the virgin spawning biomass. In the fitting procedure, both *h* and K^{sp} are estimated, with h constrained not to exceed 0.9.

The catch by mass in year *y* is given by:

$$C_y = \sum_{a=2}^{m} w_{y,a}^{mid}\, C_{y,a} = \sum_{a=2}^{m} w_{y,a}^{mid}\, N_{y,a}\, e^{-M_a/2}\, S_{y,a}\, F_y^* \qquad \text{(B6)}$$

where

$w_{y,a}^{mid}$ denotes the mass of fish of age *a* landed in year *y*,

$C_{y,a}$ is the catch-at-age, *i.e.*, the number of fish of age *a*, caught in year *y*,

$S_{y,a}$ is the commercial selectivity (*i.e.*, combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a} = 1$, the age-class *a* is said to be fully selected, and

F_y^* is the proportion of a fully selected age class that is fished.

The model estimate of the mid-year exploitable ("available") component of biomass is:

$$B_y^{ex} = \sum_{a=2}^{m} w_{y,a}^{mid} S_{y,a} N_{y,a} e^{-M_a/2}(1 - S_{y,a}F_y^*/2) \qquad \text{(B7)}$$

whereas for survey estimates of biomass in the middle of the year:

$$B_y^{surv} = \sum_{a=2}^{m} w_{y,a}^{mid} S_a^{surv} N_{y,a} e^{-M_a/2}(1 - S_{y,a}F_y^*/2) \qquad \text{(B8)}$$

where

S_a^{surv} is the year-independent survey selectivity for age *a*.

<u>Initial conditions</u>

As the first year for which data (even annual catch data) are available for the stock considered clearly does not correspond to the first year of (appreciable) exploitation, one cannot make the conventional assumption in the application of ASPM's that this initial year reflects a population (and its age structure) at pre-exploitation equilibrium. For the first year (y_0) considered in the model therefore, the stock is assumed to be at a fraction (θ) of its pre-exploitation biomass, *i.e.*:

$$B_{y_0}^{sp} = \theta \cdot K^{sp} \qquad \text{(B9)}$$

with the starting age structure:

$$N_{y_0,a} = R_{start} N_{start,a} \qquad \text{for } 2 \le a \le m \qquad \text{(B10)}$$

where

$$N_{start,2} = 1 \qquad \text{(B11)}$$

$$N_{start,a} = N_{start,a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } 3 \le a \le m-1 \qquad \text{(B12)}$$

$$N_{start,m} = N_{start,m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \big/ (1-e^{-M_m}(1-\phi S_m)) \qquad \text{(B13)}$$

where ϕ characterises the average fishing proportion over the years immediately preceding y_0.

4b-B.2. THE (PENALISED) LIKELIHOOD FUNCTION

The model is fit to CPUE and survey abundance indices, and commercial and survey catch-at-age data to estimate model parameters. Contributions by each of these to the negative of the (penalised) log-likelihood (- $\ell n L$) are as follows:

CPUE relative abundance data

The likelihood is calculated assuming that an observed CPUE abundance index for a particular fishing fleet is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp(\varepsilon_y^i) \quad \text{or} \quad \varepsilon_y^i = \ell n(I_y^i) - \ell n(\hat{I}_y^i) \qquad \text{(B14)}$$

where

I_y^i is the CPUE abundance index for year *y* and series *i*,

$\hat{I}_y^i = \hat{q}^i \left(\hat{B}_y^{ex}\right)^{\beta^i}$ is the corresponding model estimate, where $\hat{B}_y^{ex}$ is the model estimate of exploitable resource biomass, given by equation (B7),

$\hat{q}^i$ is the constant of proportionality (catchability) for CPUE abundance series *i*,

β^i is an estimable parameter and

ε_y^i from $N\left(0,(\sigma_y^i)^2\right)$.

The contribution of the CPUE data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n L^{CPUE} = \sum_i \sum_y \left[\ell n(\sigma_y^i) + (\varepsilon_y^i)^2 / 2(\sigma_y^i)^2\right] \qquad \text{(B15)}$$

where

σ_y^i is the standard deviation of the residuals for the logarithm of index *i* in year *y*.

Homoscedasticity of residuals is assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell n(I_y^i) - \ell n(q^i \hat{B}_y^{ex})\right)^2} \qquad \text{(B16)}$$

where

n_i is the number of data points for CPUE abundance index *i*.

The catchability coefficient q^i for CPUE abundance index *i* is estimated by its maximum likelihood value:

$$\ell n\,\hat{q}^i = 1/n_i \sum_y \left(\ln I_y^i - \ln \hat{B}_y^{ex}\right) \qquad \text{(B17)}$$

Survey abundance data

In general, data from the surveys are treated as relative abundance indices in the same manner to the CPUE series above, but with

$$\hat{I}_y^i = \hat{q}^i \hat{B}_y^{surv} \qquad \text{(B18)}$$

Commercial catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function under the assumption of an "adjusted" lognormal error distribution is given by:

$$-\ell\mathrm{n}\,L^{CAA} = \sum_y \sum_a \left[\ell n\left(\sigma_{com} / \sqrt{p_{y,a}}\right) + p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / 2\left(\sigma_{com}\right)^2 \right] \qquad \text{(B19)}$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year *y* that are of age *a*,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model-predicted proportion of fish caught in year *y* that are of age *a*,

where

$$\hat{C}_{y,a} = N_{y,a}\, e^{-M_a/2}\, S_{y,a}\, F_y \qquad \text{(B20)}$$

and

σ_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{com} = \sqrt{\sum_y \sum_a p_{y,a}\left(\ell n\, p_{y,a} - \ell n\, \hat{p}_{y,a}\right)^2 / \sum_y \sum_a 1} \qquad \text{(B21)}$$

Commercial catches-at-age are incorporated in the likelihood function using equation B19, for which the summation over age *a* is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group).

Survey catches-at-age

The survey catches-at-age are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation B19) where:

$p_{y,a} = C_{y,a}^{surv} / \sum_{a'} C_{y,a'}^{surv}$ is the observed proportion of fish of age *a* in year *y*,

$\hat{p}_{y,a}$ is the expected proportion of fish of age *a* in year *y* in the survey, given by:

$$\widehat{p}_{y,a} = \widehat{C}^{surv}_{y,a} / \sum_{a'} \widehat{C}^{surv}_{y,a'}$$

where

$$\widehat{C}^{surv}_{y,a} = S^{surv}_{a} N_{y,a} e^{-M_a/2}\left(1 - F^{*}_{y,a}/2\right) \quad \text{for mid-year surveys.} \qquad \text{(B22)}$$

<u>Stock-recruitment function residuals</u>

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{pen} = \sum_{y=y1}^{y2} \left[(\varepsilon_y)^2 / 2\sigma_R^2\right] \qquad \text{(B23)}$$

where

ε_y is the recruitment residual for year *y*, which is estimated for year *y*1 to *y*2 (see equation B4),

σ_R is the standard deviation of the log-residuals, which is input (0.5).

The years y_1 and y_2 are chosen to include periods to which age data relate and hence provide some information on the recruitment residuals.

4b-B.3. MODEL PARAMETERS

<u>Fishing selectivity-at-age:</u>

The commercial fishing selectivity, S_a, is estimated separately for ages 2-9, while the fishing selectivity for the surveys, S_a^{surv}, is estimated separately for ages 2-8. If not indicated otherwise, the estimated decrease from ages 8 to 9 for the commercial selectivity and from ages 7 to 8 for the survey selectivity is assumed to continue exponentially to age 13.

<u>Other parameters</u>

Plus-group:	m	13
Commercial CAA:	a_{minus}	2
	a_{plus}	9
Survey CAA:	a_{minus}	2
	a_{plus}	8
Stock-recruitment residuals:	Φ_R	0.5
	y_1	1983
	y_2	2009
Natural mortality:	M	0.2
Maturity-at-age:		
Maturity-at-age:	$f_{y,a}$	knife-edge, 1 for ages 4 and above
Weight-at-age:	$w^{sp}_{y,a}$	input, see Table C1
	$w^{landed}_{y,a}$	input, see Table C2

APPENDIX 4b-C. THE DATA

Table C1. Begin-year weight-at-age (kg) in the Western Component (4Xopqrs+5Zc) (used in VPA and SCAA).

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.2837	0.8110	1.6927	2.9881	3.8182	4.4827	5.2067	5.9535	6.9253	8.1411	9.5694	10.8088
1983	0.3032	1.2351	1.6599	2.9494	3.8883	4.6365	5.1929	6.1344	6.7116	8.0265	8.7530	10.8088
1984	0.3602	0.9441	2.6147	2.7299	3.7088	4.8566	5.5630	5.9230	6.6425	7.2250	9.0280	9.8867
1985	0.3229	0.8066	2.3010	2.8995	3.3322	4.1856	5.7031	6.6591	6.6787	7.2852	8.2189	10.3429
1986	0.4231	0.8998	1.6075	3.1362	3.5286	4.0913	4.9878	6.3287	7.2376	7.2532	8.3250	10.1377
1987	0.1852	0.6416	1.8835	2.5537	3.3212	4.1175	4.7147	5.5401	6.7221	7.3197	7.6098	9.7815
1988	0.5720	0.6959	1.3640	2.7042	3.4053	3.8648	4.6351	5.3743	6.1227	7.4498	7.9532	9.3273
1989	0.3658	0.7501	1.9007	2.6880	3.4681	4.1349	4.5173	5.4712	6.1059	7.9390	7.6334	9.6433
1990	0.2538	0.6563	1.3228	2.7839	3.3496	4.3030	5.1116	5.5696	6.4714	6.9496	9.3306	8.8579
1991	0.3662	0.5902	1.1540	2.4162	3.2882	4.1590	5.2171	6.1306	6.5893	7.4931	8.2978	10.3668
1992	0.3305	0.7757	1.3741	1.9904	3.1712	4.1519	5.0847	5.9221	6.6589	7.4591	8.6060	9.9664
1993	0.4443	0.5595	1.1683	2.2024	2.8669	3.6294	4.6682	5.4790	6.4163	7.2719	8.1475	10.0538
1994	0.3093	0.6933	1.1076	1.6171	2.6590	3.4400	3.9797	4.7881	5.8672	6.3854	7.7747	9.4573
1995	0.2125	0.4816	1.1834	1.9669	2.5634	3.4715	4.2493	4.7682	5.9722	7.3305	7.3079	9.2901
1996	0.2000	0.6133	1.0421	1.9506	2.6493	3.3368	4.5291	5.4951	6.7688	8.3818	9.8955	9.8281
1997	0.2039	0.9740	1.3395	2.1024	2.7815	3.4863	4.3238	6.3566	7.9577	7.5682	10.6733	11.2090
1998	0.3747	0.6042	0.9712	2.0163	2.7731	3.7245	4.5290	5.3637	8.1779	9.4256	9.0149	11.4484
1999	0.2215	0.6072	1.1906	1.8277	2.7679	3.6717	4.8862	6.0338	7.4871	9.2552	9.3984	11.5192
2000	0.2636	0.6972	1.2087	1.8378	2.7674	3.6777	4.8173	5.7018	7.9708	9.8798	9.9715	10.4881
2001	0.3130	0.5250	1.4793	2.3528	3.0419	3.8881	5.2178	6.6283	7.0040	9.0145	10.2932	10.4881
2002	0.2574	0.6045	1.1730	2.1147	3.2982	4.2463	5.4969	6.7310	8.3861	9.6351	10.0009	10.8935
2003	0.2201	0.7083	1.1751	2.1005	2.9864	4.2134	5.5109	6.8555	8.0233	9.3493	9.8229	11.0404
2004	0.2052	0.5661	1.4299	1.9061	2.7249	3.8904	5.5779	6.8076	8.0379	9.1784	11.0160	9.8805
2005	0.2269	0.5969	1.2428	1.8905	2.4648	3.5422	4.7240	6.1204	8.0829	11.1443	11.3839	11.5020
2006	0.3502	0.7017	1.3926	1.9257	2.5238	3.1957	4.3348	5.1940	7.2451	9.3716	12.4467	12.5318
2007	0.2232	0.6997	1.4407	2.1906	2.5424	3.4901	4.1181	5.4222	6.1747	9.6431	11.3877	10.9252
2008	0.3701	0.7717	1.3424	1.9664	2.8352	3.3650	4.3903	5.0344	6.1317	8.0581	10.9793	12.0000
2009	0.4550	0.8687	1.6664	2.1132	2.7619	3.6404	4.1722	4.9898	5.4368	8.4602	10.7045	11.4046
2010	0.0731	0.7495	1.5500	2.1800	2.7525	3.5527	4.2543	4.5143	5.0212	5.8213	11.0727	11.9463

Table C2. Mid-year weight-at-age (kg) in the Western Component (4Xopqrs+5Zc) (used in VPA and SCAA).

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.943	1.427	2.529	3.462	4.211	4.772	5.681	6.239	7.687	8.622	10.621	10.802
1983	0.881	1.349	1.983	3.373	4.367	5.105	5.651	6.624	7.220	8.381	8.886	9.188
1984	0.914	1.635	2.331	3.005	4.078	5.401	6.062	6.208	6.661	7.230	9.725	8.091
1985	0.974	1.615	2.462	3.169	3.695	4.296	6.022	7.315	7.185	7.968	9.343	9.401
1986	0.738	1.554	2.306	3.095	3.929	4.530	5.791	6.651	7.161	7.322	8.698	6.835
1987	0.943	1.475	2.266	3.046	3.564	4.315	4.907	5.300	6.794	7.482	7.909	8.806
1988	1.195	1.549	2.240	3.096	3.807	4.191	4.979	5.886	7.073	8.169	8.454	8.467
1989	0.880	1.313	2.095	3.068	3.885	4.491	4.869	6.012	6.334	8.911	7.133	10.715
1990	0.571	1.263	2.055	2.894	3.657	4.766	5.818	6.371	6.966	7.625	9.770	9.070
1991	0.906	1.344	2.153	2.866	3.736	4.730	5.711	6.460	6.815	8.060	9.030	9.778
1992	1.033	1.271	1.831	2.615	3.509	4.614	5.466	6.141	6.864	8.164	9.189	8.947
1993	0.761	1.110	1.666	2.312	3.143	3.754	4.723	5.492	6.704	7.704	8.131	8.606
1994	0.805	1.250	1.586	2.163	3.058	3.765	4.219	4.854	6.268	6.082	7.846	8.539
1995	0.671	1.132	1.806	2.296	3.038	3.941	4.796	5.389	7.348	8.573	8.781	9.392
1996	0.896	1.336	1.795	2.353	3.057	3.665	5.205	6.296	8.502	9.561	11.422	11.474
1997	0.915	1.388	1.938	2.446	3.288	3.976	5.101	7.763	10.058	6.737	11.915	11.000
1998	0.867	1.103	1.720	2.361	3.144	4.219	5.159	5.640	8.615	8.833	12.063	11.000
1999	0.806	1.193	1.682	2.419	3.245	4.288	5.659	7.057	9.939	9.943	10.000	11.000
2000	0.757	1.247	1.796	2.478	3.166	4.168	5.412	5.745	9.003	9.821	10.000	11.000
2001	0.453	1.039	1.987	2.929	3.734	4.775	6.532	8.118	8.539	9.026	10.788	13.067
2002	0.280	0.931	1.592	2.528	3.714	4.829	6.328	6.936	8.663	10.872	11.081	16.975
2003	0.590	0.977	1.536	2.376	3.528	4.780	6.289	7.427	9.281	10.090	8.875	11.000
2004	0.475	0.873	1.621	2.210	3.125	4.290	6.509	7.369	8.699	9.077	12.027	15.595
2005	0.391	0.955	1.439	2.152	2.801	4.087	5.479	5.956	9.216	14.277	14.277	11.000
2006	0.654	0.931	1.722	2.180	3.101	3.715	4.680	5.186	9.121	9.906	10.851	11.000
2007	0.660	0.948	1.573	2.525	2.973	3.944	4.567	6.229	7.352	10.195	13.091	11.000
2008	0.758	1.202	1.681	2.299	3.191	3.819	4.907	5.552	5.985	8.832	11.824	11.000
2009	0.585	1.137	1.884	2.451	3.318	4.153	4.558	5.074	5.324	11.959	12.974	13.123
2010	0.683	1.026	1.754	2.456	3.091	3.804	4.358	4.471	4.969	6.365	10.252	11.000

Table C3. Pollock landings (tonnes) in the Western Component (4Xopqrs+5Zc) (used in SCAA only).

year	catch	year	catch	year	catch
1982	18347	1992	16639	2002	6485
1983	16448	1993	14410	2003	7839
1984	15291	1994	10836	2004	8012
1985	19511	1995	7144	2005	6928
1986	17520	1996	6441	2006	3469
1987	16460	1997	9759	2007	4679
1988	17899	1998	10534	2008	4115
1989	13724	1999	4760	2009	3819
1990	15595	2000	4768	2010	3218
1991	18602	2001	5400		

Table C4. Pollock total catch-at-age (000s) in the Western Component (4Xopqrs+5Zc) (used in VPA and SCAA).

year	2	3	4	5	6	7	8	9	10	11	12	13
1982	95.41	1618.04	1351.70	371.41	1031.13	838.11	425.02	145.46	45.18	33.17	12.93	0.00
1983	44.95	1282.78	3965.86	853.58	179.05	313.82	291.22	138.23	59.16	17.35	18.61	0.00
1984	3.79	370.37	1831.89	2751.15	464.92	85.42	148.40	114.32	40.69	18.58	2.22	0.00
1985	4.64	194.79	621.34	1805.50	2142.31	327.53	37.57	100.11	99.06	62.26	29.79	0.00
1986	1.24	162.33	1410.04	1136.24	1328.96	876.49	87.70	36.68	36.68	41.43	15.09	0.00
1987	4.90	104.10	627.83	1622.12	883.39	786.09	490.10	68.45	16.94	15.46	27.74	0.00
1988	18.85	424.56	989.57	1125.72	1280.52	518.57	423.85	242.26	22.02	14.30	20.44	0.00
1989	93.26	386.48	1532.79	1128.98	575.96	463.10	147.11	129.18	65.05	6.08	7.43	0.00
1990	47.02	776.37	1102.18	1620.50	873.25	429.13	173.92	138.31	49.11	23.36	9.65	0.00
1991	57.71	1013.03	1900.25	1505.91	1395.02	346.60	157.44	55.70	48.67	25.24	9.95	0.00
1992	45.61	1250.38	2678.13	1650.93	674.64	313.60	123.60	96.26	60.73	14.49	11.51	0.00
1993	4.22	550.94	1989.43	2124.58	1143.06	317.66	92.41	27.11	10.45	6.64	5.93	0.00
1994	50.53	259.40	675.15	1327.34	1151.03	494.11	166.14	58.59	14.37	7.94	1.65	0.00
1995	23.76	263.41	536.92	948.60	676.46	293.62	63.26	17.26	3.56	1.08	0.56	0.00
1996	14.06	201.70	949.14	709.71	472.61	256.04	54.80	15.08	0.32	0.06	0.61	0.00
1997	6.32	151.29	899.72	1654.37	780.40	216.96	53.59	4.31	0.37	0.93	0.06	0.00
1998	6.63	228.15	828.70	1368.31	1261.98	306.59	46.65	16.18	1.99	0.83	0.12	0.00
1999	12.54	88.92	496.43	621.11	425.96	172.65	21.53	4.13	1.18	1.94	0.00	0.00
2000	85.66	581.26	403.77	592.03	319.42	138.93	27.25	6.24	0.92	0.19	0.00	0.00
2001	15.38	335.32	813.63	571.05	313.71	90.72	13.76	4.57	1.75	0.64	0.59	0.00
2002	7.18	190.79	786.90	1072.99	416.33	126.79	19.75	5.85	1.26	0.48	0.23	0.00
2003	2.11	111.18	1301.65	1330.90	513.01	119.70	18.20	5.50	1.16	1.39	0.24	0.00
2004	1.94	173.12	542.48	1875.64	695.72	118.23	12.77	4.29	1.66	1.31	0.47	0.01
2005	0.33	36.80	842.34	758.66	1159.79	169.51	13.20	4.59	0.52	0.01	0.01	0.00
2006	0.78	29.79	153.65	533.99	353.37	218.13	18.16	2.91	0.19	0.04	0.00	0.00
2007	5.46	68.63	369.61	452.51	618.75	223.01	28.43	2.74	0.59	0.28	0.01	0.00
2008	20.42	97.38	175.36	390.39	428.88	260.49	51.70	11.49	0.54	0.05	0.00	0.00
2009	25.06	336.37	295.95	291.00	356.52	156.97	50.50	7.49	2.18	0.01	0.01	0.01
2010	10.26	119.03	266.43	293.42	208.99	213.24	62.09	29.21	6.29	0.51	0.04	0.00

Table C5. Standardised mobile gear CPUE (tonnage class 1-3) (truncated at 2004 due to changes in management measures and fishing practices) and summer survey index (*Needler* time series only) (used in SCAA only).

