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Proceedings of the Pacific regional peer review on A Review of International Best Practices to Assigning Species to Tiers for the Purposes of Stock Assessment Based on Data Availability and Richness

May 30-31, 2016
Nanaimo BC

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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

These Proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting of May 30-31, 2016, at the Pacific Biological Station (PBS) in Nanaimo, British Columbia (BC) focusing on the creation of a tiered-approach framework for assessing groundfish stocks. The meeting included discussions on a proposed hierarchical system based on data (using a scorecard to assess data availability, quality, and reliability), candidate references points, and candidate performance metrics. Significant time was spent on the issue of data-limited species.

In-person participation included representatives from Fisheries and Oceans Canada (DFO Science and Management), University of British Columbia (UBC), U.S. National Oceanic and Atmospheric Administration (NOAA), Landmark Fisheries Research (consultant), Canadian Groundfish Research and Conservation Society (CGRCS), Pacific Halibut Management Association (PHMA), United Fisheries and Allied Workers (UFAWA), Cowichan First Nation, Nuu-chah-nulth Tribal Council, and Central Coast Indigenous Resource Alliance.

Compte rendu de l’examen par les pairs de la région du Pacifique sur l’Examen des pratiques exemplaires internationales pour l’attribution des espèces des poissons de fond à des tiers pour fins d’évaluation des stocks fondés sur la disponibilité et l’abondance de données

SOMMAIRE

Le présent compte rendu résume les discussions pertinentes et les principales conclusions de la réunion d'examen régional par des pairs du Secrétariat canadien de consultation scientifique (SCCS) de Pêches et Océans Canada (MPO), qui a eu lieu les 30 et 31 mai 2016 à la Station biologique du Pacifique de Nanaimo, en Colombie-Britannique. Elle portait sur un cadre d'approche échelonnée pour l'évaluation des stocks de poissons de fond. La réunion a porté sur des discussions concernant un système hiérarchique proposé appuyé sur les données (au moyen d'une fiche d'évaluation de la disponibilité, de la qualité et de la fiabilité des données), les points de référence proposés, et les mesures du rendement du candidat. On a consacré beaucoup de temps à la question des espèces peu documentées.

Les participants sur place comprenaient des représentants de Pêches et Océans Canada (Secteur des sciences du MPO et la direction), de l'Université de la Colombie-Britannique (UBC), de la National Oceanic and Atmospheric Administration (NOAA), de Landmark Fisheries Research (expert-conseil), de la Canadian Groundfish Research and Conservation Society (CGRCS), de la Pacific Halibut Management Association (PHMA), des United Fisheries and Allied Workers (UFAWA), de la Première Nation Cowichan, du Conseil tribal de Nuu-chah-nulth, et de la Central Coast Indigenous Resource Alliance.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS), Regional Peer Review (RPR) meeting was held on May 30-31, 2016, at the Pacific Biological Station (PBS) in Nanaimo to review a tiered-approach (TA) framework for assessing groundfish stocks in British Columbia (BC).

The Terms of Reference (TOR) for the science review (Appendix A) were developed in response to a request for advice from DFO Science, specifically the Groundfish section in the Marine Ecosystems and Aquaculture Division (MEAD). Notifications of the science review and conditions for participation were sent to representatives with relevant expertise from academia, independent governmental fisheries agencies, the commercial and recreational fishing sectors, First Nations, and environmental non-governmental organizations.

Background information was prepared and made available to meeting participants prior to the meeting

The meeting Chair, Lesley MacDougall, introduced Rowan Haigh as Co-Chair, welcomed participants, reviewed the role of CSAS in the provision of peer-reviewed advice, and gave a general overview of the CSAS process. The Chair discussed the role of participants, the purpose of the sole RPR publication (Proceedings), and the definition and process around achieving consensus decisions and advice. Everyone was invited to participate fully in the discussion and to contribute knowledge to the process, with the goal of delivering scientifically defensible conclusions and advice. It was confirmed with participants that all had received copies of the Terms of Reference, the background information, and numerous support documents.

The Chair reviewed the Terms of Reference (Appendix A) and the Agenda (Appendix B) for the meeting, highlighting the objectives and identifying the rapporteur, Lisa Lacko. The Chair then reviewed the ground rules and process for exchange, reminding participants that the meeting provided an opportunity for participants to provide feedback on the proposed framework.

Members were reminded that everyone at the meeting had equal standing as participants and that they were expected to contribute to the review process if they had information or questions relevant to the materials being discussed. In total, 26 people participated in the RPR (Appendix D).

REVIEW

Background: “Background information for a review of international best practices to assigning species to tiers for the purposes of stock assessment based on data availability and richness” (Appendix C) by Kate Rutherford

Rapporteur: Lisa Lacko

Presentations: Eight presentations were given over two days followed by discussion.

1. Why Do We Need a Tiered Approach? – Greg Workman (DFO)
2. Literature Review – Kate Rutherford (DFO)
3. The Alaskan Experience With Implementing a Tiered Approach – Jim Ianelli (NOAA)
4. DLMtool: Evaluating Performance of Data-Limited Assessment Methods – Tom Carruthers (UBC)
5. Workplan Review – Elements and Timelines – Lynne Yamanaka (DFO)

6. Candidate Data Scorecard – Jackie King (DFO)
7. Candidate Trees and Tiers – Robyn Forrest (DFO)
8. Introduction to Simulation Testing – Robyn Forrest and Andrew Edwards (DFO)

The presentations are summarized in the next section with discussion notes following each presentation. A more general summary on the major themes appears in the General Discussion section.

PRESENTATIONS

WHY DO WE NEED A TIERED APPROACH?

In a TA framework, a tier is defined as a level of classification that depends upon the availability and quality of the data for a given fish stock. The tier then determines the most appropriate stock assessment method and type of management advice for the stock. A TA framework in Canada should be aligned with best practices in other jurisdictions and be tailored to the Canadian context. It will formalize the type of assessment to be done for individual fish stocks, which will support the provision of scientific advice to fisheries managers in the contexts of conservation (sustainable harvest, Species at Risk) and eco-certification (e.g., Marine Stewardship Council).

The first presentation outlined DFO policy and legislative responsibilities, including the Sustainable Fisheries Framework (SFF) and the Species at Risk Act (SARA), and the importance of understanding the impact of various fisheries on BC marine ecosystems. The need for a TA framework from a fishery perspective was also identified and included goals such as resource stewardship, marine eco-certification, and timely stock assessment advice. Challenges currently experienced in conducting stock assessments were identified. The TA concept was defined and the objectives and expected benefits were outlined.

Discussion on this presentation focused on process. It was noted that groundfish has been following an assessment schedule for 10 years and that some process of decision-making has been applied to address data-limited species, specifically those without age data. The response was that Science is increasingly expected to provide advice for species with limited data, and that is why the TA framework is being proposed. A particular problem was species lacking adequate ageing data for statistical catch age models to be applied. It was also noted that even when ageing data are available, the data quality can be variable – e.g., the ages are imprecise and/or biased, there are too few samples to be informative, or the data provide no cohort signal. There was a question regarding whether private ageing labs could provide assistance with respect to ageing archived otoliths, but none were identified.

LITERATURE REVIEW

The second presentation highlighted the major points from the background document distributed to all participants prior to the meeting (Appendix C). The TA frameworks of four jurisdictions – Australia, the European Union (EU), New Zealand, and the United States of America (USA) – were reviewed. Their policies/legislation, tiers, harvest control rules (HCRs), and implementation were summarized. The review found several jurisdictions had implemented TA systems before the TA methods had been simulation tested due to time constraints. However, all jurisdictions identified simulation testing of methods as an important component of TA implementation. The review also highlighted the need for flexibility in the TA framework, to ensure that all fisheries are managed using an acceptable level of risk. Participants discussed the importance of ensuring that management procedures (MPs) are consistent with DFO Precautionary Approach principles.

Following the presentation, discussion focused on how a fish stock might move from one tier to another. Movement from a data-poor to a data-rich tier would likely require further collection of data. It was noted that there may be some occasions requiring a stock be moved to a more data-limited tier (e.g., Shortspine Thornyhead in Alaska was demoted when the age data were deemed “unreliable”), which was considered a less preferable outcome than improving the data available for a stock. There was also discussion regarding the frequency with which tiers should be reviewed. Advice from the International Council for the Exploration of the Sea (ICES) recommends every five years. In Alaska, a committee reviews the tier placement of all stocks every year. Simulation testing was proposed as the most appropriate means of testing the performance of alternative methods with respect to meeting objectives. Discussion points also included that the rules used to define tiers and evaluate data need to be made clear. A recommendation was made to include simulation testing of the proposed rules and criteria as well.

THE ALASKAN EXPERIENCE WITH IMPLEMENTING A TIERED APPROACH

The third presentation summarized the development and evolution of a TA framework for Alaskan federal fisheries, which are managed through the North Pacific Fishery Management Council (NPFMC). Fishery management plans refer to total allowable catch (TAC), acceptable biological catch (ABC) and overfishing level (OFL). Within the TA framework there are six tiers, defined by the following criteria:

- Tier 1 – reliable point estimates of B and B_{MSY} and reliable probability density function (pdf) of F_{MSY};
- Tier 2 – reliable point estimates of B, B_{MSY}, F_{MSY}, $F_{35\%}$, and $F_{40\%}$ (this tier is no longer used);
- Tier 3 – reliable point estimates of B, $B_{40\%}$, $F_{35\%}$, and $F_{40\%}$;
- Tier 4 – reliable point estimates of B, $F_{35\%}$, $F_{40\%}$, F_{OFL}=$F_{35\%}$;
- Tier 5 – reliable point estimates of survey biomass B and natural mortality rate M, survey trends fitted using a random-effects model;
- Tier 6 – reliable catch history from 1978 through 1995.

The tiers determine which stock assessment method is used for setting catch limits. The NPFMC’s Scientific and Statistical Committee (SSC) meets annually and makes decisions on the tier status of each stock, depending on the variance in estimates of the parameters shown above. The SSC’s determination may differ from the tier recommended by the stock assessment author.

Discussion after several of the presentations included the potential need for precautionary buffers in catch advice (i.e., reducing recommended fishing mortality or catch by *x*%), as implemented in Alaskan, Australian and ICES fisheries. Buffers are designed to buffer against uncertainty in more data-limited tiers, with the intention of evening out the risk of overfishing among data-rich and data-limited species. Participants also discussed trade-offs associated with assessments conducted in data-rich vs. data-poor tiers (e.g., requests for advice vs. capacity to provide advice; quality of advice vs. quantity of advice), and how to prioritize assessments. These topics are reviewed more fully in the General Discussion section.

DLMTOOL: EVALUATING PERFORMANCE OF DATA-LIMITED ASSESSMENT METHODS

The fourth presentation reviewed an R package called "DLMtool", where DLM stands for Data-Limited Methods. The DLMtool project, is a collaboration between UBC's Institute for the Oceans and Fisheries and the Natural Resources Defense Council (a non-profit international environmental advocacy group) (Carruthers and Hordyk 2016; Carruthers et al., 2014, 2015). The toolkit offers a powerful, transparent approach to selecting and applying various data-limited management procedures (MPs). It uses Management Strategy Evaluation (MSE), closed-loop simulation and parallel computing to make powerful diagnostics accessible. A streamlined command structure and operating model builder allow for rapid simulation testing and graphing of results.

DLMtool includes over 60 MPs (e.g., DCAC [depletion-corrected average catch], DBSRA [depletion-based stock reduction analysis]), and can incorporate the development and testing of new MPs. The package is structured so that the same MP functions tested by the MSE can also be applied to provide management (i.e., catch-limit) recommendations from real data.

DLMtool has been used for setting catch-limits by the Mid-Atlantic Fishery Management Council (USA) and is being used to test MPs in California state fisheries (California Department of Fish and Wildlife) and in the Caribbean (NOAA). It is also being reviewed for utility in seafood certification processes by the Marine Stewardship Council (MSC).

DFO Science recognised that the use of a tool such as DLMtool could greatly streamline exploration of multiple data-limited methods for Canadian fisheries and could also be useful for generating catch advice, as in some US fisheries. It was acknowledged, however, that DLMtool would require extensive further testing, customization and sensitivity analyses before implementation. This would require the creation of an advisory panel to ensure scientific rigour, and that the metrics used to measure the performance of alternative assessment methods are consistent with the Canadian Sustainable Fisheries Framework and economic fishery objectives. Further discussion reinforced the recognition that not all Pacific region groundfish stocks would be considered data-limited, and other Management Strategy Evaluation tools such as those being used for Pacific Herring or Sablefish (e.g., Cox et al., 2013; 2015[1]) would likely be more appropriate for simulation-testing of data-rich assessment methods such as statistical catch-age models.

It was noted that a current limitation of DLMtool and the proposed TA framework is that only one species/stock at a time can be assessed. That is, both methods cannot, at present, take into account multispecies interactions that characterize most of BC's groundfish fisheries. One suggestion for assessing a complex of species that are generally caught together was to choose the most vulnerable species for analysis.

A recurring discussion point was that the level of data-richness is not necessarily the most informative metric to identify the most appropriate assessment method. Two alternative approaches were discussed: (1) tier according to data-richness, then apply data-limited methods accordingly (as applied in Australia, ICES and Alaska); or (2) use a closed-loop simulation method to determine the most appropriate assessment method for each stock based

[1] Cox, S.P., Benson, A.J., Cleary, J.S. 2015. Candidate limit reference points as a basis for choosing among alternative harvest control rules for Pacific herring (*Clupea pallasi*) in British Columbia. CSAS Working Paper 2013PEL01. In revision.

on performance with respect to meeting management objectives. DLMtool provides an efficient, customizable means to screen multiple data-limited stock assessment methods and identify those that best meet conservation and economic objectives. These two approaches are explored in the General Discussion section.

A distinction was made between Management Strategy Evaluation (MSE), which involves full stakeholder engagement for provision of input on fishery objectives, model design, management procedures and performance metrics; and closed-loop simulation, which is the scientific sub-component of MSE that applies only the simulation modelling component of MSE[2]. It was noted that some applications of DLMtool have been stand-alone closed-loop simulation exercises for the purposes of scientific research. DLMtool has also been used in real-life MSE, with full stakeholder engagement (e.g., California Department of Fish and Wildlife).

WORKPLAN REVIEW – ELEMENTS AND TIMELINES

The fifth presentation outlined the timeline and deliverables for the TA framework project. Notable milestones include:

GIAB presentation	Jun 16, 2016
Select TA and tools	Mar 2017
Research document	May 2017
Place species in tiers	Aug 2017

Also described was the proposed planning initiative by the Commercial Industry Caucus (CIC): “Multi-species Management System for Rockfish.” This CIC initiative is a collaborative project with Landmark Fisheries Research (Burnaby, BC) that will have some overlapping themes with the groundfish TA project.

The limitations of the proposed TA approach with respect to addressing multispecies considerations was raised again, and it was noted that links between the TA project and the CIC project may help develop methods to incorporate multispecies issues. The draw of the simulation work on DFO Science staff’s time was raised as a concern. The long-term intent of the proposed TA approach – to work more efficiently and deliver more stock assessments – was reiterated. There was some concern expressed that the Technical Working Group would not include expertise from outside Science; however, it was emphasized that the proposed study would not be a complete MSE, which involves all groups interested in the fishery, but a closed-loop simulation study only.

CANDIDATE DATA SCORECARD

The sixth presentation outlined the details of a scorecard proposed to determine a species’ place within the candidate tiers (Appendix E). Various gradients – information available, assessment complexity, uncertainty in advice, precautionary buffer – were presented to visualize how tier-specific harvest control rules and reference points might arise. As a starting point, data availability are categorised across multiple data descriptions within four main data

[2] Closed-loop simulation is an approach borrowed in fisheries research from engineering, where all components and dynamics of a fish population and fishery are simulated in an “operating model”. Alternative stock assessment methods and management procedures are tested on this simulated system to identify best performing procedures with respect to management objectives and risk tolerances.

sources (commercial, recreational, First Nations' food/social/ceremonial, and fishery-independent) to determine whether a species is data-rich, data-moderate, or data-poor in each sector. This initial categorization could then feed into a decision tree to determine the appropriate tier category. The presenter requested feedback regarding what other data sources might be included in the scorecard.

Discussion included consideration regarding how data quality is assessed between or within each of the main data sources. It was considered unlikely that data quality assessment could become completely automated; it would require expert judgment. The example of Arrowtooth Flounder was illustrated; there is an abundance of age data available for Arrowtooth Flounder, but no cohort signal, thus statistical catch-age (SCA) models are not well informed using these data. Addition of new data-limited stock assessment methods may provide the opportunity for analysts to consider new data and method combinations that are more appropriate for the types and amount of data available for a given species. No additional data sources were identified by the RPR participants.

CANDIDATE TREES AND TIERS

The seventh presentation introduced basic principles associated with current stock assessment practices in DFO, including: (i) compliance with the Precautionary Approach (PA), (ii) model output that provides biomass estimates and uncertainty with respect to PA-compliant reference points (e.g., $0.8B_{\mathrm{MSY}}$ and $0.4B_{\mathrm{MSY}}$ for provisional upper stock reference and limit reference points, respectively), and (iii) the need to provide catch advice for all species with a TAC. To ensure that any stock assessment method will generate advice that is compliant with the PA policy, it needs to be supported by available data, be robust to uncertainty, meet management objectives, and produce acceptable trade-offs between competing objectives (e.g., conservation vs. fishing opportunities). Risk of over-fishing, in particular, should not increase if catch advice is based on more data-limited methods. Two methods that have been applied to balance risk among tiers are: (i) apply precautionary caps and/or buffers to catch advice provided in more data-limited tiers; or (ii) use closed-loop simulation modelling to select management procedures that produce catch advice that satisfies pre-identified risk thresholds. The former approach is used in tiered approaches implemented for federal Alaskan, ICES and federal Australian fisheries. The latter approach can be implemented in tools such as DLMtool.

Candidate tiers and decision trees, based on those used by ICES, were introduced to provide an example of implementation of a TA framework. In this example, data quality and quantity information collected in data scorecards and by expert judgment, was used to assign species to three high level categories (data-rich, data-moderate, and data poor) in a decision tree. Within each category, further decision nodes could be used to assign species into tiers that define the most appropriate PA-compliant stock assessment method for the available data (Figure 1).

The example given for BC groundfish was based on data availability and quality:

Tier 1 **Data**: Informative, reliable survey, age-composition, length-composition, catch, releases and biological data.
Method: Statistical catch-age models.

Tier 2 **Data**: Informative, reliable survey, length-composition, catch, releases and biological data. Statistical assessment model possible.
Method: Statistical delay-difference or surplus production models.

Tier 3 **Data:** Reliable survey, catch, releases and biological data – statistical assessment model not possible.
Method: Survey-based methods.

Tier 4 **Data:** Reliable catch, releases and biological data.
Method: Catch-based methods.

Tier 5 **Data:** Very little data.
Method: Life-history or other data-limited methods.

During discussion, participants expressed opinions that it was not desirable to apply precautionary buffers to catch advice for BC groundfish, although precautionary buffers had been implemented in other jurisdictions. The discussion returned to the two alternative approaches for accounting for risk in determining catch advice for data-limited species, i.e., let the data decide the method and use buffers for data-limited methods vs. using closed-loop simulation to select the method based on meeting objectives and pre-defined risk thresholds. In order to better characterize risk, closed-loop simulations used in this context should include a range of scenarios that try to adequately capture the major uncertainties in the fish stock-fishery-management system.

During discussion, it was noted that several other jurisdictions rely on assessment of data "reliability" in assigning fish stocks to tiers, and that assessment of reliability may be subjective. There was acknowledgement that data "reliability" may depend on the particular assessment method being used. For example, catch data for a rarely caught species may be reliable as a measure of total catch by a fishery, but may not be sufficiently reliable for parameter-estimation in a statistical stock assessment model. Similarly, a survey index may be reliable in spatial analysis of fishing grounds, but if the index series shows no trend, it may not contain any information about the productivity of the fish population.

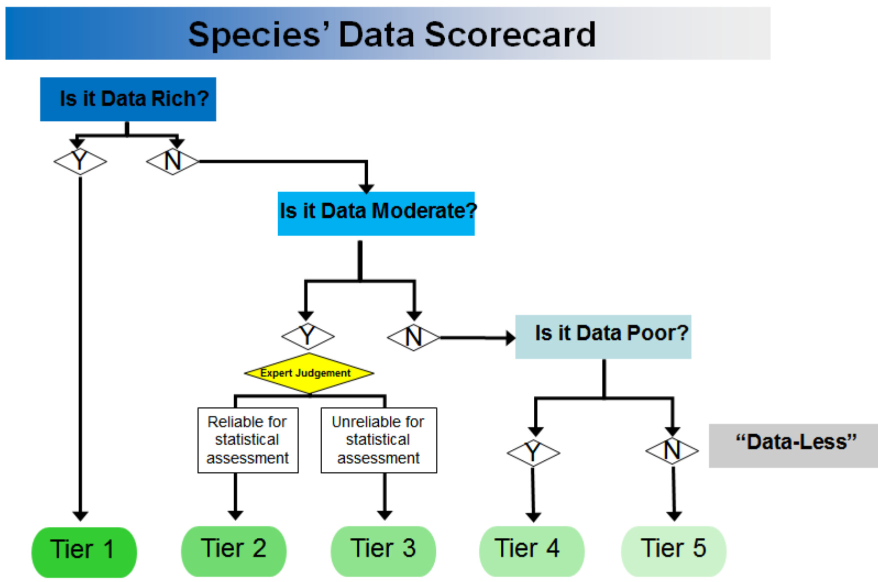

Figure 1. Flow of decisions from species data to candidate tiers.

INTRODUCTION TO SIMULATION TESTING (DAY 2, 9:05 AM)

The eighth and final presentation introduced simulation testing and some proposals for further exploration. As outlined in previous presentations, the quality and quantity of information available for each fish stock will determine the general type of assessment method – e.g., statistical stock assessment models (with decision tables) vs. alternative data-limited methods. The method could be determined directly from the available data (e.g., Figure 1), or using closed-loop simulation as mentioned in the previous section.

