Fisheries and Oceans Canada's Ecosystem Approach to Fisheries Management Working Group: case study synthesis and lessons learned

Pierre Pepin, Mariano Koen-Alonso, Stephanie A. Boudreau, Karen M. Cogliati, Cornelia E. den Heyer, Andrew M. Edwards, Kevin J. Hedges, Stéphane Plourde

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Canadian Technical Report of Fisheries and Aquatic Sciences 3553

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Fisheries and Oceans Canada's Ecosystem Approach to Fisheries Management Working Group: case study synthesis and lessons learned

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ABSTRACT

Pepin, P., Koen-Alonso, M., Boudreau, S. A., Cogliati, K. M., den Heyer, C. E., Edwards, A. M., Hedges, K. J., and Plourde, S. 2023. Fisheries and Oceans Canada's Ecosystem Approach to Fisheries Management Working Group: case study synthesis and lessons learned. Can. Tech. Rep. Fish. Aquat. Sci. 3553: v + 67 p.

Fisheries and Oceans' (DFO) national Ecosystem Approach to Fisheries Management (EAFM) working group identified 31 case studies to better understand how ecosystem knowledge is applied in the science-management cycle. The aim was to identify opportunities for, and challenges to greater integration of ecosystem variables in decision-making. This synthesis consisted of an in-depth evaluation in terms of context, scientific results, the Canadian Science Advisory Secretariat peer review and advisory process, and recommendations for decision-makers. Lessons learned may serve to provide guidance for Science, Fisheries Management and Policy sectors on how to more fully implement an EAFM.

The case studies highlighted the challenges of including ecosystem considerations in the science-management cycle. Basic fundamental scientific research and data integration, through development of ecosystem assessments are foundational elements needed to include ecosystem considerations in the development of advice. Because ecosystems seldom change dramatically from year-to-year, DFO needs to balance the short versus the longer term risks to fish stocks in management recommendations for decision-making. Case studies highlight the importance of including interactions among stocks and fisheries in management recommendations when appropriate. Integration of ecosystem considerations into the science-management cycle requires a structured and continued level of collaboration among DFO sectors (Science, Fisheries Management, Policy).

RÉSUMÉ

Pepin, P., Koen-Alonso, M., Boudreau, S. A., Cogliati, K. M., den Heyer, C. E., Edwards, A. M., Hedges, K. J., and Plourde, S. 2023. Fisheries and Oceans Canada's Ecosystem Approach to Fisheries Management Working Group: case study synthesis and lessons learned. Can. Tech. Rep. Fish. Aquat. Sci. 3553: v + 67 p.

Le groupe de travail national sur l'approche écosystémique de la gestion des pêches (EAFM) de Pêches et Océans (MPO) a identifié 31 études de cas à travers le pays conçues pour mieux comprendre comment les connaissances écosystémiques sont considérées dans le cycle de gestion scientifique. L'objectif était de mettre en évidence les opportunités et les défis que représente leur intégration dans la prise de décision. Cette synthèse consistait en une évaluation approfondie du contexte, des résultats scientifiques, du processus d'examen par les pairs et de consultation du Secrétariat canadien de consultation scientifique et des recommandations aux décideurs. Les leçons apprises pourraient orienter les Secteurs des sciences, de la gestion des pêches et des politiques sur la façon de mettre en œuvre un EAFM.

Les études de cas ont mis en évidence les défis liés à l'inclusion de considérations écosystémiques dans le cycle de gestion scientifique. La recherche scientifique fondamentale, ainsi que l'intégration des données, grâce à l'élaboration d'évaluations écosystémiques constituent les éléments fondamentaux nécessaires pour l'inclusion des considérations écosystémiques dans l'élaboration d'avis. Étant donné que les écosystèmes changent rarement de façon abrupte d'une année à l'autre, il serait avantageux pour le MPO d'équilibrer les risques à court et à long terme pour les stocks de poissons dans les recommandations de gestion pour la prise de décision. Les considérations écosystémiques vues à travers les études de cas soulignent l'importance d'inclure les interactions entre les stocks et les pêcheries dans les recommandations lorsque appropriés. L'intégration des considérations écosystémiques dans le cycle de science-et-gestion nécessite une approche collaborative structurée et continue entre les secteurs du MPO (Sciences, Gestion des pêches, Politiques).

INTRODUCTION

As a result of increasing recognition that the effects of ecosystem variables should be considered in the provision of scientific advice (Skern-Mauritzen et al. 2016; Marshall et al. 2019; Pepin et al. 2022), Fisheries and Oceans Canada (DFO) established a national working group (WG) in 2019 to develop and evaluate a framework for the implementation of an Ecosystem Approach to Fisheries Management (EAFM). An EAFM retains primarily an individual stock and fishery focus, while incorporating ecosystem variables (EVs-including climate, oceanographic and ecological factors) into stock assessments, scientific advice, fishery plans, and management decisions (i.e., the science-management cycle) to better inform stock and individual fishery-focused decisions. The National WG was multisectoral, including members from Science, Fisheries Management (FM), and Policy and Economics Sectors within the department. Its two goals were to (1) advance the integration of climate, oceanographic, and ecological variables into single-species stock assessments and scientific advice, thereby supporting the further implementation of EAFM; and (2) to identify practical steps to advance the longer-term goal of ecosystem-based fisheries management (EBFM), where species interactions and trade-offs among fisheries are to be considered more fully and explicitly (Link and Browman 2014). The purpose of the WG was partly based on the Science Sector's previous initiatives to promote an EAFM at DFO. While the Department's Sustainable Fisheries Framework (DFO 2009) constituted the introduction of EAFM concepts into departmental policies, much work remains to be done to effectively implement an EAFM when conducting stock assessments, providing scientific advice, and making fisheries management recommendations and decisions. To better understand how EAFM is being implemented across the country, highlight opportunities, demonstrate EAFM's value to the advisory and decision-making processes, and use regional variation to learn about strengths and challenges, the WG identified a series of case studies to evaluate how environmental and ecosystem change is being incorporated into the Science and Fisheries Management cycles, and how this affects decision-making. The National WG was aided in its work by corresponding Regional WGs that were responsible, in large part, for the oversight and delivery of case studies. Case studies were initially selected to provide as wide an assortment of stock assessment situations as possible, but case studies also resulted in new resources and focus on particular stocks, to the betterment of those assessments.

In May of 2019, 31 case studies (Appendix A) were identified across all the Department's administrative regions, with the intention to consider a broad range of species, environmental drivers, data quality constraints, approaches, and objectives. Although the design of the national assessment could not be exhaustive, the 31 case studies covered a wide range of approaches and were embedded in distinct regional contexts. The general purpose was to assess what was learned in the development and pursuit of each case study, what did or did not work, and what improvements to the decision-making cycle could be made to ease the integration of environmental variables to improve sustainability. Case study teams were asked to fill out a standardized report structure developed in consultation with the National EAFM WG (Appendix B). Science and FM sector participants in each case study were asked to provide their combined (or differing) perspectives on the process and share their knowledge of the value, successes, and challenges through these case study reports. Some case studies were not designed to include the provision of ecosystem-informed advice through a typical peer-review process (e.g., Canadian Science Advisory Secretariat – CSAS), yet they did provide a basis from which to evaluate what management options could or should have been considered in light of any new understanding about the environmental drivers affecting stock status. Reports from such case studies could also consider experience gained from prior or similar experience with the science-management-decision making cycle in which ecosystem-informed advice and management decisions were carried out. Individual case study reports are considered confidential because Science and FM case study leads were asked to be candid about some of the issues they encountered over the course of the science-management-decision cycle.

Herein is a synthesis of the case studies. The synthesis was performed by the Case Study Synthesis subgroup, consisting of individuals from the National EAFM WG from all regions. The subgroup completed an in-depth assessment of the outcomes of the case studies in terms of Context, Science Outcomes, CSAS Review, and Recommendations for Decision-Making Aspects. The subgroup also extracted Lessons Learned concerning Science, Science-Fisheries Management advisory process, standards to be applied in stock assessments, communications and engagement, limitations and regulatory conflicts, and operational needs.

DESCRIPTION OF CASE STUDY CHARACTERISTICS

All DFO regions contributed case studies that reflected the breadth of scientific and management foci, issues, and concerns that reflect differences in the demands for scientific analysis and management advice for the different regions (Figure 1). There were similarities in the mix of stocks in the Atlantic regions (NL – Newfoundland and Labrador, MAR – Maritimes, GUL – Gulf, and QUE – Québec), where ecosystems have not entirely recovered from the groundfish collapse of the 1990s. The combination of stock studies in Ontario & Prairie (O&P), Arctic (ARC) and Pacific (PAC) regions provided an additional diversity of taxa.

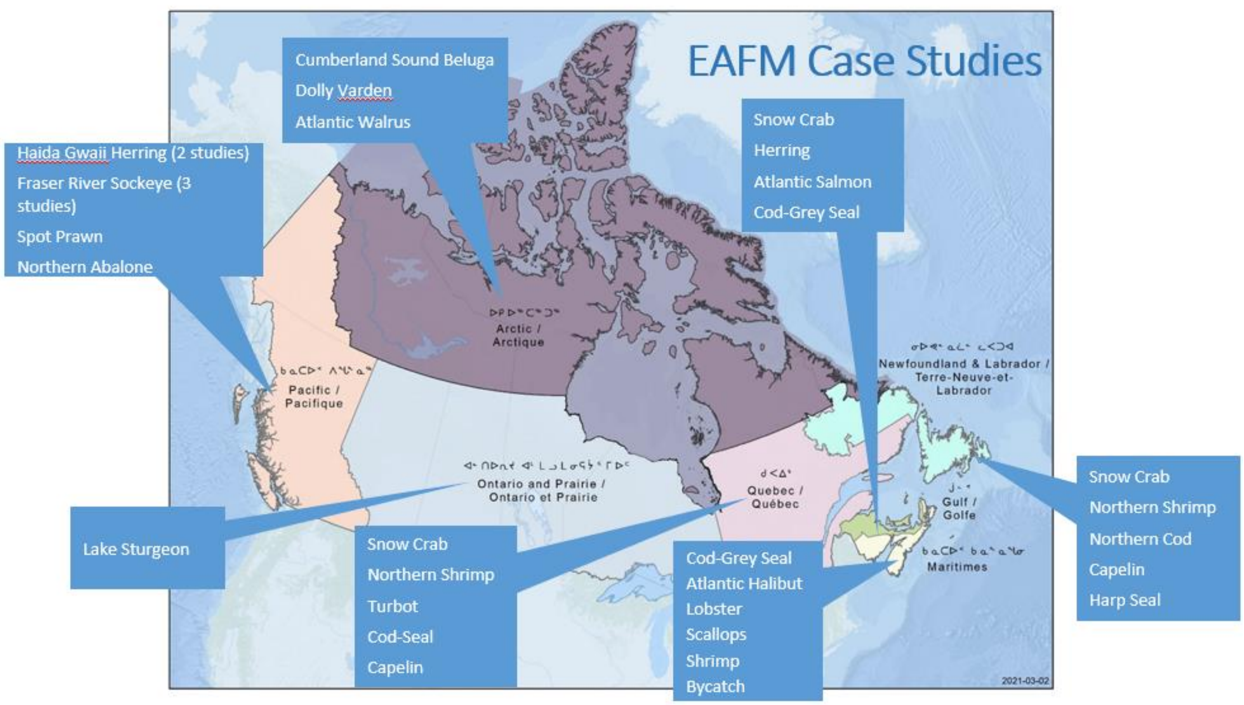

Figure 1. Distribution of case studies across DFO's seven regions. Regions are abbreviated in the text as PAC (Pacific), ARC (Arctic), O&P (Ontario and Prairie), QUE (Québec), GUL (Gulf), MAR (Maritimes) and NL (Newfoundland and Labrador).