	CPUE series (tons/hour)	Survey (numbers/tow)
1982	0.1614	-
1983	0.1783	-
1984	0.2231	9.41
1985	0.1815	8.67
1986	0.1933	12.28
1987	0.1795	7.60
1988	0.1357	22.72
1989	-	7.01
1990	0.1126	66.26
1991	0.1411	12.83
1992	0.1060	4.83
1993	0.0948	36.94
1994	0.0885	7.11
1995	0.1100	6.66
1996	0.1341	30.15
1997	0.1114	3.85
1998	0.0747	2.30
1999	0.0504	3.35
2000	0.0572	7.23
2001	0.0648	14.57
2002	0.1060	3.79
2003	0.1010	9.87
2004	0.0876	9.58
2005	-	5.62
2006	-	45.66
2007	-	8.83
2008	-	12.95
2009	-	15.60
2010	-	1.94

Table C6. Summer survey index (ages 3-8) (numbers/tow) and standardised mobile gear CPUE (ages 3-8) (truncated at 2004 due to changes in management measures and fishing practices (weight/tow).

age	Survey 3	Survey 4	Survey 5	Survey 6	Survey 7	Survey 8	CPUE 3	CPUE 4	CPUE 5	CPUE 6	CPUE 7	CPUE 8
1982	0	0	0	0	0	0	1.729	1.053	0.249	0.713	0.636	0.346
1983	0	0	0	0	0	0	1.610	4.732	0.827	0.119	0.188	0.189
1984	0.545	0.951	3.308	0.913	0.097	0.284	0.391	2.169	3.517	0.628	0.114	0.186
1985	0.101	0.498	2.844	3.613	0.747	0.000	0.164	0.589	1.869	2.147	0.307	0.026
1986	1.468	1.930	1.599	3.027	1.821	0.072	0.214	1.580	1.282	1.493	0.963	0.082
1987	0.064	0.633	1.851	1.119	2.268	1.159	0.147	0.879	1.907	0.940	0.827	0.506
1988	1.651	2.277	6.218	5.278	4.043	1.984	0.200	0.570	0.927	1.124	0.418	0.352
1989	0.098	0.488	1.359	1.957	1.868	0.568	0	0	0	0	0	0
1990	15.197	6.864	10.383	2.456	0.619	0.755	0.837	1.105	1.388	0.612	0.230	0.076
1991	1.872	1.656	2.877	2.862	0.890	0.800	0.591	1.648	1.280	1.014	0.246	0.118
1992	0.364	0.989	1.341	1.061	0.223	0.143	1.045	2.455	1.245	0.328	0.091	0.028
1993	11.942	8.135	4.141	1.815	0.514	0.017	0.479	1.875	1.604	0.599	0.131	0.040
1994	0.301	1.086	2.306	1.980	0.784	0.219	0.275	0.658	1.195	0.952	0.370	0.126
1995	1.501	1.216	1.957	0.986	0.297	0.050	0.710	1.089	1.665	0.966	0.342	0.074
1996	1.142	12.519	10.772	3.475	1.531	0.133	0.511	2.618	1.797	0.896	0.393	0.061
1997	0.351	0.477	1.616	0.763	0.081	0.090	0.217	1.295	2.218	0.781	0.182	0.031
1998	0.126	0.306	0.616	0.609	0.143	0.000	0.153	0.729	1.153	0.906	0.164	0.025
1999	0.538	0.849	0.492	0.378	0.271	0.000	0.083	0.691	0.830	0.461	0.122	0.012
2000	0.480	0.439	0.795	0.216	0.000	0.029	0.979	0.657	0.823	0.344	0.112	0.020
2001	6.976	1.825	0.652	0.177	0.093	0.022	0.582	1.323	0.681	0.311	0.070	0.012
2002	1.583	0.731	0.580	0.200	0.106	0.024	0.235	1.453	2.001	0.609	0.154	0.024
2003	0.904	6.055	2.146	0.491	0.021	0.024	0.172	2.104	1.943	0.548	0.090	0.012
2004	2.462	1.438	3.659	1.347	0.313	0.000	0.248	0.735	2.381	0.667	0.077	0.007
2005	0.083	1.228	1.349	2.412	0.420	0.000	0	0	0	0	0	0
2006	0.897	10.378	22.111	8.642	3.219	0.201	0	0	0	0	0	0
2007	0.068	0.751	3.244	3.763	0.668	0.108	0	0	0	0	0	0
2008	0.210	0.489	4.298	5.222	2.008	0.134	0	0	0	0	0	0
2009	1.088	2.056	3.570	4.877	2.614	0.024	0	0	0	0	0	0
2010	0.124	0.561	0.107	0.428	0.427	0.036	0	0	0	0	0	0

Table C7. Summer DFO research vessel survey age-disaggregated numbers per tow in the Western Component (4Xopqrs+5Zc) (used in SCAA only).

year	2	3	4	5	6	7	8	9	10	11	12	13
1982	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0	0	0	0
1984	1815943	623387	1087967	3783309	1043731	111296	324838	1238612	490607	0	0	179955
1985	0	115778	569309	3252782	4132615	854066	0	367171	111648	170971	250594	76850
1986	2283026	1679390	2206877	1828601	3462190	2082570	82434	50155	45361	19977	47581	39606
1987	41643	73275	723470	2117385	1279612	2594316	1325185	65444	120459	44724	89447	168076
1988	90124	1887821	2604828	7112096	6036667	4624461	2269427	816569	168138	0	23366	271572
1989	77569	111816	557869	1553780	2238150	2136999	649296	376228	153478	0	41133	65480
1990	33595136	17381151	7850430	11875218	2808651	707814	863983	219539	124437	89466	101716	107549
1991	1404260	2140553	1894000	3290489	3273796	1017585	914965	405326	147497	78538	18352	0
1992	538504	416083	1131382	1533504	1213184	254941	163608	34577	89227	44613	106788	0
1993	11592044	13658111	9304680	4736459	2076393	587609	18867	97753	0	0	0	32233
1994	246603	344080	1241671	2637386	2264323	896821	250951	157061	60760	0	0	30380
1995	520499	1716700	1390598	2238049	1127558	339242	57260	95844	58641	0	0	0
1996	650936	1365298	14177223	12229455	3895862	1715792	196984	0	0	0	0	0
1997	495793	401073	545564	1848631	872885	92487	103148	0	0	0	0	0
1998	68522	144129	350258	704359	696636	163552	0	41819	0	41819	0	0
1999	552186	615582	971250	562516	432220	309913	0	0	0	0	0	0
2000	1230000	548539	501592	909489	246728	0	33137	0	0	0	0	0
2001	5453277	7979054	2086730	745694	202234	106854	25274	0	0	0	0	0
2002	434214	1810689	836560	663217	228441	120834	27251	0	0	0	0	0
2003	251708	1033986	6925402	2454125	561162	23750	27601	0	0	0	0	0
2004	289628	2815371	1644419	4184877	1541128	358085	0	67419	0	44433	0	0
2005	67054	94311	1404901	1542991	2758797	479762	0	0	0	0	0	0
2006	183461	1025369	11870042	25289879	9884809	3682080	230187	0	0	0	0	0
2007	234451	78229	858788	3710824	4304320	764071	133764	9815	0	0	0	0
2008	248618	240346	559263	4915850	5972629	2297152	152836	124784	127903	0	0	0
2009	1053638	1243803	2351094	4083530	5578185	2989960	27439	518092	0	0	0	0
2010	26660	141428	642063	122291	489382	488833	41377	94696	0	13918	0	0

APPENDIX 4c. PROGRESS ON THE DEVELOPMENT OF CANDIDATE MANAGEMENT PROCEDURES FOR THE CANADIAN POLLOCK IN THE WESTERN COMPONENT (4Xopqrs+5Zc)

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ABSTRACT

Four alternative virtual population analysis (VPA)-based assessments of the Western Component of Canadian pollock are used to provide a Reference Set of Operating Models for an illustrative application of Management Strategy Evaluation (MSE) approach to the associated fishery. Results for future total allowable catches (TACs) and resource trends are shown for a variety of Candidate Management Procedures (feedback catch control rules), which are all based on the direct use on an annual survey-based index of abundance. These results are compared to anticipated outcomes under a constant TAC approach. Suggestions are made regarding aspects that need discussion and further refinement if this approach is to be taken further.

INTRODUCTION

One of the problems for the conventional "best assessment" approach to the provision of management advice (*e.g.,* for a total allowable catch (TAC)) is making a choice between different assessment methods and/or assumptions which can be equally defensible, yet lead to recommendations that differ substantially. For example, Fig. 4 of Rademeyer and Butterworth (2010) show results for four different virtual population analysis (VPA)-based assessments of the Western Component of Canadian pollock which differ appreciably in terms of their estimates of recent abundance.

One advantage of the Management Procedure Approach (or Management Strategy Evaluation – MSE) is that it directly addresses this issue. Feedback control rules that make use of future resource monitoring data (*e.g.*, if abundance indices trend up/down, the TAC is increased/decreased) are simulation tested to ensure that outcomes in terms of catches and risks to the resource remain acceptable across a plausible range of uncertainties in the assessment.

This paper provides an initial illustration of how such a MSE might be applied to the Western Component of Canadian pollock.

METHODOLOGY

MSE is based on the simulated application of the some (feedback) harvest control rule to different Operating Models (OMs) of the resource. These OMs are provided by conventional assessments, and are intended to reflect plausible representations of the underlying dynamics of the actual resource. Often the results of this application are reported integrated over a "Reference Set" (RS) of OMs, which is intended to span a few (typically 2-3) of the major uncertainty "axes" associated with the assessment of the resource. For this illustration for the

Western Component of Canadian pollock, the RS is provided by four VPA-based assessments of the resource (Appendix 4b) which are equally weighted when integrating their results.

MSE requires projections of the resource's dynamics into the future, so as to be able to simulate the impact of alternative series of future catches on the resource. Details of the projection methodology applied are provided in Appendix 4c-A. Of particular importance here is the stock-recruitment relationship assumed for the four OMs that comprise the RS (see Step 4 of that Appendix). Fig. 1 shows results for the somewhat conservative approach, based on the most recent 10 years of spawning biomass and recruitment estimates, that has been used to provide these relationships for projections ("conservative" because generally higher values of recruitment for earlier years are being ignored). The values of the standard deviation of the logged residuals, σ_R, and their auto-correlation, ρ, that characterise the variability about these relationships (see Appendix 4c-A, equations A7 to A10) range from 0.26 to 0.72 and from 0.20 to 0.80, respectively, across the four OMs.

A variety of Candidate Management Procedures (CMPs) have been considered. Appendix 4c-B provides detailed technical specifications. These CMPs are all of the type that is known as "empirical" – they use the resource monitoring data directly as input to simple formulae to provide TAC recommendations, rather than the "model-based" type which first filter these data through a usually relatively simple population dynamics model. The CMPs explored (see Table 1) range from:

- Constant catch (this is included not to imply any serious consideration for adoption, as a feedback-free CMP offers no protection against undue resource depletion, but rather to provide a convenient basis for comparison of performance against other CMPs).
- CMPs based on the slope of the trend in the available index of abundance over recent years (here the survey aggregated weight/tow), such that positive slopes lead to TAC increases and negative slopes to TAC decreases.
- CMPs also based on a target value for the abundance index, such that values above this target will lead to TAC increases, and *vice versa.*
- CMPs that incorporate constraints on the maximum TAC change between years, or place an upper bound ("cap") on the TAC.

Target based CMPs tend to yield more stable TACs over time, though the choice for the target level may raise difficulties. In this case the average value of the index over the 1984 to 1994 period (see Appendix 4c-B) has been used for illustrative purposes.

For ease of comparison of different forms of CMPs, given the ever-present trade-off between larger short term catches and greater medium term resource recovery, it is conventional to "tune" different CMPs to correspond to a common achieved average catch or resource depletion level over a specified time period. This involves adjusting the values of the CMPs control parameters to achieve a pre-specified common goal – in this case the median anticipated catch averaged over the next 10 years has been used for this purpose. The resultant tuning parameter values are reported in Table 1.

The primary objective of the MSE approach is to find the CMP which offers what is considered to be the best trade-off in anticipated performance over the conflicting objectives of:

- maximising future catches (in both the short and the longer term),
- minimising the risk of unintended resource depletion or (where pertinent) inadequate resource recovery, and
- minimising the extent of inter-annual TAC changes in the interests of Industry stability.

The CMP eventually chosen should not only be able to demonstrate this desired performance when tested under the RS of OMs, but also not show appreciable deviations from that performance for other “robustness test” OMs reflecting alternative plausible models of resource dynamics (*i.e.*, one seeks “robust” anticipated performance across the range of plausible OMs).

RESULTS

Projections results for a series of CMPs under the RS are given in Table 2. The CMPs have been tuned (*i.e.*, had their control parameters adjusted) to achieve a median 2011-2020 catch of either 5,000 t, 6,000 t, or 7,000 t. Medians and lower 2.5%iles catch and biomass “trajectories” are compared in Figs. 2 and 3. An example of some actual trajectory realisations is shown in Fig. 4. Note that the “trajectories” shown in Figs. 2 and 3 are not true trajectories but rather lines joining percentiles of the distributions of the various statistics for each future year, so that upper and lower 2.5%iles, for example, would encompass the 95% envelope for future projections.

Shade plots, showing medians and 50%, 75%, and 95% probability intervals (PIs) of a series of Performance Statistics, are shown in Fig. 5 for CMPC5b under the RS.

ROBUSTNESS TESTS

It is important to check that the performance of a CMP is reasonably robust to plausible variations of the OMs that constitute the RS. Three such “robustness tests” have been run for CMPC5b:

Rob1: Recruitment over the first four years of projections is assumed to be at the level of the lowest recruitment over the 2000-2009 period.

Rob2: The stock-recruitment relationship is derived from the last 5 years data rather than the last 10 years (equations A8-A10) (see Fig. 1).

Rob3: Recruitment over the first eight years of projections is assumed to be at the level of the lowest recruitment over the 2000-2009 period.

Results for these three robustness tests for CMPC5b are given in Table 3 and plotted in Fig. 6.

DISCUSSION

Although projections have been taken through to 2031 in this exercise, the focus has been on achieving reasonable performance over the next 10 years. Thus projection results beyond 2021 should not receive much attention – any Management Procedure that might be adopted in the immediate future is likely to have been reviewed and revised before 2021.
Fig. 2 illustrates the enhanced performance that feedback control approaches achieve over a constant catch strategy. Given feedback, resource risk (quantified by the lower 2.5%ile probability envelope for future relative to present abundances) is less (at least in the short to medium term) for the feedback compared to the constant catch approaches.

The trade-off that is typical between greater catches *vs.* additional resource risk is evident from Fig. 3.

While recovery of the resource seems guaranteed under the RS trials, this does not follow for the robustness tests considered (Fig. 6). Although CMPC5b (the CMP for which results are reported there) achieves the desired feedback response of reducing TACs in the face of poorer resource circumstances than anticipated under the RS, this is inadequate to prevent slight downward trends in resource levels for the three robustness tests considered at the lower 2.5%ile level.

Fig. 7 provides a convenient (and commonly used) basis to summarise Performance Statistics and compare them under different operating OMs for the same CMP, or different CMPs under the same OM. This suggests that on the basis of trials to date, there is little to choose amongst the alternative feedback control MP formulations that have been considered in this paper.

ASPECTS FOR POSSIBLE FURTHER INVESTIGATION

There are a number of aspects of the work presented here that warrant discussion in the context of possible future refinement of this MSE approach.

- Appropriate assumptions for projections, including in particular alternative assumptions that might be used in the development of alternative stock-recruitment relationships.
- Variation of features of the CMP not considered thus far, *e.g.*, the period over which the abundance index slope is calculated (currently 9 years – see Appendix 4c-B and Table 1), and the number of years over which abundance index average is taken for comparison with the target value in target-based CMPs (currently 3 years – see Appendix 4c-B).
- Refinement of the medium term objectives which management should seek to achieve for the resource and fishery. This includes consideration of desirable constraints on the maximum extent of the TAC change allowed from year to year, and also perhaps an upper bound on the TAC.
- Extension of the present small set of plausible robustness test OMs of this paper to include other plausible hypotheses for resource dynamics for which CMP robustness should be checked.

With such extensions and refinements, it is likely that greater differences will emerge amongst the anticipated performances of alternative forms of CMP such as those in Table 1. For example, if the extent of resource recovery is deemed inadequate for some robustness tests (see Fig. 7), this can be improved by increasing the value of the λ_{down} control parameter that multiplies the slope of the abundance index in the CMP formula (see Appendix 4c-B, equation B1), but there will be an associated risk of a larger TAC reduction in the short term. Such further results will provide a clearer basis to choose amongst alternative CMPs.

Table 1. Tuning parameter values for each CMP presented (see Appendix 4c-B for definitions of the symbols used).

	Comment	Initial TAC	λ_{up}	λ_{down}	*P*	*a*	*b*	*w*	Interannual change constraints	Cap
C=6000t	Constant catch of 6000t	-	-	-	-	-	-	-	-	-
CMPA10b	Slope-based tuned to 6000t 2011-2020 median catch	5802	1.05	1.05	9	-	-	1.0	+15%; -15%	-
CMPB3b	Slope- and target-based tunned to 6000t 2011-2020 median	4500	1.05	1.05	9	13235	10000	0.5	+15%; -15%	-
CMPC4	Slope- and target-based tunned to 6000t 2011-2020 median	4500	1.10	1.10	9	13320	9000	1.0-0.2*	+15%; -15%	-
CMPC5a	Slope- and target-based tunned to 5000t 2011-2020 median	4500	1.10	1.10	9	12179	10000	1.0-0.2*	+15%; -15%	20000t
CMPC5b	Slope- and target-based tunned to 6000t 2011-2020 median	4500	1.10	1.10	9	13722	9500	1.0-0.2*	+15%; -15%	20000t
CMPC5c	Slope- and target-based tunned to 7000t 2011-2020 median	4500	1.10	1.10	9	15204	9000	1.0-0.2*	+15%; -15%	20000t

*w_y changes linearly from the first value in 2010 to the second value in 2020 and then stays constant thereafter.

Table 2. Projections results (median and 95% PI) for a series of Performance Statistics for different CMPs under the RS. For each CMP tuning parameters were adjusted to meet the performance criterion shown in bold.