Two potential closed-loop simulation tools were identified – “mseR” (developed at Simon Fraser University and the Pacific Biological Station and used in Pacific groundfish and herring applications) and “DLMtool” (an open source R package, developed at the University of British Columbia and recently applied in a number of US fisheries). Three example sets of objectives and metrics were presented as examples for consideration (objectives used in the BC Sablefish Management Strategy Evaluation; a subset of objectives currently built into DLMtool, and a set of objectives used in the Pacific Halibut Management Strategy Evaluation). The Sablefish objectives were proposed as a starting point for any closed-loop simulations in the present TA application. Further advice regarding other objectives and performance metrics was invited.

The presenter noted that the type of advice arising from most data-rich stock assessments (e.g., statistical catch-age models) provides information about stock status and the probability of the stock breaching the limit reference point over a pre-specified period of time (i.e., probability of the stock falling into the “Critical Zone” under Canada’s Precautionary Approach). Many data-limited assessment methods (e.g., adjusting catch proportional to changes in the survey index) do not provide any information about stock status. For this reason, several other jurisdictions (ICES, Australian and federal Alaskan fisheries) apply precautionary buffers to catch advice generated from data-limited methods, to buffer against uncertainty in stock status. The presenter noted that an advantage of selecting stock assessment methods based on closed-loop simulations was that the closed-loop simulation framework could output the probability of a data-limited assessment method resulting in breached limit reference points, even if the method does not itself produce stock status estimates. This is because the operating model keeps track of the “true” stock status during the simulation period, thus allowing risk metrics to be calculated. This would avoid the requirement to add a precautionary buffer, because uncertainty is already accounted for. One participant noted that the Marine Stewardship Council is considering accepting stock assessment advice that does not provide stock status, as long as the stock has been shown to have an acceptable probability of being healthy using closed-loop simulation.

There was discussion of some proposed simulation approaches that could be used in the next phase of TA development:

1. testing the consistency of stock status assessment advice produced by each Tier, using real data from one or more Tier-1, “data-rich” species (e.g., Pacific Ocean Perch);
2. testing for potential biases in stock assessment advice from each Tier, using simulated data from an Operating Model where “true” parameter values and stock status are known;
3. closed-loop simulation to evaluate the efficacy of management strategies based on Tier-specific advice, in terms of meeting short- and long-term fishery objectives.

There was also a suggestion that multi-species closed-loop simulation testing could be attempted for some high priority species that are caught in a complex.

Concern regarding simulating the population dynamics of data-poor species was raised; specifically how analysts would be able to test performance of alternative management procedures when, by definition, little was known about the species. This concern was addressed by noting that the simulated population model would be developed using known parameters (from the literature or using DFO’s biological data), and with appropriate uncertainty applied to each parameter.

There was some discussion of whether closed-loop simulation would be used to test the performance of individual assessment methods or whether it would be used to test the whole TA framework, including the decision tree assigning species into tiers. It was suggested that the latter approach was not practical at present and that simulation testing would be done for individual assessment methods.

Discussion regarding testing performance of stock assessment methods in a multispecies context outlined the importance of eventually providing advice for an industry that functions in a multispecies environment with sometimes conflicting goals (e.g. targeted vs. avoidance fishing). It was recognized that a first step would be addressing single species data issues, and that multispecies simulation testing was currently beyond the scope of this project.

There was discussion of testing the consistency of stock status assessment advice produced by each tier (option 1 above). Essentially, under the decision tree approach (Figure 1), a data-rich stock would be assessed at each tier – sequentially using fewer data at each tier and applying sequentially more data-limited methods. One participant noted that this has been tried in the USA with little resolution because, ultimately, analysts could not know which model result most truly represented the population. It was pointed out that data-poor assessment methods would not necessarily produce more biased advice just because they used fewer or different data, and it is not possible to know which methods are likely to produce the least biased advice without simulation testing. The USA group also found that results could vary depending on the stock status (e.g., whether the stock was increasing, decreasing or stable). A suggestion was made to try the exercise using Pacific Ocean Perch (considered a relatively healthy stock) and Bocaccio (designated by COSEWIC as “Endangered”). However, there was disagreement about whether this would be a useful exercise given the above concerns.

A representative from the DFO salmon science group gave a short talk on a framework used for assessing the hundreds of salmon stocks in BC. The framework uses a risk-based approach for prioritizing allocation of resources. Stocks are assigned a risk score and a stock assessment intensity score. Areas can then be identified where high risk stocks have low stock assessment resources, and resources can be re-allocated accordingly. Overall, however, the salmon group is facing similar data limitations to those in groundfish. One RPR participant suggested that groundfish scientists might wish to work more closely with salmon scientists in the future, as they already have a process in place.

The issue of stock assessment prioritization arose. The idea that a TA framework should include some mechanism for dealing with priority was not universally recognized by the RPR participants; however, the issue is discussed more fully in the General Discussion.

GENERAL DISCUSSION

TIERING

As a number of other significant fisheries jurisdictions (Australia, the European Union, New Zealand, USA) had already completed tiering exercises, these provided potential templates for the design proposed by DFO Pacific Region Groundfish Science. In particular, the ICES framework (applied to EU fisheries) provided the most detail on design and implementation of a tiered decision-making framework.

At the onset of the TA project, the Groundfish Science group had proposed identifying and testing a suite of data-limited methods for Tiers 3 through 5, following a decision tree such as that shown in Figure 1. During development of the Tiered Approach, an R package for simulation-testing data-limited assessment methods was identified that included 60+ pre-programmed operating models and management procedures for data-limited fish stocks (www.datalimitedtoolkit.org). This R package, called DLMtool, has been peer-reviewed and tested in other fisheries jurisdictions, including federal US fisheries in the Caribbean and in California state fisheries. Customization and application of this software for Canadian fisheries could significantly increase the efficiency of identifying appropriate data-limited assessment methods for BC groundfish stocks.

During the discussion, it was determined that DLMtool could evaluate performance of all candidate stock assessment methods suitable to the data available in Tiers 3-5 simultaneously (Figure 1). Some consideration was given to amalgamating Tiers 3-5 into one 'data limited' tier for analysis by DLMtool. However, the identification of appropriate assessment methods for data-limited species was considered only one benefit of the tiering exercise. The TA process was initiated as a framework to systematically evaluate data quality and availability, to standardize how catch decisions are made with respect to appropriate assessment methods, and to provide long-term planning, especially with respect to improving data quality for priority stocks. Amalgamation of Tiers 3-5 would remove valuable information regarding the data available for each stock; this information is needed for prioritizing data-improvement initiatives. The TA framework is also intended to act as a communications tool to clients, e.g., the groundfish managers. Participants agreed to retain the five tiers as a communication tool even if DFO Groundfish Science chooses to use a closed-loop simulation approach (e.g., DLMtool) to select the most appropriate assessment method for each stock based on performance with respect to meeting management objectives (rather than determining the assessment approach based only on the available data). It was also agreed that in the near-term, the tool mseR might be more appropriate for Tiers 1 and 2.

PRIORITIZATION

In response to several requests for inclusion of prioritization in the TA framework, it was noted that there is a priority schedule in place already, which has been developed in consultation with Fisheries Management, and is based on recurring advice needed for major stocks, SARA-listed species, and stocks not recently assessed but needing advice. This schedule was followed for a number of years but adherence to the schedule has become difficult due to reductions in personnel capacity and several assessments providing problematic advice due to inadequate information in available data. The reduced ability to meet the priority schedule was one factor leading to the decision to develop a TA framework.

In essence, the TA framework should communicate to managers what assessment methods are most appropriate for any given species given data availability and quality; and from those assessment methods what kind of advice is possible. One participant suggested that we could add assessment frequency to the framework. For example, if the species appeared in Tier 1, then Science could possibly assess it every 5 years, for argument's sake. If the species occurred in Tier 3, then the frequency may need to be shorter to ensure that changes in information (e.g., declining index) are dealt with in a timely manner. Assessment frequencies could also depend on the species, potentially with respect to variation in longevity. These types of information could then inform a prioritized assessment schedule.

It was recognized that the task of prioritization cannot be borne solely by the managers but must be developed in collaboration with Science, Industry, First Nations and other interested parties. One participant suggested that perceived priorities could be communicated using a priority matrix that links the resources available for assessment and some metric that captures priority (e.g., perceived risk to the population or economic importance). This is similar to the framework described above for Pacific salmon. For example, this could be represented as a matrix with two or more rows and two or more columns, where rows indicate the resources available for assessment (e.g., data, financial or human resources), and columns indicate priorities, e.g., 1 = high priority and 2 =low priority. The "resources" could then be used to characterise what kind of assessment is available for that stock, given data and capacity considerations.

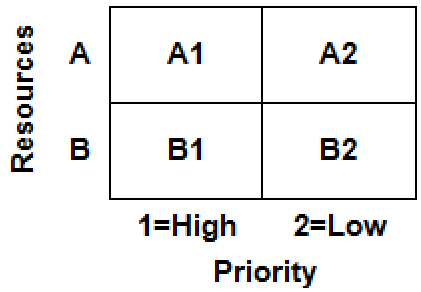

Figure 2. Sample priority matrix.

There was uncertainty regarding whether the matrix as presented would be useful as a prioritization system, but the alpha-numeric classification assigned to a species was acknowledged as a potential way to communicate to any single user group the priority that the other groups place on that species. It was noted by several participants that economic importance does not necessarily imply that the species is valuable. Economic importance could be assigned to low quota species that restrict the ability of the fishery to realise the full quota of other species due to co-occurrence in the catch. Similarly, some unassessed species may be impeding sustainable seafood certification (e.g., by the Marine Stewardship Council), and are thus restricting important national and international market access.

Priorities clearly varied among participants during the workshop. While many may have given a high priority to obvious candidate stocks, based on economic value or catch magnitude, one participant thought that more data-limited stocks should be given high priority because there is no current science advice for these. Priorities also come from other sources like program planning, special projects (e.g., genetics), and schedules for species classified under the Species at Risk Act. One participant noted that Alaskan federal fisheries use a formalized 12-factor scorecard for prioritization which covers four general categories: fishery concerns, stock health, ecosystem role, and management concerns. A number of RPR participants suggested something similar would be useful for BC groundfish, and that developing such a prioritization scorecard would be a valuable, and perhaps necessary exercise.

MOVING BETWEEN TIERS

There was concern that species assigned to the most data-limited tiers could potentially have an impact on eco-certification, which fostered the impression that it is undesirable for stocks to be in the most data-limited tiers. However, one participant re-iterated that agencies like the Marine Stewardship Council are more open to accepting closed-loop simulation results in the process of eco-certification when they are accompanied by acceptable risk metrics. In these cases, the penalty for remaining in lower tiers may be low or non-existent.

A question was raised pertaining to the development of target fisheries for stocks in the lowest tier (i.e., non-quota species with very limited data). If a stock is brought under quota management then catch advice becomes mandatory. However, according to Figure 1, candidate Tiers 1-4 should all produce catch advice. Therefore only Tier 5 species would require additional data to move up in the tier structure.

It was suggested that once a stock has been assigned a particular stock assessment method, it is unlikely that the stock would be reassigned to a more data-limited tier, except in exceptional cases where, for example, data are discovered to be unreliable (e.g., Alaska Shortspine Thornyhead age data), or because data collection ceases. Alternatively, a species in Tier 1 could potentially be assessed using methods from any tier depending on the client request, the priority, and/or the objective (i.e., a data-rich species could be assessed using a method that does not require all of the types of data available for that species). However, this might only be possible if it can be shown that performance with respect to meeting management objectives does not deteriorate with more data-limited assessment methods (see Uncertainty below).

All of the above scenarios suggest that tier status, or chosen stock assessment method, should be reviewed periodically. The EU Framework specifies a five-year cycle, while tiers in Alaskan federal fisheries are reviewed annually. A tier status update could be stock-dependent or initiated according to need. The RPR group came to no consensus on tier status update schedules for BC groundfish stocks (nor was it requested). There was consensus that whatever process is used for reviewing tiers, it would need to be a CSAP process.

TRADE-OFFS

The concept of trade-offs in a prioritization context stems from the identification of the advice that **can** be provided (Science) vs. the advice that is **desired** (clients). To some extent, this can be communicated through tools like the priority matrix (above), a priority scorecard (NOAA), the framework described for Pacific salmon, or a more formal priority-setting exercise that involves multiple stakeholders and First Nations.

Some trade-offs occur from decisions that need to be made at the client level, e.g., allocating resources to a larger number of data-moderate or data-poor assessments vs. a smaller number of data-rich assessments. This decision should be approached with caution, as the resources required to develop species stock assessments in Tiers 1 and 2 are often very similar, and until appropriate methods are identified for data-limited stocks, it is unknown whether there will be a marked reduction in resources required to complete lower tier assessments.

There was discussion regarding whether data-rich assessments are invariably more reliable than data-poor assessments. Both methods can yield potentially biased and/or imprecise measures of species population metrics. Trade-offs between simpler, faster methods with results that are potentially easier to interpret vs. more complex assessment methods that presumably characterize uncertainties and levels of risk more completely were considered. Specifically, complex methods such as Statistical Catch-Age models generally deliver decision tables with probabilities that allow a manager to select catch levels that satisfy their risk requirements, while some data-limited methods may deliver a single catch value.

Discussion regarding the selection of performance metrics identified the need for performance metrics to capture trade-offs between differing objectives (e.g., conservation vs. catch opportunity). Simulation results presented to the group comparing performance of MSY-based reference points vs. an alternative type of reference based on estimated historical biomass illustrated a case where the former provided higher, more sustainable catches but potentially compromised the stock (leaving it in the DFO Cautious Zone), while the latter resulted in the stock being in the Healthy Zone with high probability but provided significantly lower catch than could have been taken sustainably. The trade-off is partly related to values, which means that performance metrics need to represent the objectives of multiple stakeholders and First Nations.

UNCERTAINTY

One common principle associated with tiered approaches in other jurisdictions was that, as data become less abundant, advice should become more precautionary. For data-rich stocks, most statistical stock assessments provide decision tables that account for modelled uncertainty, and therefore, there is no need for additional precautionary buffers. For data-limited stocks, however, several jurisdictions apply precautionary buffers (e.g., percentage reductions, uncertainty caps) to catch advice from more data-limited tiers, with increasing penalties at lower tiers (as data become more limited). RPR participants acknowledged that a TA should have a consistent approach to risk across tiers, i.e., more data-limited advice should be more precautionary and there should not be any incentives to move species to a more data-limited tier in order to gain more catch. However, most participants disagreed with the application of arbitrary precautionary buffers for BC groundfish stocks. It was noted that closed-loop simulation (e.g., mseR, DLMtool) would allow analysts to select the assessment method for each stock that best meets management objectives within desired risk thresholds. The RPR participants largely accepted this view.

The RPR group's discussion on simulation testing using sequential data removal and stock status evaluation at successively lower tiers suggested that using a specific example species (e.g. Pacific Ocean Perch, Bocaccio) would yield results only applicable to the species being tested and would not be transferrable to other unrelated species. Additionally, the level of depletion of the species and its depletion trajectory could have a significant influence on how advice would vary among assessment methods. There were concerns that this exercise may be time-consuming and potentially uninformative; however, Dr. Carruthers suggested it would be straightforward to develop a routine in DLMtool by which the influence of depletion could be gauged, if this were a desired analysis.

CONCLUSIONS

The workshop presented existing "Tiered Approaches" from four international jurisdictions, and compared the supporting data requirements and expected outputs (including advice types). Additionally, the federal Alaskan experience was presented by a NOAA representative. Lessons learned from other jurisdictions were reviewed and appreciated by RPR participants.

A candidate data scorecard was created for assessing data availability (quantity and quality) within four sectors – commercial, recreational, First Nations, and fishery-independent. The scorecard was presented and accepted as a means of classifying species as data-rich, data-moderate, or data-poor, and communicating this information.

A candidate five-tier system was presented as a tool to communicate data availability by species and determine the path forward for decision-making regarding stock assessment advice. Tier 1 (data-rich) would use statistical catch-age models and Tier 2 (data-moderate) would use statistical "delay-difference" and/or surplus production models. Tiers 3 (data-limited), 4 (data-poor), and 5 (data-less) would be amalgamated for analysis and use various data-limited methods, selected using closed-loop simulation methods. The most likely candidate for running the closed-loop simulations is DLMtool, which incorporates numerous peer-reviewed assessment methods. DFO Science staff agreed to conduct further scoping of DLMtool to determine its suitability in this context.

Candidate management objectives and performance metrics were presented using examples from Sablefish, Pacific Halibut, and those built into DLMtool. The RPR group were not able to select further performance metrics, and a recommendation was made to proceed with the examples from Sablefish as a starting point.

Participants endorsed the development of a technical working (advisory) group (TWG), and recommended that a work plan and timelines be developed to help determine the appropriate membership for the TWG. It is expected that the TWG will assist with the completion of the decision tree, management objectives, performance metrics, simulation exercises, and evaluation, all contributing to the second CSAS working paper to be reviewed in a subsequent CSAS regional peer review.

The workshop also established that the TA project would not be conducting a full management strategy evaluation (MSE) initially, but will apply closed-loop simulation testing of management procedures to test the robustness of various assessment methods against performance metrics. The RPR group acknowledged that stakeholders and First Nations make credible and valuable contributions to full MSE processes, but this procedure was beyond the scope of the current TA project. The RPR group also recognized that the TA project could not at this time incorporate important aspects such as the multispecies nature of the fisheries, ecosystem effects, or climate change effects.

RECOMMENDATIONS

From the discussions during the TA workshop, the RPR participants identified the following recommendations:

- Develop a terms of reference and workplan for an advisory group (technical working group, TWG), identify members of the TWG, and clarify each member's duties and expected participation. The short-term next steps for a TWG are:
    - Adopt the candidate Tiers 1-5 for communication of data availability to clients but amalgamate Tiers 3-5 for analysis and simulations.
    - Design the simulation testing appropriate for each tier.
    - Do not use precautionary buffers and caps. Account for risk and uncertainty either within the stock assessment outputs (Tiers 1-2) or when using closed-loop simulation to select an assessment method (Tiers 3-5).
    - Use the data scorecard as presented in the workshop to summarise data needed for simulations and to communicate data availability.
    - Identify management objectives and performance metrics to measure performance of alternative assessment methods.
    - Articulate the methods by which species are placed in tiers.
    - Scope DLMtool and customise for Canadian groundfish fisheries, if needed.
    - Examine types of data available in more detail.
    - Examine processes by which a species moves up or down tiers.
- Write code for DLMtool to test the sensitivity of data-stripping and performance of alternative assessment methods for stocks with different abundance trends.
- Develop a prioritization scorecard that takes into account the factors important to the BC groundfish sector.
- Develop a schedule for reviewing the placement of species within the TA framework.
- Collaborate with the CIC-led advisory process: Multi-species Management Systems.

ACKNOWLEDGEMENTS

We greatly appreciate the time contributed to the RPR process by all participants. We are especially grateful for the invaluable insight and experience provided by Dr. Jim Ianelli (NOAA, Seattle) on the federal Alaskan experience with tiered approaches and Dr. Tom Carruthers (UBC, Vancouver) on the DLMtool package. We also thank Linnea Flostrand for helpful contributions during Chair discussions, Lisa Lacko for her diligent rapporteur skills, and Ann Mariscak for her logistical support.

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APPENDIX A. TERMS OF REFERENCE

A Review of International Best Practices to Assigning Groundfish Species to Tiers for the Purposes of Stock Assessment Based on Data Availability and Richness

Regional Peer Review Process - Pacific Region

May 30-31, 2016
Nanaimo, British Columbia

Co-chairs: Lesley MacDougall and Rowan Haigh

Context

An understanding of the status of species affected by a given fishery is required to support the implementation of the Sustainable Fisheries Framework and to sustainably manage the aboriginal, commercial, and recreational multi-species groundfish fisheries. Many of the species for which stock assessments are planned will be assessed for the first time, with little data available to support traditional assessment methods. Stock status advice is also required to demonstrate stewardship and meet eco-certification requirements.

In order to meet the high demand for species assessments within timeframes acceptable to managers and stakeholders, a framework for determining the assessment methodology to be applied for each species would streamline the assessment process and more efficiently use science resources. There is also a desire to achieve a degree of standardization in approaches to developing and communicating advice to stakeholders and, where possible, align stock assessments with best practices in other jurisdictions.

In other global jurisdictions, a “Tiered Approach” framework for determining the type of assessment method used for a given species or stock and science advice to be expected has been developed and utilized. These approaches classify species into tiers based on data availability, quality and richness. Membership in a tier determines the most appropriate type of assessment and management advice for the species.

Fisheries and Oceans Canada (DFO) Groundfish Science is developing a tiered approach to assign assessment types for species to tiers based on data availability, quality and richness. This tiered approach may subsequently be applied to provide advice on stock status and harvest advice for British Columbia (BC) groundfish species. It could formalize the type of assessment to be done for individual species, which will support the provision of scientific advice to fisheries managers in the contexts of conservation (sustainable Total Allowable Catches, COSEWIC, *Species at Risk Act*) and eco-certification (e.g. Marine Sustainability Certification). The development of a tiered approach for the assessment of BC groundfish will occur in three stages: (1) match data availability and quality with the appropriate types of assessment methodologies available, (2) evaluate the performance of the proposed tiered approach through simulation testing, and (3) finalize and document a tiered approach for implementation in the BC groundfish fishery.

In support of stages one and two, this Canadian Science Advisory Secretariat, Regional Peer Review will be conducted in a workshop format, where participants are asked to contribute to reviewing the “Tiered Approaches” used in other jurisdictions and developing a suite of candidate tiers for BC groundfish that will subsequently be evaluated through simulation testing (stage two). The results of the simulation testing will be used to finalize and document the tiering criteria and methods, and to develop software tools, to be used to assign BC groundfish to assessment tiers. A CSAS Regional Peer Review will be conducted for this final work.

Objectives

The objectives of this workshop are to:

1. Present existing "Tiered Approaches" from select international jurisdictions, and compare the supporting data requirements, expected outputs (including advice types) and lessons learned;
2. Examine the types of data available for BC groundfish species, with the appropriate methods to assess data quality and richness, and the appropriate methods to incorporate and communicate uncertainty;
3. Develop a set of candidate tiers for BC groundfish species for further consideration, specifying data requirements and the assessment approach for each tier; and
4. Recommend candidate metrics to evaluate the performance of the proposed tiered approach through simulation testing.