Many of the case studies involved stocks for which there had already been considerable basic research aimed at investigating the effects of environmental variability on stock dynamics and for which the role of environmental variables had been recognized in advisory and peer-review processes. Data quality for most stocks was considered principally either as being "rich" (e.g., age and size data, fishery-dependent and independent indices, analytical model(s), ecosystem assessments, etc.) or "intermediate" (e.g., size but no age data, varied abundance indices, statistical model(s), limited biological and/or environmental data), and with relatively few cases being considered data "poor" (e.g., fishery-dependent abundance indices, some size data, limited environmental data) (Figure 2). More than half of the studies involved multispecies or multi-stock interactions. Few case studies relied exclusively on qualitative evaluations of environmental effects on the stock's dynamics, although these were combined with quantitative analyses in approximately one third of the studies. The majority of case studies aimed to provide both tactical (1-2 years) and strategic (3-5 years) advice about future population status but approximately one fifth aimed to provide only tactical advice and a similar proportion aimed to provide only strategic advice. Physical environmental variables (e.g., climate, temperature) were frequent foundational elements of population studies but predator-prey interactions were also important elements of the case studies, particularly in Atlantic regions. The potential effects of unreported fishing mortality and bycatch, habitat status, and river flow, represent some of the other factors considered. Invertebrates and groundfish were the most frequently considered taxa, partly because many stocks occur in highly impacted ecosystems, while the next most frequent categories included pelagic forage stocks and anadromous populations, with only one freshwater case (Lake Sturgeon).

The majority of case studies represent ongoing work toward the incorporation of environmental data throughout the fishery science-management cycle. As a result, few case studies had definitive outcomes, implying that the science-management advisory process will continue to evolve as new understanding concerning the factors affecting stock status becomes available.

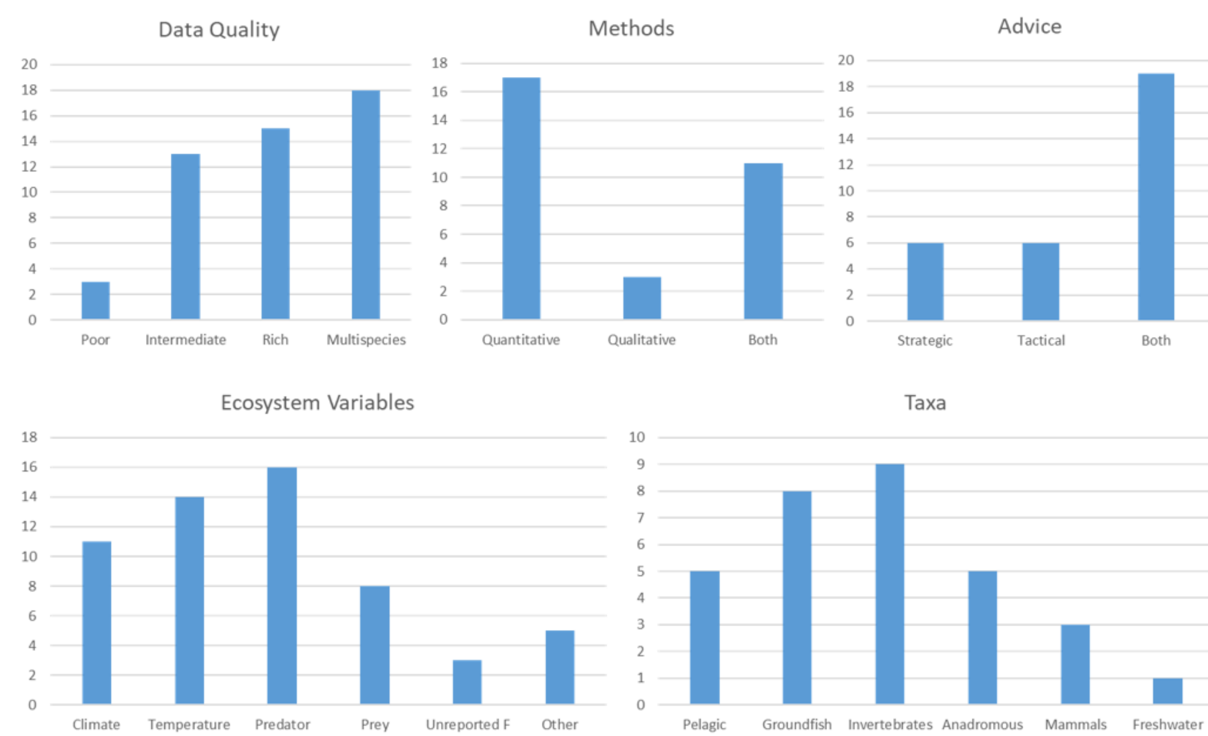

Figure 2. Frequency distributions of case study characteristics. 'Unreported F' represents unreported fishing.

APPROACH

The Case Study Synthesis subgroup developed an assessment framework of the outcomes of the case studies based on 23 questions grouped into four categories: Context (3 questions), Case Study Outcomes (6 questions), CSAS Advisory Process (9 questions), and FM Recommendations (5 questions). This structure allows tracking progress along the process that mobilizes knowledge from the basic science work to its application for informing decisions (the management recommendation). Each question was allocated a score from 1-3, along with N/A or unknown where appropriate, with the lowest score representing minimal use of environmental consideration and the highest score the more extensive or strongest use of the information (Appendix C).

All case studies were evaluated and objectively scored by two to five members of the subgroup (median 3), with regional representatives on the subgroup responsible for all reports from their region because this allowed greater contact with the investigators and resource managers responsible for each case study if clarifications were required. Science representatives evaluated questions relating to FM outcomes in collaboration with regional representatives from FM that had been involved with the case study and/or management of the stock. The final score for each question in a case study was defined as the total frequency of scores from all the evaluators for all case studies. Summarizing and interpreting the overall outcomes of the case studies based on the compilation of the scores from all evaluators served as the basis for the narrative in this synthesis report.

To evaluate the transfer of environmental knowledge throughout the science-management cycle from generation to application at the regional level, and to provide some comparability across regions, the scores for each category of questions were standardized as follows. Because the number of case studies varies among regions (Appendix A) and the number of questions vary among categories (Appendix C), the standardized average scores (final score divided by number of evaluators) for a category of questions in a given region was defined as the sum of the average scores from all the questions in that category for a region's set of case studies, relative to the maximum possible score for that category of questions for that region (schematically, a maximum category score = 3 × number of questions in the category × number of case studies in the region). If questions were not applicable for a case study or if the answer was unknown, those cells were given a score of zero for that region in that category because they did not satisfy those elements for the case study. This standardized score represents the fraction of the maximum possible performance of the regional case studies in a given category of questions, and allows comparisons among categories within a region, and across regions (Appendix D).

The second task of the subgroup was to identify the most important lessons learned from the case studies based on commonalities, as well as unique outcomes, identified from the conclusions developed by each regional WG or representative. The lessons learned from all regions were synthesized into general themes which were then categorized into four topic matter groups (Process; Science; Communications and engagement; Advice needs to be actionable). The lessons learned summarize both the outcome derived from the case studies and the actions that are needed to ensure incorporation of EAFM considerations in the science-management-decision cycle.

CASE STUDY SYNTHESIS SCORING SUMMARY

Context – History, description, and rationale of integrating environmental variables

The level of historical and contextual knowledge of environmental conditions considered in the case studies varied greatly among regions, but there were some generalities (Figure 3). There were several case studies for which contextual information about changes in environmental variables were missing altogether, while others benefited from years of work in producing this type of information (Figure 3a). Most regions reported that a partial assessment of environmental conditions was considered in some stock assessments, with the exception of O&P and ARC regions where ecosystem assessments were generally not available. Only NL reported comprehensive ecosystem assessments including oceanographic (physical and biogeochemical) and assessments of the marine community based on multispecies surveys in all case studies. Most regional case studies provided at least a partial assessment of environmental conditions (and changes in them) which may be relevant to stock dynamics, either through stock-specific development of environmental indicators or from State of the Ocean reports appropriate to the region. Based on a consensus evaluation of the case study reports, the subgroup determined that partial assessments appeared in 27% of case studies and 20% had full assessments (physics to top predators), the latter occurring principally in NL and for the Haida Gwaii Pacific Herring case study. Forty-three percent of the case studies were not linked to a regional environmental summary of ecosystem components (Figure 3c).

The integration of ecosystem variables (EVs) was expected (or anticipated) to improve the case study (e.g., stock assessment) through an explicit relationship to the EV or a time-varying parameterization (Figure 3b). The EVs included were most often based on basic scientific research and occasionally on methods and approaches to address assessment model gaps or misfits. The majority of case studies identified a specific mechanism (or hypothesis) driving the relationship with the EV or included EVs as model parameters. As an exception, a MAR case study on by-catch estimates did not incorporate EVs explicitly to determine how they might affect the overall impact of the catches of non-target species, however the by-catch itself would be the ecosystem variable of interest to decision-makers.