		C=6000t		CMPA10b		CMPB3b		CMPC4		CMPC5a		CMPC5b		CMPC5c	
P_{2021}/P_{target}	$B^{4\text{-}8}$	1.57	(0.23; 4.03)	1.50	(0.29; 4.04)	1.50	(0.29; 4.01)	1.50	(0.29; 3.98)	1.54	(0.36; 4.11)	1.50	(0.29; 3.98)	1.44	(0.24; 3.86)
	B^{sp}	4.66	(0.67; 9.64)	4.33	(1.28; 9.12)	4.60	(1.22; 9.17)	4.54	(1.14; 9.24)	4.85	(1.57; 9.62)	4.55	(1.14; 9.24)	4.23	(0.72; 8.86)
	B^{surv}	4.87	(0.29; 25.73)	4.83	(0.87; 26.80)	4.97	(0.76; 24.57)	4.94	(0.75; 26.04)	5.44	(1.10; 27.85)	4.94	(0.78; 26.09)	4.49	(0.50; 24.42)
P_{2016}/P_{2011}	$B^{4\text{-}8}$	3.77	(1.29; 13.39)	3.96	(1.38; 14.26)	4.12	(1.44; 14.30)	4.15	(1.45; 14.56)	4.35	(1.60; 14.88)	4.16	(1.45; 14.56)	3.99	(1.40; 14.20)
	B^{sp}	3.63	(1.57; 9.56)	3.74	(1.80; 10.18)	4.01	(2.10; 10.39)	4.06	(2.14; 10.74)	4.23	(2.30; 10.86)	4.06	(2.15; 10.75)	3.91	(1.97; 10.38)
	B^{surv}	4.08	(0.31; 35.72)	4.62	(0.29; 40.88)	4.92	(0.31; 40.87)	5.02	(0.31; 43.72)	5.27	(0.32; 45.12)	5.02	(0.31; 43.77)	4.72	(0.30; 40.79)
P_{2021}/P_{2011}	$B^{4\text{-}8}$	4.09	(0.82; 19.71)	3.92	(0.85; 19.65)	3.89	(0.84; 19.14)	3.87	(0.83; 19.39)	4.02	(0.89; 19.76)	3.87	(0.82; 19.40)	3.72	(0.70; 19.03)
	B^{sp}	9.53	(1.77; 37.01)	9.44	(2.89; 39.61)	9.55	(3.00; 38.18)	9.53	(2.92; 39.57)	10.45	(3.84; 41.25)	9.52	(2.95; 39.66)	8.76	(1.97; 37.61)
	B^{surv}	10.45	(1.14; 91.89)	10.72	(1.14; 98.94)	10.70	(1.23; 89.92)	10.56	(1.20; 93.73)	11.82	(1.36; 98.65)	10.57	(1.20; 93.81)	9.41	(1.01; 87.60)
P_{2031}/P_{2011}	$B^{4\text{-}8}$	3.81	(0.70; 17.91)	2.80	(0.42; 15.41)	2.70	(0.42; 15.37)	2.69	(0.42; 15.34)	2.95	(0.48; 15.89)	2.79	(0.42; 15.36)	2.71	(0.41; 14.86)
	B^{sp}	10.26	(1.02; 40.02)	5.40	(0.43; 27.59)	5.14	(0.44; 26.03)	5.05	(0.43; 26.09)	6.17	(0.51; 30.03)	5.29	(0.46; 27.58)	4.75	(0.42; 26.09)
	B^{surv}	12.94	(0.90; 57.14)	5.80	(0.44; 36.34)	5.63	(0.44; 33.40)	5.50	(0.44; 34.81)	6.74	(0.49; 40.68)	5.77	(0.44; 36.52)	5.17	(0.38; 34.43)
C_{2011}		6000	(6000; 6000)	4837	(4837; 4837)	4723	(4723; 4723)	4837	(4837; 4837)	4837	(4837; 4837)	4837	(4837; 4837)	4837	(4837; 4837)
C_{2012}		6000	(6000; 6000)	4654	(4112; 5363)	4633	(4492; 5431)	4657	(4112; 5358)	4496	(4112; 5211)	4654	(4112; 5363)	4807	(4225; 5509)
$C_{2011\text{-}2015}$		6000	(6000; 6000)	4707	(3755; 5922)	4762	(4205; 5826)	4711	(3767; 5917)	4255	(3588; 5650)	4707	(3755; 5922)	5138	(4115; 6227)
$C_{2015\text{-}2020}$		6000	(6000; 6000)	7347	(4656; 10966)	7234	(4703; 10634)	7356	(4712; 10937)	5775	(3362; 9607)	7347	(4656; 10966)	8802	(6018; 11917)
$C_{2011\text{-}2020}$		**6000**	(6000; 6000)	**6000**	(4234; 8344)	**6000**	(4509; 8087)	**6000**	(4259; 8328)	**5000**	(3531; 7510)	**6000**	(4234; 8344)	**7000**	(5031; 9007)
$C_{2011\text{-}2030}$		6000	(6000; 6000)	10075	(5837; 13166)	10267	(5432; 14856)	10238	(5717; 14720)	8809	(4567; 12499)	10148	(5712; 13153)	11190	(6845; 13745)
$AAV_{2011\text{-}2015}$		8.6	(8.6; 8.6)	9.5	(5.0; 13.5)	7.5	(4.4; 12.3)	9.5	(5.0; 13.4)	11.0	(5.4; 15.0)	9.5	(5.0; 13.5)	9.5	(5.4; 13.8)
$AAV_{2011\text{-}2030}$		2.1	(2.1; 2.1)	11.5	(11.5; 11.5)	10.8	(10.8; 10.8)	12.1	(12.1; 12.1)	12.2	(12.2; 12.2)	11.2	(11.3; 11.2)	10.5	(10.6; 10.5)

Table 3. Projections results (median and 95% PI) for a series of Performance Statistics for CMPC5b under the RS and three robustness tests: Rob1 (next 4 years have poor recruitment), Rob2 (future recruitment from average 2005-2009), and Rob3 (next 8 years have poor recruitment). Note that the CMPC5b tuning parameters remained unchanged for its application to the three robustness tests shown. Consequently there are changes to ability to meet the target value to which this CMP was tuned for the RS (see values shown in bold).

		RS		Rob1		Rob2		Rob3	
P_{2021}/P_{target}	$B^{4\text{-}8}$	1.50	(0.29; 3.98)	1.34	(0.12; 3.72)	0.77	(0.10; 2.26)	0.53	(0.11; 1.15)
	B^{sp}	4.55	(1.14; 9.24)	1.97	(0.14; 4.70)	1.80	(0.14; 5.35)	0.73	(0.10; 2.22)
	B^{surv}	4.94	(0.78; 26.09)	2.07	(0.11; 11.67)	1.90	(0.10; 12.17)	0.68	(0.05; 4.84)
P_{2016}/P_{2011}	$B^{4\text{-}8}$	4.16	(1.45; 14.56)	1.39	(0.44; 2.68)	2.17	(0.62; 5.44)	1.03	(0.34; 2.05)
	B^{sp}	4.06	(2.15; 10.75)	1.81	(0.67; 2.84)	2.47	(0.91; 4.38)	1.46	(0.48; 2.63)
	B^{surv}	5.02	(0.31; 43.77)	1.54	(0.13; 14.58)	2.42	(0.20; 22.51)	1.39	(0.11; 13.60)
P_{2021}/P_{2011}	$B^{4\text{-}8}$	3.87	(0.82; 19.40)	3.46	(0.61; 16.08)	2.16	(0.44; 8.15)	1.57	(0.35; 4.61)
	B^{sp}	9.52	(2.95; 39.66)	4.17	(0.67; 15.69)	4.37	(0.67; 13.39)	1.84	(0.43; 4.16)
	B^{surv}	10.57	(1.20; 93.81)	4.47	(0.29; 47.53)	4.16	(0.20; 46.86)	1.48	(0.13; 16.13)
P_{2031}/P_{2011}	$B^{4\text{-}8}$	2.79	(0.42; 15.36)	2.97	(0.41; 15.90)	1.88	(0.28; 8.77)	3.23	(0.41; 15.51)
	B^{sp}	5.29	(0.46; 27.58)	6.16	(0.43; 30.92)	2.88	(0.22; 12.28)	6.73	(0.40; 28.39)
	B^{surv}	5.77	(0.44; 36.52)	7.00	(0.44; 42.53)	3.25	(0.19; 15.78)	7.97	(0.38; 40.17)
C_{2011}		4837	(4837; 4837)	4837	(4837; 4837)	4837	(4837; 4837)	4837	(4837; 4837)
C_{2012}		4654	(4112; 5363)	4648	(4112; 5360)	4632	(4112; 5321)	4648	(4112; 5360)
$C_{2011\text{-}2015}$		4707	(3755; 5922)	4553	(3639; 5895)	4602	(3689; 5884)	4553	(3639; 5895)
$C_{2015\text{-}2020}$		7347	(4656; 10966)	5711	(3605; 10075)	6225	(3901; 10486)	5402	(3527; 9931)
$C_{2011\text{-}2020}$		**6000**	(4234; 8344)	**5153**	(3680; 7766)	**5443**	(3878; 8115)	**5017**	(3631; 7721)
$C_{2011\text{-}2030}$		10148	(5712; 13153)	8199	(4396; 12013)	7443	(4286; 12213)	6569	(4131; 10133)
$AAV_{2011\text{-}2015}$		9.5	(5.0; 13.5)	9.5	(5.5; 14.3)	9.5	(5.3; 14.0)	9.5	(5.5; 14.3)
$AAV_{2011\text{-}2030}$		11.2	(11.3; 11.2)	10.6	(10.6; 10.6)	10.6	(10.6; 10.6)	10.0	(10.0; 10.0)

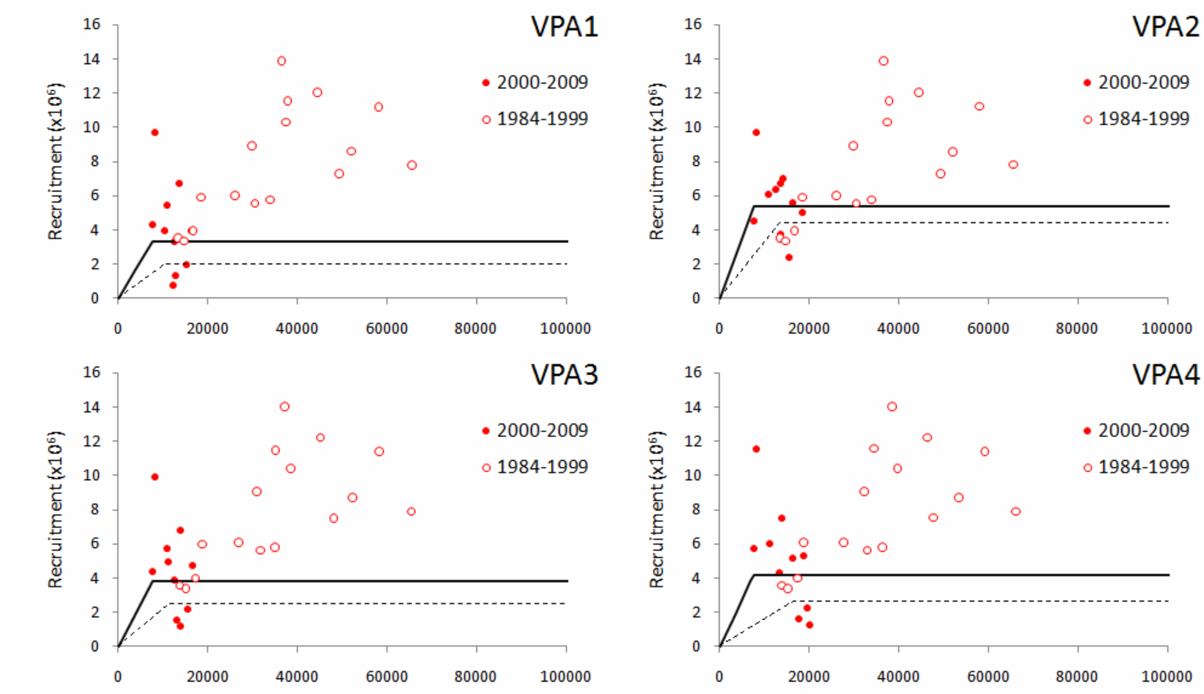


Fig. 1. Stock-recruitment relationships based on the 2000-2009 period and assumed for future projections for each of the four OMs in the RS. The past "data" are also shown. The stock-recruitment curve, based on the 2005-2009 recruitment geometric average, is shown by the dashed line. With reference to Rademeyer and Butterworth (2010), and Fig. 4 thereof, these plots correspond respectively to:

VPA1: St1_BC_withBias: Stone Base Case;
VPA2: St2_BC_withBias_no2010: Stone, excluding the 2010 survey biomass estimates;
VPA3: R1_sig001: Rademeyer Base Case;
VPA4: R3_sig03: Rademeyer, with more flexibility on age 9 fishing mortality.

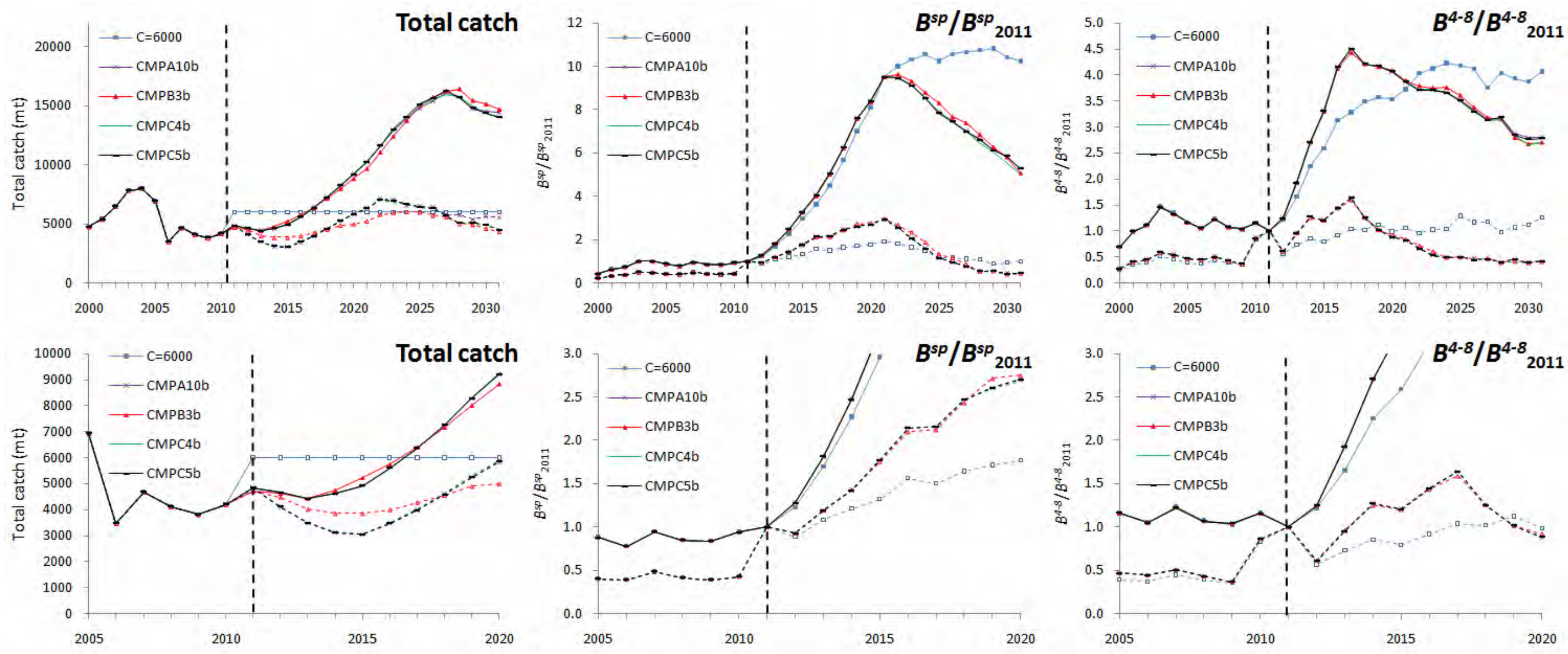


Fig. 2. Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass, and exploitable (ages 4 to 8) biomass (both in terms of 2011 level) for a series of CMPs (all tuned to a median 2011-2020 catch of 6,000 t under the RS). The bottom row repeats the top row, but with different scales for improved discrimination.

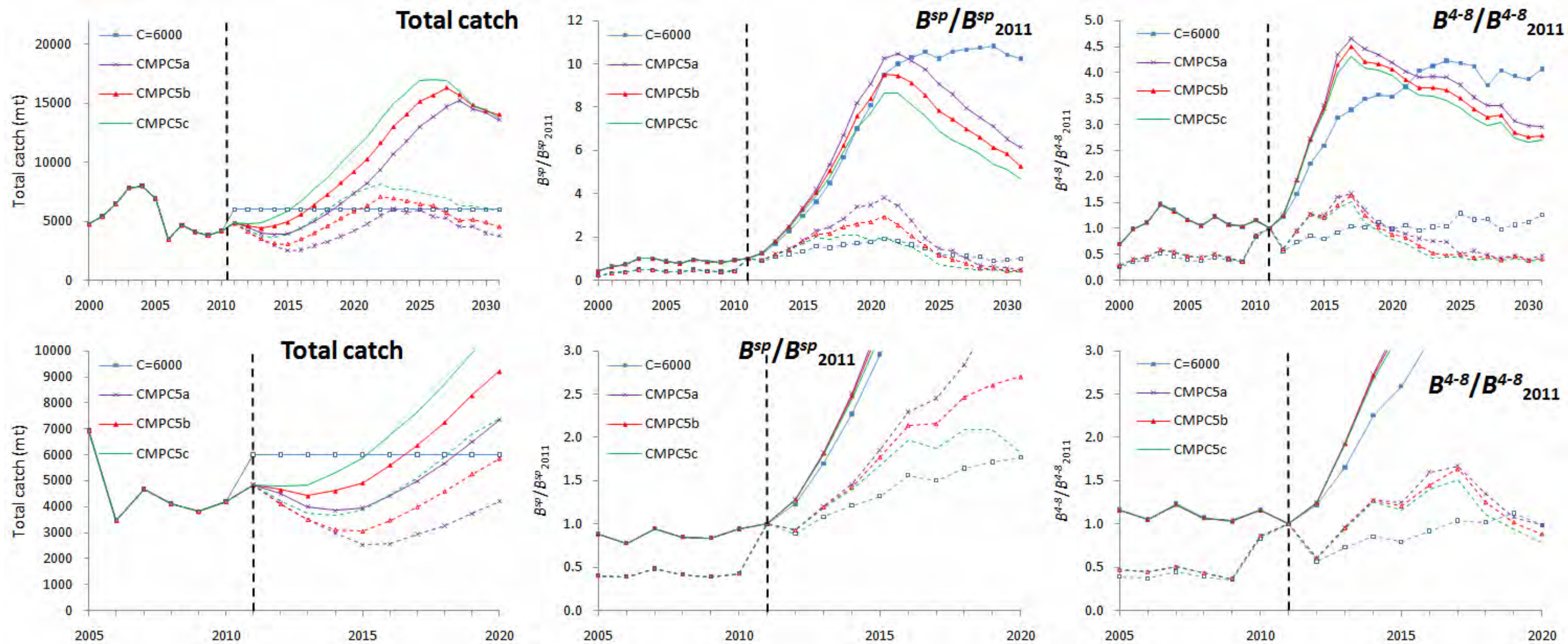


Fig. 3. Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass, and exploitable (ages 4 to 8) biomass (both in terms of 2011 level) for a constant catch (6,000 t) and three variants of CMPC5, tuned to three different level of median 2011-2020 catch, under the RS. The bottom row repeats the top row but with different scales for improved discrimination.

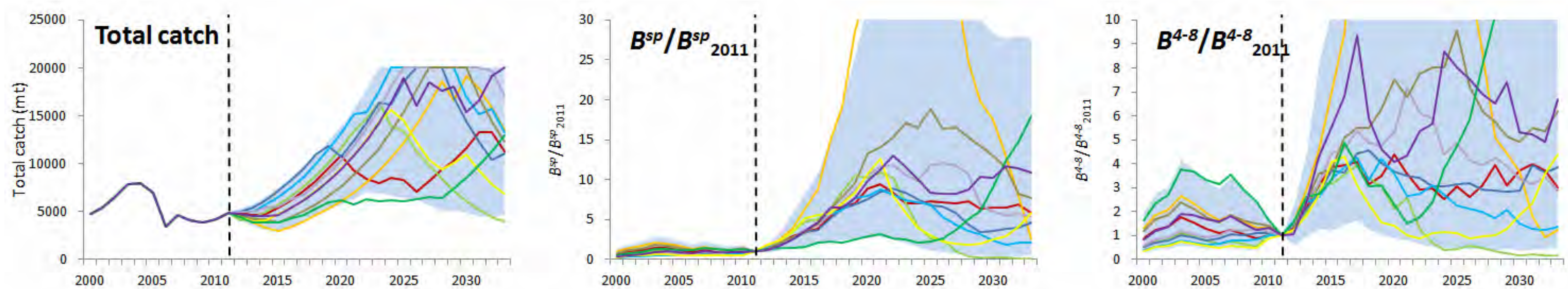


Fig. 4. Ten "worm" trajectories for TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2011 level) for CMPC5b under the RS. The 95% PI are shown by the light shading.