Expected Publication

- Proceedings

Expected Participation

- DFO (Science Branch, Fisheries Management Branch)
- Commercial and recreational fishing interests
- First Nations
- Non-government organizations
- Academia

APPENDIX B. AGENDA

Regional Peer Review Meeting (RPR)

Canadian Science Advisory Secretariat
Centre for Science Advice Pacific

A Review of International Best Practices to Assigning Species to Tiers for the Purposes of Stock Assessment Based on Data Availability and Richness

May 30-31, 2016

Pacific Biological Station, Seminar A & B
Chair: Lesley MacDougall / Rowan Haigh

DAY 1 – Monday May 30, 2016

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping CSAS Overview and Procedures	Chairs
0915	Review Terms of Reference	Chairs
0920	Why the Tiered Approach	Greg Workman Neil Davis
1015	***Break***	
1050	Literature Review – International examples	Kate Rutherford
1115	Implementation of a Tiered Approach in Alaska	Jim Ianelli
12:00	***Lunch Break***	
1300	DLMtool - Evaluating performance of data limited assessment methods	Tom Carruthers
1345	Workplan review – Elements and Timelines	Lynne Yamanaka Greg Workman
1415	Candidate Data Scorecard	Jackie King
1445	***Break***	
1500	Candidate Trees and Tiers	Robyn Forrest Chris Grandin
1615	Recap – what we've covered	RPR Participants
1630	Adjourn for the Day	

DAY 2 – Tuesday, May 31, 2016

Time	Subject	Presenter
0830	Introductions Review Agenda & Housekeeping Review Status of Day 1	Chairs
0900	Introduction to Simulation Testing	Robyn Forrest Andrew Edwards
1030	***Break***	
1100	Review of Candidate Trees - Feedback	Chris Grandin Robyn Forrest Jackie King RPR Participants
1200	***Lunch***	
1300	Feedback Discussion continued	RPR Participants
1400	Recap • Parking Lot • Agreed upon candidate tiers for testing	RPR Participants
1430	***Break***	
1445	Next Steps – Chair to review • Workplan • Next steps • Deliverables • Advisory Panel – representation from sectors	Chairs
1545	Other Business arising from the review	Chairs & Participants
1630	***Adjourn meeting***	

APPENDIX C. BACKGROUND INFORMATION

Background Information for

A Review of International Best Practices to Assigning Species to Tiers for the Purposes of Stock Assessment Based on Data Availability and Richness

Kate Rutherford

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Regional Peer Review Workshop

May 30-31, 2016

Nanaimo, BC

C.1. INTRODUCTION

Adoption of ecosystem-based fisheries management has been identified as a high priority in fishery management plans for British Columbia (BC) groundfish fisheries. An understanding of the status of all (or as many as possible) ecosystem components affected by a given fishery is required to (i) implement ecosystem-based fishery management, and (ii) to successfully and sustainably manage the multi-species groundfish individual transferable quota (ITQ) fishery. DFO and the fishing industry require stock status advice to demonstrate sound stewardship and to meet eco-certification requirements. Finally, there is a desire to achieve a degree of standardization in approaches to developing and communicating advice to stakeholders and, where possible, align stock assessments with best practices in other jurisdictions.

Groundfish Science is required to provide Science advice on the status of, or risk to, all species of groundfish impacted by fishing activities. Although there are only about 32 groundfish species managed under quota, there are a possible 200 species that could fall under the research mandate of Groundfish Science. DFO currently lacks capacity and informative data to produce the required stock assessments within timeframes acceptable to managers and stakeholders. Furthermore, some species (or stocks) are being formally assessed for the first time, and a formalised agreed-upon framework is desirable for determining what kind of stock assessment should be conducted.

To date there has not been a standard protocol for classifying species as data-rich or data-poor and identifying the most appropriate assessment tools. In some cases, analysts have tried to fit complex models to poor quality, or uninformative data, resulting in highly uncertain science advice for use by resource managers. While there are some species (e.g., Pacific Ocean Perch, Sablefish) in the BC groundfish fishery with long time-series of catch and abundance data that can be used in a full statistical catch-age stock assessment, there are many others with inadequate data to conduct such assessments. In addition, although some species or stocks may have enough data for a full assessment they may be of lower economic importance and therefore have not received any stock assessment effort.

The Groundfish Integrated Fisheries Management Plan (IFMP) identified the need to increase the number of species that receive quantitative stock assessment advice. This includes the goal of, by 2017, identifying and acquiring the data required to provide science advice for all groundfish species. This is complemented by the short-term goal of, by 2015, evaluating alternative approaches to assessing data-limited species and assessing the applicability of these approaches for providing advice for management of BC groundfishes.

A first step for increasing the number of species assessed is to categorize the amount and quality of stock assessment data available for different species, and then to recommend assessment approaches for each based on this information. Similar approaches, often called “tiered approaches”, have been developed in other international jurisdictions (e.g., USA, Australia, New Zealand, Europe).

Tiering is the general concept of separating fish species or stocks into categories, i.e., tiers, according to the quality, quantity, and types of data available, ranging from data-rich to data-poor. The concept includes the idea that different assessment methodologies would be used to provide scientific advice for the different tiers, and that the uncertainty in results and subsequent management advice increases as you move from the data-rich towards the data-poor tiers.

C.2. LITERATURE SEARCH

We reviewed the peer-reviewed and grey literature to better understand the approaches taken by the other international jurisdictions and to assess their applicability to the BC groundfish fishery. Elements of the approaches that were examined included legislation/policy requirements, how tiers were developed, implementation highlights and issues, and benefits resulting from these approaches.

Summaries of these documents, ordered by jurisdiction and then author, can be found in Section C.10.

C.3. LEGISLATION/POLICY

Most jurisdictions were faced with legislation that required them to provide assessment advice for all species, requiring development of a system for assessing data-limited species within a very short timeframe.

C.3.1. USA

The primary legislation governing the United States' federal marine fisheries is the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act [MSA]). The MSA was enacted in 1976 and coincided with the extension of jurisdiction out to 200 nautical miles from shore. Key objectives of the Act are to prevent overfishing, rebuild overfished stocks, increase long-term economic and social benefits, and ensure a safe and sustainable supply of seafood (NOAA). The MSA has had two significant revisions; the first in 1996 with the passage of the Sustainable Fisheries Act (SFA) and then in 2007 with the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act. One of the most significant changes coming out of the reauthorization of the MSA was the requirement for scientifically-derived annual catch limits (ACLs) for all federally-managed stocks in the United States, with some limited exceptions (Newman et al. 2015). This included the formation of Scientific and Statistical Committees (SSCs) and the creation of a peer review process to separate conservation from allocation (Grabacki 2008).

The MSA established eight regional fishery management councils which included representation from coastal states and fishery stakeholders. The North Pacific Fishery Management Council (NPFMC) was an early proponent of using a formal harvest strategy with species categorized into tiers (Goodman et al. 2002). With the reauthorization of the Magnuson-Stevens Act all USA Councils had to implement scientifically-derived annual catch limits (ACLs) (Newman et al. 2015). The Councils are required to develop Fishery Management Plans (FMPs) to set ACLs for all federal stocks, with the specific objective of reaching an MSY-related target reference point (MSY = Maximum Sustainable Yield). Management decisions must be consistent with the ten National Standards in the Sustainable Fisheries Act (SFA). National Standard 1 states that "*Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the Optimum Yield from each fishery for the US fishing industry*". The Guidelines recognize the difficulties involved in estimating MSY and propose suitable proxies for reference points (Restrepo 1998, Edwards 2015).

The setting of annual fishing levels (or TACs) is a three-step process:

1. Based on scientific knowledge, an overfishing limit (OFL) is defined for each stock.
2. A buffer is applied to the OFL to determine the acceptable biological catch (ABC); the ABC is a catch level equal to or less than the OFL.
3. The ACL is set equal to or below the ABC, and accounts for ecological, social and economic factors in addition to uncertainty in management controls. (Edwards 2015).

C.3.2. Australia

For Australia's federally managed fisheries, also known as Commonwealth fisheries, ecosystem-based fisheries management (EBFM) approaches were adopted as a way of implementing ecologically sustainable development (ESD) (Smith et al. 2013).

Since the early 1990s, as part of the EBFM approach, Australia has been increasing formalization of harvest strategies to manage principal fish stocks (Smith et al. 2013). Commonwealth legislation includes an explicit economic objective of maximizing the net economic returns from fishing activities, as well as the need to operate under the principles of ESD. This involved early adoption of target and limit reference points but the adoption of formal control rules were only used from about 2005 onwards (Smith et al. 2013).

The Southern and Eastern Scalefish and Shark Fishery (SESSF) was the first Commonwealth fishery to formally adopt the use of a formal harvest strategy. The SESSF is a multispecies, multi-gear fishery that operates under individual transferable quotas. Development of the harvest strategy was made necessary by environmental legislation and the need to meet a corresponding set of sustainability criteria. The SESSF was given conditional certification in 2003, with one of the conditions being that a formal harvest strategy for key target species would be introduced by 2006 (Smith et al. 2008). The harvest strategy was developed in 2005 and implemented in 2006, with the key innovation being the adoption of formal decision rules for determining assessment methodologies for species based on available data (Smith et al. 2008).

Shortly after the SESSF adopted its formal harvest strategy framework, the federal Minister for Fisheries issued a direction to the Australian Fisheries Management Authority (AFMA) to recover overfished stocks and prevent future overfishing in all Commonwealth fisheries (DAFF 2005). This required the development and implementation of a harvest strategy policy to be applied to all target stocks under federal jurisdiction (accompanied by implementation of fishery-independent surveys and improved monitoring of fishing removals). The intent was to manage stocks sustainably and profitably, end overfishing, and ensure currently overfished stocks were rebuilt within reasonable timeframes (Smith et al. 2013). The Harvest Strategy Policy was implemented on 1 January 2008 and specified explicit targets and limits for stock management. It also required the implementation of decision rules so that the harvest strategy for each stock would meet the intent of the policy (DAFF, 2007).

C.3.3. European Union

Member countries of the European Union (EU) are guided by the Common Fisheries Policy (EC 2371/2002) which has the objectives of enabling a productive and competitive fisheries industry and ensuring the sustainable management of resources (Le Quesne et al. 2013).

In 2006, the European Commission (EC; the European Union's executive body which represents the interests of the EU as a whole) set out a plan for moving towards the management of fisheries resources in the context of maximum sustainable yield (MSY) by 2015 (COM (2006) 360 final). MSY was interpreted as the Maximum Sustainable Yield that can be generated on a stock by stock basis. The plan states that B_{MSY} and F_{MSY} (biomass and fishing mortality at MSY, respectively) reference points should be defined for all stocks and the status of stocks and catch advice should be assessed in relation to these reference points (Le Quesne et al. 2013). The International Council for the Exploration of the Seas (ICES) is the primary provider of scientific advice for fish stocks in European Atlantic waters (Le Quesne et al. 2013) and ICES developed the MSY framework for advice beginning in 2009 (Lassen 2012). A transition period was established for the MSY framework to be put in place with the aim of adjusting fishing mortalities to levels corresponding to MSY by 2015 (Lassen 2012).

Prior to implementation of the plan, common practice was for fish stocks to be either quantitatively assessed (data-rich) or not (data-poor). Quantitative management advice was only provided for stocks with full assessments (Le Quesne et al. 2013). For data-poor stocks, advice was qualitative based on expert judgment of whether the stocks appeared to be increasing, declining or stable under current catch rates. There was a lack of guidance on how to provide quantitative advice with regards to management objectives which resulted in a disconnect between the development of data-deficient assessments and data-deficient management advisory procedures (Le Quesne et al. 2013).

In an effort to improve the provision of scientific advice, the EC proposed an automatic 25% reduction in fishing opportunities for stocks without scientific advice. There was also pressure put on Member States to fulfil obligations for data collection and reporting, and scientific agencies were tasked with developing assessment methods and harvest control rules for data deficient situations (Le Quesne et al. 2013). ICES established working groups to work on these methods.

C.3.4. New Zealand

The New Zealand Fisheries Act of 1996 initiated the requirement of estimating current-year biomass and the biomass needed to produce MSY. A 2008 amendment stated that all Quota Management System (QMS) fisheries must have a total allowable catch (TAC) defined that is "*not inconsistent with the objective of maintaining the stock at or above, or moving the stock towards or above, a level that can produce maximum sustainable yield*" (Ministry of Fisheries 2008, Edwards 2015). In 2008, the Harvest Strategy Standard (HSS) (Ministry of Fisheries 2008) and accompanying Operational Guidelines (Ministry of Fisheries 2007, revised 2011) were produced.

The HSS promotes the use of a harvest strategy which is defined as the management actions needed for a particular stock to reach (i.e. fluctuate around) its target reference points and to avoid limit reference points. Reference points may be formulated in terms of biomass, fishing mortality or proxies for these (Edwards 2015).

Fisheries Assessment Working Groups convened by the Ministry for Primary Industries (MPI) have terms of reference that include a requirement "*to assess, based on scientific information, the status of fisheries and fish stocks relative to MSY-compatible reference points and other relevant indicators of stock status*" (Ministry for Primary Industries, 2014). In addition, the working groups may be required to define the projected consequences of different TAC implementations to provide guidance for management.

C.4. TIERS

Jurisdictions were examined in the context of how stocks were placed into tiers and then how science and management advice was provided within those tiers. The tiering approaches varied in their complexity from a simple categorization into three tiers, i.e., data-rich, data-moderate, and data-poor, to greater numbers of tiers or subcategories within tiers.

C.4.1. United States

With the reauthorization of the US Magnuson-Stevens Act in 2006 there was a requirement for all Councils to provide Annual Catch Limits (ACLs) for all managed fisheries by 2011 with the goal of ending overfishing, improving accountability within the fisheries management system, and encouraging research into more precise assessments (Newman et al. 2015). This required the development of methods for setting ACLs for hundreds of previously unassessed species/stocks. One of the biggest challenges was dealing with stocks with limited data. Most

Councils adopted a tiered approach and placed species into categories for setting the ABCs and control rules. The tiered approaches varied, based on unique considerations stemming from each Council's interpretation of the MSA and National Standard 1 Guidelines, the information available and the ecological and management context of each region's managed fisheries (RPW 2012). Methods for classifying these stocks based on data availability vary by region but there are some general considerations for separation. Generally, data-rich stocks have been assessed using quantitative stock assessment methods (statistical catch-at-age models, surplus production models, virtual population analysis, etc.) to set OFLs and ABCs (Newman et al. 2015). These models use data such as catch, relative abundance and biological information to determine current biomass and the fishing rate relative to maximum sustainable yield (Newman et al. 2015). The data-limited category includes species for which data are moderate to poor. Data-moderate methods provide some feedback on stock status using information such as an index of abundance or biological sampling data (Newman et al. 2015). Data-poor methods are often based solely on catch history. Tables 1-6 detail the tiering approaches used by a selection of the regional management councils in the USA. At the time of writing, the Caribbean and New England Fishery Management Councils did not appear to be using a tiered approach.

In the USA, the North Pacific Fishery Management Council (NPFMC) inaugurated the tier system in fisheries (Goodman et al. 2002) with amendment 44/44 of the Fishery Management Plans for Groundfish of the Gulf of Alaska and of the Bering Sea and Aleutian Islands Area. The amendment was proposed to compensate for uncertainty in estimating fishing mortality rates at a level of MSY and specified the following conditions: (i) reducing fishing mortality rates as biological parameters became more imprecise, (ii) relating fishing mortality rates directly to biomass for stocks below target abundance levels and set to zero if a stock became critically depleted, and (iii) maintaining a buffer between the Allowable Biological Catch (ABC) and the Overfishing Limit (OFL) (Goodman et al. 2002). To address these requirements, the scientists at the National Marine Fisheries Service's (NMFS) Alaska Fisheries Science Center (AFSC) proposed a new definition of overfishing characterized by six levels or tiers of reliable information available to fisheries scientists. The OFLs would be determined by the tier that best characterized the available information. The amendment describes the types of estimates required for each tier, the calculations for OFLs and ABCs, and an increasing buffer between the limit and the catch as uncertainty in the results increased. The tiers were amended in 1998 by amendment 56/56 and this version is presented in Table 1.

C.4.2. Australia

In 2005, the SESSF became the first Australian fishery to implement a comprehensive harvest strategy framework in 2005, and the framework implemented a tier-based system of assessments and associated formal harvest control rules (Table 7; Smith et al. 2008). The framework was designed to build in a precautionary approach, where target fishing mortality rates decrease as uncertainty about stock status increases (Smith and Smith 2005). Species were assigned to one of four tiers based on amount and type of information available to assess stock status, with Tier 1 having the highest quality information (Smith et al. 2008).

With the implementation of the Commonwealth HSP, scientists were required to provide advice for previously unassessed species in other fisheries. The Guidelines encourage the use of a tiered approach to control rules to cater to different levels of certainty (or knowledge) about a stock, using the SESSF as an example of tiering (DAFF 2007).

Australia explicitly attempts to seek a balance between the costs of data collection and assessment with the benefits of improved assessment (i.e., more catch) to ensure cost effective fisheries management. There have been a number of publications outlining the underlying “catch cost risk” trade-off (e.g., Dowling et al. 2013) in terms of biological, economic and ecosystem risk. Australia has also made use of triggers for low value fisheries whereby once the catch for a species hits a certain level, actions for data collection and analysis are implemented (Smith et al. 2013). This allows for low-cost, baseline monitoring of low-value fisheries with options to ramp up monitoring if required.

C.4.3. European Union

In Europe, a number of elements were identified as needed to improve management of data-limited stocks. These included improving data collection and reporting, improving assessment methods that utilize limited data, and developing tested and robust management control rules consistent with broad policy principles even if they cannot be applied with regards to MSY objectives (Le Quesne et al. 2013).

In efforts to improve the provision of advice and management for data-deficient stocks ICES conducted a series of workshops and working group meetings to develop a tiered approach. In 2012, ICES introduced its data-limited stocks (DLS) approach that provided a structured framework for assessing and advising across a range of data categories. The DLS approach defines six stock categories (Table 8) based on data availability, with uncertainty increasing through the categories 1-6. Within each category, different stock assessment procedures and harvest control rules were proposed (ICES 2012b). The basis for the control rules ranged from MSY, to MSY-proxies, to “common sense rules” with no biological basis (Le Quesne et al. 2013). Within each category, ICES recognized that more than one assessment method could be used and that methods were expected to evolve (ICES 2012b). The DLS approach had two over-arching principles, the “uncertainty cap” and the “precautionary buffer”.

The uncertainty cap is meant to account for the greater amount of uncertainty from data-deficient methods, while the precautionary buffer is applied to all stocks where stock status or exploitation rate relative to quantitative reference points is not known (ICES 2012b). However, based on expert judgment, there may be exceptions to the application of the precautionary buffer. In cases where both cap and buffer are utilized, the buffer is applied after the cap has been applied (Le Quesne et al. 2013).

C.4.4. New Zealand

In New Zealand, fish stock assessments are classified by the availability of a reliable abundance index and whether the resource is valuable enough to spend the resources to conduct an assessment (Minister for Primary Industries 2014). There are four categories based on the type of assessment that can be done (Table 9), with Levels 2-4 being considered as data-poor. These data-poor stocks do not have MSY-compatible reference points and estimation of stock status within a quantitative framework has not been attempted (Edwards 2015). The Operational Guidelines do however recognise that the requirements of the Fisheries Act “need to be applied in different ways for different fisheries depending on the available data.” They further define analytical and conceptual proxy reference points that can be used in lieu of an analytical assessment (Ministry of Fisheries 2011).

C.5. IMPLEMENTATION

Within each jurisdiction there have been variations on the implementation of tiered approaches to stock assessment and management. There were also many references (e.g. Smith et al. 2013, ICES 2013a) highlighting the need for testing the efficiency of tiered approaches in accounting for increased uncertainty with less information, specifically whether resulting advice is more precautionary.

C.5.1. United States

In the USA, it was an ambitious task to implement the mandate to provide ACLs for all managed stocks by 2011. The mandate required the assessment of data availability, development of new methods and application of the new methods without a lot of additional resources (Newman et al. 2015). There is considerable variation among the eight councils in terms of: the numbers of stocks managed using data-rich vs data-poor methods, the resources that are dedicated to assembling data, and the effort spent on assessment prioritization and scheduling (Newman et al. 2015). As noted previously, the NPFMC had already implemented a tiered approach (Table 1). The remaining Councils implemented different approaches to providing ACLs; for some this included a tiered approach (Tables 2-6). A review (RPW 2012) noted that for a variety of reasons some councils implemented tiers that were never or rarely used. The authors suggested that possible reasons for doing so might include using the tiered classification to communicate higher or lower risk scenarios, and also to provide a frame of reference for improving information availability and prioritizing stocks for assessment. Overall, the implementation of specific ABC control rules provided structure as well as greater consistency and transparency (RPW 2012).

An initial review of the Alaskan management system noted that the approach, including the tiering (Table 1), appeared to be working well judging by the continuing productivity of the target stocks (Goodman et al. 2002). The review, however, did recommend the use of management strategy evaluation (MSE) to provide assurance that the harvest strategy was robust and likely to meet the objectives of the MSA (Goodman et al. 2002). By October 2003, the Alaska Fisheries Science Center responded that many of the MSE-related suggestions from Goodman et al. (2002) had been addressed, although there were still some suggestions that had not yet been implemented (Thompson and Ianelli 2004).

There has been intensive testing (e.g., Carruthers et al. 2014) of data-limited methods. Testing confirmed that classifying stocks solely according to the amount and types of data available may not be appropriate. A large quantity of data provides no guarantee of reliable information on which to base decision making, i.e., data-rich stocks are often information-poor (Carruthers et al. 2014).

The USA was successful in implementing the ACL mandate for all federally managed stocks by the 2011 deadline. Measures of success are tracked and published annually and include metrics on the number of stocks that are subject to overfishing, the number of stocks that are overfished, the number of stocks that have rebuilt, and the number of stocks with unknown status (Table 10). As an example, in 2009, prior to the ACL mandate, the overfishing status of 52% of stocks was unknown and the overfished status of 61% was unknown. By 2015, these percentages had reduced to 34% and 51%, respectively. In addition, the USA has been tracking the number of stocks that have been rebuilt since 2000. The number of rebuilt stocks was 18 in 2009 and 39 in 2015.