Conclusions and recommendations

1. *Contextual knowledge of environmental conditions in each regional Case Study varies greatly.*
2. *Most regions have some partial assessment of environmental conditions reported within stock assessments and changes that may be relevant to stock dynamics but only NL appears to have ecosystem assessments readily available to stock assessments.*
3. *Point 2 highlights a lack of consistency in the development of ecosystem assessments across different DFO regions. In most regions, there is no consistent systematic effort which synthesizes environmental and ecosystem data that can be made available to Science Advisory processes. To some degree this reflects differences in access to ecosystem data and synthesis metrics (e.g., in the form of an open access database or resources to collect ecosystem data) and/or the absence of programs directed to produce such summaries. In other instances, data availability and/or quality limit the development of partial or complete ecosystem assessments. Together, these factors likely limited the capacity of DFO case study scientists to provide a solid evidence-based foundation to move toward EAFM.*

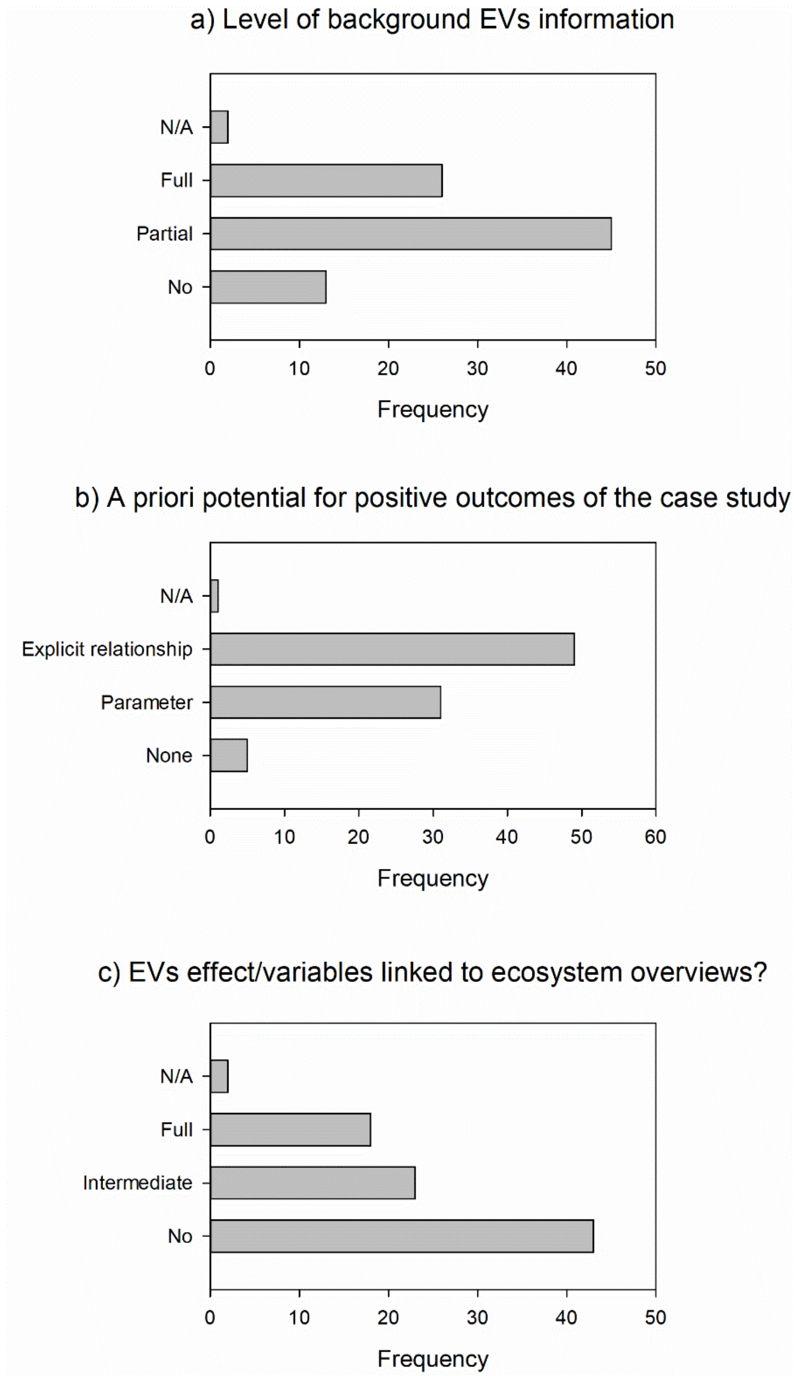

Figure 3. Summary of the scores of answers to the questions in the Context section (see text for details).

Case Studies – Process, progress, and outcomes

Approximately 36% of scores indicate the case studies were considered complete while 10% of scores indicate that they were in an early stage of development, despite reporting progress in the work (Figure 4a). For those in development or ongoing, this was partly because investigators intended to pursue the work further to include them in Science Advisory and peer-review processes, or the work had been delayed. Stock assessments are iterative processes which progressively address concerns around methodology and interpretation; increasing knowledge, including EVs, can improve the outcome of the evaluation and projections of stock status. This indicates that the success of incorporating EVs into scientific advice may be more nuanced than expected.

Most case studies involved data-intermediate or data-rich circumstances and two case studies were principally qualitative in approach. Given the data richness, most case studies used empirical (data-based) relationships (56%) to evaluate the effects of EVs in the analyses (Figure 4a). Incorporation into models occurred in 34% of case studies, and descriptive statements were used in the remaining 10% (Figure 4a). Most often the case studies with fully incorporated EVs (and with empirical relationships) considered multi-species interactions (18 of 31 case studies), which highlights the need for multi-stock considerations when developing recommendations for decision-making. This was most evident in the Atlantic regions with case studies considering predator-prey interactions; these case studies were also generally the most advanced. EVs included were climate (11 case studies), temperature (13), prey (10), and predator (15).

Descriptive approaches were more frequent for data poor stocks and/or where the EV effect was subsumed in processes in which "environmental variability" is based on past historical observations (e.g., management strategy evaluation, recovery potential assessment) (Figure 4a). There was considerable variability among scores from different evaluators. Quantitative assessments of the effect of EVs were considered in 41% of the case studies while qualitative assessments occurred in 23% of them (Figure 4e). The scoring revealed that the effects of EVs were not considered to have been assessed in 25% of case studies, with unknown/NA being scored for the remaining case studies.

Consideration of EVs was principally driven by input from Science but there was evidence in the case study reports of a growing appreciation by FM that they must be explicitly taken into consideration in development of advice for decision-making (Figure 4c, d). Science, or Science in combination with FM, evaluated that EVs were likely important drivers of stock dynamics. This suggests that for the most part, there is a general common understanding of what are the relevant drivers for a stock. The case studies indicated that EVs were considered equally important to decision-making, strategic planning, and risk analysis. In only 5% of case studies were the request for EVs driven by FM and it was unclear/NA in a further 4% of cases (Figure 4c). EVs were not considered relevant to management action in only ~10% of scores (Figure 4d).

The effect of including EVs on the outcome of case studies was considered substantial for ~30% of studies and moderate for ~30%. A similar percentage considered the effect not applicable (20%) or unknown (8%), with a limited effect for the remaining 12% (Figure 4f).

Conclusions and recommendations

1. *Predator-prey interactions are important considerations, and were most frequently considered in Atlantic stock assessments, which highlights the need for multi-species considerations in the development of advice and in the subsequent decision-making.*

2. *Consideration of EVs was principally driven by input from Science but there is growing appreciation by FM that they must be taken into account in development of advice.*
3. *EVs play a moderate to important role in the outcome of the Science Advisory and peer-review processes in the majority of case studies – note that most were low hanging fruit (i.e., prior work had demonstrated a possible role in population dynamics) but the in-depth analyses provided substantive support for the need to include them to inform the development of management measures.*
4. *It follows that the consideration of EVs in the science-management cycle should be the default approach in the development of Terms of Reference (ToRs) and in the evaluation of current and future stock status.*

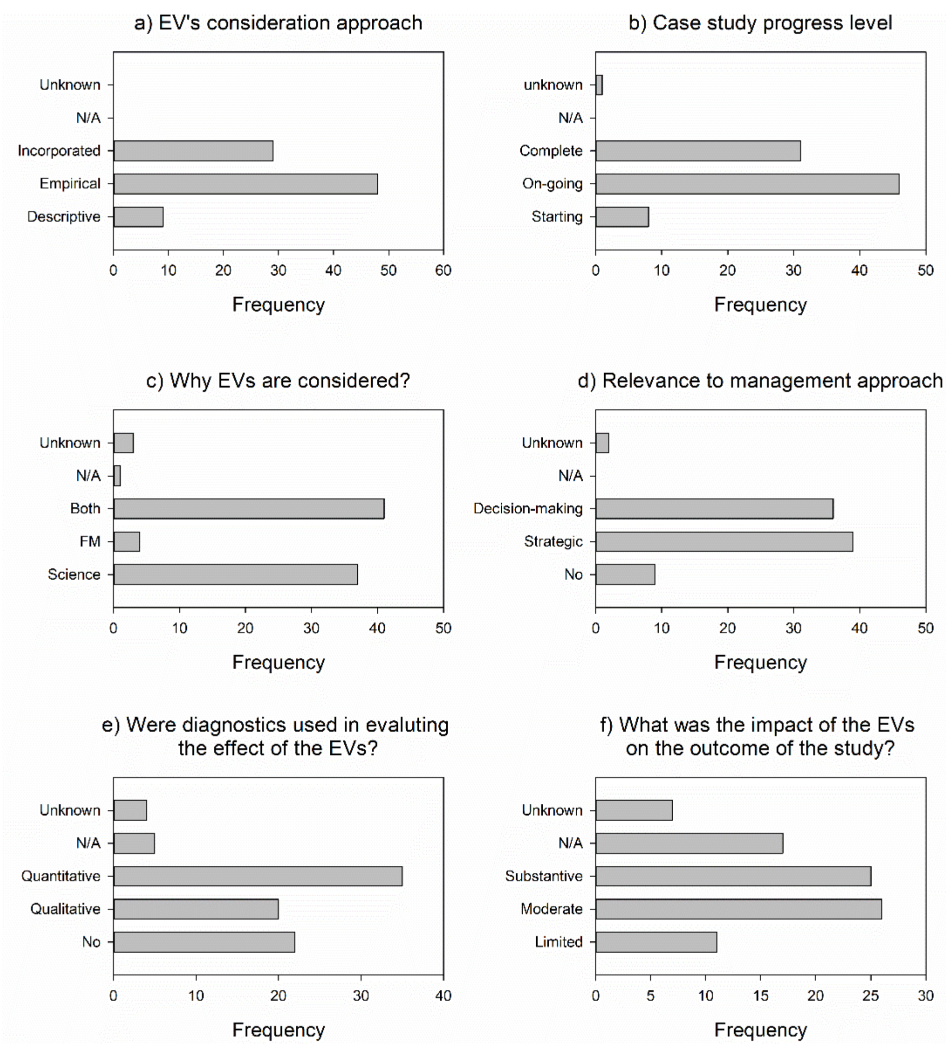

Figure 4. Summary of the or scores of answers to the questions in the Case Study Outcomes section (see text for details).