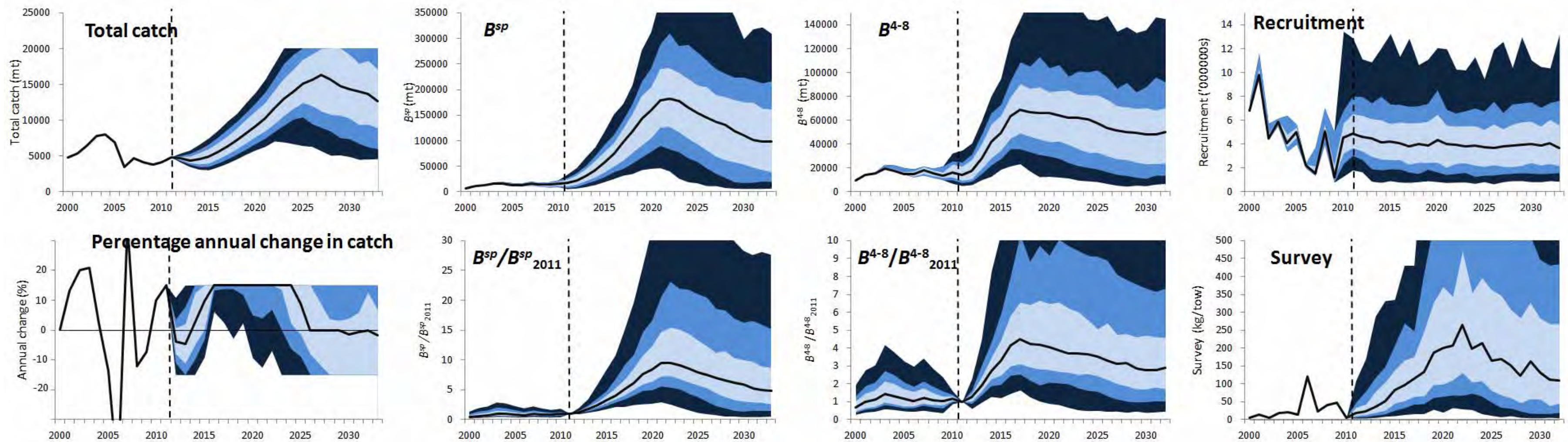


Fig. 5a. 95%, 75%, 50% PIs and median for a series of Performance Statistics for CMPC5b.

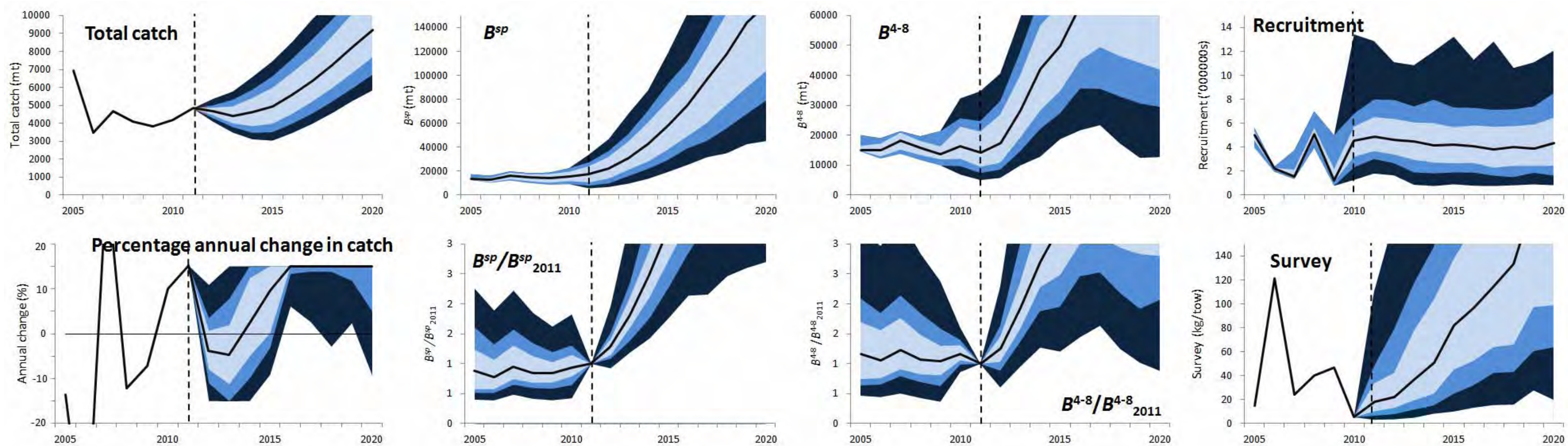


Fig. 5b. As Fig. 5a but with different scales for improved discrimination.

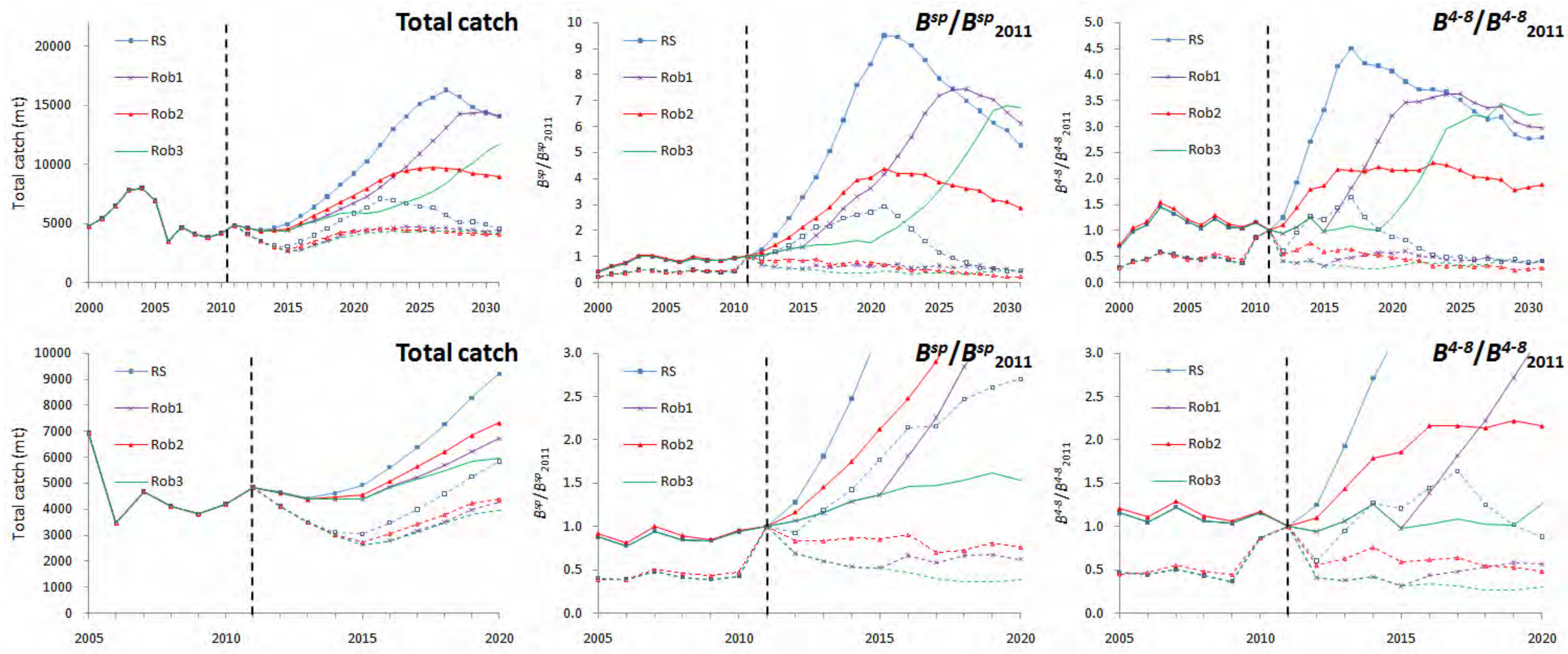


Fig. 6. Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass, and exploitable (ages 4 to 8) biomass (both in terms of 2010 level) for CMPC5b under the RS and three robustness tests: Rob1 (4 years of poor recruitment), Rob2 (future recruitment from average 2005-2009), and Rob3 (8 years of poor recruitment). The bottom row repeats the top row but with different scales for improved discrimination.

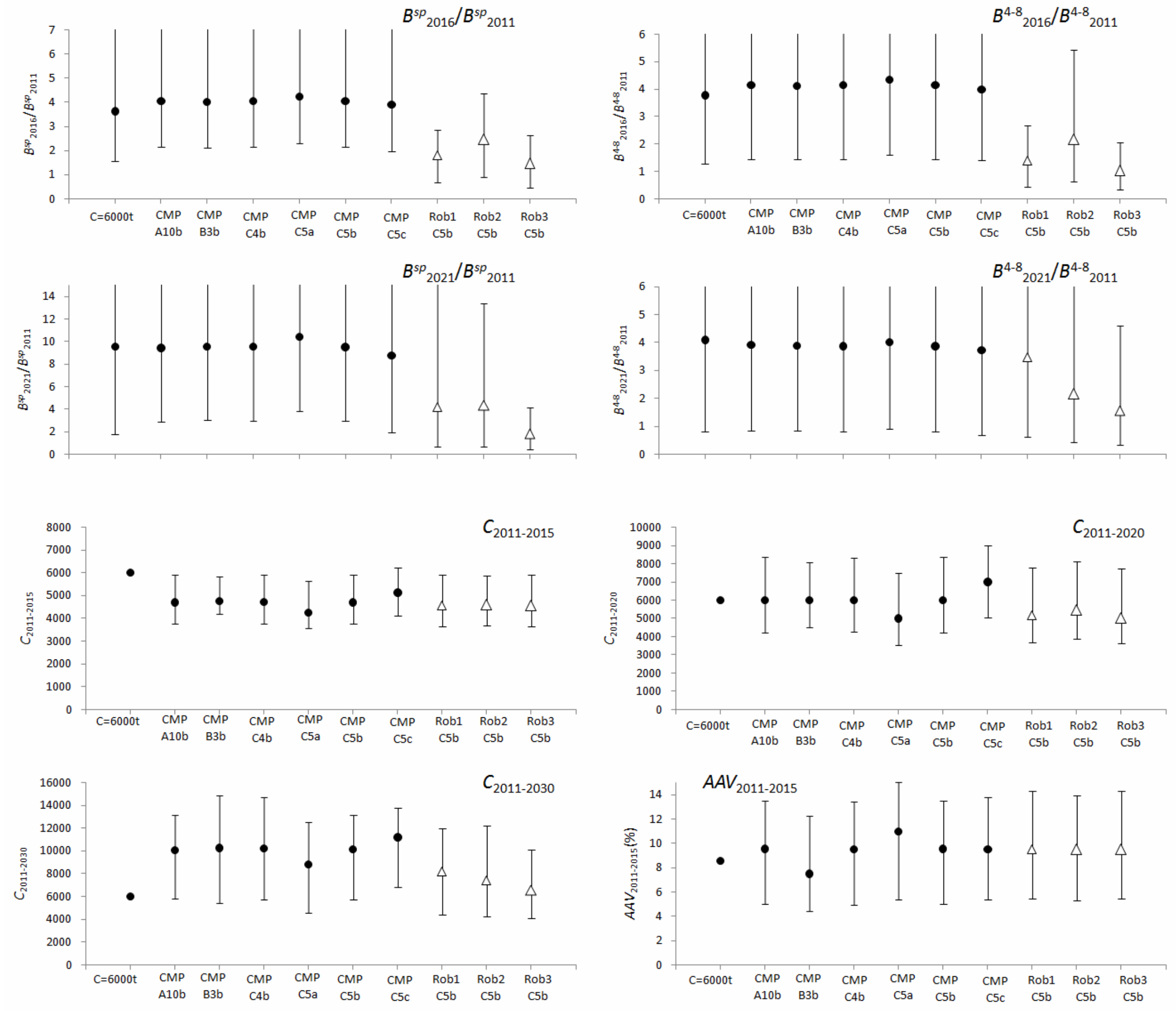


Fig. 7. Medians and 95% PI (probability intervals) for a series of Performance Statistics for different CMPs applied to the RS, followed by the application of CMPC5b to three robustness tests.

APPENDIX 4C-A. CANDIDATE MANAGEMENT PROCEDURES TESTING METHODOLOGY FOR CANADIAN POLLOCK IN THE WESTERN COMPONENT (4XOPQRS+5ZC)

PROJECTION METHODOLOGY

Projections into the future under a specific Candidate Management Procedure (CMP) are evaluated using the following steps.

Step 1: Begin-year numbers at age

The components of the numbers-at-age vector at the start of 2010 ($N_{2010,a}$: *a* = 2,…, *m*) are obtained from an assessment of the resource using VPA. The 2010 recruitment ($N_{2010,2}$) is generated deterministically from the estimated stock-recruitment relationship (see below). Error is included for ages 2 to 7 because these are poorly estimated in the assessment given limited information on these year-classes, *i.e.*:

$$N_{2010,a} \rightarrow N_{2010,a} e^{\varepsilon_a} \qquad \varepsilon_a \text{ from } N\left(0,(\sigma_R)^2\right) \tag{A1}$$

where σ_R is estimated in the process of fitting a stock-recruitment relationship to the outputs from that assessment as described below. Equation A1 is approximate in that it omits to adjust for past catches from the year-class concerned, but these are so small that the differential effect is negligible.

Step 2: Catch

These numbers-at-age are projected one year forward at a time given a catch for the year concerned.
For 2010:
A catch of 4,200 t is assumed.
From 2011 onwards:

C_y is as specified by the CMP.

This requires specification of how the catch is disaggregated by age to obtain $C_{y,a}$, and how future recruitments are specified.

Step 3: Catch-at-age

The selectivity each year is selected randomly from the selectivity vectors for the last 10 years (2000 to 2009) estimated in the assessment. The selectivity vectors for 2000 to 2009 are computed as follows:

$$S_{y,a} = F_{y,a} / \max\left(F_{y,a}\right) \tag{A2}$$

where the maximum is taken across the ages for that year.
From this it follows that:

$$F_y = C_y / \sum_a w_{y,a}^{mid} N_{y,a} e^{-M_a/2} S_{y,a} \tag{A3}$$

where $w_{y,a}^{mid}$ is each year selected randomly from the weight-at-age vectors for the last 10 years (2000 to 2009) used in the assessment (Table A1), and hence that:

$$C_{y,a} = N_{y,a}\, e^{-M_a/2} S_{y,a} F_y \qquad \text{(A4)}$$

The numbers-at-age can then be computed for the beginning of the following year (y+1):

$$N_{y+1,2} = R_{y+1} \qquad \text{(A5)}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - C_{y,a}\right) e^{-M_a/2} \qquad \text{for } 2 \le a \le m-1 \qquad \text{(A6)}$$

These equations reflect Pope's approximation.
The maximum age m is 13 (not a plus-group).

Step 4: Recruitment

Future recruitments (age 2) are provided by a 'hockey-stick' stock-recruitment relationship with autocorrelation in the stock-recruitment residuals:

$$R_y = \begin{cases} \alpha e^{(\varepsilon_y^{SR} - \sigma_R^2/2)} & \text{if } B_{y-2}^{sp} \ge B_{\min}^{sp} \\ \dfrac{\alpha}{B_{\min}^{sp}} B_{y-2}^{sp} e^{(\varepsilon_y^{SR} - \sigma_R^2/2)} & \text{if } B_{y-2}^{sp} < B_{\min}^{sp} \end{cases} \qquad \text{(A7)}$$

where

$$\varepsilon_y^{SR} = \rho \varepsilon_{y-1}^{SR} + \sqrt{1-\rho^2}\,\zeta_y$$

with ζ_y from $N\left(0, \sigma_R^2\right)$,

$$\alpha = \exp\left(\sum_{y=2000}^{2009} \ln R_y \Big/ 10\right) \text{ and} \qquad \text{(A8)}$$

$B_{\min}^{sp} = \min\left(B_y^{sp}\right)$ for the 1998-2007 period.

ρ is obtained by minimising the following negative log-likelihood function:

$$-\ln L^{SR} = \sum_{2000}^{2009} \left[\ln \sigma_R + \left(\frac{\varepsilon_y^{SR} - \rho \varepsilon_{y-1}^{SR}}{\sqrt{1-\rho^2}} \right)^2 \Big/ 2\sigma_R^2 \right] \qquad \text{(A9)}$$

with

$$\sigma_R = \sqrt{1/10 \sum_{y=2000}^{2009} \left(\varepsilon_y^{SR}\right)^2} \qquad \text{(A10)}$$

$$B_y^{sp} = \sum_{a=1}^{m} f_a w_{y,a} N_{y,a} \qquad \text{(A11)}$$

where $w_{y,a}$ is each year selected randomly from the weight-at-age vectors for the last 10 years (2000 to 2009) used in the assessment (Table A2), and

f_a is the maturity-at-age, taken to be 0 to age 3 and 1 from age 4 and above.

Step 5:
The information obtained in Step 1 is used to generate a value of the abundance index I_{2011} (summer survey, in terms of biomass). Indices of abundance in future years will not be exactly proportional to true abundance, as they are subject to observation error. Log-normal observation error is therefore added to the expected value of the abundance index evaluated:

$$I_y^i = q^i B_y^i e^{\varepsilon_y^i} \quad \text{(A12)}$$

$$\varepsilon_y^i \quad \text{from } N\left(0,\left(\sigma^i\right)^2\right) \quad \text{(A13)}$$

where

B_y^i is the biomass (or numbers) available to the survey:

$$B_y^{summer} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a}^{surv} N_{y,a} e^{-M_a/2}\left(1 - S_{y,a} F_y / 2\right) \quad \text{(A14)}$$

The survey selectivities are taken as the catchabilities (q_a^i) estimated in that assessment, renormalised so that $\max(q_a^i) = 1$. The survey selectivity is assumed to be zero for age 2, and for ages 9 and above the selectivity is assumed to remain flat at the age 8 level.

The constant of proportionality q^i is as estimated for the assessment in question by:

$$\ell n\, \hat{q}^i = 1/27 \sum_{y=1984}^{2010}\left(\ln I_y^i - \ln \hat{B}_y^i\right) \quad \text{(A15)}$$

$$\hat{\sigma}^i = \sqrt{1/27 \sum_{y=1984}^{2010}\left(\varepsilon_y^i\right)^2} \quad \text{(A16)}$$

$$\varepsilon_y^i = \ell\text{n}(I_y^i) - \ell\text{n}(q^i \widehat{B}_y^i) \quad \text{(A17)}$$

where the survey index of biomass I_y^i is given in Table A3.

Step 6:
Given the new survey indices I_{y+1}^i compute TAC_{y+1} using the CMP.

Step 7:
Steps 1-6 are repeated for each future year in turn for as long a period as desired, and, at the end of that period, the performance of the candidate MP under review is assessed by considering statistics such as the average catch taken over the period and the final spawning biomass of the resource.

PERFORMANCE STATISTICS

A number of mathematical expressions (Performance Statistics) are used to measure achievement of the competing aims of avoiding undue depletion of the resource, maximising catch on average over time, and minimising the extent of inter-annual catch variation in the interests of Industry stability.