Another measure of progress used by NMFS is the Fish Stock Sustainability Index (FSSI). The FSSI is a quarterly index that measures the performance of 199 key commercial and recreational stocks; the FSSI increases when a stock's status improves (meaning that it is no longer subject to overfishing, no longer overfished, its biomass has increased to at least 80% of target, or it is rebuilt (). Since 2000 the index has increased from 382.5 to 758 (out of a maximum possible score of 1000).

C.5.2. Australia

In Australia, the tiers in the SESSF were first implemented for 2006. An immediate result was a more consistent approach across species and stocks (Smith et al. 2008). In general the response from managers and industry was favourable with development of TACs being faster and less contentious than previously (Smith et al. 2008).

There were, however, some issues with the implementation. The harvest strategy was not phased in and there were major changes to the TACs leading to distrust of the system by industry (Smith et al. 2008. Industry was also reluctant to reduce catches when assessments were more uncertain. Smith et al. (2008) also noted that there was an issue of tier shopping, the temptation to choose a tier based on which gives the “right” answer, e.g., a species being placed in Tier 3 because it gave a better answer than being placed in Tier 1. They felt that there was a general lack of understanding of model-based tiers and that more education was needed to communicate that the more data-poor tiers will lead to lower TACs.

In addition, the Australian SESSF harvest strategy framework was not simulation-tested prior to implementation and some of the tier rules did not perform as expected. A later release of the Commonwealth Harvest Strategy Policy (HSP) facilitated testing of the SESSF framework, as the HSP defined targets (including the use of maximum economic yield rather than maximum sustainable yield), limits, and acceptable levels of risk in not meeting targets. This information was not available when the SESSF harvest strategy was implemented in 2005 (Smith et al. 2008). During 2006 and 2007 the SESSF underwent management strategy evaluation (MSE) by Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO). The project identified problems with the initial implementation of the HSF and developed improvements, especially to Tier 3 and 4 rules (Smith et al. 2008). Testing also demonstrated that the SESSF HSF is consistent with, and meets the requirements of, the Commonwealth Harvest Strategy Policy and that the Tier 1 rule achieves its aims for a range of species with differing life histories (AFMA 2014). The MSE testing framework developed in the CSIRO project is available for further testing of any future proposed revisions to elements of the HSF. The 2009 Harvest Strategy Framework for the SESSF (AFMA 2014) is updated when modifications are made (to date in July 2011, February 2014, and February 2015).

The full implementation of the Commonwealth HSP in 2008 was also developed over a short time period, included a large number of species/fisheries, and experienced capacity limitations. For these reasons some strategies were not fully tested using MSE prior to implementation. Since then, there has been MSE testing for a range of fisheries and species to ensure that the strategies are compliant with the intent of the policy which prescribes clear quantitative targets and limits, as well as acceptable levels of risk for breaching those limits (Smith et al. 2013). For some cases, this resulted in changes to the initial specifications, which significantly changed management outcomes and undermined the confidence of industry in the process (Smith et al. 2013).

Each year the status of Australian stocks is reported for Australian Commonwealth Fisheries. Following the introduction of the HSP in 2008 there was a drop in the number of stocks subject to overfishing due entirely to how rapidly catches, and consequently fishing mortality were reduced (Smith et al. 2013). The number of stocks with an uncertain status declined and of the stocks that could be assessed, the proportion subject to overfishing or that were overfished also declined (Table 11), with the SESSF being a major contributor to the decreases. The impact on stocks experiencing overfishing has been more immediate than the recovery of some of the overfished stocks (Smith et al. 2013).

C.5.3. European Union

In the EU, a large number of experts contributed to the development, implementation, and testing of the ICES tiering (ICES 2012, 2013b). The ICES DLS approach (ICES 2012b) assigns species into categories or tiers using a series of decision trees. For each of the resulting tiers, formal harvest control rules are identified based on the outcome of the assessment method that was used in that tier. In their review, Le Quesne et al. (2013) noted that there was a change in mindset from only conducting quantitative assessments when required data are available, to conducting quantified assessments with the data that are available with a variety of different data-limited assessment methods. They also noted that there is a gradient of information which allows for a range of choices of assessment method in each tier, to make maximum use of available data. This recognizes that the definitions of data-rich or data-poor was overly simplistic, resulting in useful information not being fully utilized.

Prior to the implementation of the DLS approach in 2012, 122 of 200 stocks did not have a quantitative forecast and advice (Le Quesne et al. 2013). For these stocks there was only qualitative advice based on expert judgment of whether stocks appeared to be increasing, decreasing or stable under current catch levels (based on landings, catches, relative abundance or catch:abundance ratio). Once the DLS approach was implemented, advice was provided for 68 data-limited stocks, an increase from 2010 where quantitative advice was only provided for 10 data-limited stocks (ICES 2012a).

The primary contribution of the DLS approach was formalization of the management process by linking harvest control rules to appropriate analyses (Le Quesne et al. 2013). The approach also provided more transparency, certainty, stability, and clarity in setting catch opportunities for data-deficient stocks (Le Quesne et al. 2013).

When the DLS approach was implemented, not all methodologies had been simulation-tested (ICES 2012b). In successive working group meetings, needs for required testing were identified and plans made to prioritize the testing; in addition, recommendations were made on the assignment of data-limited stocks to target categories (ICES 2012a). The working groups also identified a need to investigate the robustness of the ICES DLS approach to decreasing information to ensure a consistent approach to risk across data categories (Le Quesne et al. 2013).

A question of the overall DLS approach is, “do we get more conservative catch advice if less data are available?” This was initially tested using management strategy evaluation (MSE) and involved starting with a data-rich stock in Category 1, and then systematically stripping away data from this stock to demote it to lower categories, each time applying one of the methods appropriate to that category, focusing on the methods most commonly used by ICES (ICES 2013b). Very generally, the DLS approach performed better for well-managed stocks but deteriorated for stocks that became or were overexploited (ICES 2013b) and testing continues.

In addition to simulation testing, the working groups also spent considerable time reviewing data-limited assessment methods and the effectiveness of the precautionary buffer (ICES 2014).

C.5.4. New Zealand

Although New Zealand classifies its stocks into levels, it cannot be considered as a tiered approach and still involves *ad hoc* decision-making (Le Quesne et al. 2013). New Zealand had primarily adopted biomass targets, rather than fishing mortality rates or limits, but with the introduction of the HSS the need to consider fishing mortality was introduced (Mace 2012).

C.6. CONCLUSIONS

Tiered approaches have been implemented in a variety of ways in other international jurisdictions with the general theme of attempting to use as much of the available information for a species as possible. Overall, at least a couple of common themes can be identified.

In an ideal world, it is preferable to spend more time developing and simulation-testing a tiered framework before implementation. Smith et al. (2008) noted that prior testing could have avoided some issues, but acknowledged that it was better to implement a harvest strategy knowing that it will likely change, rather than delay until it is perfect.

Another common theme is the ability to have some flexibility in the framework. In the USA, there have been multiple interpretations of the Magnuson-Stevens Act and the National Standards, which acknowledges the different regional environments. In Australia, it was noted that there was a need for a clear policy that allows flexibility in adoption, implementation, and review of harvest strategies at the individual fishery level. It was also noted that there were considerable costs to implement the harvest strategy policy and that there will be some continued costs for ongoing adjustments to the HSP and to implement periodic major reviews and re-setting of the policy (Smith et al. 2013)

Almost every jurisdiction emphasised the need for simulation-testing of the harvest strategies, including tiering, to ensure that they were being applied with increasing precaution as the amount of uncertainty in advice increased (e.g., Le Quesne et al. 2013). This was often suggested in terms of MSE but also included some simpler testing methods. It was generally accepted that strategies might need to be implemented before testing due to time constraints, but that strategies should eventually undergo simulation-testing.

The jurisdictions examined differed somewhat on the requirement to move species towards the data-rich tiers. ICES made the specific point of improving data-collection compliance to move assessments to a higher category (Le Quesne et al. 2013). However, they also suggested a strategic ranking of target data categories as it is not feasible for all stocks to be data-rich. Agencies must balance the costs associated with data collection and assessment with the additional fishing opportunities that may be achieved with a more quantitative assessment.

In Australia, the HSP Guidelines state that a full quantitative assessment is not expected for all stocks but that all fisheries should be managed at an acceptable level of risk (Le Quesne et al. 2013). Australia has a legislative requirement for cost-effective fisheries management and it is accepted that low value fisheries may have to be precautionary and only require a low value of research below a certain threshold (Smith et al. 2013). In its review of the HSP, the Department of Agriculture, Fisheries, and Forestry (DAFF 2013) reported that the HSP would benefit from being supported by performance indicators and by a reporting regime that reports on the implementation and performance of harvest strategies.

Le Quesne et al. (2013) provided some good recommendations for tiered approaches, in general. They noted tiered approaches should have a consistent approach to uncertainty and precaution and that fishing opportunities should not be greater for species assessed with data-deficient methods, i.e. there should not be any incentives to be in a more data-limited category. They also recommended that the definition of appropriate risk thresholds is necessary to ensure that management procedures are consistent with the precautionary approach, and that resource requirements for data collection and assessment should be considered when establishing target data categories and assessment frequency. This final theme was also noted in the recent NOAA publication on prioritizing fish stock assessments (Methot 2015).

Another major advance out of the tiering approaches has been the increase in development, application, and testing of data-poor assessment methods (e.g., Carruthers et al. 2014, Newman et al. 2015). This is seen as work in progress and will likely continue to evolve.

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C.8. TABLES

Table C.1. Tiering approach (T) used by the North Pacific Fishery Management Council.

T	How to tier	Setting TACs
1	Operates on the best available information; requires estimates of biomass (B) and biomass at the level of MSY (B_{MSY}), and a reliable description of uncertainty (or probabilities) around the variables involved in calculating fishing mortality at MSY. Sufficient information to determine a target biomass level, which would be obtained at equilibrium when fishing according to the control rule with recruitment at the average historical level.	1a) $F_{ABC} \leq$ the harmonic mean of the probability distribution function (pdf) 1b) $F_{ABC} \leq$ the harmonic mean of the pdf x stock biomass estimate 1c) $F_{ABC} = 0$ The control rule is biomass-based, for which fishing mortality is constant when biomass is above the target and declines linearly down to a threshold value when biomass drops below the target. Fishing mortality is 0 below the threshold (0.05 of target biomass).
2	The amount of uncertainty (probabilities) cannot be reliably assessed for variables associated with fishing mortality at MSY (F_{MSY}). Require reliable point estimates of B, B_{MSY}, F_{MSY}, $F_{35\%}$, $F_{40\%}$. Sufficient information to determine a target biomass level, which would be obtained at equilibrium when fishing according to the control rule with recruitment at the average historical level.	2a) $F_{ABC} \leq F_{MSY}$ x estimated fishing mortality 2b) $F_{ABC} \leq F_{MSY}$ x estimated fishing mortality x stock biomass estimate 2c) $F_{ABC} = 0$ The control rule is biomass-based, for which fishing mortality is constant when biomass is above the target and declines linearly down to a threshold value when biomass drops below the target. Fishing mortality is 0 below the threshold (0.05 of target biomass).
3	Reliable estimates of biomass at MSY are not available. Set the target abundance level at an estimate of the long-term average biomass that would be expected under average recruitment and a fishing mortality rate that would reduce the lifetime spawning stock to 40% of what it would be in the absence of fishing. Sufficient information to determine $F_{40\%}$ and its corresponding biomass $B_{40\%}$. Spawner-recruit relationship is uncertain so MSY cannot be estimated with confidence. Require reliable point estimates of B, $B_{40\%}$, $F_{35\%}$, $F_{40\%}$. Sufficient information to determine a target biomass level, which would be obtained at equilibrium when fishing according to the control rule with recruitment at the average historical level.	3a) $F_{ABC} \leq$ F40% 3b) $F_{ABC} \leq$ F40% x stock biomass estimate 3c) $F_{ABC} = 0$ The control rule is biomass-based, for which fishing mortality is constant when biomass is above the target and declines linearly down to a threshold value when biomass drops below the target. Fishing mortality is 0 below the threshold (0.05 of target biomass).
4	Target abundance levels cannot be known. Require reliable point estimates of B, $F_{35\%}$, $F_{40\%}$. Biological reference points cannot be determined, fishing occurs at a constant fishing mortality which is chosen to be conservative according to findings in the scientific literature.	$F_{ABC} = \leq F_{40\%}$
5	Based on natural mortality (M). Require reliable point estimates of B, and natural mortality rate M. Biological reference points cannot be determined, fishing occurs at a constant fishing mortality which is chosen to be conservative according to findings in the scientific literature.	$F_{ABC} = 0.75$ x M
6	Biomass and reference points cannot be determined. Usually based on catch time series. Require reliable catch history from 1978 through 1995. Fishing mortality cannot be determined so catch constrained to 75% of average historical catch.	ABC = 0.75 x OFL

Table C.2. Tiering approach (T) used by the Pacific Fishery Management Council.

T	How to tier	Setting TACs
1	Data rich stocks for which a relatively data-rich, quantitative stock assessment can be conducted on the basis of catch-at-age, catch-at-length, or other data. OFLs and overfished/rebuilding thresholds can generally be calculated for these species. From Terms of reference 2014: A. Reliable compositional (age and/or size) data sufficient to resolve year-class strength and growth characteristics. Only fishery-dependent trend information available. Age/size structured model. B. As in a, but trend information also available from surveys. Age/size structured model. C. Age/size structured assessment model with reliable estimation of the stock recruit relationship.	OFLs and overfished/rebuilding thresholds can generally be calculated. For ABC, Council specifies a P* based on SSC input, maximum P* is 0.45
2	Less data reliability - some biological indicators are available, including a relatively data-poor quantitative assessment or a non-quantitative assessment. May not have a recent, quantitative assessment but there may be a previous assessment or some indicators of the status of the stock. It is difficult to estimate overfished and overfishing thresholds for this category of species a priori, but indicators of long-term, potential overfishing can be identified. Typically, spawning biomass, level of recruitment, or current fishing mortality is unknown. OFL levels typically established on the basis of a historical catch-based approach (e.g. average catch, DCAC or DB-SRA), trends in a fishery independent survey or some other index of current biomass. From Terms of Reference 2014: A. M*survey biomass assessment (as in Rogers 1996). B. Historical catches, fishery-dependent trend information only. An aggregate population model is fit to the available information. C. Historical catches, survey trend information, or at least one absolute abundance estimate. An aggregate population model is fit to the available information. D. Full age-structured assessment, but results are substantially more uncertain than assessments used in the calculation of the P* buffer. The SSC will provide a rationale for each stock placed in this category. Reasons could include that assessment results are very sensitive to model and data assumptions, or that the assessment has not been updated for many years. E. Assessments of a complex of species cannot be designated as a category 1 assessment unless there is good evidence that the component species have very similar life history characteristics and similar rates of biological productivity.	OFLs and ABCs for species in this category are typically set at a constant level and some monitoring is necessary to determine if this level of catch is causing a slow decline in stock abundance. For ABC, SSC recommends a sigma value larger than that for category 1 stocks, and Council chooses P* or straight reduction from OFL. Approaches for setting ABC: - continue to apply a buffer of .25 for consistency with current practice until SSC has developed and applied an appropriate analytical framework, or - set value of sigma to two times the coefficient of variation (CV) for category 1 stocks. Values not based on formal analysis of assessment outcomes and could change substantially when SSC reviews additional analyses.
3	Data poor stocks - includes minor species which are caught, but for which there is, at best, only information on landed biomass. For species in this category, there is limited data to quantitatively determine MSY, OFL, or an overfished threshold. From Terms of Reference 2014: A. No reliable catch history. No basis for establishing OFL. B. Reliable catch estimates only for recent years. OFL is average catch during a period when stock is considered to be stable and close to BMSY equilibrium on the basis of expert judgment. C. Reliable aggregate catches during period of fishery development and approximate values for natural mortality. Default analytical approach depletion-corrected average catch (DCAC). D. Reliable annual historical catches and approximate values for natural mortality and age at 50% maturity. Default analytical approach depletion-based stock-reduction analysis (DB-SRA).	Typically, average catches are used to determine the OFL. Greater scientific uncertainty so bigger buffer. For ABC, SSC recommends a sigma value larger than that for category 1 and 2, and Council chooses P* or straight reduction from OFL. Approaches for setting ABC: - continue to apply a buffer of .5 for consistency with current practice until SSC has developed and applied an appropriate analytical framework, or - set value of sigma to four times the coefficient of variation (CV) for category 1 stocks. Values not based on formal analysis of assessment outcomes and could change substantially when SSC reviews additional analyses.

Table C.3. Tiering approach (T) for Western Pacific Fishery Management Council.

T	How to tier	Setting TACs
1	Overfishing limit (OFL) and uncertainty in OFL are estimated from statistically-based stock assessment models and are considered reliable.	ABC = (P* percentile of the probability distribution of OFL) X OFL
2	Overfishing limit (OFL) and uncertainty in OFL are estimated from statistically-based stock assessment models but are not considered reliable.	ABC = (P* percentile of the probability distribution of OFL) X OFL
3	Overfishing limit (OFL) and uncertainty in OFL are estimated using DCAC, SRA and through resampling and are not considered reiliable.	ABC = (P* percentile of the probability distribution of OFL) X OFL
4	Overfishing limit (OFL) and uncertainty in OFL are unknown; MSY is known but there is no current fishery for the stock.	ABC = 0.91 X F_{MSY}
5	Most data-poor. OFL and uncertainty in OFL are unknown. MSY also unknown, but rely on long-term catch data, where available.	Three potential scenarios to choose from based on stock status: ABC = 1.0 X median catch, if median catch > B_{MSY} ABC = 0.67 X median catch, if median catch is < B_{MSY} but > MSST (Minimum Stock Size Threshold) ABC = 0.33 X median catch, if median catch is < MSST (considered overfished)

Table C.4. Tiering approach (T) of the Gulf of Mexico Fishery Management Council.

T	How to tier	Setting TACs
1	A quantitative assessment provides both an estimate of overfishing limit based on MSY or its proxy and a probability density function of overfishing limit that reflects scientific uncertainty. Specific components of scientific uncertainty can be evaluated through a risk determination table. Landings data, but no assessment, are available, and the expert opinion of the SSC suggests recent landings may be unsustainable.	The overfishing limit (OFL) is the yield resulting from applying FMSY or its proxy to estimated biomass. ABC = yield at P*; 0.30 ≤ P* ≤ 0.50 P* is determined by a risk determination table that is used by the SSC to evaluate elements of uncertainty within stock assessments.
2	An assessment exists but does not provide an estimate of MSY or its proxy. Instead, the assessment provides a measure of overfishing limit based on alternative methodology. Additionally, a probability density function can be calculated to estimate scientific uncertainty in the model-derived overfishing limit measure. This density function can be used to approximate the probability of exceeding the overfishing limit, thus providing a buffer between the overfishing limit and acceptable biological catch.	ABC = yield at P* of 0.30 as default. Council may choose to substitute a P* of 0.40 or 0.50 on the basis of available information. Assessments do not provide an estimate of MSY or its proxy but instead provide a measure of OFL based on alternative methodology.
3a	No assessment is available, but landings data exist. The probability of exceeding the overfishing limit in a given year can be approximated from the variance about the mean of recent landings to produce a buffer between the overfishing limit and acceptable biological catch. Based on expert evaluation of the best scientific information available, recent historical landings are without trend, landings are small relative to stock biomass, or the stock is unlikely to undergo overfishing if future landings are equal to or moderately higher than the mean of recent landings. For stock complexes, the determination of whether a stock complex is in Tier 3a or 3b will be made using all the information available, including stock specific catch trends.	ABC = mean landings + 1 standard deviation as default. Council may choose to subsitute the mean of recent landings, or 0.5 or 1.5 standard deviations above mean landings on the basis of the time series of data.
3b	No assessment is available, but landings data exist. Based on expert evaluation of the best scientific information available, recent landings may be unsustainable.	ABC = 75% of OFL as default, where OFL = mean landings; based on expert judgment of landings data. Council may choose to substitute multipliers of 65%, 85%, or 100% of OFL.

Table C.5. Tiering approach (T) of South Atlantic Fishery Management Council.

T	How to tier	Setting TACs
1	Assessment information: Quantitative assessment provides estimates of exploitation and biomass; includes MSY-derived benchmarks. (0) Advice on Uncertainty: Complete; for assessments that provide a complete statistical (e.g. Bayesian resampling approach) treatment of major uncertainties, incorporating both observed data and environmental variability, which are carried forward into reference point calculation and stock projections. Key determinant of this level is that uncertainty in both assessment inputs and environmental conditions are included. (0) Stock status: neither overfished nor overfishing, and stock is at high biomass and low exploitation relative to benchmark values. (0) Productivity/Susceptibility: Low Risk. High productivity, low vulnerability and susceptibility, score < 2.64 (scoring from Hobday et al. 2007)	P* used to account for scientific uncertainty where possible
2	Assessment information: Quantitative assessment provides estimates of either exploitation or biomass, but not MSY benchmarks; requires proxy reference points. (-2.5) Advice on Uncertainty: High; for assessments that include resampling (e.g. Bootstrap or Monte Carlo techniques) of important or critical inputs such as natural mortality, landings, discard rates, age and growth parameters. Resampling is also carried forward and combined with recruitment uncertainty for projections and reference point calculations, including reference point distributions. Key determinant for this level is that reference point estimates distributions reflect more than just uncertainty in future recruitment. (-2.5) Stock status: neither overfished nor overfishing, but stock may be in close proximity to benchmark values. (-2.5) Productivity/Susceptibility: Moderate Risk. Moderate productivity, vulnerability and susceptibility, score 2.64 - 3.18 (scoring from Hobday et al. 2007)	Depletion-based stock reduction analysis (DB-SRA) methods and P* utilized to determine ABC
3	Assessment information: Quantitative assessment that provides relative measures of exploitation or biomass; absolute measures of status are unavailable; references may be based on proxies. (-5) Advice on Uncertainty: Medium; for assessments in which key uncertainties are addressed via statistical techniques and sensitivities, but the full uncertainties are not carried forward into the projections and reference point calculations. Projections may, however, reflect uncertainty in recruitment and population abundance. Although outputs include distributions of F, FMSY as in the High category, in this category fewer uncertainties are addressed; for example, a distribution of FMSY which only reflects uncertainty in recruitment. (-5) Stock status: stock is either overfished or overfishing. (-5) Productivity/Susceptibility: High Risk. Low productivity, high vulnerability and susceptibility, score >3.18 (scoring from Hobday et al. 2007)	Depletion-corrected average catch (DCAC) methods used, does not provide OFL, only ABC. Analysis does not provide necessary details to inform a P* choice.
4	Assessment information: Reliable catch history available. (-7.5) Advice on Uncertainty: Low; for assessments lacking any statistical treatment of uncertainty. Sensitivity runs or explorations of multiple assessment models may be available. Key determinant for this level is that distributions for reference point are lacking. (-7.5) Stock status: stock is both overfished and overfishing. (-7.5)	ABC and OFL derived on a case-by-case basis. Use decision tree to guide evaluations for initial OFL and ABC recommendations. Decision tree includes set of questions and considerations to guide establishment of ABCs, and builds an administrative record to support decision. Questions: 1. Will current catches affect the stock? NO - recommend move stock to ecosystem species category; YES - go to #2

T	How to tier	Setting TACs
		2. Will increased catch lead to decline or other stock concerns? NO - ABC = 3rd highest point in the 99-08 time series; YESD - go to #3 3. Is the stock part of a directed fishery or primarily bycatch with other species? DIRECTED - ABC = median 99-08; BYCATCH/INCIDENTAL - go to #4 4. Evaluate the situation and information. If bycatch, issues to consider include trends in fishery, current regulations, and the effort outlook. If directed fishery is increasing, and bycatch of stock of concern is also increasing, the Council may need to find a means to reduce interactions or bycatch mortality. If that is not feasible, the Council will need to impact the directed fishery. Changes to Tier being considered as many stocks lack the fishery-dependent data required to apply Tier 4 methods. May revise and add tiers.
5	Assessment information: Scarce or unreliable catch records. (-10) Advice on Uncertainty: None; for assessments that only provide single point estimates, with no sensitivities or other evaluation of uncertainties. (-10) Stock status: either status criterion is unknown. (-10)	

Table C.6. Tiering approach (T) of Mid-Atlantic Fishery Management Council.