Canadian Science Advisory Secretariat (CSAS) – Environmentally informed scientific advice and peer review

For the case studies for which a CSAS peer-review process was completed or were intended to be part of a CSAS process at a future date, the level of discussion about the potential importance of EVs to the assessment process was moderate to high, but there were also several occurrences for which the level of interaction between sectors was limited or N/A (Figure 5a). Environmental variables were incorporated (n=11 case studies) or planned (n=3) in the Terms of Reference (ToRs) of many case studies but in several instances they were either N/A (n=14) or not included specifically (n=3) (Figure 5b). The findings of the case studies were accepted in most instances in which CSAS reviews were conducted (Figure 5c). In some instances, environmental variables were not used in the production of quantitative advice (QUE, PAC, O&P, MAR), possibly as a result in part to the high standards for acceptance of evidence that goes beyond evaluating stock status in CSAS processes, or partly because EVs did not affect the outcome of the assessment or the harvest advice. However, EVs were considered to be informative to the advisory and peer-review processes in general and well beyond a background level of knowledge because they highlight issues that may have to be considered in the future, even though they were not necessarily integrated into decision frameworks and recommendations *per se* because of their overall consequence to stock projections were unknown (Figure 5e).

In most instances, strategic projections were either not planned or not considered (Figure 5d), which likely reflects the general approach by DFO toward more tactical decision-making. EVs were considered mostly as background or for informative purposes (Figure 5e). In the case studies, environmental variables were incorporated into the assessments as model parameters about twice as often as being either implied or as linked analyses (Figure 5f) which may be indicative of the fundamental research that provided the foundation for the analyses. This is in contrast to a gap analysis (Kulka et al. 2022) which showed a different pattern where 48% (102/212 stocks) made use of environmental data in stock assessments, and likely reflects the choice of case studies here compared to a broader survey of DFO assessed stocks in the gap analysis. Again, the lack of follow-through to the CSAS review process resulted in a number of N/A approximately equal to the scores of linked and/or implied analyses. EVs had clear implications to future population status in 6 case studies and projections were planned in 6 others, in about equal proportion to instances where they were not. The importance of EVs to stock status was considered as important or as primary drivers (score > 2) in 15 case studies but unknown in 4 and not critical in 5 case studies that were evaluated in Science Advisory and peer-review processes (Figure 5g).

There is a marked contrast between the demonstration that EVs are important determinants of population change (Figure 5g) and in their use to provide strategic forecasts of future stock status (Figure 5h) or their considerations in terms of management measures (such as determining limit reference points (LRP), integrated fisheries management plans (IFMP), Precautionary Approach (PA) frameworks) (Figure 5i). Strategic forecasts of stock status were most frequently applied in instances where stock status is considered to be in the cautious or critical zones of their PA frameworks. Scores indicated that the consequences of knowledge about EVs do not always translate into management recommendations (Figure 5j). EVs were included in Science Advisory Reports (SARs) recommendations in 12 of the 14 case studies that went through a peer-review process, while they were reported as not applicable in the 17 case studies that did not go through a Science Advisory and peer-review process (including in all for O&P and PAC).

Conclusions and recommendations

1. *EVs represent important elements to consider in the context of any/all stock assessment processes and should be incorporated in the ToRs.*
2. *There is a marked contrast between the demonstration that EVs are important determinants of population change and their consideration in terms of management measures (e.g., IFMPs, PAs, LRPs). The latter were most frequently applied in instances where stock status is currently cautious or critical.*
3. *There are strong indications that use of EVs in CSAS reviews requires considerable investment to "substantively demonstrate the consequences of changing environmental conditions" on stock status – this highlights the very high standards for acceptance of evidence that goes beyond simply evaluating stock status.*

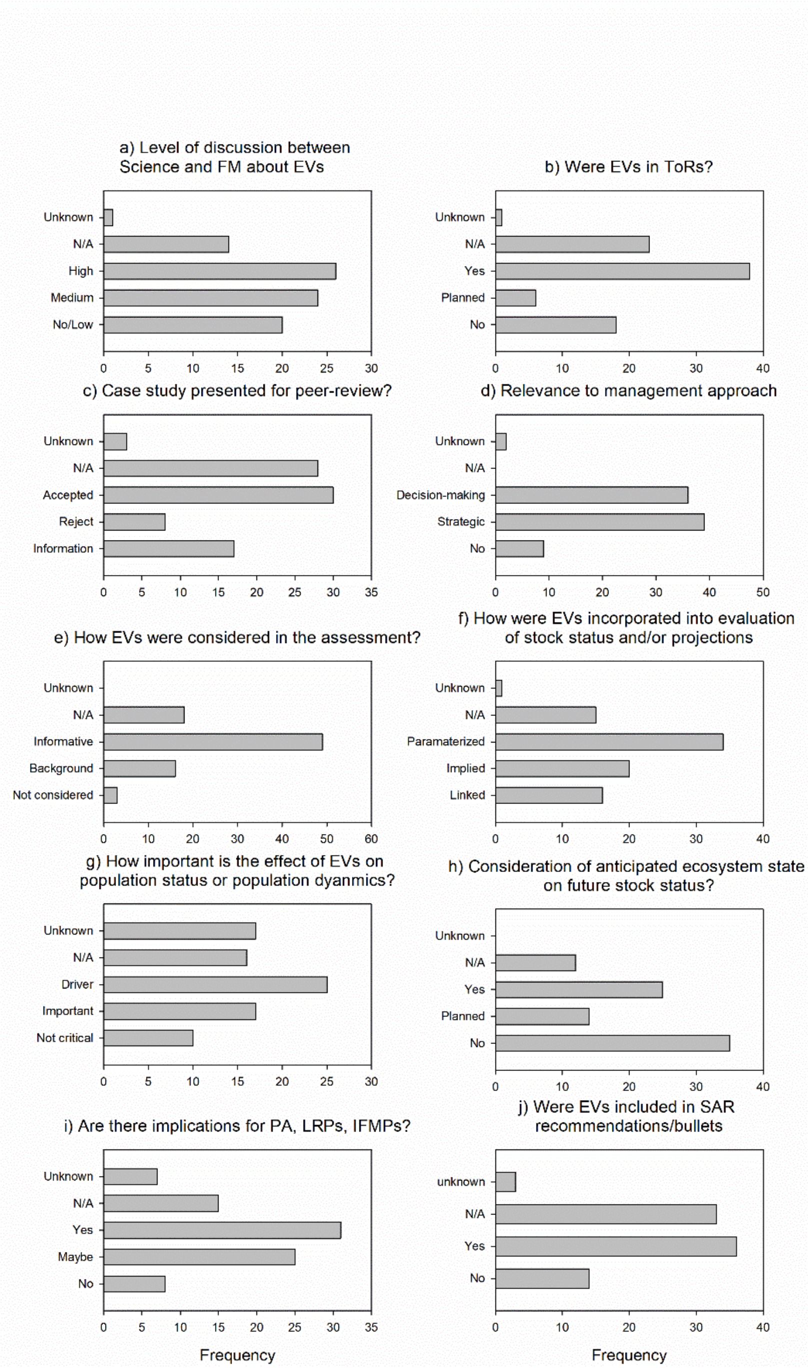

Figure 5. Summary of the scores of answers to the questions in the CSAS Advisory and peer-review section (see text for details).

Fisheries Management and Decision-making

The absence of operational requirements or policies to guide the application of ecosystem considerations in the development of management recommendations makes it difficult to pinpoint the ultimate methods by which EVs are used in the decision-making context. Despite being considered in advisory meetings, during the consultation process with stakeholders (Figure 6a) and during post-assessment discussions between scientists and resource managers for case studies that underwent CSAS processes (Figure 6c, n=14), environmental variables were included in management recommendations in roughly half (Figure 6b). In instances where there has been a dramatic change in population status EV information appears to influence management recommendations (e.g., 4T herring/cod, most NL stocks, 4RST shrimp) (Figure 6b), which suggests that EVs are given more importance following important stock and/or ecosystem changes. In other cases, EVs were considered important to the scientific advice but not in any resulting FM recommendations to decision-makers (Figure 6e), possibly because their consequence to the status of the stock or projections were not critical and were small relative to other factors (e.g., socio-economic outcomes). However, this raises the concern that the relevance of EVs is only fully acknowledged after something has gone wrong rather than being systematically included from a strategic perspective. Socio-economic considerations are a regular piece in the standard process of decision making, but how this information is integrated is not necessarily obvious. Environmental variables were clearly considered in all but 5 case studies (Figure 6d) but it was not possible to evaluate whether and how these were contextualized relative to past, ongoing or anticipated environmental change.

EVs were an element of the FM recommendations in half of the case studies that underwent CSAS review, and represented important background knowledge in most of the other case studies. In most instances the consequences of environmental variations were considered in terms of their implications to future population status (strategic or longer-term considerations), and in a minority of cases the information was simply taken directly from the SAR (Figure 6c). Other than the cases that did not undergo a CSAS review, the use of EVs in the management recommendations were approximately equally scored as influencing the recommendations, or not, or as background information only (Figure 6e).

Conclusions and recommendations

1. *The consequences of knowledge about EVs have a highly inconsistent impact on management recommendations.*
2. *Only in instances where there has been a large (i.e., dramatic) change in population status does the information appear to influence the recommendations (4T herring and cod, most NL stocks, 4RST shrimp). It would be within the scope of the Precautionary Approach to incorporate EVs into science and advice prior to stock, fishery, or ecosystem collapse.*
3. *The case studies highlight the need to develop a structured approach to operationalize the application of ecosystem considerations in the development of recommendations for decision making and better characterize short- and medium term risks to stock(s).*