Resource depletion/recovery

(a) $\dfrac{P_{2021}}{P_{\text{target}}}$, where P_y is the population size in year *y*, and P_{target} is pre-defined recovery target population size, for which the 1984-1994 average is used

(b) $\dfrac{P_{2016}}{P_{2011}}$;

(c) $\dfrac{P_{2021}}{P_{2011}}$

(d) $\dfrac{P_{2031}}{P_{2011}}$;

For each of these, population can be measured as the exploitable biomass (B_y^{4-8}), spawning biomass (B_y^{sp}), or survey biomass (B_y^{surv}), where:

$$B_y^{4-8} = \sum_{a=4}^{8} w_{y,a}^{mid} N_{y,a} \qquad \text{(A18)}$$

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{mid} N_{y,a} \qquad \text{(A19)}$$

$$B_y^{surv} = \sum_{a=1}^{m} w_{y,a}^{mid} S_{y,a}^{surv} N_{y,a} e^{-M_a/2}\left(1 - S_{y,a} F_y \big/ 2\right) \qquad \text{(A20)}$$

Catches over time

(Average) annual catch over short, medium, and long terms:

$$C_{2011},\ C_{2012},\ \sum_{y=2011}^{2015} C_y \Big/ 5,\ \sum_{y=2016}^{2020} C_y \Big/ 5,\ \sum_{y=2011}^{2020} C_y \Big/ 5 \text{ and } \sum_{y=2011}^{2030} C_y \Big/ 20$$

Catch variation

Average annual variation in catch over short and long terms:

$$AAV_{2011-2015} = \frac{1}{5}\sum_{y=2011}^{2015} \left| C_y - C_{y-1} \right| / C_{y-1} \text{ and}$$

$$AAV_{2011-2030} = \frac{1}{20}\sum_{y=2011}^{2030} \left| C_y - C_{y-1} \right| / C_{y-1}$$

Table A1. Mid-year weights-at-age (kg) matrix for Canadian pollock in the Western Component (4Xopqrs+5Zc). Note: a missing value for age 12 in 2008 has been replaced by the average of the five previous years, while missing values for age 13 have been replaced by 11.

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.943	1.427	2.529	3.462	4.211	4.772	5.681	6.239	7.687	8.622	10.621	10.802
1983	0.881	1.349	1.983	3.373	4.367	5.105	5.651	6.624	7.220	8.381	8.886	9.188
1984	0.914	1.635	2.331	3.005	4.078	5.401	6.062	6.208	6.661	7.230	9.725	8.091
1985	0.974	1.615	2.462	3.169	3.695	4.296	6.022	7.315	7.185	7.968	9.343	9.401
1986	0.738	1.554	2.306	3.095	3.929	4.530	5.791	6.651	7.161	7.322	8.698	6.835
1987	0.943	1.475	2.266	3.046	3.564	4.315	4.907	5.300	6.794	7.482	7.909	8.806
1988	1.195	1.549	2.240	3.096	3.807	4.191	4.979	5.886	7.073	8.169	8.454	8.467
1989	0.880	1.313	2.095	3.068	3.885	4.491	4.869	6.012	6.334	8.911	7.133	10.715
1990	0.571	1.263	2.055	2.894	3.657	4.766	5.818	6.371	6.966	7.625	9.770	9.070
1991	0.906	1.344	2.153	2.866	3.736	4.730	5.711	6.460	6.815	8.060	9.030	9.778
1992	1.033	1.271	1.831	2.615	3.509	4.614	5.466	6.141	6.864	8.164	9.189	8.947
1993	0.761	1.110	1.666	2.312	3.143	3.754	4.723	5.492	6.704	7.704	8.131	8.606
1994	0.805	1.250	1.586	2.163	3.058	3.765	4.219	4.854	6.268	6.082	7.846	8.539
1995	0.671	1.132	1.806	2.296	3.038	3.941	4.796	5.389	7.348	8.573	8.781	9.392
1996	0.896	1.336	1.795	2.353	3.057	3.665	5.205	6.296	8.502	9.561	11.422	11.474
1997	0.915	1.388	1.938	2.446	3.288	3.976	5.101	7.763	10.058	6.737	11.915	11.000
1998	0.867	1.103	1.720	2.361	3.144	4.219	5.159	5.640	8.615	8.833	12.063	11.000
1999	0.806	1.193	1.682	2.419	3.245	4.288	5.659	7.057	9.939	9.943	10.000	11.000
2000	0.757	1.247	1.796	2.478	3.166	4.168	5.412	5.745	9.003	9.821	10.000	11.000
2001	0.453	1.039	1.987	2.929	3.734	4.775	6.532	8.118	8.539	9.026	10.788	13.067
2002	0.280	0.931	1.592	2.528	3.714	4.829	6.328	6.936	8.663	10.872	11.081	16.975
2003	0.590	0.977	1.536	2.376	3.528	4.780	6.289	7.427	9.281	10.090	8.875	11.000
2004	0.475	0.873	1.621	2.210	3.125	4.290	6.509	7.369	8.699	9.077	12.027	15.595
2005	0.391	0.955	1.439	2.152	2.801	4.087	5.479	5.956	9.216	14.277	14.277	11.000
2006	0.654	0.931	1.722	2.180	3.101	3.715	4.680	5.186	9.121	9.906	10.851	11.000
2007	0.660	0.948	1.573	2.525	2.973	3.944	4.567	6.229	7.352	10.195	13.091	11.000
2008	0.758	1.202	1.681	2.299	3.191	3.819	4.907	5.552	5.985	8.832	11.824	11.000
2009	0.585	1.137	1.884	2.451	3.318	4.153	4.558	5.074	5.324	11.959	12.974	13.123
2010	0.683	1.026	1.754	2.456	3.091	3.804	4.358	4.471	4.969	6.365	10.252	11.000

Table A2. Begin-year weights-at-age (kg) matrix for Canadian pollock in the Western Component (4Xopqrs+5Zc).

	2	3	4	5	6	7	8	9	10	11	12	13
1982	0.284	0.811	1.693	2.988	3.818	4.483	5.207	5.954	6.925	8.141	9.569	10.809
1983	0.303	1.235	1.660	2.949	3.888	4.637	5.193	6.134	6.712	8.027	8.753	10.809
1984	0.360	0.944	2.615	2.730	3.709	4.857	5.563	5.923	6.643	7.225	9.028	9.887
1985	0.323	0.807	2.301	2.900	3.332	4.186	5.703	6.659	6.679	7.285	8.219	10.343
1986	0.423	0.900	1.608	3.136	3.529	4.091	4.988	6.329	7.238	7.253	8.325	10.138
1987	0.185	0.642	1.884	2.554	3.321	4.118	4.715	5.540	6.722	7.320	7.610	9.782
1988	0.572	0.696	1.364	2.704	3.405	3.865	4.635	5.374	6.123	7.450	7.953	9.327
1989	0.366	0.750	1.901	2.688	3.468	4.135	4.517	5.471	6.106	7.939	7.633	9.643
1990	0.254	0.656	1.323	2.784	3.350	4.303	5.112	5.570	6.471	6.950	9.331	8.858
1991	0.366	0.590	1.154	2.416	3.288	4.159	5.217	6.131	6.589	7.493	8.298	10.367
1992	0.331	0.776	1.374	1.990	3.171	4.152	5.085	5.922	6.659	7.459	8.606	9.966
1993	0.444	0.560	1.168	2.202	2.867	3.629	4.668	5.479	6.416	7.272	8.148	10.054
1994	0.309	0.693	1.108	1.617	2.659	3.440	3.980	4.788	5.867	6.385	7.775	9.457
1995	0.213	0.482	1.183	1.967	2.563	3.472	4.249	4.768	5.972	7.331	7.308	9.290
1996	0.200	0.613	1.042	1.951	2.649	3.337	4.529	5.495	6.769	8.382	9.896	9.828
1997	0.204	0.974	1.340	2.102	2.782	3.486	4.324	6.357	7.958	7.568	10.673	11.209
1998	0.375	0.604	0.971	2.016	2.773	3.725	4.529	5.364	8.178	9.426	9.015	11.448
1999	0.222	0.607	1.191	1.828	2.768	3.672	4.886	6.034	7.487	9.255	9.398	11.519
2000	0.264	0.697	1.209	1.838	2.767	3.678	4.817	5.702	7.971	9.880	9.972	10.488
2001	0.313	0.525	1.479	2.353	3.042	3.888	5.218	6.628	7.004	9.015	10.293	10.488
2002	0.257	0.605	1.173	2.115	3.298	4.246	5.497	6.731	8.386	9.635	10.001	10.894
2003	0.220	0.708	1.175	2.101	2.986	4.213	5.511	6.856	8.023	9.349	9.823	11.040
2004	0.205	0.566	1.430	1.906	2.725	3.890	5.578	6.808	8.038	9.178	11.016	9.881
2005	0.227	0.597	1.243	1.891	2.465	3.542	4.724	6.120	8.083	11.144	11.384	11.502
2006	0.350	0.702	1.393	1.926	2.524	3.196	4.335	5.194	7.245	9.372	12.447	12.532
2007	0.223	0.700	1.441	2.191	2.542	3.490	4.118	5.422	6.175	9.643	11.388	10.925
2008	0.370	0.772	1.342	1.966	2.835	3.365	4.390	5.034	6.132	8.058	10.979	12.000
2009	0.455	0.869	1.666	2.113	2.762	3.640	4.172	4.990	5.437	8.460	10.705	11.405
2010	0.073	0.750	1.550	2.180	2.753	3.553	4.254	4.514	5.021	5.821	11.073	11.946

Table A3. Stratified mean catch per tow (kg) of pollock from the DFO summer research vessel survey in 4X strata corresponding to the Western Component.

Year	Stratified mean wt/tow
1984	35.65
1985	39.23
1986	36.59
1987	37.27
1988	93.07
1989	31.70
1990	86.20
1991	30.48
1992	13.86
1993	37.15
1994	18.20
1995	14.35
1996	64.51
1997	8.84
1998	6.10
1999	5.30
2000	5.79
2001	14.84
2002	6.13
2003	18.37
2004	20.86
2005	15.16
2006	121.01
2007	23.90
2008	40.44
2009	47.04
2010	5.39

APPENDIX 4C-B. TECHNICAL SPECIFICATIONS OF CANDIDATE MANAGEMENT PROCEDURES

The Candidate Management Procedures (CMPs) formula for computing the TAC each year is as follows:

$$C_{y+1} = w_y C_y \left[1 + \lambda_{up/down} s_y\right] + \left(1 - w_y\right)\left[a + b\left(J_y - 1\right)\right] \qquad \text{(B1)}$$

where

C_y is the total TAC recommended for year *y*,

w_y is a year-dependent tuning parameter,

$\lambda_{up/down}$ are tuning parameters; λ_{up} is used if $s_y \geq 0$ and λ_{down} is used if $s_y < 0$,

s_y is a measure of the immediate past trend in the survey abundance index (see details below) as available to use for calculations for year *y*,

a and b are tuning parameters, and

J_y is a measure of the immediate past level in the survey abundance index relative to a target level as available to use for calculations for year *y*:

$$J_y = \frac{\sum_{y-2}^{y} I_y \Big/ 3}{\sum_{1984}^{1994} I_y \Big/ 11}$$

where I_y is the survey abundance index in year *y*.

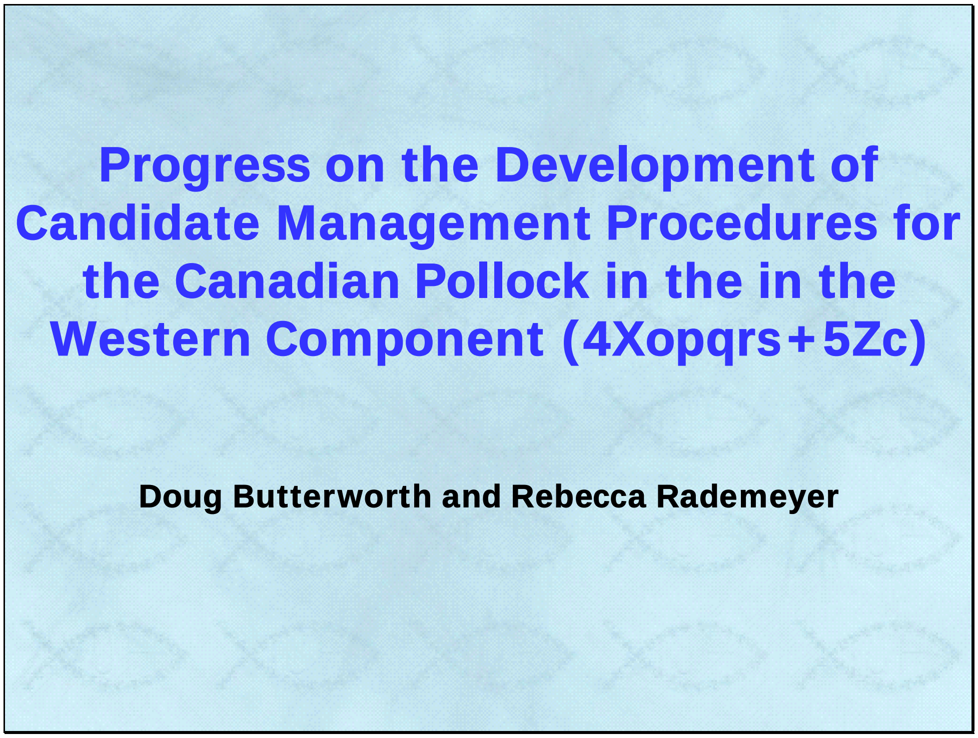
The trend measure s_y is computed by linearly regressing $\ln I_y$ *vs*. year *y*' for $y' = y - p$ to $y' = y$.

where *p* is a tuning parameter.

Constraints on the interannual TAC change have also been introduced and in some cases a cap (upper bound) on the TAC has been imposed.

APPENDIX 4d. POWERPOINT PRESENTATION OF THE PROGRESS ON THE DEVELOPMENT OF CANDIDATE MANAGEMENT PROCEDURES FOR THE CANADIAN POLLOCK IN THE IN THE WESTERN COMPONENT (4Xopqrs+5Zc).

Slide 1



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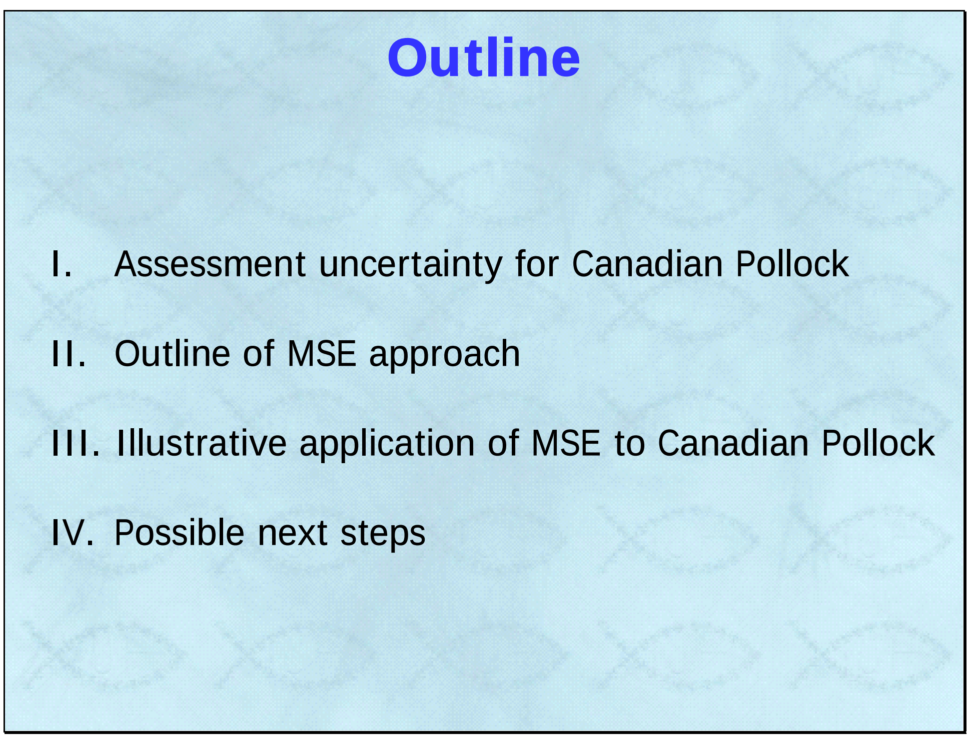

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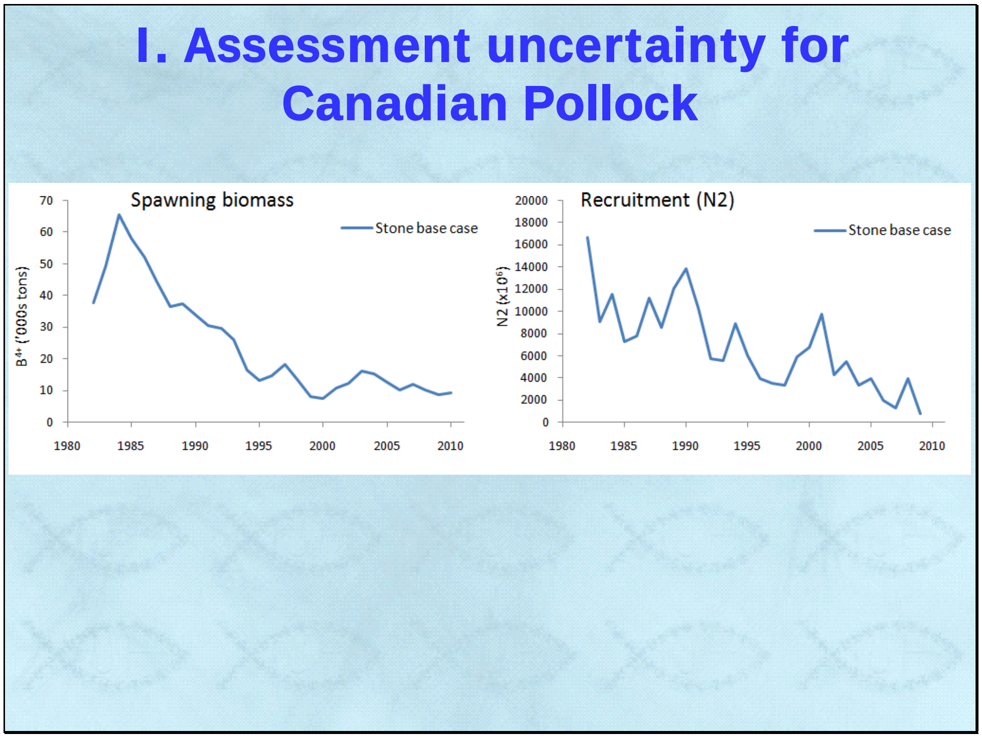

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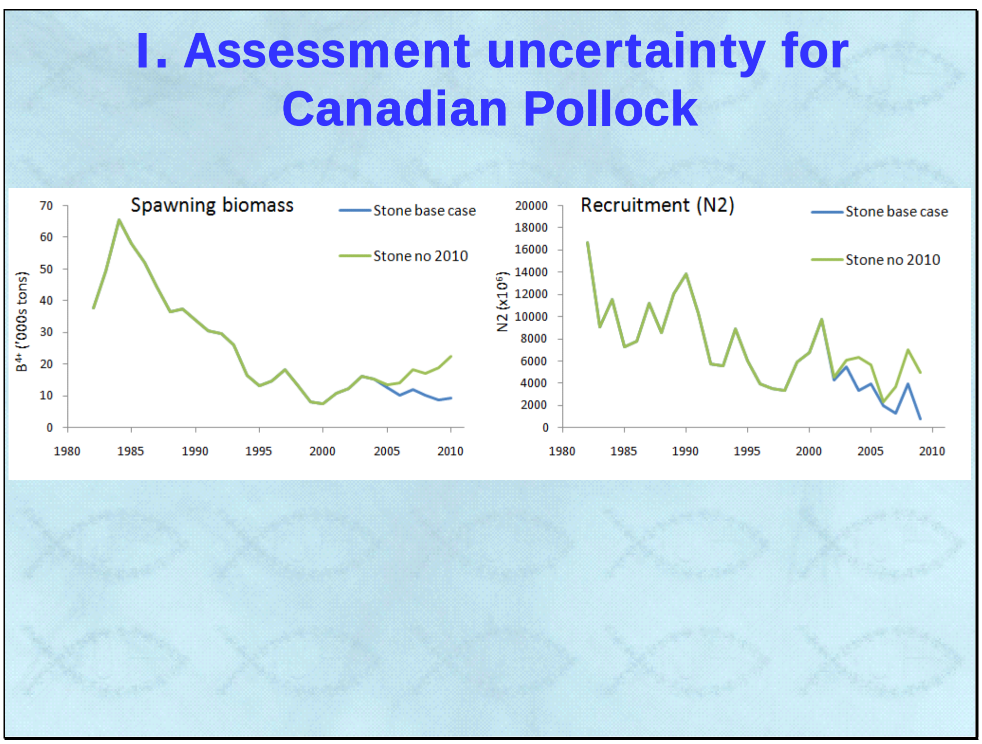
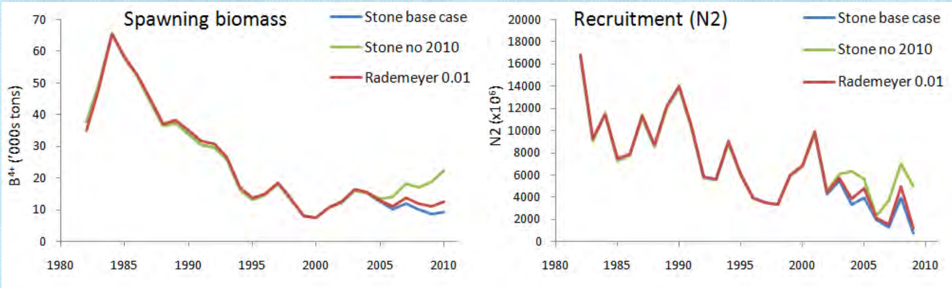