T	How to tier	Setting TACs
1	Ideal assessment All important sources of uncertainty are fully and formally captured in the stock assessment model and the probability distribution of the OFL calculated within the assessment provides an adequate description of uncertainty of OFL. The OFL distribution is estimated directly from the stock assessment. Example attributes of level 1 stock assessment: - appropriate and necessary details of the biology of the stock, the fisheries that exploit the stock, and the data collection methods included in the model - estimation of stock status and reference points in the same framework such that the OFLs promulgate all uncertainties throughout estimation and forecasting - the assessment estimates relevant quantities including FMSY (or proxy), OFL, biomass reference points, stock status, and their respective uncertainties - no substantial retrospective patterns in the estimates of fishing mortality (F), biomass (B), and recruitment (R) are present in the stock assessment methods	ABC is solely based on the basis of an acceptable probability of overfishing (P*), determined by the Council's risk policy, and the probability distribution of the OFL as provided from the assessment model.
2	Preferred assessment Assessment has greater uncertainty than level 1. The estimation of the probability distribution of the OFL directly from the stock assessment model fails to include some important sources of uncertainty so require expert judgment during the preparation of the stock assessment and the OFL distribution is deemed best available science by SSC. Example attributes of level 2 stock assessment: - missing key features of the biology of the stock, the fisheries that exploit the stock, and the data collection methods - estimates relevant quantities, including reference points (may be proxies) and stock status, together with respective uncertainties, but the uncertainty is not fully promulgated throughout the model or some important sources may be lacking - estimated of the precision of biomass, fishing mortality rates, and their respective reference points are provided in the stock assessment	ABCs determined by using an acceptable probability of overfishing (P*), determined by the Council's risk policy, but with the OFL distribution based on the specified distribution developed in the stock assessment process and as accepted by the SSC.

T	How to tier	Setting TACs
	- accuracy of the maximum fishing mortality threshold (MFMT) and future biomass is estimated in the stock assessment by using ad hoc methods.	
3	Acceptable assessment Assessments at this level are judged to over- or under-estimate the accuracy of the OFL. Attributes of a stock assessment that would lead to being included in level 3 are the same as level 2, except that the assessment does not contain estimates of the probability distribution of the OFL or the probability distribution provided does not, in the opinion of the SSC, adequately reflect uncertainty in the OFL estimate.	The SSC adjusts the distribution of the OFL and develops an ABC by applying the Council's risk policy to the modified OFL probability distribution. The SSC evaluates a set of default or other amounts of uncertainty in the OFL probability distribution based on literature review and an evaluation of ABC control rules. Default distribution adopted by the SSC is a lognormal distribution with a coefficient of variation (CV) of 100%. Value of CV developed from an analysis of several simulation studies that evaluated the accuracy of estimates from statistical catch-at-age models. A default control rule of 75% of FMSY may be applied if an OFL distribution cannot be developed.
4	Unreliable assessment Assessments have reliable estimates of trends in abundance and catch, but absolute abundance, fishing mortality rates, and reference points are suspect or absent. Example attributes of level 4: - assessment approach is missing essential features of the biology of the stock, the fisheries that exploit the stock, and the data collection methods - stock status and reference points are estimated, but are not considered reliable - assessment may estimate some relevant quantities such as biomass, fishing mortality or relative abundance, but only trends are deemed reliable - large retrospective patterns usually present - uncertainty may or may not be considered, but estimates of uncertainty are probably substantially underestimated	ABC set based on ad hoc, alternative approaches (e.g. adjustment to long-term catch history or survey index values) Generally may not increase ABCs unless the following two circumstances are met: - biomass-based reference points suggest the stock is greater than BMSY, and stock biomass is stable or increasing. If biomass-based reference points are not available, best available science indicates that stock biomass is stable or increasing, and, - the SSC must provide a determination that, based on best available science, the proposed increase in ABC is not expected to result in overfishing. SSC must provide a description of why increase is warranted, describe the method used to derive the increased ABC, and provide a certification that the increase in ABC is not likely to result in overfishing.

Table C.7. Tiering approach (T) of the Australian Southern and Eastern Shark and Scalefish Fishery (SESSF) as of 2015.

T	How to tier	Setting TACs – Rules
1	Robust quantitative assessment that provides estimates of current biomass (B_{CUR}) from a base-case stock assessment and estimates are available for B_{40}, B_{20}, and F_{40}.	If $B_{CUR} > B_{35}$, $F_{TARG} = F_{48}$ If $B_{20} < B_{CUR} < B_{40}$, $F_{TARG} = F_{48} *((B_{CUR}/B_{20} -1)$ If $B_{CUR} < B_{20}$, $F_{TARG} = 0$ The RBC is calculated by applying F_{TARG} to the current biomass B_{CUR} to calculate the total catch (including discards) in the next year, using the agreed base case assessment model: RBC = Catch[$F_{TARG} \rightarrow B_{CUR}$] At Tier 1, $B_{LIM} = B_{20}$, the maximum value for $F_{TARG} = F_{48}$ and the breakpoint in the HCR occurs at B_{35}. Alternative reference points may be adopted for some stocks to better pursue the objective of maximizing economic returns across the fishery as a whole.
2	No longer used	
3	Species that do not have a quantitative stock assessment, but do have information available on the age structure of annual catches and annual total catch weight, as well as knowledge of basic biological parameters, e.g. natural mortality, age-length relationships, length/weight relationships, stock recruitment relationship steepness, age at maturity and age at recruitment to the fishery; i.e., enough information for yield per recruit analysis. Robust estimates of M and current fishing mortality (F_{CUR}), but no direct estimates of current biomass.	Yield per recruit calculations are used to calculate F values that will reduce the spawning biomass to 20% (F_{20}), 40% (F_{40}) and 48% (F_{48}) of the unexploited level. TA value is assigned for F_{RBC} using F_{CUR}. This relationship has properties similar to the Tier 1 harvest control rule, with the default proxies of F_{20} as the limit and F_{48} as the target fishing mortality rate. The following formula, which adjusts the current catch C_{CUR} according to the ratio of the intended and current exploitation rates, is then used to calculate the recommended biological catch C_{RBC}: $C_{RBC} = ((1 - e -F_{RBC})/(1 - e\text{-}F_{CUR})) * C_{CUR}$ where F_{CUR} is the estimated current fishing mortality, and F_{RBC} is the selected F for the recommended biological catch from the control rule. The estimate of fishing mortality is limited to be no less than 0.1 of natural mortality. The current catch level (C_{CUR}) is calculated as the average catch over the past 4 years (where catch = landings + estimated discards). F_{CUR} generally derived from catch curve analyses (requiring age and/or length frequency data, but not catch rates or abundance indices). Consistent with the Harvest Strategy Policy (HSP), which establishes a more precautionary approach to harvest control rules for species for which assessments are more uncertain, it is considered appropriate to apply a discount factor to the RBCs derived from Tier 3 and 4 assessments. The discount factors to be applied are 5% for Tier 3 and 15% for Tier 4. These values take account of the relative uncertainties in the assessments and reference points at each of these Tier levels.
4	Least amount of information about current stock status. No reliable information on either current biomass or current fishing mortality but information on current catch levels and trends in catch rates.	The Tier 4 control rule is of the form: RBC = C * max(0, ($CPUE_{MEAN}$ - $CPUE_{LIM}$)/($CPUE_{TARG}$ - $CPUE_{LIM}$)) where: $CPUE_{TARG}$ is the target catch per unit effort (CPUE) for the species $CPUE_{LIM}$ is the limit CPUE for the species $CPUE_{MEAN}$ is the average CPUE over the most recent m years C* is a catch target derived from a historical period that has been identified as a desirable target in terms of CPUE, catches and status of the fishery The form of the rule is linear and can result in large catches at high CPUE levels which could deplete the stock very quickly, therefore, a maximum catch level C_{max} is imposed when the CPUE is above the target level, and the multiplier is set to zero when the CPUE is below the limit. Consistent with the Harvest Strategy Policy (HSP), which establishes a more precautionary approach to harvest control rules for species for which assessments are more uncertain, it is considered appropriate to apply a discount factor to the RBCs derived from Tier 3 and 4 assessments. The discount factors to be applied are 5% for Tier 3 and 15% for Tier 4. These values take account of the relative uncertainties in the assessments and reference points at each of these Tier levels.

Table C.8. The data limited stock (DLS) approach of the International Council for Exploration of the Seas (ICES).

T	How to tier	Setting TACs
1	Data rich - full analytical assessment and forecast used for advice	1.1.1 Biomass estimate > MSY $B_{trigger}$: use Baranov catch equation 1.1.2 Biomass estimate < MSY $B_{trigger}$: use ICES MSY Control Rule 1.1.3 Stock size is low (below B_{lim}), outlook is for further decline unless fishing mortality is reduced more rapidly: ICES may advice on more rapid transition or application of F_{MSY}-HCR as soon as possible 1.2 Biomass estimate = extremely low: Recovery plan and possibly zero catch are advised
2	Quantitative assessment and forecast available but they are only considered indicative of trends in fishing mortality, recruitment and biomass	2.1.1 Biomass estimate > MSY Btrigger: use Baranov catch equation, apply uncertainty cap to Cy+1 2.1.2 Biomass estimate < MSY Btrigger: use ICES MSY Control Rule, apply uncertainty cap to Cy+1 2.1.3 Biomass estimate = extremely low: Precautionary approach
3	Survey-based trends assessment - surveys are reliable indicators of trends in stock metrics such as mortality, recruitment and biomass but no quantitative assessment is available Sufficient information to determine a target biomass level, which would be obtained at equilibrium when fishing according to the control rule with recruitment at the average historical level.	3.1.0 FSQ to F0.1 known: Known F ratio, apply uncertainty cap to Cy+1 3.1.1 Index > MSY Btrigger & FSQ > F0.1: FMSY in 2015, apply uncertainty cap to Cy+1 3.1.2 Index > MSY Btrigger & FSQ ≤ F0.1: survey adjusted status quo catch, apply uncertainty cap to Cy+1 3.1.3 Index < MSY Btrigger & FSQ ? F0.1: ICES MSY Control Rule, apply uncertainty cap to Cy+1, apply precautionary buffer to Cy+1 3.1.4 Extremely low biomass: Precautionary approach 3.2 Index available & no proxies for MSY Btrigger & F: survey adjusted status quo catch, apply uncertainty cap to Cy+1, apply precautionary buffer to Cy+1 3.3 Biomass estimate increasing or stable: Fproxy, apply uncertainty cap to Cy+1, apply precautionary buffer to Cy+1 Note: F_{SQ} - current F
4	Catch data available over a short time series - a time-series of catch can be used to approximate MSY Catch-only methods - have biomass level Reasonable biomass level, catch or landings data available and approximation of FMSY/M and M possible.	Apply DCAC 4.1.1 Recent catch > DCAC: DCAC faster step increase, apply uncertainty cap to Cy+1 4.1.2 Recent catch < DCAC: DCAC slower step increase, apply uncertainty cap to Cy+1 Use catch curves to approximate F 4.1.3 Catch curves, apply uncertainty cap to Cy+1, apply precautionary buffer to Cy+1 Reasonable biomass level, habitat dependent, sedentary species, habitat area known, density, size, discard rate borrowed from appropriate area. 4.1.4 Data borrowing, apply precautionary buffer to Cy+1 Low biomass level 4.2 Extremely low biomass: Precautionary approach
5	Data-poor - compile all available information. Limited landings data available, no indication of F relative to proxies.	Short & long-lived: 5.2 No positive trends in stock indicators: Cy+1 = Cy-1, apply precautionary buffer to Cy+1 5.3 Biomass thought to be extremely low: Precautionary approach Short-lived: 5.2.1 Biomass and recruitment estimates unknown: No advice
6	Bycatch or negligible landings - stocks with landings that are negligible in comparison to discards. Also stocks that are part of stock complexes and primarily caught as bycatch species in other targeted fisheries. Bycatch methods - compile all available information. Limited landings data available, no indication of F relative to proxies.	Short & long-lived: 6.2 No positive trends in stock indicators: Cy+1 = Cy-1, apply precautionary buffer to Cy+1 6.3 Biomass thought to be extremely low: Precautionary approach

Table C.9. Description of New Zealand's assessment categories.

Level	Evaluation Method	Description
1	Full Quantitative Stock Assessment	There is a reliable index of abundance and an assessment indicating status in relation to targets and limits.
2	Partial Quantitative Stock Assessment	An evaluation of agreed abundance indices (e.g. standardized CPUE) or other appropriate fishery indicators that have not been used in a full quantitative stock assessment to estimate stock or fishery status in relation to reference points.
3	Qualitative Evaluation	A fishery characterization with evaluation of fishery trends (e.g. catch, effort, unstandardized CPUE, or length-frequency information) has been conducted but there is no agreed index of abundance
4	Low information evaluation	There are only data on catch with no other fishery indicators

Table C.10. Status of US Fisheries, 2007 – 2015.

Year -->	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number of stocks/stock complexes	528	531	522	528	537	449	478	469	473
Number with known status re: overfishing	244	251	250	253	258	284	300	308	313
Number not on overfishing list	203	210	212	213	222	255	272	282	285
Number on overfishing list	41	41	38	40	36	29	28	26	28
Number with unknown status re: overfishing	284	280	272	275	279	165	178	161	160
Number with known status re: overfished	199	199	203	207	219	219	230	228	233
Number not on overfished list	145	153	157	157	174	178	190	191	195
Number on overfished list	45	46	46	48	45	41	40	37	38
Number with unknown status re: overfished	329	332	319	321	318	230	248	241	240
Number of stocks rebuilt in year	3	4	4	3	6	6	2	3	2
Number of stocks rebuilt since 2000	10	14	18	21	27	32	34	37	39

Table C.11. Status of Australian stocks, 2005 – 2014.

Year -->	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Number of stocks assessed	83	97	96	98	101	96	95	93	93	92
Fishing mortality status										
Not subject to overfishing	15	41	45	57	73	71	77	77	78	77
Subject to overfishing	12	5	6	8	10	8	6	4	3	2
Uncertain	56	51	45	33	18	17	12	12	12	13
Biomass status										
Not overfished	25	31	33	44	59	56	58	63	65	66
Overfished	17	15	11	13	12	11	11	9	11	12
Uncertain	41	51	52	41	30	29	26	21	17	14

C.9. FIGURES

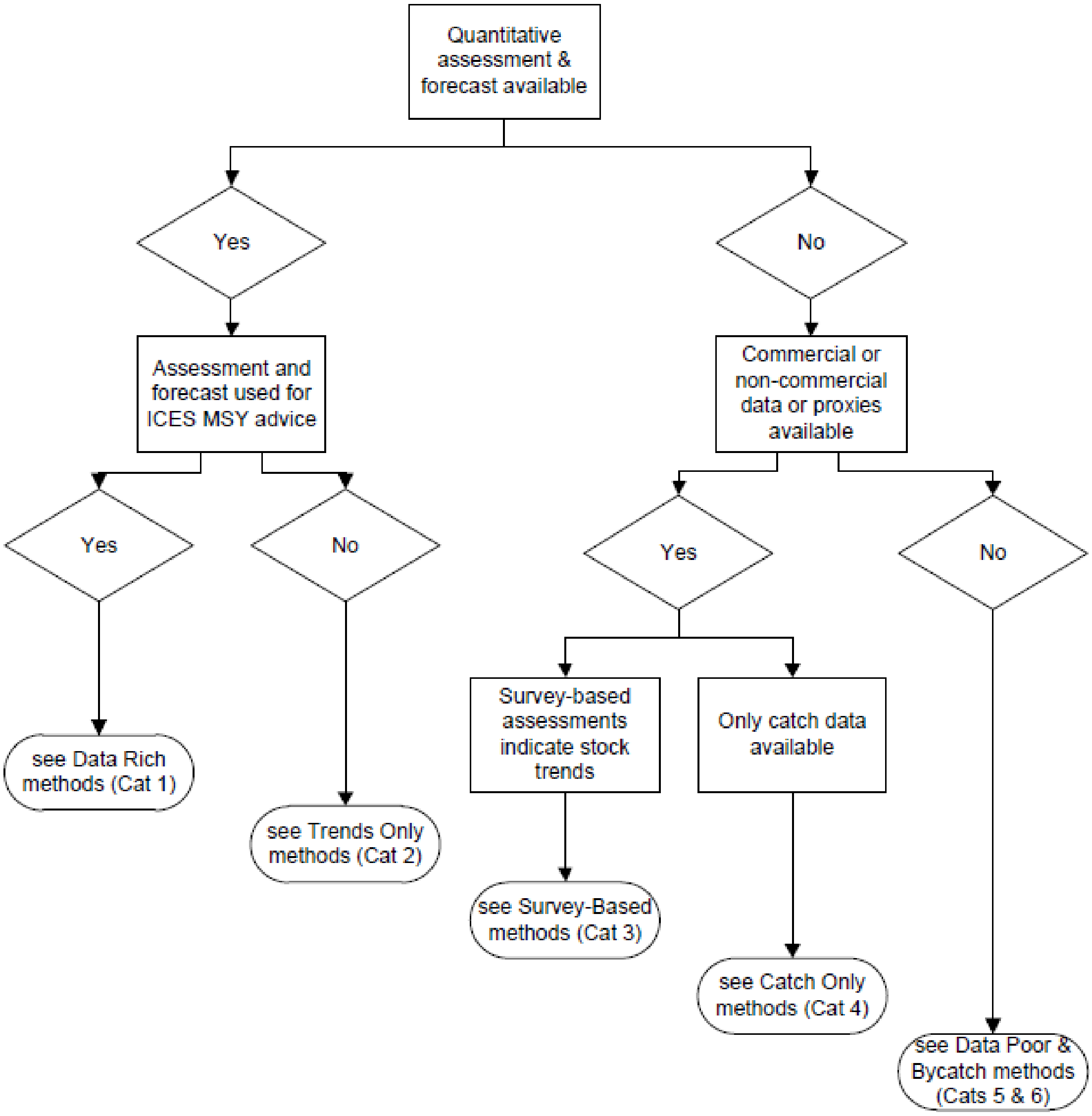

Figure C.1. Overview of the ICES data assessment categories, from data-rich to data-poor (from ICES 2012b).

C.10. ANNOTATED LITERATURE SEARCH

C.10.1. Australia

Australian Fisheries Management Authority (AFMA). 2014. Harvest Strategy Framework for the Southern and Eastern Scalefish and Shark Fishery 2009 (amended February 2014).

This document summarizes the objectives of the Commonwealth Fisheries Harvest Strategy Policy 2007 (HSP): "the sustainable and profitable use of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels, and within the context, maximise the economic returns to the Australian community".

In its simplest form, harvest strategies are designed to pursue an exploitation rate that keeps fish stocks at maximum economic yield (MEY) and ensures stocks are above a limit biomass level (B_{LIM}) at least 90% of the time. The Harvest Strategy Framework (HSF) for the SESSF was developed in 2005 and sets out the management actions needed to achieve defined biological and economic objectives, describes indicators used for monitoring the condition of stocks, the types of assessments conducted and the rules applied to determine recommended total allowable catches.

This HSF uses a three tier approach designed to apply different types of assessments and cater for the different amounts of data available for different stocks. The HSF adopts increased levels of precaution with increased uncertainty about stock status in order to reduce the level of risk associated with uncertainty.

Each tier has its own harvest control rule (HCR) that is used to determine a recommended biological catch (RBC). The RBC is the best scientific advice on what total fishing mortality (all landings + all discards) should be for each species/stock. Once the RBC has been determined from the results of the assessment and the application of the relevant HCR, a TAC is calculated based on TAC setting rules.

The document provides background on the SESSF, objectives of the SESSF harvest strategy, monitoring programs, reference points and decision rules for the setting of TACs, and methods of reporting on the implementation of the SESSF.

DAFF. 2005. Securing our Fishing Future – Ministerial Directive to AFMA. Department of Agriculture, Fisheries and Forestry, Canberra.

This ministerial directive came at a time when the status of many Australian fisheries was reported as poor. The minister directed the Australian Fisheries Management Authority (AFMA) to end overfishing, limit the risk of future overfishing, and manage the broader environmental impacts of fishing.

AFMA was tasked with taking a more strategic, science-based approach to setting total allowable catch and/or effort levels with the aim of managing stocks sustainably and profitably. They were to develop harvest control rules based on maximum sustainable yield with specified target and limit reference points.