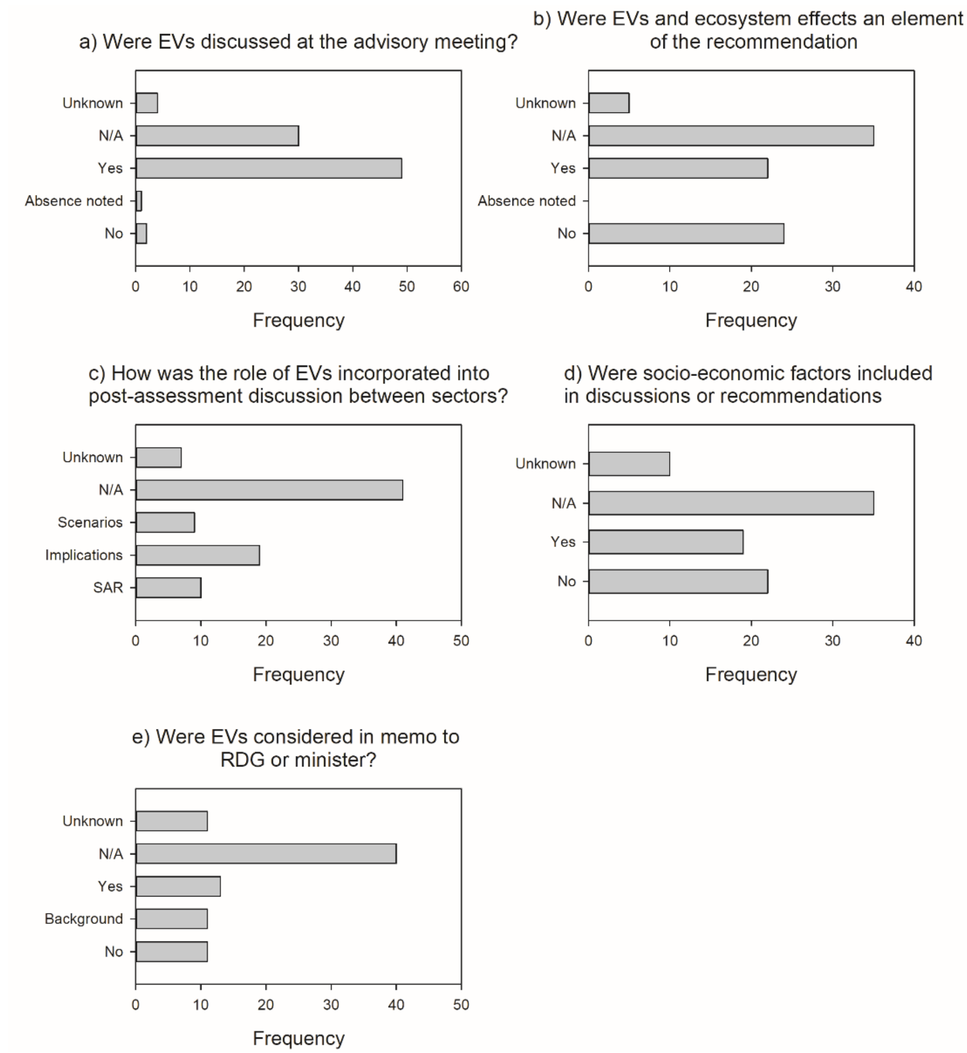

Figure 6. Summary of the scores of answers to the questions in the Fisheries Management Recommendations section (see text for details).

Regional Differences in Case Study Dimensions

Across the regions, contextual information/data was provided in most, but not all, case studies (Figure 7). The most extensive and consistent description of the state of the ecosystem was provided in NL and least in O&P and ARC. Climate-scale fluctuations in environmental conditions were most noted in PAC and QUE. Most regions included some context of the extent of environmental change but it was often partial.

Empirical relationships are the dominant foundation for consideration of EVs and NL region has the greatest integration, with GUL, MAR and QUE slightly less so while the remaining regions demonstrated greater variability in overall scores.

Development of advice based on changes in environmental state was most pronounced in NL and GUL, somewhat less so in ARC, O&P and QUE, partly owing to the status of case studies and CSAS reviews, and least complete in MAR and PAC.

Recommendations gave the greatest consideration to environmental change in the NL and QUE regions but the impact was somewhat less in GUL and ARC, O&P. The absence of CSAS reviews in MAR, PAC and some QUE case studies limits what inferences can be derived about the importance currently given to environmental change in decision-making.

Conclusions and recommendations

1. *The integration of environmental considerations into the science, advisory and decision-making processes is greatest in NL and regions bordering the Gulf of St. Lawrence and highly variable in other regions.*
2. *The availability of comprehensive ecosystem assessments as part of routine stock assessments represents a limitation to consistent integration of EVs into evaluation of stock status but that may also reflect differences in the perspectives about how important ecosystem processes are to a region.*
3. *The overall limited consequences of ecosystem status to management recommendations for decision-making may highlight the difference in importance between tactical and strategic issues – this may require some thought by Science and FM management about how to avoid irreparable consequences of serious harm to stock status by leaving it too late to take action if ecosystem trends are not embedded in the science-management processes.*

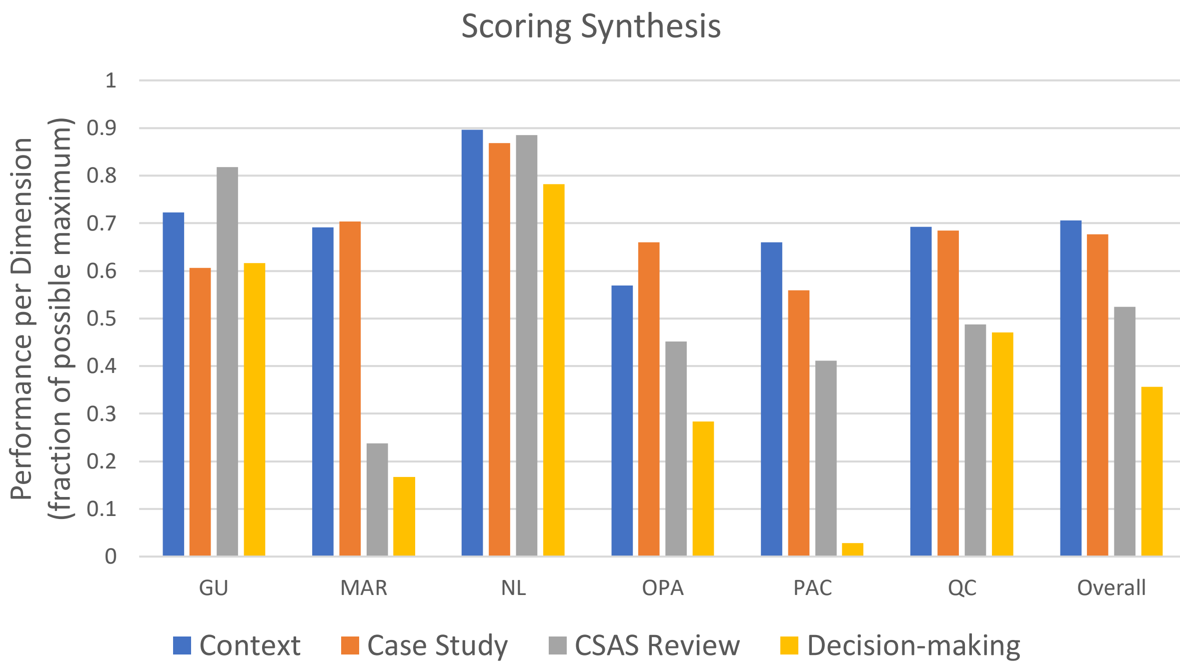

Figure 7. Performance, estimated as the total average score for all case studies from each region relative to the maximum possible score (number of questions per dimension × number of case studies × maximum score (3)) for contextual, case study completion or progress, inclusion in CSAS review process and decision-making categories of the case study evaluations (Appendix D).

LESSONS LEARNED

Lessons learned represent key principles identified from the reading, evaluation, and synthesis of the case study reports. They were derived partly from the findings of the scoring exercise or the investigators' conclusions in the case study reports themselves, and through debate among the members of the Synthesis subgroup concerning the emergent properties identified in the conduct and outcomes of the case studies. The subgroup identified four broad categories under which to group their findings:

(1) Process – which consists of the fundamental elements that must be considered in evaluating and taking management action to ensure that ecosystem change is explicitly taken into consideration in the science-management cycle.

(2) Science – foundational elements that are essential for Science's development of ecosystem-based knowledge, understanding, and preparation of advice.

(3) Communications and engagement – issues concerning the need for early public engagement that will require a Departmental approach to present the value of an EAFM because it involves development of new elements in the science-management cycle which almost always raise concerns among all rightsholders/stakeholders.

(4) Advice needs to be actionable – making scientific advice actionable represents one of the most important and difficult tasks identified from the case studies. The findings of the group highlight the need to adapt current science-management processes, expectations, and management considerations to ensure that ecosystem change on current and future stock status are explicit rather

than implicit parts of recommendations. Furthermore, the case studies highlighted the need for approaches on how to combine tactical (i.e., short-term) with strategic (i.e., medium to long term) patterns of change in stock status and anticipated ecosystem conditions in development of management recommendations.

Process

Building on the strong collaboration among the EAFM WG, there needs to be structured coordination and inclusive discussion among scientists, resource managers, policy makers, and economists in the development of EV-based recommendations to decision-makers. Currently, the degree of coordination varies greatly among regions and stocks within a region. Early discussions of the need for and importance of EV-based advice are critical and should be continued and integrated throughout the assessment cycle. Environmental considerations need to be embedded in Advisory meeting Terms of Reference (ToRs), and in development of Integrated Fisheries Management Plans and/or PA frameworks.

Development of EV-based scientific advice is an iterative process that requires considerable effort by Science before FM is able to consider it in the development of recommendations for decision-making. Advisory committees and processes should consider the consequences of failure to explicitly deal with uncertainties – i.e., consider that the cost of inaction may be greater than the future risk of not forming recommendations based on strong evidence (for which fully quantitative and/or qualitative EV-based Scientific advice may still be in development). Not taking into account EV-related negative or positive impacts on the stocks could result in irreparable harm to the stocks or missed fishing opportunities.

While the lack of linkage between some case studies and advisory and peer-review processes represented a limitation to the evaluation of EV-based science on management outcomes, it remains clear that making ecosystem considerations part of the ToRs for the assessment and that the SAR is explicit and efficient at describing the role of EVs on the current and anticipated stock status represent critical elements in the transfer of knowledge that must be emphasized in the training and preparation of Science Advisory processes.

Ensuring that methods supporting EV-based advice are thoroughly documented prior to advisory meetings is particularly critical for the introduction and fast adoption of environmentally-based analyses in the assessments, as well as for evaluating the effectiveness of such approaches within the decision-making process. If the EV-based science is perceived as not strong enough, then acceptance of the EV-based science in the advice will likely be hindered. Allocation of time and resources for document preparation is an essential foundation of the Science Advisory and peer-review process.

Science

The case studies have demonstrated that effects of EVs are frequently evaluated in Science advisory meetings but their inclusion in the scientific assessments is being done on an *ad hoc* basis that can result in an inconsistent application of an ecosystem approach in the evaluation of stock status.

It is therefore essential to develop a standardized framework for integrated ecosystem assessments (*sensu* Levin et al. 2009) based on agreed upon ecosystem indicators, and carried out on an annual basis to evaluate changes in ecosystem status (outside of the single-stock assessment process) to ensure a consistent availability of ecosystem knowledge for the scientific advisory and peer-review processes. These should be used to investigate possible linkages among stocks and help identify known or hypothesized mechanisms underlying the use of EVs in stock assessments.

The development of joint environmental and stock assessment working groups, based on bio-geographically constrained underpinning, should be considered essential and prioritized to enhance incorporation of environmental information in the Science Advisory and peer-review process.

Most environmental variables do not show dramatic variations from year-to-year but rather display multi-year trends. This highlights the need to develop strategic (2-5 year) assessments of potential consequences of ecosystem change and management procedures to stock dynamics and should focus on trends in multiple indicators that can provide foundational information in stock assessments and the development of recommendations. Effort should be dedicated to the development of strategic approaches that can guide tactical recommendations for decision-making to reduce medium-term risk (or take advantage of it) when informed by medium-to-long environmental and ecosystem trends that are likely to affect ecosystem and/or stock productivity.