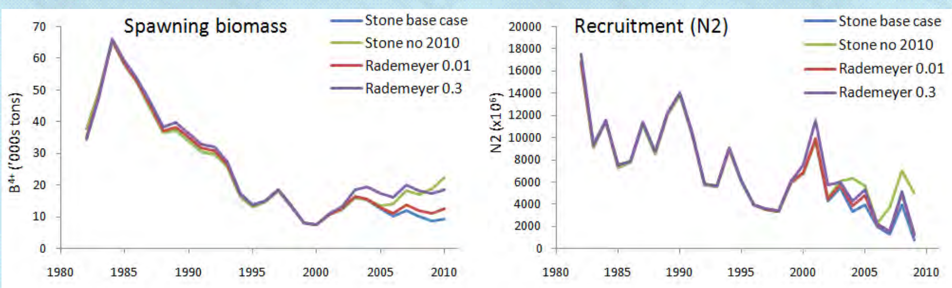
Slide 5

I. Assessment uncertainty for Canadian Pollock



Slide 6

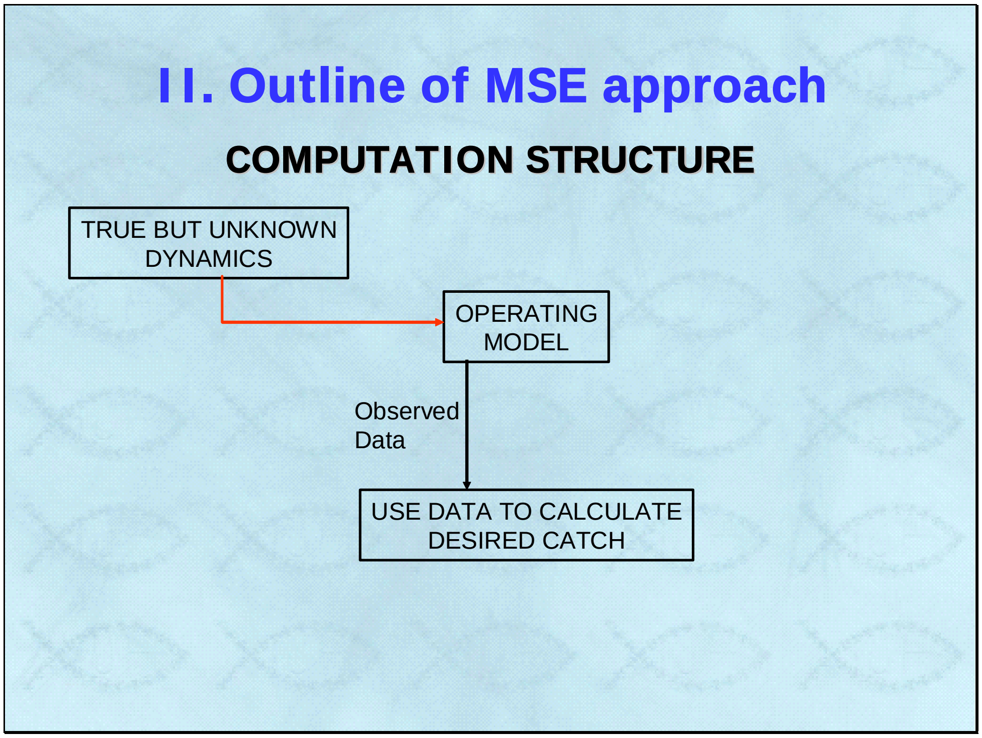
I. Assessment uncertainty for Canadian Pollock



Marked TAC advice difference depending on which is chosen.

How can we deal with this uncertainty?

Slide 7



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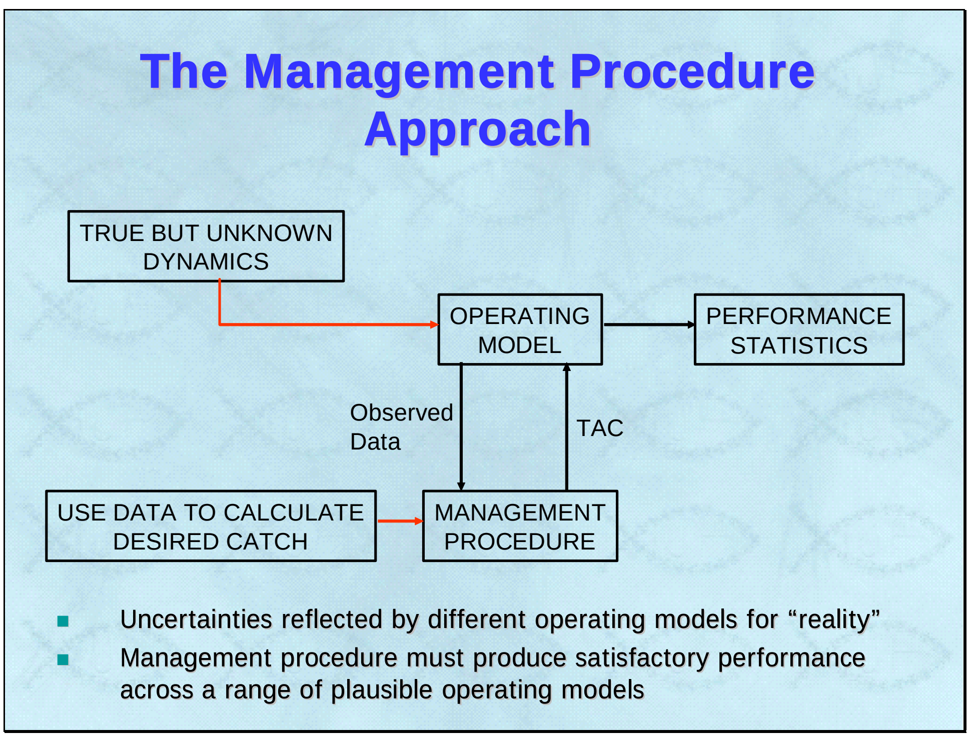


Slide 9

Objectives for Management

- High catch in short and longer term
- Small chance of unintended reduction and/or inadequate recovery
- Small changes in catch from year to year

Conflicting → Trade-offs

Aim

Find a management procedure which:

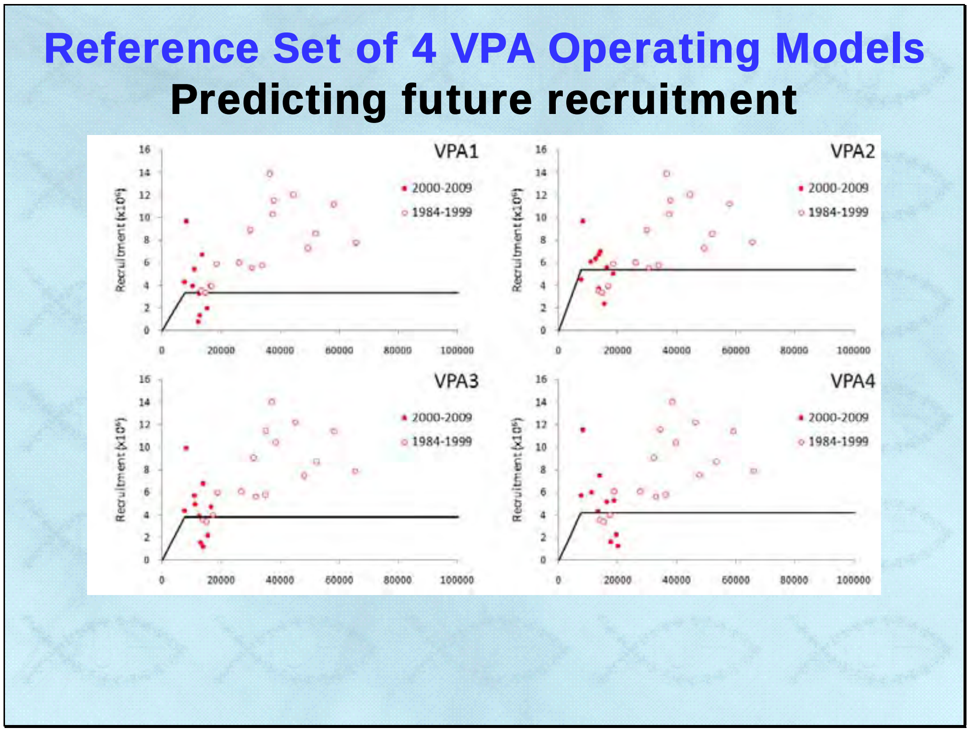
- Provides desired trade-offs
- Is (through feedback) reasonably robust in achieving this performance to changes in the operating model (underlying reality)

Slide 10

How it works

- Operating model "OM"
  - Provided by alternate assessments
  - Split into Reference Case ("best assessment") and robustness tests
  - Sometimes integrate over Reference Set includes 2-3 major uncertainties
- Management procedure "MP"
  - From simple population model fit and control rule
  - Empirical (e.g. adjust TAC based on trends in abundance indices)

Slide 11



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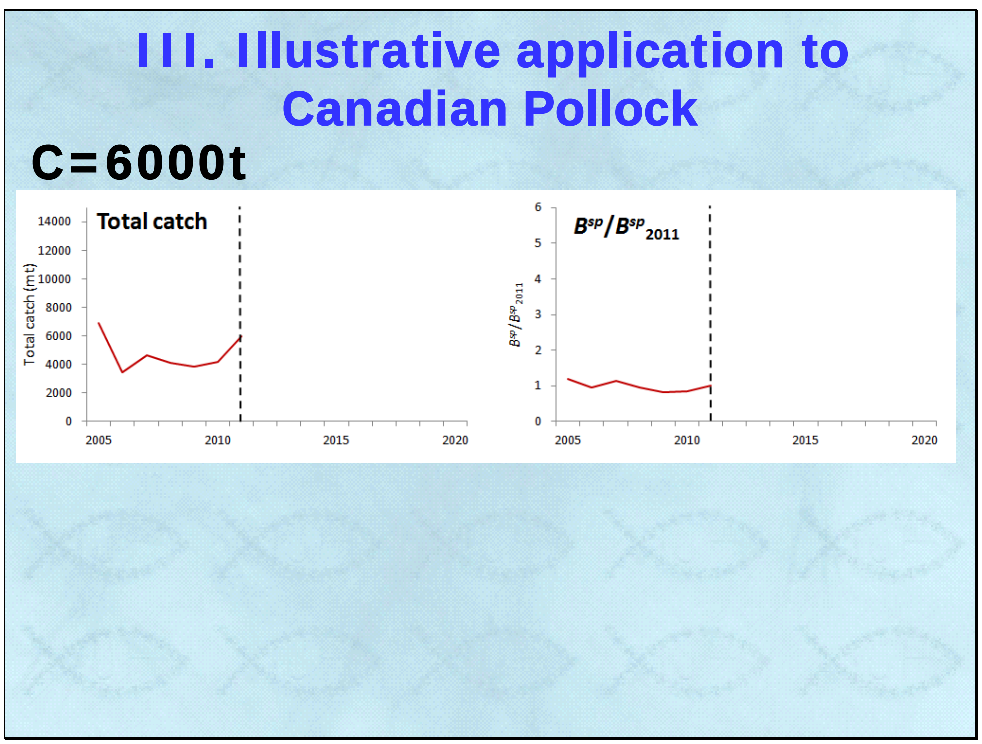

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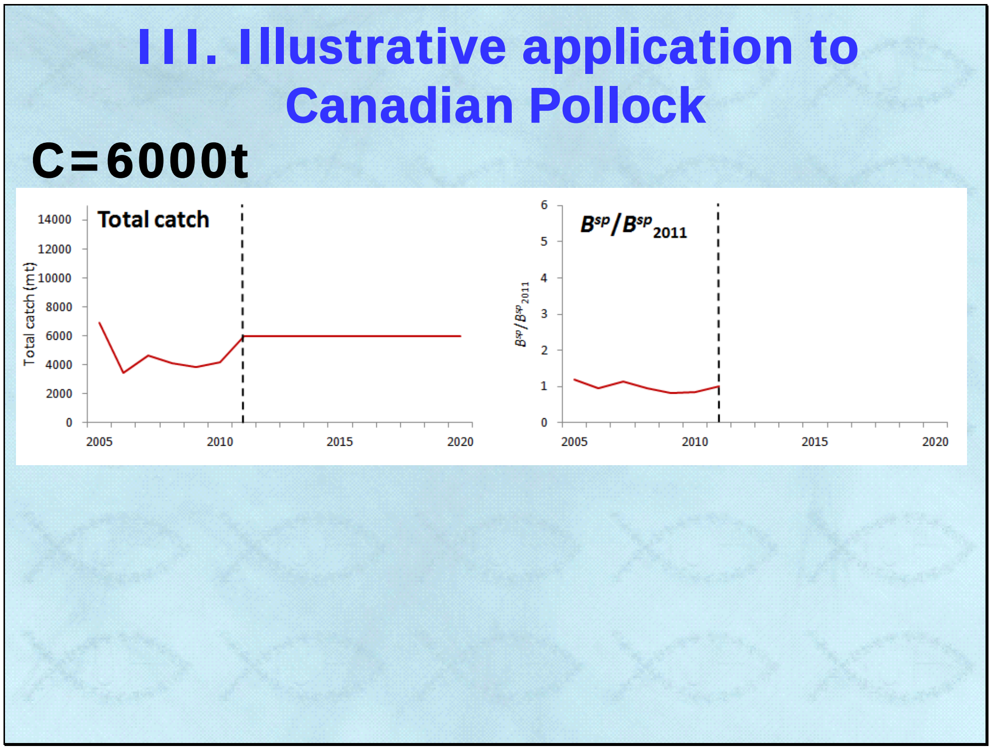

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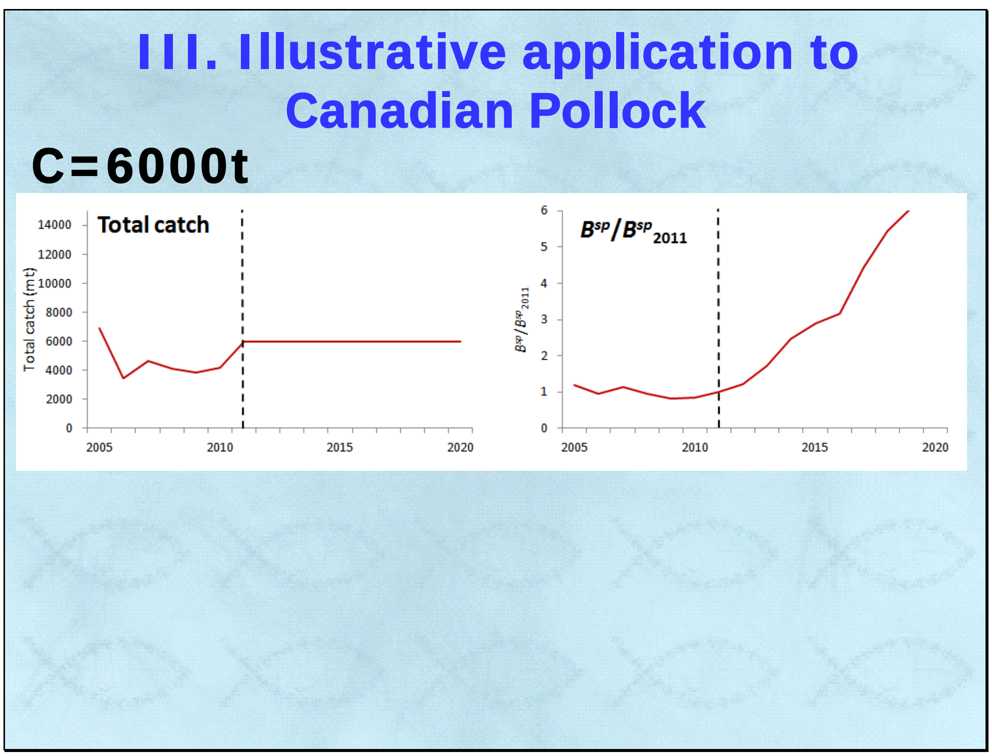

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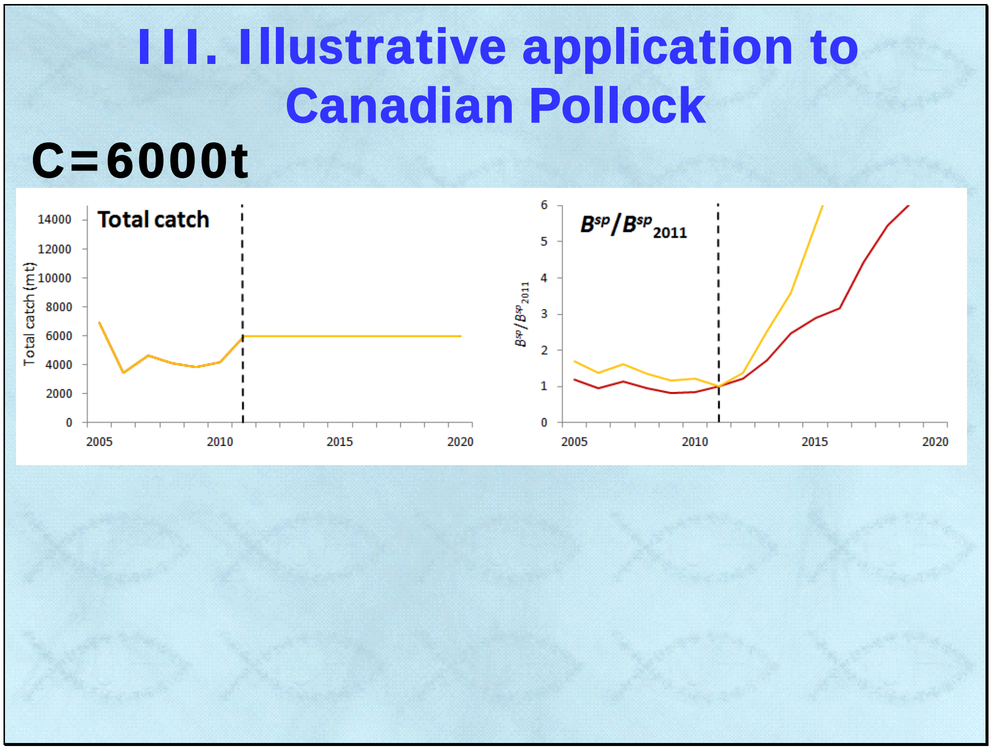