In addition, the directive contained instructions for increasing fishery monitoring, minimizing discards, establishing surveys and removal of excess fishing capacity.

DAFF. 2007. Commonwealth Fisheries Harvest Strategy Policy and Guidelines. Australian Department of Agriculture, Fisheries and Forestry, Canberra, Australia, pp. 55.

This document contains the core elements of the Commonwealth Fisheries Harvest Strategy Policy, including objectives, interpretation, roles and responsibilities, application, amending, and reporting and reviewing. Key objectives of the HSP are to stop overfishing, to recover overfished stocks, and to promote longer term profitability for the fishing industry.

The bulk of the document contains the guidelines for implementing the HSP and is meant to provide assistance in developing fishery-specific harvest strategies with the goal of a common approach applied across all fisheries.

The guidelines are a comprehensive background document for: the HSP, the concept of maximum economic yield (MEY), management tools to implement a harvest strategy, approaches for data-poor species and fisheries, recovery and rebuilding strategies, how to turn recommended biological catches (RBC) into management advice, determining harvest strategies for developing fisheries, the technical aspects of management strategy evaluation (MSE), exceptional circumstances that do not meet the intent of the HSP, and the process for amending harvest strategies over time.

Dichmont, C.M., A.E. Punt, N. Dowling, J.A.A. De Oliveira, L.R. Little, M. Sporcic, E. Fulton, R. Gorton, N. Klaer, M. Haddon, D.C. Smith. 2015. Is risk consistent across tier-based harvest control rule management systems? A comparison of four case studies. Fish and Fisheries.

The authors look at four case studies – Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF), the US west coast groundfishery, the US Alaskan crab fishery, and the European Union fisheries – to contrast the types of tier systems available and to assess the extent to which each system constrains risk to be equivalent among tiers.

The paper describes the policy structure, implementation and risk equivalency of the four tier systems. They determine that all of the jurisdictions have the goal of reducing risk when data are poorer. However, only the Australian system has the explicit assumption that risk associated with all species should be equivalent irrespective of the data available (Smith et al. 2014). In addition, the Australian system has no expectation for a fishery to move towards a more data-rich tier over time, especially if the fishery is of low-value. Other systems have the explicit aim to move towards the more data-rich tiers.

To demonstrate the differences in the systems the authors placed the SESSF species into the US and ICES frameworks through comparison of data types, assessment methods and harvest control rules. They found relatively strong agreement, with higher tier SESSF stocks being assigned to higher tiers in the other systems.

The authors discuss the somewhat subjective assignment of control variables that determine buffers used between tiers for the various systems. They also note that management strategy evaluation (MSE) is generally recognized as the best practice approach for comparing management systems.

The authors provide an overview and comparison of the four systems in terms of: is there a "clear definition of risk?", basis of tier system, highest data type, number of tiers, presence of subtiers, and MSE tested? They also summarize the positives and negatives of each system and conclude that all of the systems involve an element of expert judgment.

Of interest to our project are the four recommendations the authors make for how tiers should be developed in the context of achieving risk equivalency.

Dowling, N.A., C.M. Dichmont, W. Venables, A.D.M. Smith, D.C. Smith, D. Power, D. Galeano. 2013. From low- to high-value fisheries: Is it possible to quantify the trade-off between management cost, risk and catch? Marine Policy 40: 41-52.

The main purpose of the paper was to understand how to trade ecological and economic risk and costs associated with management against the benefits, represented by catch. This relationship is known as the risk-cost-catch frontier.

As part of quantifying biological risk, the authors ranked species in terms of overfished and overfishing and then combined the rankings with the four tier levels developed in Smith (2005) and Smith et al. (2008). To provide additional detail and contrast the authors replaced the original four tiers with eight tiers, with Tier 0 having the highest quality information.

No further details were provided on this eight-level tiering approach.

Note: an attempt has been made to contact the first author to get more information.

Haddon, M., N. Klaer, D.C. Smith, C.C. Dichmont, A.D.M. Smith. 2012. Technical reviews for the Commonwealth Harvest Strategy Policy. FRDC 2012/225. CSIRO. Hobart. 69 p.

This document contains a series of reviews of the Commonwealth Fisheries Harvest Strategy Policy (HSP). Of interest to our BC project is the section on data-poor fisheries and tiered harvest strategies.

The review poses key questions, in relation to the HSP implementation and the limitations for data poor fisheries. They provide several definitions of data poor and for their purpose define a fishery or stock as data poor if “information is insufficient to produce a defensible quantitative stock assessment”. They reproduce a table from Restrepo et al. (1998) that uses fishery and stock assessment attributes to describe data richness.

The authors discuss the use of tiered approaches in various Commonwealth fisheries and the results of a study on AFMA’s information needs (Dichmont et al. 2013) that has developed a tier system that has been expanded from the system used in the SESSF (in spreadsheet as Australia Dowling). The work shows that the tier assessment system has two components – the stock assessment method to develop the index of abundance and the method to determine the target or MEY.

The authors also discuss the risk-cost-catch trade-off and the interaction across tiers between economic costs and benefits to achieve an acceptable level of risk. The idea of a discount factor being applied to the recommended catch levels for more uncertain tiers has been used in New Zealand and the US. The application of this will require extensive simulation testing.

Data-poor assessment methods are discussed, including the use of empirical stock status indicators (e.g., catch, CPUE, mean age, total mortality). There has been a push for research into data-poor methods for assessment but not the same amount of work into the effectiveness of different data-poor control rules.

The authors discuss data-related issues, particularly what the minimum information requirements should be for a fishery.

Haddon, M. (ed.). 2012. Reducing Uncertainty in Stock Status: Harvest Strategy Testing, Evaluation, and Development. General Discussion and Summary. CSIRO Marine and Atmospheric Research. 42 p.

This document reports on stream two of the Reducing Uncertainty in Stock Status project that was instigated within the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). One of the objectives of the project was to attempt to reduce the number of fisheries in the uncertain status classification within the annual ABARES Fishery Status Reports.

The second stream related to using management strategy evaluation (MSE) to test the particular harvest strategies implemented in five different fisheries. The present document presents the executive summaries of each of the MSE projects and then a brief discussion of the findings, and finally the separate standard reporting framework that details each fishery.

One of the questions in the reporting framework: Do adjustments to RBCs reflect increasing uncertainty at higher tiers?

McIlgorm, A. 2013. Literature study and review of international best practice in fisheries harvest strategy policy approaches. A report to the Department of Agriculture Fisheries and Forestry (DAFF). Canberra, by ANCORS, University of Wollongong.

Five years after the implementation of the Australian Harvest Strategy Policy (HSP) in 2007, the author examines current sources and standards for international best practice (IBP).

The study compares IBP for common fishery reference points and control rules, as well as other less developed policy areas: multi-species fisheries, data-poor fisheries, low value species and fisheries, managing discarding, different productivity levels of various species, different trophic levels and roles, application of risk based approach.

The author provides an overview of 1) international legal obligations as sources of IBP, 2) harvest strategy features, or equivalent, in countries or regions that have strong fisheries management (USA, NZ, EU, Norway, Iceland), 3) international codes of conduct developed by FAO, and 4) eco labelling and certification schemes.

The author then examines both the core and developing harvest strategy features of other countries to determine IBP in terms of reference points.

Tiering is discussed in the context of “Application of risk based approaches”. The Australian approach of applying increasingly precautionary approaches to estimating RBCs and TACs as uncertainty increases represents IBP in this regard.

The author concludes that the HSP is seen to be meeting requirements of international agreements and meets or exceeds standards in other countries with a reputation for good fisheries management practices. He noted that in the future, more emphasis would need to be put on the marine ecosystem diversity and environment which will require clarification of the role of the HSP in Australia’s multi-agency approach to fishery and marine environment issues.

Sainsbury K. 2008. Best practice reference points for Australian fisheries. Report to the Australian Fisheries Management Authority, R2001/0999, Canberra, Australia.

The author defines 'best practices' as those that have been demonstrated to work well in successful and highly admired examples. In this paper the author used qualitative expert judgment to select examples of best practices in fisheries. He approached individuals with knowledge of fisheries assessment and the use of reference points to choose fisheries that illustrated best practice for a range of issues.

The author provides definitions of target, limit and trigger reference points and provides an in-depth discussion on the various reference points. Best practice reference points are considered for five elements of environmental management that are central to modern fishery management – the target species; by-catch species; threatened, endangered or protected species; habitats; and food webs.

The fisheries identified included the Pacific halibut, Alaskan groundfish, US West Coast groundfish, US northeast scallops (as an example of recovery), southern ocean icefish and krill, and Icelandic cod. Also identified were elements of the ICES system, Australia's Ecological Risk Assessment and the Marine Stewardship Council (for Australian western rock lobster, New Zealand hoki, Alaskan pollock, Atlantic cod and South Georgia toothfish).

Sloan, S. R., Smith, A.D.M., Gardner, C., Crosthwaite, K., Triantafillos, L., Jeffries, B. and Kimber, N (2014) National Guidelines to Develop Fishery Harvest Strategies. FRDC Report – Project 2010/061. Primary Industries and Regions, South Australia, Adelaide, March. CC BY 3.0

The authors introduce harvest strategies as representing a best practice approach to fisheries management decision making (Smith et al. 2013; McIlgrom 2013).

The overall aim of the project was to develop National Guidelines to Develop Fishery Harvest Strategies and the project had three objectives:

1. Undertake a review and analysis of the present situation of harvest strategies in Commonwealth and State-managed fisheries.
2. Develop a common definition for nationally consistent harvest strategies.
3. Develop an agreed set of over-arching principles for Harvest Strategies across Australia

The project identified that a harvest strategy brings together all of the key scientific monitoring, assessment and management elements used to make decisions about the intensity of fishing activity to be applied, or catch to be removed from, a fish stock or fisheries management unit.

The report was structured to answer questions about the following harvest strategy components which have been developed to form the National Guidelines:

1. A national harvest strategy definition;
2. A description of the key elements of a harvest strategy;
3. A set of harvest strategy design principles;
4. A harvest strategy design process (the key steps to be followed); and
5. Considerations for specific fishery scenarios.

Smith, A.D.M., D.C. Smith, G.N. Tuck, N. Klaer, A.E. Punt, I. Knuckey, J. Prince, A. Morison, R. Kloser, M. Haddon, S. Wayte, J. Day, G. Fay, F. Pribac, M. Fuller, B. Taylor, L.R. Little. 2008. Experience in implementing harvest strategies in Australia's south-eastern fisheries. Fisheries Research 94: 373-379.

The authors provide brief background information on Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF), harvest strategies used in the past and the framework that was adopted for the SESSF in 2005. They also document modifications to the framework and discuss the general experience of applying the framework in the SESSF.

Legislative requirements led to the development and adoption of a SESSF harvest strategy framework in 2005. Less than half of the stocks in the quota management system had been assessed previously with a quantitative stock assessment so it was not possible to use a single HCR. Instead, the fishery adopted the idea of a tiered approach from similar fisheries in USA (Goodman et al. 2002) and extended that approach somewhat. Each species was assigned to one of four tiers based on data availability and other types of information to assess stock status, with tier 1 representing the highest quality of information and target fishing mortality rates decreasing as Tier levels increase. The authors outline the types of assessments used for each Tier and detail the harvest control rules applied to produce a recommended biological catch (RBC).

The authors describe both the positive and negative aspects of implementing the harvest strategy framework and summarize the lessons learned. In particular, the authors note that it would have been preferable to spend more time developing and testing the framework and strategies prior to implementation, e.g., using management strategy evaluation (MSE).

Measures of success include reduction in the time and effort required to reach agreement on TAC recommendations, a more streamlined assessment process, and the ability of the tiers to deal with data-poor to data-rich stocks. The most important lesson learned was the need for flexibility, i.e., it is better to implement a harvest strategy system recognizing it will change, rather than delay until it is "perfect".

Smith, A.D.M., D.C. Smith, M. Haddon, I.A. Knuckey, K.J. Sainsbury, S.R. Sloan. 2013. Implementing harvest strategies in Australia: 5 years on. ICES Journal of Marine Science 71: 195-205.

The authors review the Australian experience in implementing the Harvest Strategy Policy (HSP), five years after its adoption. They provide background information on the goals of the HSP, how the HSP was implemented, the achievements of the HSP, and issues with implementation, including issues that still need to be resolved or that have developed since implementation.

The authors detail achievements of the HSP and the challenges of implementing. Overall, the authors conclude that the HSP has been a worthwhile endeavour. They note that one of the primary lessons learned is the need for a clear policy that still allows flexibility in adoption, implementation, and review of harvest strategies at the individual fishery level. They note that the use of management strategy evaluation (MSE) in developing and testing potential strategies was widely used.

The use of a tiered approach is given in the context of the Southern and Eastern Scalefish and Shark Fishery (SESSF) which was the first Commonwealth fishery to adopt a more formal approach to harvest strategies. The use of tiers to reflect uncertainty is a practical application of the precautionary approach but there is still uncertainty about the actual application of precaution at the higher, more uncertain tiers.

Other topics of note for BC are the discussions on possible impacts of multi-year TACs, the impacts on individual species in a multispecies fishery where the HSP sets targets for the fishery as a whole, and linkages with ecosystem considerations.

Wayte, S.E. (ed.) 2009. Evaluation of new harvest strategies for SESSF species. CSIRO Marine and Atmospheric Research, Hobart and Australian Fisheries Management Authority, Canberra. 137 p.

The objectives of the evaluation were to:

- Collate the experience with the first year of adoption of the SESSF harvest strategy framework, and recommend immediate improvements to the framework.
- Formally test the consistency and robustness of the harvest strategy framework using simulation approaches (management strategy evaluation), and recommend longer term improvements to the framework.

The document is made up of a number of separate papers that address the two objectives. One paper outlined the implementation of the Harvest Strategy Framework (HSF), current issues and problems, and recommendations for modifications. Recommendations included clarity on targets and thresholds for each Tier and also the elimination of Tier 2. There were also recommendations to introduce precaution into the HSF by applying Tier specific multipliers to Recommended Biological Catch calculations, and to change the shape of the Tier 3 and Tier 4 harvest control rules.

Several papers addressed the requirement of the HSF for formal testing with management strategy evaluation (MSE). Papers described the testing of Tier 1 rules on three species, the testing of the original and improved Tier 3 and 4 rules, as well as tests for evaluating proposed rules for changing the total allowable catch in response to the most recent year's catch per unit effort.

The papers emphasized the need for testing and the authors concluded that formal testing of the harvest strategy framework provided all stakeholders with confidence that the fishery is being managed in accordance with agreed sustainability objectives. The MSE testing framework developed in this project can be used to evaluate any future proposed changes to the HSF.

C.10.2. ICES

Froese, R., T.A. Branch, A. Proelß, M. Quaas, K. Sainsbury, C. Zimmermann. 2011. Generic harvest control rules for European fisheries. Fish and Fisheries 12: 340-351.

The authors state that European fisheries are in deep trouble; most stocks are overfished and many are outside of safe biological limits (EC 2009). This has resulted in the European Commission calling for the development of long-term management plans once European fisheries are brought back from the brink.

In response the authors propose a set of generic harvest control rules based on six pillars:

1. The rules are compatible with economic optimization of fisheries management

2. The rules are firmly rooted in international agreements and other relevant instruments to which the European countries and the EU are parties
3. The rules adhere to the precautionary principle, which is a binding principle of EU law
4. The rules build on relevant experiences with harvest control rules in other regions, such as Australia, New Zealand and the USA
5. The rules take into account species interactions and support the move towards ecosystem-based fisheries management
6. The rules account for the known biological properties of European stocks

Their suggested harvest control rules are a reference and trigger biomass (BMSY), a target biomass (1.3 BMSY), a limit biomass (0.5 BMSY), total allowable catch, TAC reductions, mixed fisheries rule, discard rule, bycatch rule, and a size structure rule. The authors describe each and provide a rationale and justification for each.

They examine whether the proposed HCR could have prevented the collapse of the North Sea Herring stocks in 1978 and how the stock would have rebuilt under the new rules. They also look at how the HCR dealt with cyclic phases of low and high recruitment for another species.

ICES. 2012. Report of the Workshop on the Development of Assessments based on LIFE history traits and Exploitation Characteristics (WKLIFE), 13–17 February 2012, Lisbon, Portugal . ICES CM 2012/ACOM:36. 140 pp.

This report documents a workshop convened by ACOM to investigate the feasibility of developing a methodology for providing assessments and advice on data deficient stocks.

Purposes were:

a. identify options for determining proxies for F_{MSY} for stocks without quantitative forecasts, using life history traits and exploitation characteristics;
b. identify methods for estimating current exploitation based on available limited information (for instance catch and survey data);
c. apply the above to 122 stocks and identify stocks for which this can be used and stocks for which there is insufficient information;
d. identify the data to be collected for the 122 stocks in order to implement the approach under a) and b); and
e. identify options for multi-annual harvest rules for the stocks where there is sufficient information to apply the approach under a) and b).

In efforts to address the purpose of the workshop, the group investigated generic data-poor methods to establish per-recruit models, the estimation of MSY from catch and resilience (production models), and productivity-susceptibility analysis.

The workshop participants examined 122 stocks. Traditionally, these species are regarded as data-poor but during discussions at the workshop it was decided that this designation was unhelpful and largely inaccurate as the majority of these stocks have more information available than either catch or landings.

A categorization system was proposed and adopted at the workshop with the identification of seven categories of stock ranging from data rich through to truly data-poor. The WKLIFE project is not concerned with the data rich stock category but it is presented for completeness.

In addition, the workshop participants did a preliminary evaluation of the proposed ICES F_{MSY} harvest control rules (WKFRAME3) on selected stocks.

The report concluded that the workshop demonstrated that ICES should be endeavouring to move more stocks into the data-adequate category over time. They recommend compiling life history traits for stocks from as many sources as possible, e.g., FishBase, databases.

ICES. 2012. Report of The Workshop to Finalize the ICES Data-limited Stock (DLS) Methodologies Documentation in an Operational Form for the 2013 Advice Season and to make Recommendations on Target Categories for Data-limited Stocks (WKLIFE II), 20–22 November 2012, Copenhagen, Denmark. ICES CM 2012/ACOM:79. 46 pp.

This second workshop was convened by ACOM to finalize the ICES data-limited stock (DLS) guidance document for the 2013 advice season and to consider further developing methodologies for DLS. Beginning in 2011, the DLS approach was implemented with 68 data-limited stocks being assessed for the 2012 season. This was a more than six-fold increase from the 10 data-limited stocks that were assessed in 2010. In addition, more species were assessed throughout 2012.

During the workshop the draft document used during the 2012 advice season was reviewed and updated and a final document was produced (ICES CM 2012/ACOM:68). This guidance document was used as the basis for deciding upon the prioritization of the simulations to be undertaken in 2013 before the third and final meeting of WKLIFE.

For the 133 data-limited stocks, the participants at WKLIFE II discussed the categorization of methods and their information requirements (required and optional). During discussions within WKLIFE II it was noted that the DLS Categories 1 to 6 do not represent a hierarchy of methods but are merely a useful categorization and moving from category to category requires a robust framework. The participants noted that it was a priority to investigate the robustness of the ICES DLS approach to decreasing information using simulation testing, particularly for the application of precautionary measures such as uncertainty caps and precautionary buffers. They also discussed the use of productivity-susceptibility analysis (PSA) to separate high and low risk stocks and to rationalize the movement between categories.

Of some interest was the discussion on assignment of stocks into categories 3 and 4. By definition, Category 3 stocks are those for which *survey indices (or other indicators of stock size such as reliable fishery-dependent indices [cpue and mean length in the catch) are available that provide reliable indications of trends in total mortality, recruitment and biomass*. However, there was general agreement that if only fishery-dependent is available the stock should be assigned to category 4 where a precautionary buffer would be applied.

ICES. 2012. ICES Implementation of Advice for Data-limited Stocks in 2012 in its 2012 Advice. ICES CM 2012/ACOM 68: 42 pp.

This paper outlines the ICES framework that was developed to provide quantitative assessments in relation to F_{MSY} for data-limited stocks.   Principles of this framework include using all available data, basing the advice on the same principles applied for stocks with full analytical assessments, and that the precautionary approach should be followed.

The starting point is the categorization of stocks according to the data and analyses that are available. The categorization is intended to reflect decreasing availability of data and, therefore less certainty in conclusions about fishing pressure and the state of the stock. This implies that exploitation rates advised for stocks below the top, data-rich category will be more conservative than F_{MSY}.

ICES conducted a series of workshops (e.g., WKLIFE, RGLIFE, WKFRAME III) to develop guidelines for categorization of stocks. Based on the guidelines from these workshops, the ICES Secretariat worked with the Advisory Committee (ACOM) and the Expert Groups (EGs) to categorize data-limited stocks according to WKLIFE and RGLIFE approaches, and based on the categorization and in the context of the precautionary approach, apply a methodology that provides quantitative advice for stocks given the information available.

The document describes the six categories developed by ICES and the methods suggested to provide quantitative advice. Section C.10 presents the decision trees used for classification into categories 1 to 6, as well as the decision trees for the method to be used within each of categories 2 to 6. The authors state that some methods have been tested by simulation, others require further simulation work, and some are based on common sense. It is pointed out that work is ongoing and this guidance document is likely to be updated and modified as methods evolve. It is also recognized that there are alternative approaches to the methods proposed and EGs may find that there are methods that are more suitable for a specific stock while maintaining the same principle of precaution as the general framework.

In addition, the paper makes note of four areas for future research: consideration of dynamic and static conditions (e.g., predators, prey, impacts on natural mortality, growth, and recruitment), methods for data-limited, short-lived species, productivity and susceptibility analysis, and uncertainty in survey indices.

ICES. 2012. Report of the Workshop 3 on Implementing the ICES Fmsy Framework, 9-13 January 2012, ICES, Headquarters. ICES CM 2012/ACOM:39. 33 pp.

Participants at this workshop were tasked with further developing the empirical approach to providing advice when no estimate of population size exists. The work followed on versions that were developed in 2010 and modified in 2011. The document provides background context on the ICES MSY policy for advice and the harvest control rule that generates the advice.

The primary development of the workshop was a generic expression, as well as a table, to describe the empirical approach using productivity status, trend in the stock, and exploitation status. A further development was the introduction of a precautionary factor. They present the approach as an option for the basis of advice for data-poor stocks in 2012.