Comprehensive foundational information is necessary for the implementation of even a modest ecosystem approach (i.e., incorporation of one or more EVs in a single-species stock assessment). This information includes basic data (e.g., water temperature, salinity, water quality, biogeochemistry, prey availability, predator abundance and stomach contents, length, weight, age, etc.) as well as details of the interaction among fisheries (e.g., bycatch) and/or stocks (e.g., species interactions). Many existing monitoring programs would likely need to be enhanced to provide this type of information, as well as the resulting datasets managed in ways that facilitate access and integration for stock and ecosystem analyses.

Communications and engagement

Stakeholder involvement, through advisory committees and processes, and formal engagement and consultation including Indigenous and local knowledge holders, can help in the assessment of environmental drivers and their inclusion in decision-making recommendations. Additionally, the use of environmental drivers/mechanisms is often conditional on the perception of gain, loss, and actionability. Avoiding potential conflicts could be addressed through existing policies, such as the Integrated Aboriginal Policy Framework and Policy on Science Integrity, or through new policies related to CSAS's Policy on Conflict of Interest or a Socio-Economic Analysis Framework for Ecosystem Approach.

Complex approaches, analyses, or ecosystem assessments make it more challenging for non-experts to understand and apply EV-based analyses in the advisory cycle. While ecosystem interactions can be inherently complex, identifying clear links between specific stocks and EVs can help facilitate the acceptance of such approaches.

Advice needs to be actionable

Regardless of stock status, ecosystem assessments should be fundamental elements of all advisory and peer-review processes and should serve to inform FM of general ecosystem trends that may affect the stock now or in the future. In order to make this requirement actionable, work should be undertaken to develop recommendations about how ecosystem trends may affect outcomes (e.g., risk of deterioration or improvement in stock status) associated with tactical and strategic decision-making (e.g., Is there disconnect between observed ecosystem trends and short-term decision-making preventing the achievement of longer-term stock objectives?).

DFO's current fisheries management paradigm is primarily a single-stock approach, linked to the precautionary approach directives, though the *Fisheries Act* does not constrain or prevent a multi-stock approach or use of ecosystem considerations in development of recommendations for decision-making. However, the single-stock perspective should not be considered as a hindrance to the use of EV considerations in management. When ecological interactions are identified as important, advice should aim to be comprehensive and identify potential risks of unwanted outcomes that result from interactions among stocks and the lack of coordination in the corresponding management decision for the interacting stocks. This is particularly important when multi-stock interactions are important factors affecting the productivity of one or more stocks.

The 2019 amendments to the *Fisheries Act* create several opportunities to increase consideration of EVs in fisheries management. Section 2.5a states the Minister may consider an ecosystem approach when making decisions under the Act. In addition, the Fish Stocks provisions – FSP (sections 6.1-6.3) require that environmental conditions affecting prescribed major fish stocks be taken into account in their management. This is the first legislative imperative to consider EVs in fisheries management and the EAFM Initiative's case studies demonstrate that the work can directly support DFO in meeting this obligation.

The mismatch between spatial scales of assessment processes, data, and management units can limit acceptability of EV-based analyses. The FSPs are being interpreted in the Case Studies as based on the concept of "one stock - one LRP", which may limit consideration of broader EAFM goals given the potential complexity of interactions with EVs that were identified in the case studies. While in a general sense LRPs should be aligned with the proper biological population, and management stocks defined based on these populations, in practice LRPs need to be aligned with the scales that best describe the dynamics of the exploited stock, this being the entire population or ecologically relevant subunits. This alignment is expected to capture the scale at which the stock would be more responsive to EV effects.

Because the role of EVs becomes more evident from a strategic perspective, the current focus on short-term recommendations for decision-making can hinder the consideration of EVs and their implications for future stock status because the impact of changing ecosystem status in the short-term may be modest. Evaluations of risk of adverse outcomes in the medium to long term made without considering anticipated future states neglects anticipation and planning for potential impacts of future change, whether positive or negative.

Development of operational approaches that allow for the provision of science advice in a format that facilitates uptake into the development of recommendations for the decision-making process is essential, both in terms of forming EV-based Science advice and guiding consideration of EVs by FM in the development of management and decision-making recommendations. Operational approaches should aim to categorize short- and medium-term risks, whether qualitatively or quantitatively, and how they should be considered in the development of management recommendations that balance short-term (1-2 year) actions with forecasts or expectations of longer term (3+ years) changes in environmental conditions that are affecting a stock's productivity.

CONCLUSIONS

- Case studies highlighted the challenges of including ecosystem considerations in the science-management cycle partly because of the current focus on short-term decision-making, and regional priorities and concerns.
- Basic fundamental scientific research, along with data availability, quality, and integration, through development of comprehensive ecosystem assessments closely linked to the advisory and peer-review processes, are foundational elements needed in order to provide a consistent and defensible approach to including ecosystem considerations in our understanding, forecasts, and development of advice concerning stock status.

- Ecosystems seldom change dramatically from year-to-year but rather display multi-year trends (although there are exceptions – e.g., resulting from marine heat waves, climate extremes) and therefore DFO needs to balance the short versus the longer term risks to fish stocks throughout requests for advice, management recommendations, and decision-making.
- Ecosystem considerations seen through the case studies highlight the importance of including interactions among stocks and fisheries in the evaluation and development of management recommendations, particularly when predator-prey interactions indicate that management decisions on one stock have consequences to other populations.
- Development of operational approaches for the adaptive application of ecosystem considerations in the development of management recommendations and decision-making are essential. Gaps in ecological, economic, social/cultural, and institutional governance will need to be evaluated and addressed in order to provide a foundation for an ecosystem approach to fisheries management.
- Integration of ecosystem considerations into the science-management cycle requires investment in people and resources, along with a structured, coordinated and continued level of collaboration and integration among DFO sectors (Science, Fisheries Management, Policy) that requires a formalized framework for addressing both immediate and long term consequences of management decisions under changing ecosystem conditions.

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APPENDIX A

Summary details of case studies provided by the principal investigators, as they were developed at the start of the EAFM initiative (with some updated outcomes provided by the principal investigators in June 2022), including the relevance to resource management, the methods and their rationale as well as information pertaining to data availability, taxa, whether multispecies links were considered, when the assessment was to be carried out, whether a retrospective analysis was included in the assessment, the frequency of assessments, whether the case study was applicable to other stocks, whether the stocks was included in the fish stock provisions, whether the case study received funding and whether the advice was tactical (1-2 years) or strategic (3-5 years).

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
QUE	Capelin 4RST	Prey, Predator	Q	poor	Pelagic	yes	2020	no	biennial	yes	yes	part	strategic

Fisheries management questions (what FM questions will the case study answer)

There was no specific FM questions but obvious needs for this data-poor stock with no abundance indices. FM has also general concerns about capelin because of its potential role as a forage species in the specific context of 4RS cod recovery plan. Sciences developed the approach outlined in column F aimed (1) at testing if candidate indices of capelin abundance in the GSL would respond to EVs similarly to what was described for 3KL capelin, therefore providing a validation of their validity (weight-of-evidence), and (2) using complementary approaches to assess the senility of capelin stock in GSL to current level of commercial fishing.

Methods (describe purpose, methods, and expected outcomes)

1) Literature review and resulting research:
    - Fishery performance index (CPUE) in the GSL related to EVs predicting capelin survival (2Y+) in eastern NL (Lewis et al. 2019)
    - Proof-of-concept: fishery performance vs biomass index in Lewis et al. (2019) model

- Time series of capelin in the diet of main predators in the GSL (Deroba 2018) and consumption estimates by main demersal predators
- Cross-regional contribution to stock assessment in QUE and NL

2) Qualitative Network Models (QNM):
   - Elaboration of conceptual model: key EVs and strength of links
   - Simulations: sensitivity of capelin to key EVs and commercial fishery
3) To be presented at the stock assessment CSAS meeting (February 2021)

Why was method selected

- Generalized Additive Models (GAMs) were used to apply the conceptual model of bottom-up control of cohort strength developed for capelin in 2JKL to the new bottom trawl abundance indices;
- EVs were considered to structure the analyses aimed at developing and validating capelin abundance indices derived from bottom-trawl survey data and in testing hypothesis related to possible effects of bottom temperature and predation risk from demersal fish on capelin availability to the bottom trawl;
- Estimates of capelin consumption by abundant demersal fish in 4RST (cod, turbot): to provide additional indices of the 'availability' of capelin
- Qualitative Network models (QNM) were applied as a way of considering the effect of multiple drivers of capelin within scenario-based simulations (data poor stock) (but no document was peer-reviewed)

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
QUE	Greenland Halibut 4RST	Temperature, Oxygen, Prey, Predator	M	intermediate	Groundfish	yes	2021	no	biennial	yes	yes	part	strategic

Fisheries management questions (what FM questions will the case study answer)

FM had a specific question regarding the impact of deep-water warming in the GSL on turbot stock following the description of (1) clear negative trend in turbot biomass since the late 2000's and (2) evidence of a lack of growth of an initially abundant cohort produced in the mid 2010's. FM has also general concerns about capelin because of its potential role as a forage species in the specific context of 4RS cod recovery plan.

Methods (describe purpose, methods, and expected outcomes)

1) Development of an empirical relationship between production and an E variable (bottom temperature)
2) Development of a method to determine risk equivalent exploitation for objectives under projected future E variable (bottom temperature)
    - An explicit risk conditioning framework can be developed for achievability of objectives given bottom temperature
    - Non-stationary reference points or decision rules can be developed based on projected bottom temperature

Why was method selected

The Risk Conditioning Framework is a method that could be used to account for non-stationary stock dynamics driven by EVs. The application with Greenland halibut is an example based on an empirical relationship between stock production and EVs

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
QUE	Northern Shrimp 4RST	Temperature, Predation	Both	intermediate	Invertebrate	yes	2020	no	biennial	yes	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

FM had a specific questions regarding the impact of deep-water warming and the unexpected and massive increase of redfish biomass in the GSL on northern shrimp stock following the description of a clear negative trend in shrimp biomass initiated in the late 2000's.

Methods (describe purpose, methods, and expected outcomes)

1) Multi-species qualitative modeling
   Objectives: knowledge synthesis, identification and testing of key interactions and hypotheses, qualitative predictions of shrimp responses to changes in fishing pressures and ecosystem drivers
2) Spatial-temporal modeling with fishing pressure and ecosystem covariates
   Objective: assess the relative influence of water temperature, fishing effort and redfish density on shrimp biomass distribution
3) Risk conditioning for ecosystem drivers
   Objectives: characterize uncertainty contributed by ecosystem drivers and demonstrate semi-quantitative and quantitative methods for developing risk conditioning factors

Why was method selected

1) Qualitative Network models (QNM) were applied as a way of considering the effect of multiple drivers on shrimp abundance within scenario-based simulations (data rich stock but with no stock assessment model).