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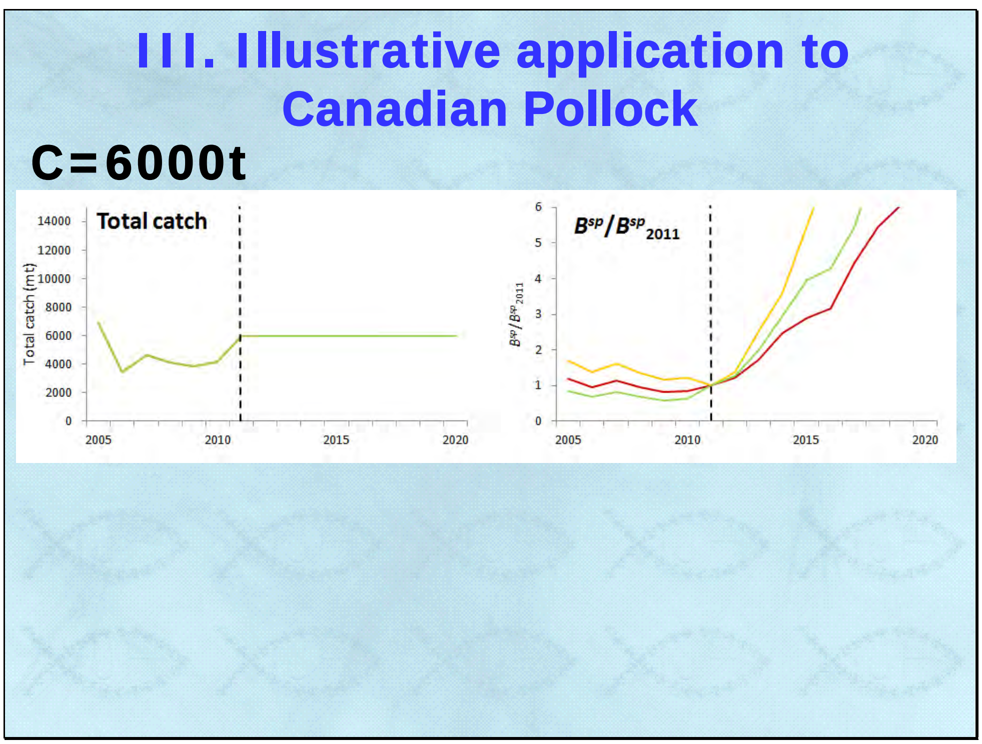

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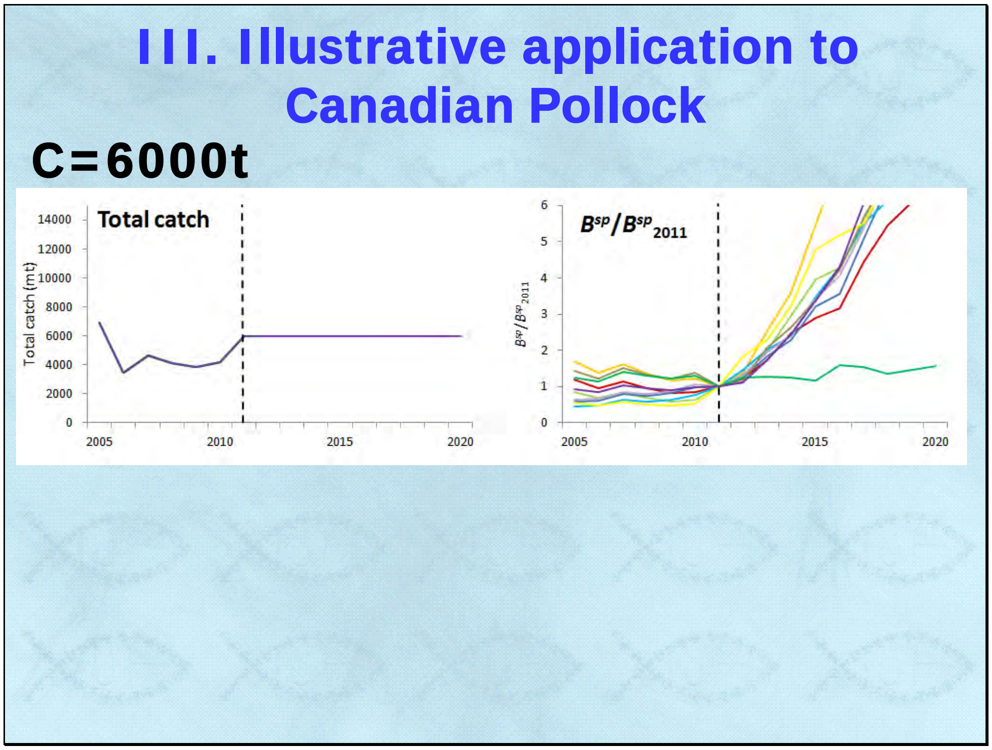

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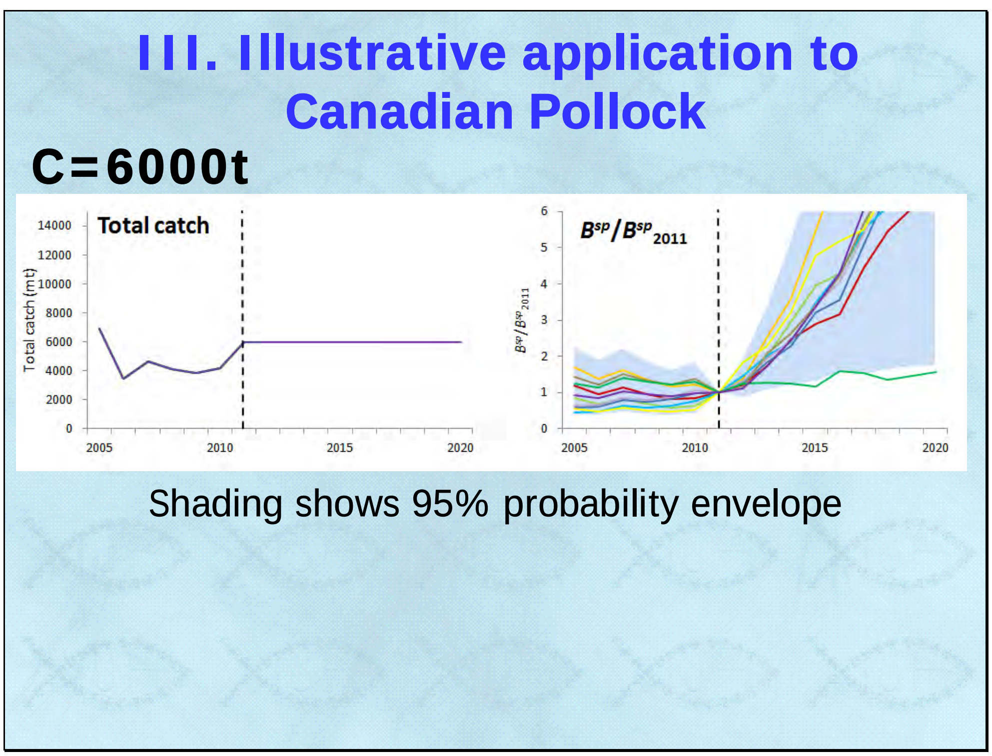
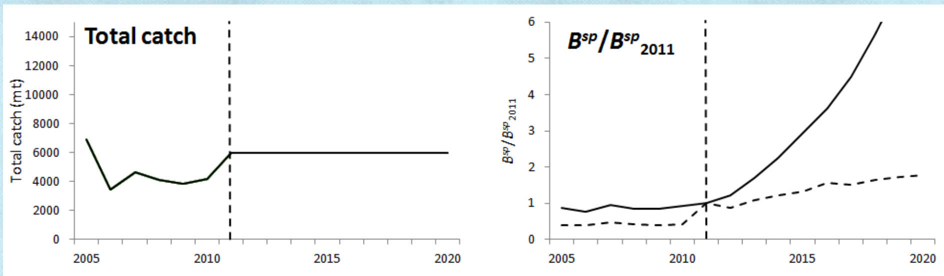


Slide 19

III. Illustrative application to Canadian Pollock

C=6000t



Standard reporting format showing median and lower 2.5%-ile

Slide 20

Abundance index slope based CMP: CMPA10b

$$C_{y+1} = C_y\left[1 + 1.05 s_y\right]$$

Index used: summer RV survey – ***s*** is annual trend

Annual TAC change constraints: +15%, -15%

How it works:

index increasing -> slope ***s*** positive -> TAC increased

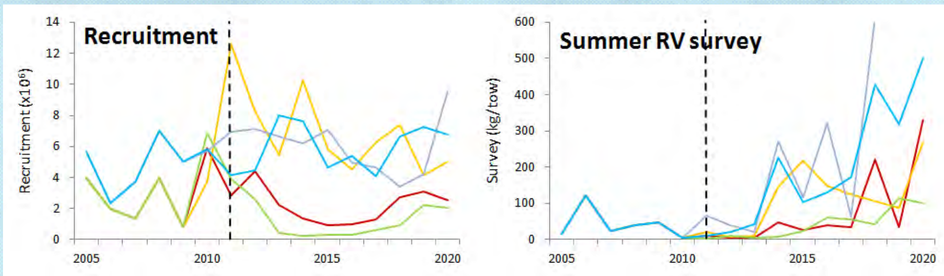
index decreasing -> slope ***s*** negative -> TAC decreased

slope ***s*** = +10% p.a -> TAC increase of 10.5%

Slide 21

Future recruitment and survey results

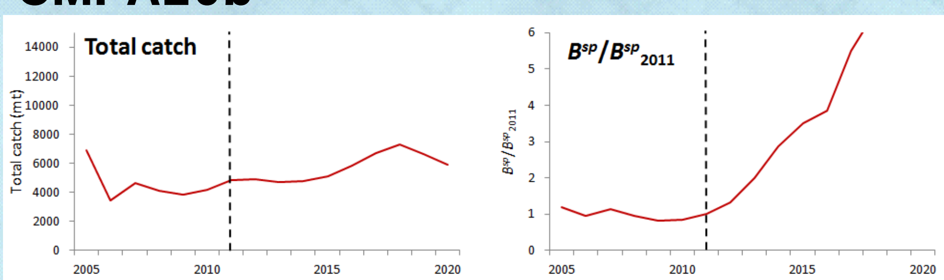
CMPA10b



Slide 22

Abundance index slope based CMP: CMPA10b

CMPA10b



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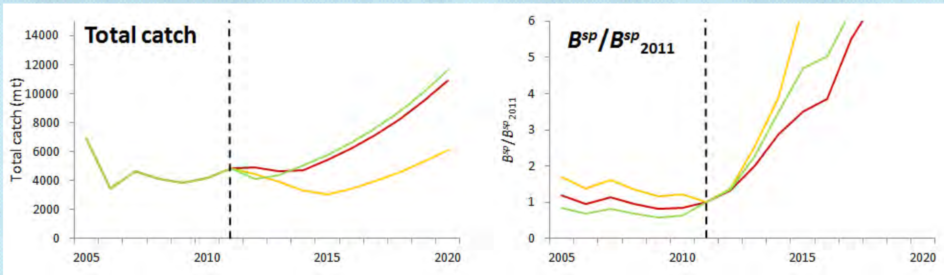
Abundance index slope based CMP: CMPA10b

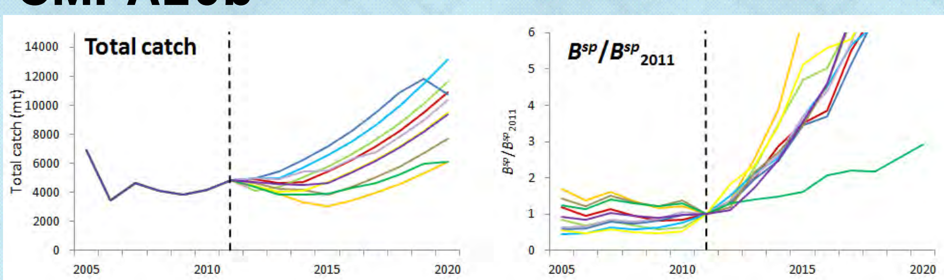
CMPA10b



Slide 24

Abundance index slope based CMP: CMPA10b

CMPA10b



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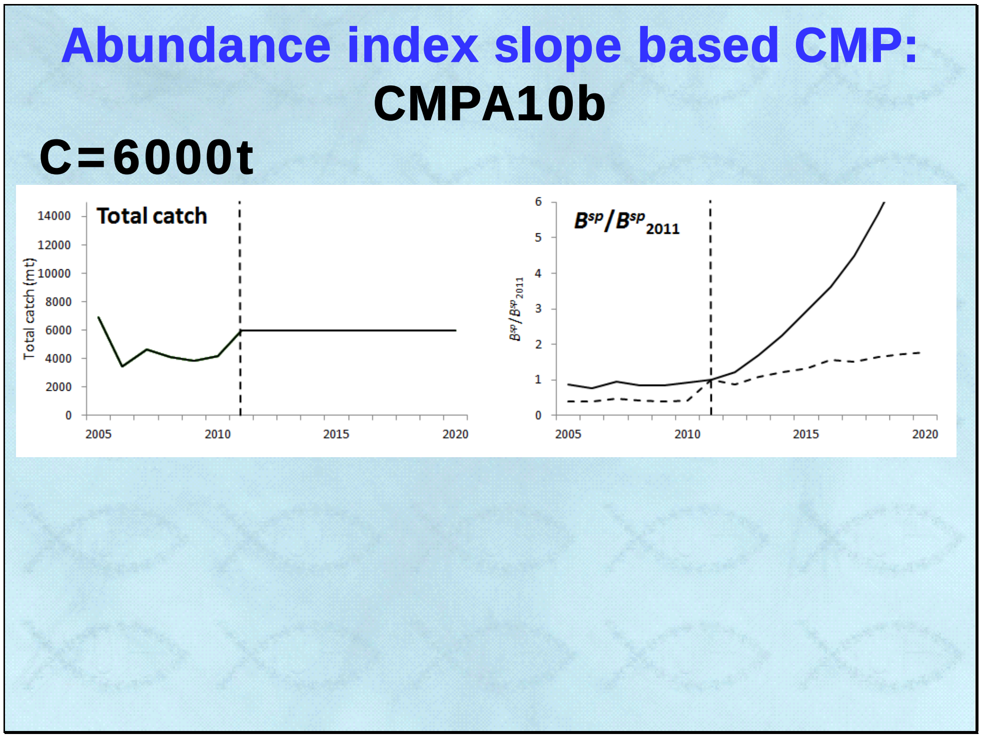
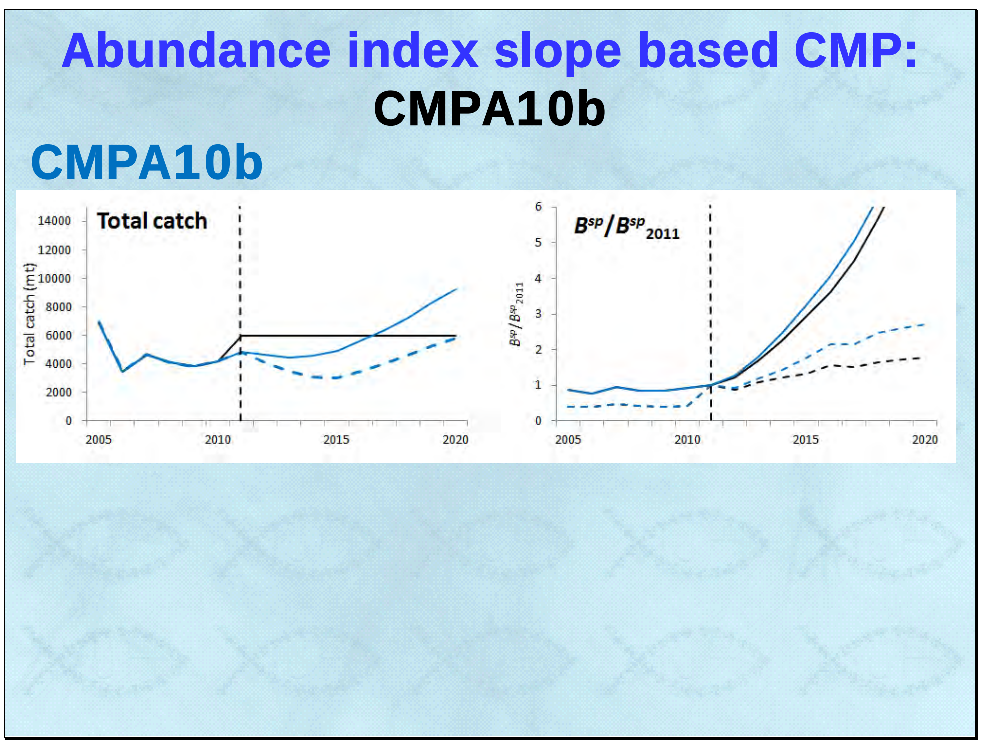


Slide 26



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Slope plus target based CMP: CMPC5b

$$C_{y+1} = w_y C_y\left[1 + 1.1 s_y\right] + \left(1 - w_y\right)\left[13722 + 9500\left(J_y - 1\right)\right]$$

$$J_y = \frac{\sum_{y-2}^{y} I_y \Big/ 3}{\sum_{1984}^{1994} I_y \Big/ 11}$$

w_y: changes linearly from 1.0 in 2010 to 0.2 in 2020 then stays constant thereafter

Annual TAC change constraints: +15%, -15%

Cap of 20 000t

How it works:

- Target is abundance index at average level over 1984-1994
- If average index over last three years is above/below target, we increase/decrease TAC
- Over time put more weight on target compared to slope component of formula

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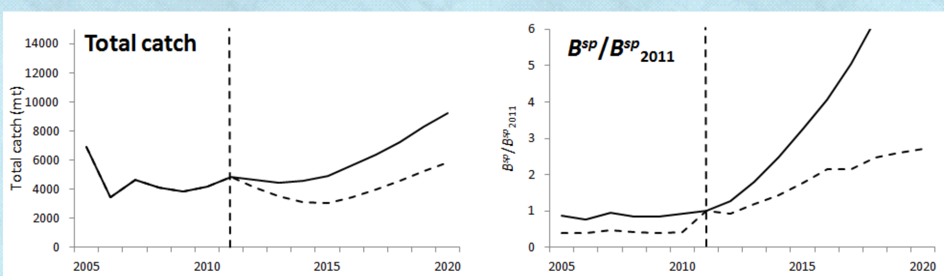
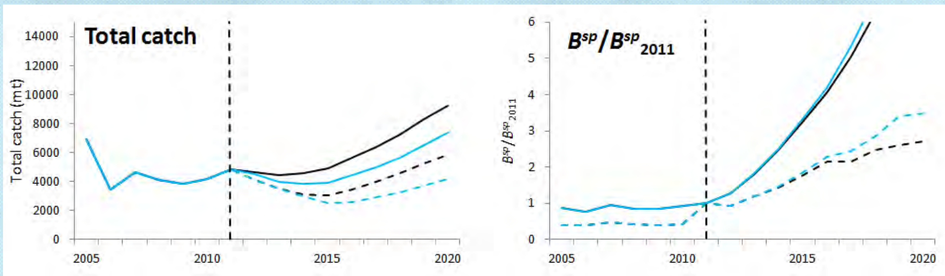
Slope plus target based CMP: CMPC5b



Slide 29

Slope plus target based CMP: CMPC5b



CMPC5b – tuned to 6000t median catch
CMPC5a – tuned to 5000t median catch

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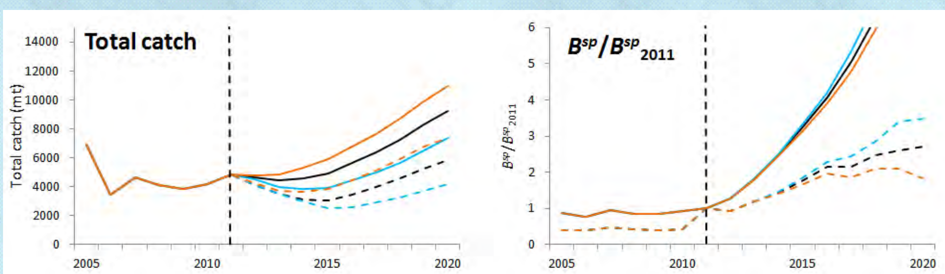
Slope plus target based CMP: CMPC5b



CMPC5b – tuned to 6000t median catch
CMPC5a – tuned to 5000t median catch
CMPC5c – tuned to 7000t median catch