The report also provides a very brief summary of data poor initiatives in other jurisdictions, i.e., Australia, New Zealand, and USA.

ICES. 2013. Report of the Working Group on Methods of Fish Stock Assessments (WGMG), 30 September - 4 October 2013, Reykjavik, Iceland. ICES CM 2013/SSGSUE:09. 130 pp.

The workshop was based on four terms of reference (ToR). The first was a brief review of current mixed fishery and multispecies approaches which ended with a recommendation for evaluating a mixed fishery approach under a minimum realistic multispecies operating model.

The second ToR investigated the robustness of the DLS approach as a framework for providing advice. Management strategy evaluation was used to determine if the DLS framework provided more conservative advice when less data are available, i.e. when one moves down the DLS categories. The presented simulations did not include feedback as it was intended to do a comparison of the catch advice that each DLS category would provide under a variety of identical stock situations. The results indicated that the DLS approach does not always provide increasing precaution with increasing uncertainty. This is evident for scenarios of overexploitation or increasing exploitation (SSB declining).

The second ToR also looked at different harvest control rules from those suggested by ICES (2012 dls) for age-aggregated approaches. This included consideration of survey index confidence interval and length-based reference points.

The third ToR reported on efforts of an Assessment Methods Evaluation Scheme conducted in conjunction with the World Conference on Stock Assessment Methods (WCSAM, Boston, July 2013 and looked forward to possible future development of the simulation exercise.

The final ToR evaluated existing recent software for estimating MSY reference points and possible improvements. They conducted a comparison of methods applied to two ICES datasets and highlighted the problems with estimating reference points from stock-recruit data.

ICES. 2013. Report of the Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other key parameters for Data-limited Stocks (WKLIFE III), 28 October–1 November 2013, Copenhagen, Denmark. ICES CM 2013/ACOM:35. 98 pp.

This third workshop was convened to build on the work of past ICES workshops to:

a. Identify preferred options for determining proxies for FMSY for stocks without quantitative forecasts, using life-history traits and exploitation characteristics.
b. Identify key methods for estimating current exploitation based on available limited information (for instance, catch and survey data).
c. Investigate/define the methods to determine the relationship between life-history traits and the variance of stock development indices.
d. Identify the synergies in (a), (b) and (c) to make further advances in the development of quantitative methodologies for data-limited stocks.
e. Review the simulation work identified at WKLIFE II and make recommendations on current and future method choices for data-limited stocks.
f. Investigate the application of PSA to inform the advice for sustainable fisheries for data-limited and data-rich stocks. It should speak directly to the application (and magnitude) of the precautionary buffer for data-limited species. The susceptibility parameter(s), weightings (note-see NMFS), vulnerability, scaling, etc. should be designed for PSA criteria relevant to start the process, formalize/quantify each by ecoregion and then drill down to finer scales as required.

The workshop report includes a review of simulation work undertaken both before and during the workshop incorporating age-based and length-based approaches to data-limited stocks; information on time-series smoothers and a Dynamic Factor Analysis (DFA) approach to multiple abundance/biomass indices from surveys; Productivity and Susceptibility Analysis (PSA) in the Mediterranean, Celtic Seas and Northeast Atlantic (NEA); issues raised by ACOM and ICES expert groups since the last meeting of WKLIFE II; and recommendations for topics to be discussed at a fourth WKLIFE workshop.

ICES. 2014. Report of the Workshop on the Development of Quantitative Assessment Methodologies based on LIFE-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE IV), 27–31 October 2014, Lisbon, Portugal. ICES CM 2014/ACOM:54. 243 pp.

During this workshop a summary of ICES' simulation testing to date was presented. Findings indicated that some harvest control rules in the DLS approach were not working as expected (e.g. Category 3.2) and would fail to recover overexploited stocks. Further testing was recommended.

The report also provides a review of data-limited methods (Annex 4). There is a summary of the methods, data requirements, assumptions, outputs and caveats, as well as any testing that was conducted on a given method, including simulation testing. They also note several summaries on data limited methods, notably a review of world practices in fisheries assessment methods for FAO including a review of data-poor assessment methods and their application to management by Butterworth and Geromont (2014), and another paper evaluating data-poor methods within an MSE framework by Carruthers et al. (2014).

Workshop participants also examined catch-, length-, and survey-based methods for ICES stocks in assessment categories 3, 4, 5, and 6 and reported on the outcomes of their application. They also tested empirical, survey-, and length-based harvest control rules for data-limited stocks within a management strategy evaluation framework using 50 data-limited stocks under two fishery scenarios: development and overexploitation. There was some discussion on application of the Precautionary Approach buffer. This included an overview on the USA and Australian use of buffers and how stock productivity and resilience could help determine the magnitude and timeframe for application of the buffers.

ICES. 2015. Report of the Fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks (WKLIFE V), 5–9 October 2015, Lisbon, Portugal. ICES CM 2015/ACOM:56. 157 p.

This report documents the fifth Workshop on the Development of Quantitative Assessment Methodologies based on Life-history traits, exploitation characteristics, and other relevant parameters for data-limited stocks (WKLIFE V). The purpose of the workshop was to identify and develop operational methods for the provision of plausible MSY proxies for all ICES category 3 and 4 stocks.

The WKLIFE V workshop was successful in developing operational methods for setting reference point proxies for stocks in categories 3 and 4 and these methods will be implemented by ICES scientists with expert knowledge of the stocks and fisheries in a subsequent ICES meeting [WKProxy]

Participants looked at a number of methods and applied them to data-limited and data-rich case studies in order to evaluate the strengths and weaknesses of each method for application to the ICES DLS approach (ICES 2012). Reviewed approaches included

1. length-based indicators and reference points,
2. spawning potential ratio (SPR),
3. catch and cpue-based methods, and
4. catch-based methods.

The report sets out the methods, data requirements, outputs expected, method of operation, testing, caveats, and software. All subgroups used a common example (*Nephrops* in southwest and south Portugal (FUs 28–29)), in order to facilitate discussion and comparison of the methods and approaches. In addition some methods were tested on other species/stocks.

At the conclusion of the workshop it was considered premature to specify a decision tree to guide the appropriate method for category 3 and 4 stocks. However, initial guidance was provided on a method appropriate to each stock (28 stocks listed) based on data availability and these will be examined at the WKProxy workshop.

Workshop participants also evaluated the prospects of managing other crustaceans and molluscs (excluding *Nephrops*). Information was provided on landings, effort, abundance indices, and biological data. The use of minimum landing size (MLS) was investigated for managing fisheries while approximately achieving MSY. This is a management approach that might be taken where assessment is not possible.

Lassen, H., C. Kelly, M. Sissenwine. 2012. ICES Advisory Framework 1977-2012: From MSY to Precautionary Approach and Back. ICES Journal of Marine Science 71 (2): 166-172.

In this report the authors do not provide any new information. They summarize background information on the changing landscape of how ICES has provided fisheries management advice. They note that ICES' fisheries advice has swung between two viewpoints: one with a focus on fishing mortality based advice to another where the emphasis is on biomass oriented advice.

In response to meeting the most current international agreements, ICES devised the MSY framework in 2009, focusing on the yield and a set of fishing mortalities that would maximize the yield (F_{MSY}), and a Spawning Stock Biomass (SSB) above a threshold value to avoid impairment of recruitment. The authors describe the MSY framework and note that it is a decision rule that determines the target fishing mortality for various levels of SSB.

They describe how the MSY framework categorises the information available for a stock and proposes a suite of methods which can be applied, with increasingly approximate metrics, to develop catch advice. There are six categories described and as you move from category 1 (precise assessment) through to the lower categories the advice becomes more precautionary, reflecting the decreasing amount of available data.

In 2012, ICES developed an approach for data-limited fisheries which includes considerations regarding uncertainty and precaution that need to be applied. The approach is intended to move in the direction of sustainable exploitation, taking into account the species' biological characteristics and uncertainty in information.

The paper also included a section on short-lived stocks that did not appear to be applicable to the Pacific coast groundfish situation.

The authors also document the transition to MSY fishing starting in 2011, with F being reduced in five equal steps from the start year to full implementation in 2015.

Le Quesne, W., M. Brown, J. de Oliveira, J. Casey, C. O'Brien. 2013. Data-deficient fisheries in EU waters. Study. Centre for Environment, Fisheries and Aquaculture Science (CEFAS).

The authors provide background on fish stock assessment and discuss the resulting spectrum of methods that have been developed to accommodate varying amounts and availability of data.

In this study stocks are considered 'data-rich' if they are assessed in relation to defined MSY based fishing mortality and biomass reference points and all other stocks are considered 'data deficient'. The authors describe the models (e.g., age-based, surplus production) and data requirements for data-rich fisheries and go on to address the nature and challenges of data-deficient fisheries, including the reasons that data-deficient fisheries exist.

ICES was asked by the European Commission to establish a program to develop data-deficient assessment methods and data limited management control rules and in 2012, ICES implemented the data limited stocks approach (DLS). Under the DLS approach stocks are assigned to one of 6 data categories ranging from fully assessed data-rich stocks to by-catch species with almost no information. The categories are defined based on data availability and uncertainty increases as you move down through the data categories from 1 to 6. The DLS approach proposes different stock assessment procedures and management control rules for each data category. The basis of the management control rules also varies across data categories ranging from decision in respect of MSY proxies through to common sense rules with no specific biological foundation.

The authors discuss the use of management strategy evaluation (MSE) for testing the robustness of paired data-deficient assessment methods and management control rules to uncertainty but they note that limited MSE evaluations have been applied to date to the ICES DLS approach.

They also provide some background on how other jurisdictions (United States, Australia, New Zealand and NAFO) approach data-limited fisheries and point out possible drivers that lead to the different approaches. These drivers include differences in data-collection regimes which leads to different data being available in different regions, variation in management requirements between regions, and variation in resources available for data collection analysis and assessment.

The authors believe that the European approach (i.e. DLS) to data-deficient fisheries is a significant step forward and provides a clear and structured approach to the management of data-deficient stocks. They acknowledge that more work is needed to ensure a consistent approach to risk and precaution and conclude with recommendations for actions in relation to data-deficient fisheries.

C.10.3. New Zealand

Edwards, C.T.T. 2015. Review of data-poor assessment methods for New Zealand fisheries. New Zealand Fisheries Assessment Report No. 2015/27. 24 p.

The author provides an overview of data-poor methods in use internationally, drawing in particular on those presented at the world conference on stock assessments methods (WCSAM) held in Boston MA, USA, in July 2013. The author first defines data-poor fisheries and describes the legislative frameworks of New Zealand, Australia and United States. In New Zealand there is a requirement "to assess, based on scientific information, the status of fisheries and fish stocks relative to MSY-compatible reference points and other relevant indicators of stock status" (Ministry for Primary Industries, 2014). As part of the process, assessments are categorized according to four levels of complexity from level 1 (full quantitative stock assessment) to level 4 (low information evaluation). Data-poor fisheries are classified as belonging to assessment levels 2-4 and represent about 80% of all fisheries in New Zealand (by numbers). Within the concept of data-poor the author introduced the idea of capacity-poor fisheries as fisheries that may not be data-limited but are limited by technical capacity (i.e. the scientific capacity to carry out a stock assessment is not available).

The author reviews catch-only methods, length-based methods, non-parametric and time-series models, swept area methods, and process-based methods used in various jurisdictions. He provides the method, outputs and example applications of the method and in addition, documents the data requirements required for each method. He then identifies potential applications to data-poor stock assessment methods to fisheries in New Zealand and concludes with a section on translating assessment results into management actions. Australia and United States are putting more scientific emphasis on the decision making process, rather than on estimates of status.

The information provided in tables 2 and 3 may provide guidance for the choice of assessment methods for British Columbia groundfish fisheries.

Mace, P.M. 2012. Evolution of New Zealand's fisheries management frameworks to prevent overfishing. ICES DocumentCM2012/L: 09. 13 pp.

Since 1986, New Zealand has managed its fisheries using a quota management system based on individual transferable quotas. The Fisheries Act requires that the management target is based on maximum sustainable yield (MSY) and implies that it is achieved by keeping the biomass near or above the biomass level associated with MSY, i.e., B_{MSY}. The author notes that New Zealand was one of the few countries to use biomass targets, rather than fishing mortality targets.

The author reviews the implementation and evolution of the quota management system and the subsequent development of the Harvest Strategy Standard (HSS) and supporting guidelines through 2005-2008. The HSS set target and limit reference points and the need to examine fishing mortality rates was introduced.

The author provides a summary of the increased number stocks assessed against the HSS and notes that future work will involve development of methods to determine the status of stocks with limited information.

Ministry of Fisheries. 2008. Harvest Strategy Standard for New Zealand Fisheries. Ministry of Fisheries, New Zealand.

The Harvest Strategy Standard (HSS) is a policy statement of best practice in relation to the setting of fishery and stock targets and limits for fish stocks in New Zealand's Quota Management System (QMS). The document outlines the core elements of the HSS, including objectives and appropriate probabilities of achieving outcomes.

There is a companion document entitled "Operational Guidelines for New Zealand's Harvest Strategy Standard", which incorporates both technical and implementation guidelines.

The HSS is concerned with the application of best practice in relation to the setting of fishery and stock targets and limits, but it is focused on single species biological considerations and related uncertainties, and includes only limited consideration of economic, social, cultural or ecosystem issues. Although the HSS will form a core basis for the Ministry's advice to the Minister, other considerations such as environmental principles and economic, social, and cultural factors also play a role in the advice to, and decisions by, the Minister.

Ministry of Fisheries. 2011. Operational Guidelines for New Zealand's Harvest Strategy Standard. Ministry of Fisheries, New Zealand.

The operational guidelines for New Zealand's Harvest Strategy Standand (HSS) consist of two parts:

1. Technical Guidelines – guidance on calculations of biological reference points to be used as inputs to setting fishing targets, and the basis for the default limits specified in the Harvest Strategy Standard
2. Implementation Guidelines – include sections on the transition period for implementing the Harvest Strategy Standard, the roles and responsibilities of science working groups and management working groups in estimating biological reference points and setting management targets, and the implications of implementing the Harvest Strategy Standard

The guidelines note that each fishery-stock combination is unique, with differences in the types, amounts and quality of data available to calculate biological reference points and assessing the status of stocks relative to MSY-compatible reference points or better and related limits.

C.10.4. USA

DiCosimo, J., Methot, R. D., and Ormseth, O. A. 2010. Use of annual catch limits to avoid stock depletion in the Bering Sea and Aleutian Islands management area (Northeast Pacific). – ICES Journal of Marine Science, 67: 1861–1865.

The paper describes the background of the US federal fisheries and the need for changes that have arisen from the Magnuson-Stevens Fishery Conservation and Management Act (MSA) (and its revisions), to end and prevent overfishing by the use of annual catch limits (ACLs) and accountability measures.

The authors note that in the Northeast Pacific, science-based overfishing levels and acceptable biological catches (ABCs) have been implemented for each stock or assemblage, with buffers between the two to avoid overfishing. Total allowable catches are set at or below the acceptable biological catch. Since 1996, the use of a set of six tiers has been used to calculate the overfishing limit (OFL) and acceptable biological catch (ABC). They also detail the accountability measures that are in place to ensure that quotas are not exceeded (e.g., allocations by season, area, and gear type, in-season fishery closures, on extensive observer coverage and vessel monitoring).

The authors believe that the Northeast Pacific has become a model for other regional fishery management councils. Other councils are moving to amend their plans to include ACLs and accountability measures.

Fisheries Leadership & Sustainability Forum. 2012. Risk Policy and managing for uncertainty across the regional fishery management councils. Prepared in support of the New England Fishery Management Council Risk Policy Workshop, March 20–21, 2013.

This report was written as a resource for fishery managers and to provide a platform for sharing progress and lessons learned across council regions. The report consists of eight regional profiles, which provide a high-level overview of the different approaches adopted by each of the eight regional councils and their Scientific and Statistical Committees (SSC) to manage risk and account for uncertainty in their specification processes.

These regional profiles build on the original “Risk Policy and Managing for Uncertainty Report” published by the Fisheries Leadership & Sustainability Forum in 2010.

Included in the background section are a review of the National Standard 1 guidelines for establishing Allowable Catch Limits (ACLs) and a general overview of the approaches councils have taken to comply with the ACL mandate and to account for scientific and management uncertainty. If a Council has taken a tiered approach it is described along with how the overfishing limit and allowable biological catch is determined for each tier.

The discussion section captures some of the high-level themes across regional risk policies. This includes the need for a balance of structure and flexibility, managing risk, accommodating data limitations, management uncertainty, and the tools, processes and relationships that can be used to guide risk considerations.

This report was a valuable document for identification of tiered approaches used in the US.

Goodman, D., Mangel, M., Parkes, G., Quinn, T., Restrepo, V., Smith, T., Stokes, K. 2002. Scientific review of the harvest strategy currently used in the BSAI and GOA groundfish fishery management plans. North Pacific Fishery Management Council, Anchorage, AK, p. 153.

The authors were tasked with providing an independent scientific review of the current harvest strategy within the North Pacific Fishery Management Council fisheries management plan for the Bering Sea/Aleutian Islands/Gulf of Alaska groundfish fisheries.

The authors successfully produced a primer which included approaches to fishery management, discussion on uncertainty and risk, objectives of the fishery, the role of science, and an overview of fisheries management in the US (i.e. Magnuson-Stevens Act (MSA)). They summarize that the basic objectives of fishery management are to catch the greatest amount of fish possible while taking account of the need to ensure long-term viability of the stock and other ecological considerations.

The authors summarize the elements of the harvest control rules and TAC-setting process used by the North Pacific Fishery Management Council, as well as providing historical background on the development of the system. A key factor in the system is the classification of stocks into six Tiers depending on the information available, with Tier 1 having the most information and Tier 6 having the least.

The authors review how well the harvest strategy meets the goals of managing and conserving the target stocks, from a single species perspective, as set out by the Magnuson-Stevens Fishery Conservation and Management Act and the National Standard Guidelines. They discuss the treatment of F_{MSY} as either a target or a limit, with the end result of a policy change to treat F_{MSY} as a limit and not a target.

The authors discuss the use of F_{MSY} proxies when the estimates of F_{MSY} are too unreliable to be applied in management, due to lack of data or other uncertainties. They point out that the tier system captures this concept and F_{MSY} estimates are only used for Tier 1, while other, more data-poor tiers make use of a series of proxies. The authors concluded the F35% and F40% proxies for MSY used in the fishery management plans were defensible and appeared to be supported by the literature as being reasonable for typical groundfish species. However, they pointed out that for species that have very low productivity and characterized by highly episodic recruitment, harvest at those levels may be too high. They comment that the Tier system would be improved by consideration of different life history types.

Grabacki, S.T. 2008. Sustainable Management of Alaska's Fisheries: A Primer. (accessed April 29, 2016).

This paper provides an overview of management for Alaskan fisheries. The author compares the roles of the federal and state agencies and notes that both have a clear separation between conservation decisions and allocation decisions.

He describes the stock assessment process of using the best scientific information to provide guidance to the North Pacific Fishery Management Council for determining annual harvest levels for each stock. The tiered approach used for quota establishment is described. In addition, the paper describes the review process of science and allocation, the jurisdiction of the agencies and how they collaborate, as well as other fishery considerations such as bycatch reduction and habitat protection.

Mace, P.M., N.W. Bartoo, A.B. Holland, P. Kleiber, R.D. Methot, S.A. Murawski, J.E. Powers, G.P. Scott. 2001. National Marine Fisheries Service Stock Assessment Improvement Plan. Report of the NMFS National Task Force for Improving Fish Stock Assessments. NOAA Technical Memorandum NMFS-F/SPO-56. 175 pp.

This report on the stock assessment improvement plan is one component of the Science Quality Assurance Program which consists of several other elements including the NOAA Fisheries Data Acquisition Plan and the Stock Assessment Improvement Plan. The report also addresses recommendations from the National Research Council study on Improving Fish Stock Assessments (NRC 1998).

The task force identified three tiers of assessment excellence to consider in the analysis of the resources required to improve stock assessments. They specified region-by-region program and staffing requirements to meet these tiers and recommended that NMFS should aggressively pursue more funding and staffing to modernize data collection and assessment capabilities in order to move assessments towards the higher tiers of excellence.

The task force classified all stocks based on levels of input data (catch, index of abundance, life history data) and assessment status (level, which roughly indicates the level of modeling effort/ complexity/ sophistication applied to each species, and frequency). Descriptions of the scoring factors are given for each criterion. There are six levels to describe how assessments are conducted (0 to 5) (Note: the numbering order is different from other tiering schemes with 0 being the most data-limited and 5 being the most data-rich).

This report may provide guidance for an initial scoping of BC groundfish species.

Methot Jr., R.D. (editor). 2015. Prioritizing fish stock assessments. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-152, 31 p.

This document describes a national framework for the prioritization of stock assessments. Although the prioritization will take place under the direction of the national framework the process will be implemented at a regional level in coordination with existing regional processes and planning bodies.

The document provides background on US legislation, the scientific stock assessment process and information out of the Marine Fish Stock Assessment Improvement Plan (SAIP; Mace et al. 2001). The SAIP provided an initial description of stock assessment for the National Marine Fisheries Service; this included the definition of five levels at which an assessment could be conducted.

The prioritization includes first time assessments for previously unassessed stocks, updating existing assessments, and upgrading assessments to use new data and/or methods. This document outlines the need for prioritization, stocks to be included, and an overview of the five steps in the prioritization process. The prioritization process is expected to be an annual process and management strategy evaluation (MSE) will be an important tool to refine the process.

This document outlines a process that may be useful in the context of our BC project, particularly the section on determining target assessment level (what is right level of data inputs and complexity for a stock's assessment?), including cost vs benefit. There is expected to be an update to the SAIP that will more fully explore this concept.

Restrepo, V.R., Thompson, G.G., Mace, P.M., Gabriel, W.L., Low, L.L., MacCall, A.D., Methot, R.D., Powers, J.E., Taylor, B.L., Wade, P.R. and Witzig, J.F. 1998. Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO-31. 54 p.

Purpose was to provide technical guidance on specifying optimum yield (OY) that is consistent with the 1998 Guidelines for National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. In addition, guidance is provided for developing reference points to guide management decisions.

The authors discuss the definition of "limits" in reference to the precautionary approach and the development of MSY-related parameters. Where MSY-related parameters cannot be estimated or when estimated values are deemed unreliable the use of proxies will be necessary. This report refers to situations that require proxies as "data-moderate" and "data-poor" and offers guidance to categorize stocks.