2) Spatial-temporal modeling with fishing pressure and ecosystem covariates was used to assess the relative influence of water temperature, fishing effort and redfish density on shrimp biomass distribution.
3) The Risk Conditioning Framework is a method that could use to account for non-stationary stock dynamics driven by EVs. The application with Greenland halibut is an example based on an empirical relationship between stock production and EVs.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
QUE	Snow Crab 4RST	Temperature, Density	Q	intermediate	Invertebrate	no	2021	yes	yearly	yes	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

FM had concerns regarding the impact of an increase in bottom temperature in snow crab habitat in the GSL on the assessment and management of this species.

Methods (describe purpose, methods, and expected outcomes)

Adaptive management to protect reproductive output implies temperature-dependent limit reference points or flexible exploitation rate and minimum legal size
Objective 1: Develop predictive relationship for size-at-terminal molt based on temperature and density.
Objective 2: Model risk of sperm limitation as a function of adult sex ratio and female fecundity under various climate change and management scenarios.

Why was method selected

Data and knowledge relating key population dynamics for stock productivity to EVs were available to develop an empirical relationship to forecast stock productivity under nonstationary EVs.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
QUE	Northern Gulf Cod 4RS3Pn – Seals	Predation, unrepresented F	M	rich	Groundfish	yes	2021	yes	biennial	yes	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

Following the demonstration of the role that changes in seal-mediated natural mortality had on the trajectory and recovery potential of the 4T cod stock, FM has a specific question regarding the potential role of natural mortality due to seal predation on 4RS cod stock productivity.

Methods (describe purpose, methods, and expected outcomes)

1) Simplified management strategy evaluation using southern Gulf of St. Lawrence (sGSL) cod-grey seal model to establish how a PA framework should account for predation-driven Allee effects in the face of expanding predator populations when this is relevant.
2) Integrated assessment model with better accounting of unreported catch & estimated age-dependent trends in natural mortality.
3) Extended single species model, with seals as a covariate, to build understanding of the factors that limit productivity.
4) Minimum realistic model including key interacting species (cod-seals-pelagic fish). Provide better integration of uncertainty, estimates of key parameters (functional response) and facilitate long-term (strategic) management.

Why was method selected

To explicitly consider predator-prey interactions in the assessment of northern Gulf cod.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	4X5Y Cod	Predation, unrepresented F	M	rich	Groundfish	yes	2020	yes	multiyear	yes	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- What are the drivers of natural mortality in the 4X5Y cod stock?
- Is it possible to quantify under-reported 4X5Y cod catch from groundfish and lobster fisheries?
- What is the relative impact of seal predation on cod compared to the Groundfish fishery?

Methods (describe purpose, methods, and expected outcomes)

- Quantify cod discards: 1) from the groundfish fishery and compare to historical results; and 2) from the lobster fishery based on data mining.
- Perform literature review to determine survival probabilities of captured cod.
- Determine effect of grey seal predation using a type II functional response model and tagging results.
- A statistical catch at age or VPA model will be developed to account for seal predation, using published grey seal diets.

Why was method selected

Studies have indicated that grey seal predation has contributed to elevated M in adjacent Northwest Atlantic cod stocks, but the impact of grey seals on 4X5Y cod mortality is unknown. Here similar quantitative methods are used to test assumptions about sources of natural mortality. The projection from the cod-seal modelling explicitly incorporated predation mortality from seals.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	Atlantic Halibut	Temperature, Habitat	M	intermediate	Groundfish	no	2020	no	multiyear	no	yes	unfunded	S/T

Fisheries management questions (what FM questions will the case study answer)

1) The FM question is to assess health of the stock and evaluate harvest strategies and provide TAC advice. Temperature influence on recruitment and growth will be evaluated and closed loop simulations will be used to evaluate the risk of harvest strategies and interim assessment advice procedures.
2) The 2021 framework also update the bycatch analysis.

Methods (describe purpose, methods, and expected outcomes)

- Incorporate appropriate EVs (temperature influence on stock-recruitment, variation in growth and maturity associated with thermal regime) into the assessment.
- Develop closed-loop simulations that will allow for evaluation of risk of various harvest strategies.

Why was method selected

- A spatially structured assessment model was chosen to enable subsequent work that would explore spatial variation in growth and maturity in the stock. Time-varying natural mortality was also included in the model.
- Notably, the index of abundance from the DFO RV survey in 4VWX provides index of recruitment, although the inclusion of the index from DFO RV survey in 3NOP did not improve model performance.
- Closed loop simulation were used, as in the previous assessment, to explore range of harvest strategies. The simulations assumed long-term mean recruitment, which is precautionary given projections of expanded thermal habitat for juvenile halibut.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	Bycatch - multispecies	unrep F	Both	rich	Groundfish	yes	N/A	yes	multiyear	yes	no	funded	S/T

Fisheries management questions (what FM questions will the case study answer)

Outcomes of this case study are expected to inform FM on its Fishery Catch Monitoring policy under the DFO Sustainability Fisheries Framework, Rebuilding Plans under the Fish Stock Provisions of the Fisheries Act, and its move towards a broader Ecosystem Approach to Fisheries Management. Specific areas this case study is expected to provide information to FM are:

1) Provide information that can be used to evaluate the impact of a fishery on multiple species caught as bycatch, both in terms of quantity and spatial distribution.
2) Provide information that can be used to evaluate how changes in target species catch by a fleet may impact other species within the ecosystem.
3) Provide information that can be used to evaluate total fishing mortality on specific bycatch species (e.g., species at risk) from a suite of fleets.
4) Provide area-based estimates of observer coverage (e.g., by NAFO, SFA or similar) that can be used to evaluate bias (temporal, spatial or vessel effects) in observer coverage.
5) Provide landed and discarded species on observed trips that can be used to evaluate multispecies catch profile of different groundfish fishing fleets.
6) Provide information that can be used to evaluate operational characteristics of the fishery and individual vessels (e.g., numbers of license-holders, active licenses, and vessels).
7) Provide information that will enable overall quick visual assessment of relative amounts of landed versus discarded species by fleet, including species-specific maps suitable for external use.

Methods (describe purpose, methods, and expected outcomes)

- Purpose: explicit matching of commercial trip records with at-sea observer records as a first step towards evaluating bycatch.
- Methods: R package of generalized data extraction and linking tools for Maritimes region databases (MARFIS and ISDB).
- Outcomes: unambiguous identification of individual fleets; one-to-one match of trip and set records; quality control on data entry and primary keys; bias evaluation for observer data; identification of species catch profiles by fleet.

Why was method selected

To understand the extent and characteristics of fishing activity for a fleet (including bycatch), both the commercial landings and observed catch data must be examined together. In the Maritimes Region, the databases that store the commercial and observer data are MARFIS and ISDB, respectively. These two databases were built independently and each was created to address a unique goal. This case study was focused on the development of an R package, called Mar.fleets, to consistently identify fleet participants and extract the appropriate commercial landings data for a given fishery, as well as identifying the component of that fishery that was observed at sea.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	Lobster	Temperature, Predation	M	poor	Invertebrate	yes	unknown	yes	multiyear	yes	yes	unfunded	strategic

Fisheries management questions (what FM questions will the case study answer)

What effect has previous changes to management measures (e.g., MLS increases) had on lobster production and how can that inform future decisions?

Methods (describe purpose, methods, and expected outcomes)

The overarching goal is to use the contrast in management intervention, and timing/magnitude of climate/ecosystem changes to describe the relative importance of the factors which have led to the changes in lobster production across the various lobster management areas using:

- Generalized additive modelling - variance partitioning of drivers
- Structural equation modelling - evaluate putative causality
- Spectral analysis - explore cyclicity of productivity patterns

Why was method selected

The EVs were chosen as they had historically been suggested to impact catch rates by some preliminary statistical analyses and through Local Ecological Knowledge. GAMs were chosen as the nonlinearity in relationships can be readily incorporated without forcing a functional relationship.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	Scallops	SST, Phytoplankton	M	rich	Invertebrate	no	2021	no	multiyear	maybe	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

Can oceanographic variables be used to predict condition for Georges Bank Sea Scallop?

1) If yes, which variables influence condition?
2) If yes, can the relationship be quantified to determine if this improves the prediction of condition for the upcoming year? Does this improve the prediction of fully recruited biomass / reliability of stock status level relative to existing reference points?
3) If yes, how could this methodology be incorporated into the PA Framework in the future?

Methods (describe purpose, methods, and expected outcomes)

- This project uses satellite remote sensed sea surface temperature (SST) data from Jan-Mar of the current year and previous year to develop a linear model to predict the condition of scallop in the upcoming summer on Georges Bank.
- The additive effect of Jan-Mar SST in the current and previous year explains over 70% of the variation in scallop condition in the summer of the current year.
- Scallop condition in the summer of the current year is a parameter used to estimate the population biomass of scallop on Georges Bank for the fishing year.
- The SST-Condition model provides a better estimate of scallop condition than the currently used method. Incorporating this model at the delay-difference assessment model projection step should lead to more accurate biomass estimates and improved science advice for the upcoming fishing season.

Why was method selected

- A recent study identified a strong correlation between scallop condition (SC) and satellite derived sea surface temperature (SST) during the first few months of the year on the Canadian portion of Georges Bank (GB; (Liu et al. 2021)). The SC-SST relationship observed in this study resulted in significantly improved SC predictions compared to the currently used method. This model, along with other potential SC-EV models, such as modelled bottom temperature and Chlorophyll-a concentration, were also used to predict SC.
- The predictions from the top 5 models were then used in a retrospective analysis of the stock assessment. The biomass estimates from these retrospective model runs were compared to the actual model observed biomass.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
MAR	Shrimp	Temperature, Predation	M	intermediate	Invertebrate	yes	2020	no	yearly	yes	yes	funded	tactical

Fisheries management questions (what FM questions will the case study answer)

1) Provide a biomass estimate that accounts for the influence of temperature and predation.
2) Provide a prediction of annual biomass estimates for upcoming years that will assist with projection of annual catch levels. These biomass estimates will incorporate environmental variables. The predictions will enable development of a decision table to guide determination of annual total allowable catch (TAC).

Methods (describe purpose, methods, and expected outcomes)

1) Assimilate georeferenced data from the survey and fishery and incorporate environmental metrics.
2) Develop mesh(s):
    a. Define the finest spatial resolution that the data is recorded.
    b. Define spatial extent you want to model.
    c. Acquire environmental or auxiliary data.
    d. Generate several meshes for testing.
3) Develop a precision or covariance matrix from the mesh to explicitly state the degree of connectedness.
4) Develop GAM model:
    a. Model formulation
    b. Simple GAM Space only
    c. Space with forcing factors
    d. Model evaluation(s) for each model and model comparison statistics
5) Simulation testing of model.
6) Reference point development from best fit model.