Note: Higher catch target -> less recovery
greater risk

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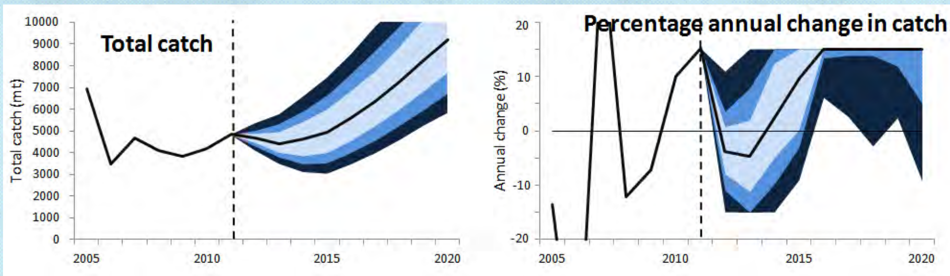
Slope plus target based CMP: CMPC5b



Shows median and then shadings of 50%, 75% and 95% probability intervals

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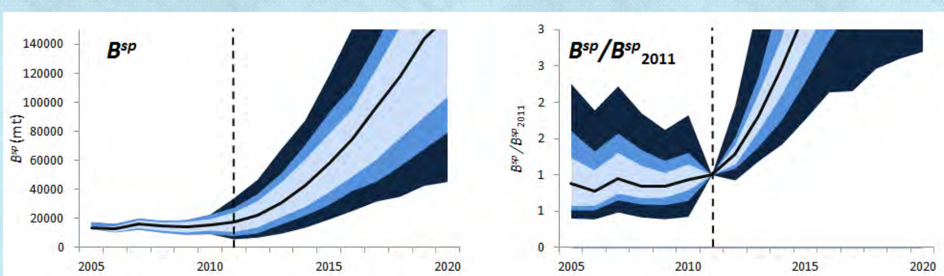
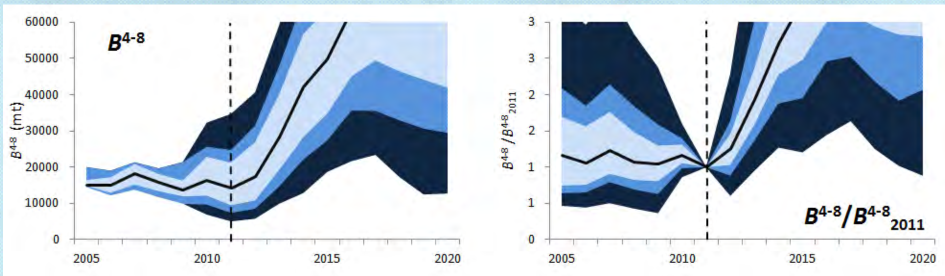
Slope plus target based CMP: CMPC5b



Shows median and then shadings of 50%, 75% and 95% probability intervals

Slide 33

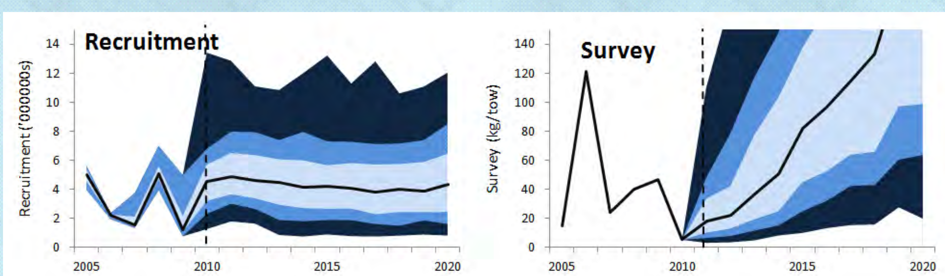
Slope plus target based CMP: CMPC5b



Shows median and then shadings of 50%, 75% and 95% probability intervals

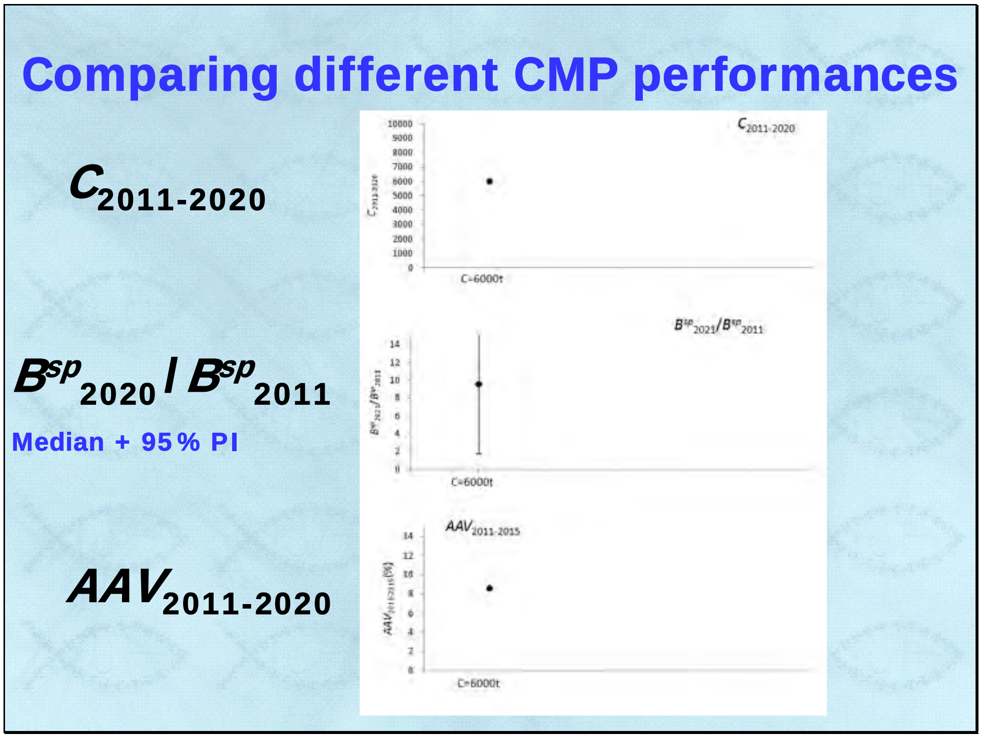
Slide 34

Slope plus target based CMP: CMPC5b



Shows median and then shadings of 50%, 75% and 95% probability intervals

Slide 35



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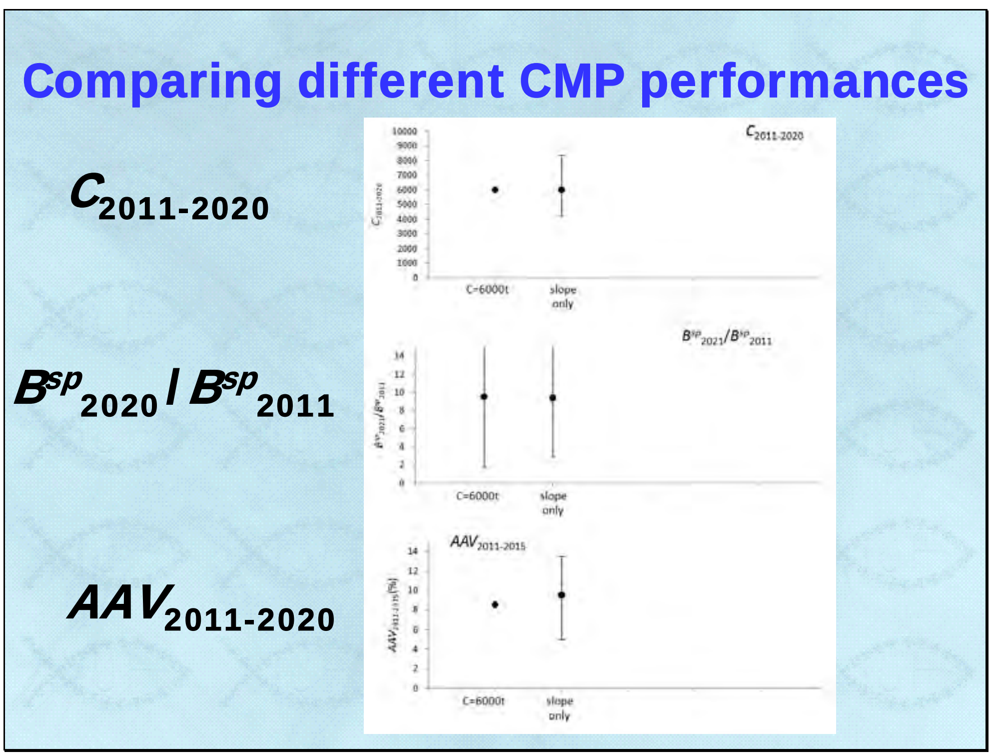
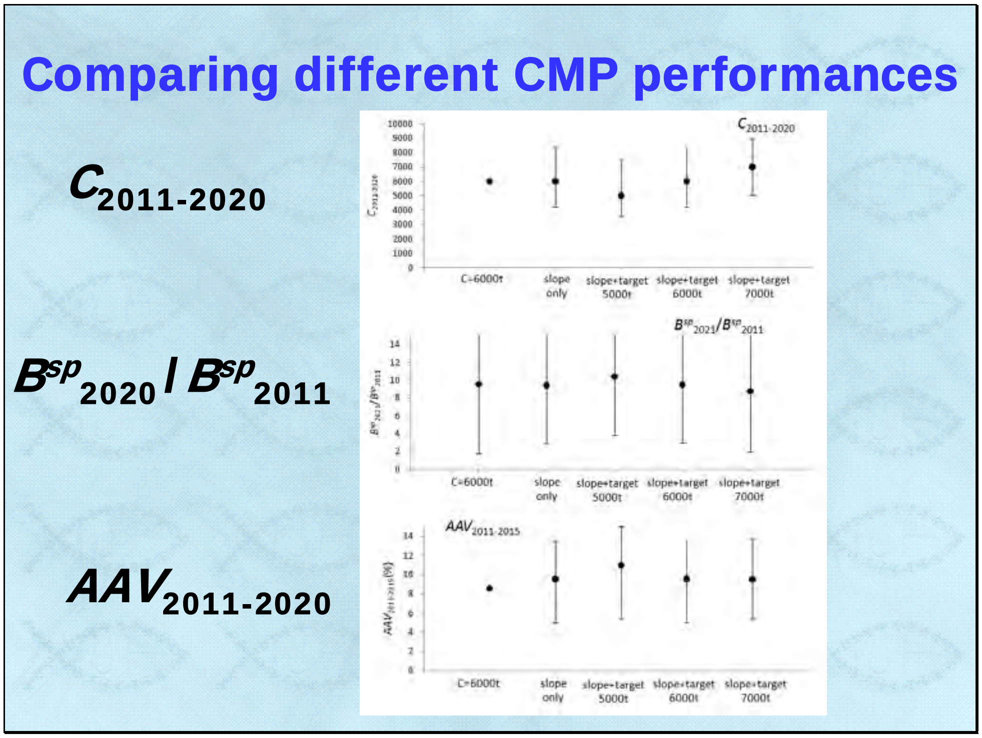


Slide 37



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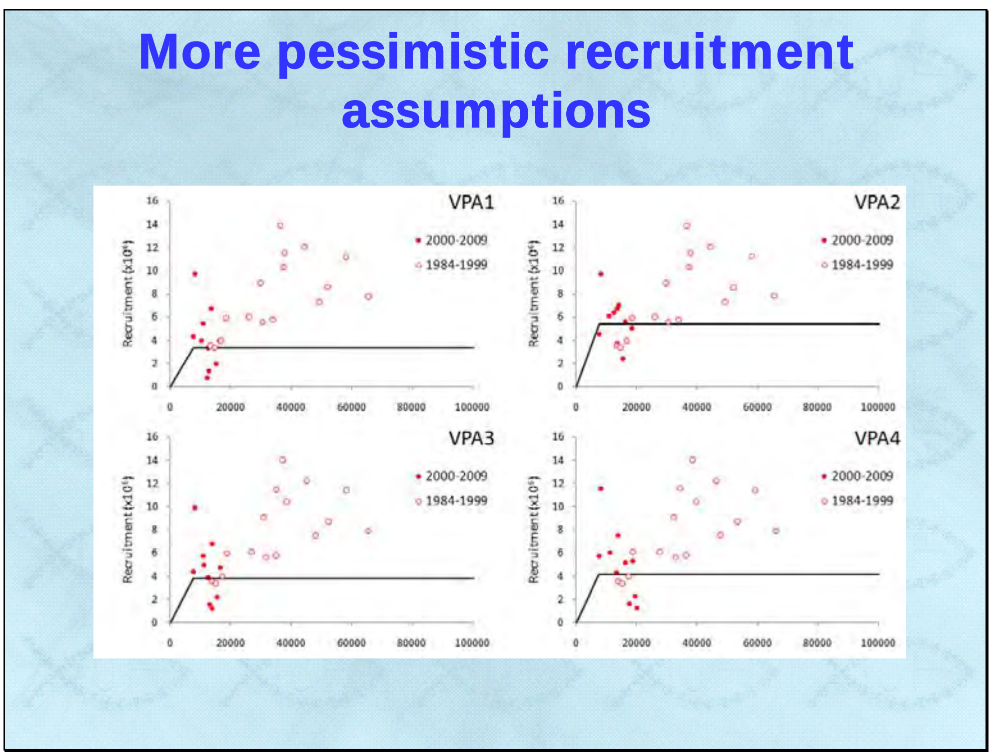

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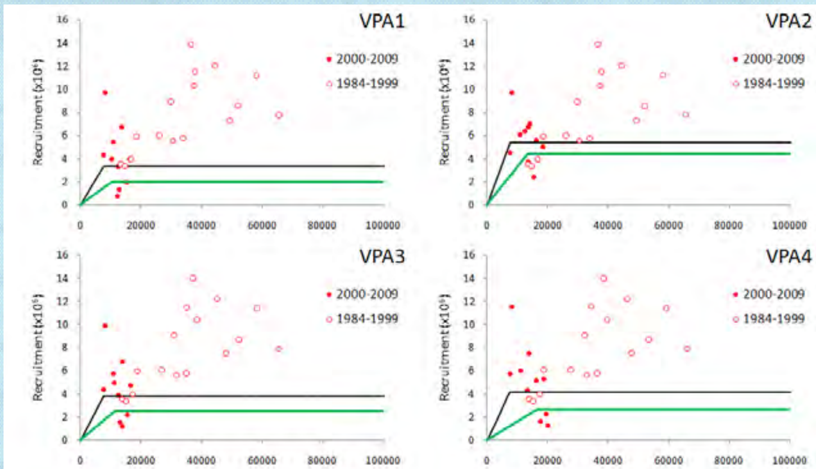
More pessimistic recruitment assumptions



Green curves based on last 5 instead of 10 years

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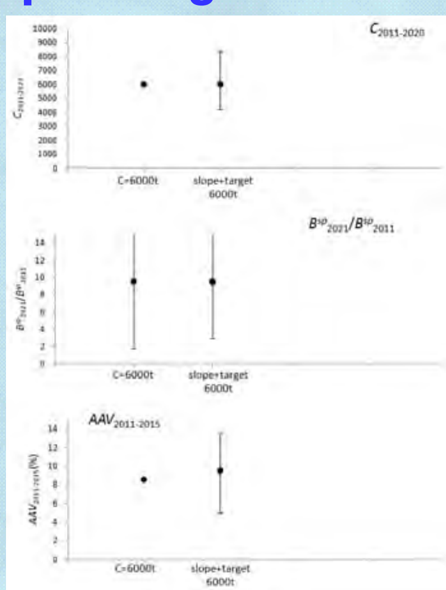
Comparisons adding robustness tests for slope+target 6000t

$C_{2011\text{-}2020}$

$B^{sp}_{2020} / B^{sp}_{2011}$

$AAV_{2011\text{-}2020}$



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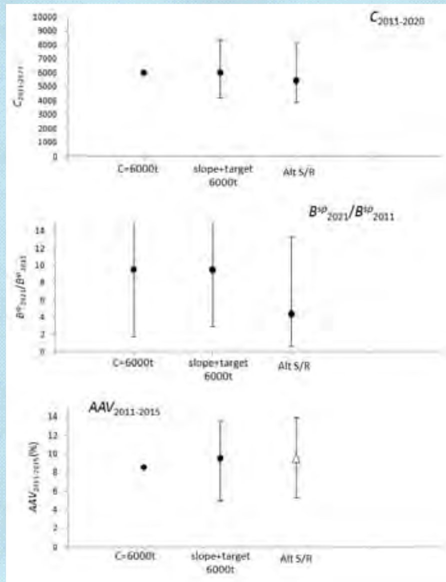
Comparisons adding robustness tests for slope+target 6000t

$C_{2011\text{-}2020}$

$B^{sp}_{2020} / B^{sp}_{2011}$

$AAV_{2011\text{-}2020}$



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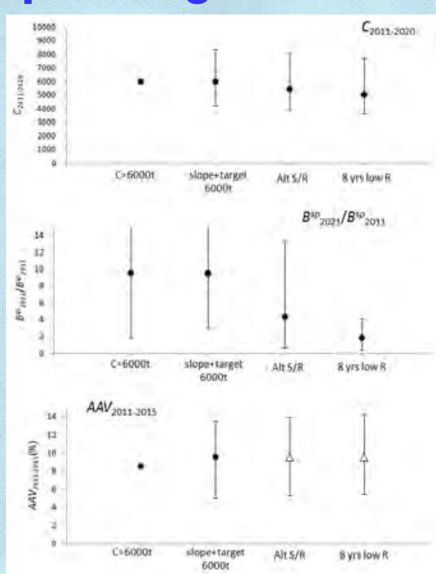
Comparisons adding robustness tests for slope+target 6000t

$C_{2011\text{-}2020}$

$B^{sp}_{2020} / B^{sp}_{2011}$

$AAV_{2011\text{-}2020}$



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IV. Possible next steps

1. **Refine medium-term management objectives**
   - What would ideal catch levels be?
   - What risk of unintended stock depletion is acceptable?
   - What restrictions might be placed on annual TAC changes and a maximum TAC?
2. **What are the most appropriate assumptions for projections (i.e. S/R relationships)?**
3. **What further alternative Operating Models (robustness tests) need be considered to span uncertainties?**
4. **How might the Management Procedures shown be improved? Further potential data inputs (beyond surveys) available perhaps?**

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Thank you for your attention

APPENDIX 5. SUGGESTED PERFORMANCE STATISTICS TO ASSESS CANDIDATE MANAGEMENT PROCEDURES FOR THE CANADIAN POLLOCK IN THE WESTERN COMPONENT (4Xopqrs+5Zc)

RESOURCE DEPLETION/RECOVERY

(a) $\frac{P_{2021}}{P_{\text{target}}}$, where P_y is the population size in year *y*, and P_{target} is pre-defined recovery target population size, for which the 1984-1994 average is used (subject to revision);

(b) $\frac{P_{2016}}{P_{2000}}$;

(c) $\frac{P_{2021}}{P_{2000}}$

(d) $\frac{P_{2031}}{P_{2000}}$;

For each of these, population can be measured as the exploitable biomass (B_y^{4-8}) and spawning biomass (B_y^{sp}), where:

$$B_y^{4-8} = \sum_{a=4}^{8} w_{y,a}^{mid} N_{y,a} \qquad (1)$$

$$B_y^{sp} = \sum_{a=1}^{m} f_{y,a} w_{y,a}^{mid} N_{y,a} \qquad (2)$$

CATCH OVER TIME

(Average) annual catch over short, medium, and long terms:

(a) C_{2011};

(b) C_{2012};

(c) $C_{2011-2015} = \sum_{y=2011}^{2015} C_y \Big/ 5$;

(d) $C_{2016-2020} = \sum_{y=2016}^{2020} C_y \Big/ 5$;

(e) $C_{2011-2020} = \sum_{y=2011}^{2020} C_y \Big/ 10$; and

(f) $C_{2021-2030} = \sum_{y=2011}^{2030} C_y \Big/ 10$

CATCH VARIATION

Average annual variation in catch over short and long terms:

(a) $AAV_{2011-2020} = \frac{1}{10}\sum_{y=2011}^{2020}\left|C_y - C_{y-1}\right| / C_{y-1}$; and

(b) $AAV_{2021-2020} = \frac{1}{10}\sum_{y=2021}^{2030}\left|C_y - C_{y-1}\right| / C_{y-1}$.