The authors provide some default target and limit control rules and consider the appropriateness of proxies for the data-poor and data-moderate stocks. They note that it is imperative to enhance data collection and analyses to improve the setting of these targets and limits. They also consider special situations such as changes in the selectivity of fishing gear, mixed-stock situations, data issues, and changes in productivity due to the environment.

This paper is one of the earliest to promote the idea of categorizing stocks based on data richness.

C.10.5. Data Poor Methods

Bentley, N. 2015. Data and time poverty in fisheries estimation: potential approaches and solutions. ICES Journal of Marine Science 72(1): 186-193.

The author introduces several challenges for estimation in data-poor fisheries: quantitative methods have become increasingly sophisticated with requirements for large amounts of data, and there are increased demands from legislators and managers for fisheries scientists to provide advice on all fisheries, including data-poor.

The author outlines the key challenges, discusses general approaches and speculates on practical solutions. He defines the concept of fisheries estimation as encompassing “the general challenge of estimating the parameters and current state of a model of a fishery”, and notes that he does not use the term data-limited and prefers to think that there is a continuum from data-poor to data-rich. He also describes how it is most often that the data-poor species are of low value and there is a correlation between value and the amount of data collected and the time put into analysis (time poverty).

The author describes two approaches to fisheries estimation for data-poor fisheries, tier-based and continuum-based, and some of the benefits and challenges of each. He notes that one potential problem of the tier-based approach is that fisheries may get stuck in a methodological tier instead of making the most of the data available, i.e., brought down to the lowest common denominator in each tier. In a continuum-based approach the same models are used for data-rich to data-poor with less certainty for the data-poor. One problem of this approach is the technical difficulty of applying the same mode.

The author also describes an alternative approached suggested by Punt (2008) which distinguishes between two types of fisheries estimation based on their purpose. Strategic estimation is for strategic decision-making such as selecting a management procedure from a set of candidates; it is more comprehensive, more integrated, and more statistical. Tactical estimation guides tactical decision-making such as whether to change the TAC this year or not; it is simpler, more empirical and needs fewer datasets. He notes that both methods are required but should be separated and run in parallel.

The remainder of the paper focuses on strategic fisheries estimation using a continuum-based approach using the same model for all fisheries. The author proposes potential solutions in four main categories: Priors, Data, Algorithms, and Review. One comment of interest in the Review section was that the fisheries with the most data set high expectations on what can be considered as an acceptable level of uncertainty and that many data-poor fisheries are likely to be considered deficient. Reviewers must maintain a balance between opposing risks of inappropriate management action due to estimation inaccuracy and inappropriate management inaction due to estimation uncertainty.

The author concluded that the real time and cost savings will come from doing strategic estimation only occasionally and in between management decision-making can be driven by a tactical management procedure. He also warns that it is not beneficial to overplay the benefit of data-poor methods as there is the risk of reduced funding for data collection, analysis and modelling.

Carruthers, T.R., Punt, A.E., Walters, C.J., MacCall, A., McAllister, M.K., Dick, E.J., Cope, J. 2014. Evaluating methods for setting catch limits in data-limited fisheries. Fish. Res. 153, 48–68.

The authors state that the development of methods for assessing stocks with limited data have been spurred by the requirements to set scientifically-based catch limits in many jurisdictions, e.g., USA, Australia and New Zealand. They provide an overview of the requirements of the reauthorized Magnuson-Stevens Act to provide annual catch limits for all federally managed stocks, noting that not all stocks have adequate information to conduct a quantitative stock assessment so alternative methods are being used.

The authors use a management strategy evaluation (MSE) framework to test the performance of a number of static and dynamic catch-, depletion-, and abundance-based data-limited methods, along with four reference methods. The data and information requirements for each method were documented and the MSE process was described.

Results were provided for each method in terms of the probability of overfishing, stock status, and yield performance for various starting levels of stock biomass and for a number of life history types. Historical catch methods appeared to be worse than maintaining current fishing levels and only methods that used current abundance, historical fishing effort, and stock depletion had good performance across all depletion levels.

Chrysafi, A., and Kuparinen, A. 2016. Assessing abundance of populations with limited data: Lessons learned from data-poor fisheries stock assessment. Environ. Rev. 24: 25-38.

The authors provide a very brief description of global laws and policies in regards to sustainable fisheries, e.g., FAO, Magnuson-Stevens Act. It is essential to provide advice for any fishery, regardless of data richness, to achieve the goals of sustainable exploitation. This has seen a movement to develop alternative approaches to stock assessment with indicators and models tailored to data poor situations.

The authors describe the characteristics of data-poor fisheries and present state of the art methods from the simplest to the most advanced that can be implemented in a data-poor framework, along with increasing biological realism, data richness and input requirements. They discuss trade-off of various approaches and the management implications and difficulties associated with different assessment approaches.

They note that there are gaps in current approaches due to limited information which means assessment models are simplified, important biological processes are excluded, and uncertainty in the outcomes is not appropriately quantified. They also point out that not taking uncertainty into account in decision making could lead to dangerous management practices so performance evaluation and management strategy evaluation (MSE) are critical for approaches to identify their behaviour and weaknesses.

The authors cite work by Bentley (2015) on problems of tiering fisheries when there is actually a gradient of information from data-rich to data-poor. They also cite the work of Punt et al. (2011) on data borrowing from data-rich stocks (“Robin Hood” approach) and cite work (e.g., Kuparinen et al. 2012) on the use of hierarchical Bayesian methods to assess data-poor stocks.

The authors conclude that there is some controversy whether more simplistic models should be built or more complex approaches are required. Regardless of the approach they state that the most critical part for successful management is having all stakeholders embrace the approach to be used.

Dick, E.J., A.D. MacCall. 2010. Estimates of sustainable yield for 50 data-poor stocks in the Pacific coast groundfish fishery management plan. NOAA Technical Memorandum NMFS-SWFSC-460: 201 pp.

The Pacific Fishery Management Council’s fishery management plan covers 90+ stocks and as of 2010 only 30 of those species had been assessed. For data-poor species various *ad hoc* methods had been used in the past to estimate overfishing limits (OFLs), e.g. average catch or maximum catch.

In an attempt to improve on methods such as average catch, the authors used two recently developed catch-based methods: depletion corrected average catch (DCAC) and depletion-based stock reduction analysis (DB-SRA). Both methods required a reconstruction of catches (landings and discards) for each of the stocks. Catches from various sources were aggregated by species, year and source (all other strata, e.g., gear, were combined). Estimates of discards were applied to all commercial landings and recreational catch, including discards was estimated. The authors document the various sources for the catch data and include the rationale for choosing sources.

As well as a reconstructed time series of historical catch, both of these models rely on species-specific information related to stock productivity. The authors document the model inputs, including the use of life history information (e.g., natural mortality) and briefly describe the two models. DB-SRA was used to estimate OFLs for 42 of the 50 stocks and DCAC was used for the remaining 8 remaining stocks. OFLs are expressed as probability distributions, reflecting the uncertainty in model parameters and they selected median values as point estimates of OFL, as this statistic is most consistent with National Standard 1 guidelines. Their results suggested that status quo harvest levels range from light exploitation of some stocks to potential overfishing of others. This information could help inform decisions regarding prioritization of future stock assessments for unassessed species.

For these methods it was assumed that catch was known without error and the authors noted that it would be possible to include uncertainty by assigning probability distributions to the catch time series. They also note the need to prioritize funding for catch monitoring programs and historical catch reconstruction efforts as gaps in historical catch data affect the accuracy of these types of assessments as well as traditional stock assessments.

Dowling, N.A., D.C. Smith, I. Knuckey, A.D.M. Smith, P. Domaschenz, H.M. Patterson, W. Whitelaw. 2008. Developing harvest strategies for low-value and data-poor fisheries: Case studies from three Australian fisheries. Fisheries Research 94: 380-390.

Using three case studies, the authors provide insight into developing harvest strategies for small, low-value fisheries that are consistent with the intent of the Australian harvest strategy policy to cease or avoid overfishing, to rebuild overfished stocks, and to maintain stocks at levels corresponding to the maximum economic yield.

The authors outline the key considerations and process for developing harvest strategies for Australia's small fisheries and describe four general principles for the development of harvest strategies for low-value fisheries. These general principles include (i) the development of sets of triggers with conservative response levels, with progressively higher data and analysis requirements at higher response levels, (ii) identifying data gathering protocols and subsequent simple analyses to better assess the fishery, (iii) archiving biological data for possible future analysis, and (iv) the use of spatial management, either as the main aspect of the harvest strategy or an augmentation with other measures.

The value of an iterative approach involving stakeholders and managers was emphasized.

Geromont, H. F., and Butterworth, D. S. 2014. Generic management procedures for data-poor fisheries: forecasting with few data. ICES Journal of Marine Science.

The authors provide some background information on the difficulties of managing data-poor stocks and describe methods that have been used. They describe what a management procedure is and propose the development of generic management procedures, with species grouped by longevity/productivity (low, medium, and high) and perceived depletion levels (severely depleted, moderately depleted, near target). This resulted in nine “baskets” and for this work they looked at how well TAC-based harvest control rules performed for a “species” of medium productivity undergoing severe depletion. They separate testing into data-poor and data-moderate categories. The data-poor tests had only catch history and some mean length data, while the data-moderate tests also included an index of abundance.

They found that the data-moderate management procedures outperformed the data-poor ones but that the data-poor were still reasonable over a wide range of uncertainty. They concluded that simple management procedures could provide the basis to develop candidate management procedures for data-poor stocks that provided relatively stable future catches.

Honey, K.T., Moxley, J.H., Fujita, R.M. 2010. From rags to fishes: data-poor methods for fishery managers. Managing Data-Poor Fisheries: Case Studies, Models & Solutions, 1: 159-184.

The authors introduce the paper with the need for establishing annual catch limits (ACLs) by 2011, and the subsequent requirement to improve understanding of fish stock dynamics and to increase efforts to develop new, more efficient ways to do fish stock assessments when a full assessment is not possible. They review methods presented at a workshop held in December 2008 on identifying methods for estimating potential reference points for managing data-poor fisheries.

The authors present a new framework to help managers and stakeholders consider and choose appropriate analytical methods and alternative management approaches based on available data (type, quantity, quality) and feasibility constraints (scale, value, implementation costs). They highlight the limitations and considerations for each method and illustrate with case studies.

They provide some information on data-poor fisheries and methods for dealing with these, including tiers. Their proposed framework consists of four steps: 1. Gauge data richness; 2. Data richness informs analytical options; 3. Apply fishery evaluation methods; and, 4. Apply decision-making methods.

To assist in Step 1, gauging data richness, the authors develop a scorecard which allows them to qualitatively and quantitatively record the data available for a fishery. Step 2 links the various information types with approaches available for fishery evaluation. For Steps 3 and 4 the authors describe various data-poor methods and demonstrate with case studies. Methods include trend analysis of indicators, vulnerability analysis, extrapolation, decision trees, and management strategy evaluation (MSE) methods.

Looking forward the authors anticipate increased use of flexible decision trees to make informed decisions with limited information; the trees are simple, adaptable and transparent. They also propose the use of MSE for testing different expected outcomes and management strategies and to test various data-poor methods.

Newman, D., J. Berkson, L. Suatoni. 2015. Current methods for setting catch limits for data-limited fish stocks in the United States. Fisheries Research 164: 86-93.

This paper examines the implementation of the requirement of the 2006 reauthorized Magnuson-Stevens Act for scientifically-derived annual catch limits (ACLs) for all federally managed stocks. ACLs are the standard mechanism to limit catch and trigger measures to ensure accountability.

Many unassessed stocks are often of lower value and fewer resources have been assigned for data collection and assessment. This made the implementation of the ACL requirement a significant undertaking. The authors present a summary and assessment of how the ACL mandate has been implemented for data-limited stocks in the various regions. Through the review of 47 management plans and communication with National Marine Fishery Service (NMFS) staff, the authors looked at regional variations, analyzed progress and challenges, and made recommendations for improving procedures going forward.

They provide definitions of data-rich, -moderate, and –poor and summarize by region the number of stocks that fall into each category. It was noted that there were significant regional differences in how data-limited methods and control rules were used to set OFLs and ABCs. Federally, 30% of stocks were classified as data-rich, 11% as data-moderate, and 59% as data-poor. There was, however, considerable regional variability.

The authors note that the ACL mandate has increased scientific innovations for data-limited fisheries and there has been an increase in the number of data-poor methods, as well as an increase in the use of management strategy evaluation (MSE) to evaluate the efficacy and applicability of the methods.

Nationwide there are regional differences in the number of stocks, the types of data, the lengths of time series and the availability of resources which have influenced the types of data-limited methods that have been used. An example is that the Pacific region has invested considerable resources in catch reconstruction but not all regions have the ability to do this.

The authors conclude with four measures to continue the forward momentum of providing OFLs/ABCs for federal stocks: 1) conduct a thorough review of existing data; 2) increase the use of MSE to test methods and to test the relative value of collecting various types of data – this may help data collection efforts; 3) streamline regional stock assessment processes to improve efficiency; and 4) improve coordination among NMFS centres.

APPENDIX D. PARTICIPANTS

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Abbreviations:
AFSC........Alaska Fisheries Science Center
CCIRA ......Central Coast Indigenous Resource Alliance
CGRCS ....Canadian Groundfish Research and Conservation Society
CSAP........Centre for Science Advice Pacific
DFO..........Fisheries and Oceans Canada
FM ....Fisheries Management
NOAA .......U.S. National Oceanic and Atmospheric Administration
PHMA.......Pacific Halibut Management Association
SAFE........Science, Salmon and Freshwater Ecosystems
UFAWU....United Fishers and Allied Workers Union

APPENDIX E. GROUNDFISH DATA SOURCES

1. Commercial Fishery Data – Groundfish Science Databases

   a. 2006 onwards

      - Landings from Dockside Monitoring
      - Trawl at-sea observer program
      - Line electronic monitoring coupled with logbook
        - Species ID, releases, effort, location data considered complete

   b. 1996-2006

      - Landings from Dockside Monitoring
      - Trawl at-sea observer program
        - Species ID, releases, effort, location data considered complete
      - Some Line logbooks

   c. 1954-1996

      - Landings from sales slip data
        - Still some species within aggregates, e.g. skates
      - Logbooks for releases, effort
        - Species ID, releases, effort, location data not always complete

   d. Pre-1954

      - Landings in Dominion Bureau of Statistics
        - Most species within an aggregate, e.g. lingcod in a ‘cod’ group,
        - Round and dressed weights; liver weights for sharks
        - War years are sparse or non-existent

2. Recreational Fishery Data – Area databases

   a. iREC – 2013 onwards

      - Mandatory internet reporting
        - licence holders randomly selected each monthly period
        - Fishing location and method, species kept, species released by ‘logbook’

   b. Creel surveys

      - Landing interviews expanded by aerial surveys for boat counts
        - Landed fish observed; released fish from fisher recall
        - Limited species ID and biological sampling
      - Years and months conducted vary by area
        - most ‘robust’: Strait of Georgia creel survey 1980 onwards

3. FSC Data – FOS database

   - FSC landings that are combined with a commercial fishing trip are recorded in DFO’s Fisheries Operating System (FOS)

- Solely FSC fishing trips are not recorded in FOS

4. Fishery Independent Data
   a. Peer Reviewed Literature
      - Estimates of natural mortality, fecundity, maturity, growth
   b. Research Surveys – Groundfish Science database (includes collaborative surveys)
      - CPUE, biomass estimates, age structures, length, weight, sex, spatial information, genetic samples

Table E.1. DFO Pacific research surveys – gear types and activity.

Survey	Gear	Number of Years	First Year	Recent Year
Hecate Strait Multispecies Assemblage Survey	Trawl	11	1984	2003
Hecate Strait Pacific Cod Monitoring Survey	Trawl	3	2002	2004
Hecate Strait Synoptic Survey	Trawl	6	2005	2015
Queen Charlotte Sound Synoptic Survey	Trawl	8	2003	2015
Strait of Georgia Synoptic Survey	Trawl	2	2012	2015
West Coast Haida Gwaii Synoptic Survey	Trawl	6	2006	2014
WCVI Synoptic Survey	Trawl	6	2004	2014
WCVI Thornyhead Survey	Bottom	3	2001	2003
Sablefish Stratified Random	Trap	13	2003	2015
IPHC Longline Survey	Longline	12	2003	2015
Inside Rockfish Survey (North)	Longline	7	2003	2014
Inside Rockfish Survey (South)	Longline	4	2005	2013
PHMA Outside Rockfish Survey (North)	Longline	5	2006	2015
PHMA Outside Rockfish Survey (South)	Longline	4	2007	2014
Strait of Georgia Lingcod YOY Trawl Survey	Shrimp Trawl	4	1991	2005
West Coast Vancouver Island Shrimp Survey	Shrimp Trawl	39	1975	2015

Table E.2. DFO Pacific research surveys – coverage by Pacific Marine Fisheries Council (PMFC) area.

Survey	Major Statistical Areas							
Hecate Strait Multispecies Assemblage Survey	-	-	-	-	-	5C	5D	-
Hecate Strait Pacific Cod Monitoring Survey	-	-	-	-	-	5C	5D	-
Hecate Strait Synoptic Survey	-	-	-	-	5B	5C	5D	-
Queen Charlotte Sound Synoptic Survey	-	-	-	5A	5B	5C	-	5E
Strait of Georgia Synoptic Survey	4B	-	-	-	-	-	-	-
West Coast Haida Gwaii Synoptic Survey	-	-	-	-	-	-	-	5E
WCVI Synoptic Survey	-	3C	3D	5A	-	-	-	-
WCVI Thornyhead Survey	-	3C	3D	-	-	-	-	-
Sablefish Stratified Random	-	3C	3D	5A	5B	5C	5D	5E
IPHC Longline Survey	-	3C	3D	5A	5B	5C	5D	5E
Inside Rockfish Survey (North)	4B	-	-	5A	-	-	-	-
Inside Rockfish Survey (South)	4B	-	-	-	-	-	-	-
PHMA Outside Rockfish Survey (North)	-	-	-	-	5B	5C	5D	5E
PHMA Outside Rockfish Survey (South)	4B	3C	3D	5A	5B	5C	-	-
Strait of Georgia Lingcod YOY Trawl Survey	4B	-	-	-	-	-	-	-
West Coast Vancouver Island Shrimp Survey	-	3C	3D	5A	5B	-	-	-

Table E.3. DFO Pacific research surveys – summary statistics on sets, species, samples and specimens.

Survey	Ave. # Sets/Yr	# Spp	# Spp Sampled	Total # Samples	Total # Specimens
HS Multispecies Assemblage Survey	107	166	92	8,954	489,799
HS Pacific Cod Monitoring Survey	199	113	4	951	32,128
Hecate Strait Synoptic Survey	179	287	90	9,670	210,910
Queen Charlotte Sound Synoptic Survey	261	328	91	14,530	267,941
Strait of Georgia Synoptic Survey	48	126	47	1,011	16,892
West Coast Haida Gwaii Synoptic Survey	116	268	68	5,352	110,134
WCVI Synoptic Survey	149	260	82	8,750	185,985
WCVI Thornyhead Survey	68	88	21	1,319	53,934
Sablefish Stratified Random	118	124	40	4,662	227,803
IPHC Longline Survey	170	85	23	3,413	38,143
Inside Rockfish Survey (North)	67	64	38	2,050	32,669
Inside Rockfish Survey (South)	67	51	30	817	20,579
PHMA Outside Rockfish Survey (North)	196	85	29	2,504	30,795
PHMA Outside Rockfish Survey (South)	193	80	27	1,828	21,588
SofG Lingcod YOY Trawl Survey	69	136	32	576	17,622
WCVI Shrimp Survey	130	265	57	12,186	247,652

Table E.4. Data scorecard for BC commercial fisheries.

		Data-Rich Species	Data-Moderate Species	Data-Poor Species
Landings	Years Monitored	20	8	20
	Years Estimated	40	88	-
Releases	Years Monitored	20	8	20
	Years Estimated	40	88	-
Effort	Years Monitored	20	8	20
	Years Estimated	40	88	-
Reliable CPUE				
Annual age composition	> 1 generation	X		
	(adequate for SCA)	X		
	<1 generation		X	
Annual length composition	> 1 generation	X	X	
	(adequate for SCA)	X		
	<1 generation			X
Length-weight relationship		X	X	
Sex ratio		X	X	X
Spatially explicit info		X	X	X
Selectivity/catchability		X	X	
Fishing mortality		X	X	

Table E.5. Data scorecard for BC recreational fisheries.

		Data-Rich Species	Data-Moderate Species	Data-Poor Species
Landings	Years Monitored	-	16	-
	Years Estimated	-	80	-
Releases	Years Monitored	-	16	-
	Years Estimated	-	80	-
Effort	Years Monitored	-	16	-
	Years Estimated	-	80	-
Reliable CPUE				
Annual age composition				
Annual length composition				
Length-weight relationship				
Sex				
Spatially explicit info				

Table E.6. Data scorecard for BC Food-Social-Ceremonial (FSC) fisheries.

		Data-Rich Species	Data-Moderate Species	Data-Poor Species
Landings	Years Monitored	-	10	-
	Years Estimated	-	-	-
Releases	Years Monitored	-	10	-
	Years Estimated	-	-	-
Effort	Years Monitored	-	10	-
	Years Estimated	-	-	-
Reliable CPUE				
Annual age composition				
Annual length composition				
Length-weight relationship				
Sex				
Spatially explicit info				

Table E.7. Data scorecard for BC fisheries-independent sources (research/charter surveys).

		Data-Rich Species	Data-Moderate Species	Data-Poor Species
Reliable survey index	mean CV <0.3	X		
	mean CV >0.3		X	X
Biomass estimate		X	X	X
Natural mortality	BC estimate	X	X	
	Literature	X	X	X
Maturity	BC estimate	X	X	
	Literature	X	X	X
Growth	BC estimate	X	X	
	Literature	X	X	X
Fecundity	BC estimate	X		
	Literature	X	X	
Annual age composition		X	X	
Annual length composition		X	X	
Length-weight relationship		X	X	
Sex		X	X	
Stock structure		X	X	
Spatial distribution		X	X	
Habitat associations		X	X	