Why was method selected

The EVs of greatest influence on the ESS northern shrimp stock were identified as bottom temperature and predation. The method chosen for the Eastern Scotian Shelf (ESS) northern shrimp cases study was based on the novel spatial dynamic surplus production modelling approach (Pedersen et al. 2019), initially developed and applied to assess the NL region shrimp stocks.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Fraser River Sockeye Salmon - EDM	Climate, Environment	M	rich	Anadromous	no		yes	One off simulation study, implications for yearly assessment	likely	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

Provide pre-season forecasts of adult recruits of Fraser River Sockeye Salmon.

Methods (describe purpose, methods, and expected outcomes)

Purpose: Simulation-test this novel approach.
Methods: Investigate Empirical Dynamic Modelling (an equation-free approach) for incorporating ecosystem variables into advice.
Outcome: A new tool for the EAFM toolbox, including R package tailored for DFO applications, and if successful include in annual forecasting for management.

Why was method selected

- Although EDM was previously applied to nine stocks of Fraser River Sockeye Salmon (Ye et al. 2015), it has not been rigorously evaluated within DFO and is not currently used to provide advice to managers.
- Participants at a national DFO workshop (Edwards et al. 2017) recommended further investigation of EDM for incorporating an ecosystem approach into assessments.
- This method allows for the recovery of complex dynamics, including those where single environmental variables can reflect complex ecosystem interactions, without the use of traditional mathematical equations, i.e., the inclusion of EV considerations, without knowledge on the state of the relationships.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Fraser River Sockeye Salmon - RPA	Climate, Environment, Competition	Both	rich	Anadromous	no	2021	yes	One off RPA	maybe	yes	funded	strategic

Fisheries management questions (what FM questions will the case study answer)

- main piece of advice being requested = allowable harm
- additionally informed:
  - Biology, Abundance, Distribution and Life History Parameters
  - Threats and Limiting Factors to the Survival and Recover
  - Recovery Targets
  - Scenarios for Mitigation of Threats and Alternatives to Activities

Methods (describe purpose, methods, and expected outcomes)

- Purpose: provide advice on threats to survival and recovery, and the feasibility of recovery
- Methods: Threats assessment (DFO 2014). Guidance on assessing threats, ecological risk and ecological impacts for species at risk. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/013. (Erratum: June 2016)
- Future productivity scenarios:
  - recursive Bayes version of Kalman filter models (Ricker & Larkin) to estimate the pattern of alpha over time
  - using the last 4 estimates of alpha (paired with their corresponding betas) to project forward
  - selecting from the posterior estimates of alpha to replicate increases & decreases in productivity
- Outcome: Recovery Potential Assessment already reviewed at regional CSAS meeting.

Why was method selected

- Threats assessment already peer reviewed.
- Future productivity scenarios need to be ‘realistic’ for climate and EV impacts; built on the stock assessment use of Ricker & Larkin models.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Fraser River Sockeye Salmon - MSE	Climate, Environment, Competition	M	rich	Anadromous	no		yes	One off MSE -- implications for yearly stock assessments	maybe	yes	funded	strategic

Fisheries management questions (what FM questions will the case study answer)

Fisheries Management requested assessment of the robustness of current escapement plans to changes in productivity and identify if alternative escapement plans would perform better under different future productivity scenarios.

Methods (describe purpose, methods, and expected outcomes)

Purpose: assess and improve current escapement plans in order to account for changes in productivity
Methods: closed-loop forward simulations (48 years / 12 sockeye generations), using recursive Bayesian Ricker, 5 generation Ricker, and recursive Bayesian Larkin stock-recruit models, using current productivity (and multipliers from current) drawn from the posteriors of the last four years of estimated alphas ; testing scenarios that consisted of a range of productivity changes as a proxy for cumulative impacts of changes in EV and different levels of fishing intensity
Outcomes: CSAS reviewed escapement plans.

Why was method selected

- The Recovery Potential Assessment used these methods to identify Allowable Harm under productivity scenarios.
- These models are currently used as the OM for FR sockeye stock assessment, escapement forecasting.
- Closed-loop simulation is a standard MSE approach, this project allows input from stakeholders on EV and productivity scenarios in the development harvest control rules and strategies.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Haida Gwaii Herring - TVP	Predators, Competition	M	rich	Pelagic	likely		yes	One off simulation study	yes	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

The current herring assessment allows for TVP (time varying parameters), by allowing natural mortality to vary through time, although specific mechanisms are unidentified. Given this, how should TVP be accounted for in reference points and associated advice to FM? How does factoring in TVP into reference points change our understanding of rebuilding objectives in HG (and can that be extrapolated coastwide)? Should existing reference points be revised to account for TVP?

Methods (describe purpose, methods, and expected outcomes)

Purpose: understand the consequences of failing to account for time-varying productivity (TVP) in reference points and harvest control rules.
Methods: Feedback simulations (and literature review) to identify conditions under which reference points should be revised to account for TVP, to evaluate alternative methods for calculating TVP in reference points, and to understand the consequences of each.
Outcome: evaluation of the performance of alternative methods of representing TVP in stock assessment advice.

Why was method selected

- Closed-loop simulation allows for testing management procedures (MPs) in a completely simulated environment, in order to select MP that are robust to uncertainty in underlying system dynamics.
- Time-varying M is a critical component of the herring stock assessment, leading to the question of whether time-varying reference points such as dynamic B0 should be used to calculate reference points.
- Used R package openMSE, which incorporates MPs that include time-varying M and calculation of dynamic reference points.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Haida Gwaii Herring - ecosystem info	Environment (e.g., temperature, climate), Prey, Predators, Competitors	Both	rich	Pelagic	yes		yes	biennial	yes	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

What are some of the environmental variables (physical and biological), such as temperature and predators, that mechanistically influence HG herring? What are the status and trends of these variables? How can this information be incorporated into stock assessment advice, and what will this look like?

Methods (describe purpose, methods, and expected outcomes)

Purpose: include ecosystem information in advice.
Methods: Identify mechanistic hypotheses and describe the influence of environmental variables (physical and biological) on HG herring. Assemble time series of and describe trends in these variables (for example, temperature, predators).
Outcome: recommend standardized format for summarizing the trends in ecosystem indicators for inclusion in stock assessments and communicating risk.

Why was method selected

- The root cause of the time varying natural mortality rates has not been identified or linked to an EV, but it is thought to reflect underlying changes in the ecosystem.
- Indicators selected based on published mechanistically-linked pressures and responses, i.e., not re-inventing the wheel.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Spot Prawn	Climate, Oceanographic	M	rich	Invertebrate	no		yes	yearly	maybe	yes	funded	strategic

Fisheries management questions (what FM questions will the case study answer)

- Develop a robust management procedure that is risk adverse, considers climate and oceanographic influences, and includes conservation goals. All three elements will allow the Department to address elements of the Precautionary Approach and new Fish Stock Provisions.
- To note, this case study is led by industry - a subsequent CSAS process may be required by Science to use the findings from the study. In addition, the study will split the coast into bioregions to incorporate the impacts of climate and the environment. Depending on the results, this may suggest different management procedures when in the cautious zone.

Methods (describe purpose, methods, and expected outcomes)

Purpose: evaluate escapement-based management procedures against conservation objectives.
Methods: Closed loop simulations of management procedures and retrospective analysis. Climate and oceanographic indices will be incorporated into the stock-recruitment estimation procedure. Including these indices would allow scaling of future projections with changes in ocean productivity.
Outcome: climate-informed management procedures.

Why was method selected

- Commercial, recreational and FN stakeholders are concerned that the current approach is not achieving conservation and economic objectives.
- Using EVs (temperature and climate-based) previously incorporated in the stock-recruitment relationship, along with closed-loop testing, allows stakeholders to help develop MP more robust to impact of environmental changes on Spot Prawn productivity and population dynamics.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
PAC	Northern Abalone-Sea Otter	Predation, Oceanographic	Both	rich	Invertebrate	yes	2021	no	Survey every year, no formal assessment, except under SARA	maybe	no		strategic

Fisheries management questions (what FM questions will the case study answer)

The information was used by COSEWIC to re-assess the species, which in turn will trigger the SARA review and regulatory process. The EVs were included in the standardized density indices (i.e., abundance trends) and the total mortality estimates in the CSAS Pre-COSEWIC Research Document.

Methods (describe purpose, methods, and expected outcomes)

Purpose: to standardized survey indices that account for environmental variability and changes in abalone behavior due to presence of predators Methods: Generalized additive models (GAMs) were used to test for significant linear or non-linear effects of these EVs on Northern Abalone density. Outcome: standardized survey indices; Ganton and Komich (2020).

Why was method selected

- Exploratory analyses indicated that density at the survey index sites were influenced by substrate type, wave exposure, depth, salinity and the presence of food sources, and predators on those food sources.
- Standardizing survey indices to account for those influences is considered 'good practice' in stock assessment.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
NL	2J3KL Cod	Prey/Predation	M	rich	Groundfish	yes	2020	yes	yearly	maybe	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- How is the annual and projected stock growth of 2J3KL (Northern) Cod influenced by status and trends of main prey (capelin)?
- How should environmental changes in capelin status and trends influence the maximum authorized harvest level decision for 2J3KL Cod?
- Additional question in conjunction with Harp Seal Case Study: What is the likely impact of harp seal predation on 2J3KL Cod?.

Methods (describe purpose, methods, and expected outcomes)

Two main models:
a. NCAM, a state-space assessment model with varying M; work would further inform M based on capelin availability and/or cod condition,
b. capcod, a simple bioenergetic-allometric model where cod production is driven by capelin availability.
Additional analyses are also planned to explore harp seal predation effects; while it was initially planned to include comparative analyses between NL and Northern GSL, this comparative work has not advance, but the inclusion of seal predation/effects in NCAM and capcod remains ongoing.

Why was method selected

This case study was built upon prior and ongoing research, so the methods used are in part a legacy of this prior work. In the case of NCAM, this is the currently accepted assessment model, so it is a natural starting point for additions and expansions while providing a solid base for comparisons with current practice. The capcod model is an evolution of the bioenergetic model used for the evaluation of capelin and seal effects on cod trajectory, and provides a relatively simple modelling platform that embeds ecologically important organizing features like body size and allometric scaling of vital rates.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
NL	2J3KL Capelin	NAO, Ice, prey, Predator	M	intermediate	Pelagic	yes	2020	yes	yearly	maybe	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

- Can Science provide FM with pre-season and in-season TAC advice/adjustments for capelin based on most current information about environmental variables that impact capelin trends (i.e., ice retreat, capelin larvae, capelin condition)?
- Can this advice being improved by considering other environmental/ecological variables (e.g., predator diet/consumption)?

Methods (describe purpose, methods, and expected outcomes)

Bayesian model including timing of sea ice retreat, capelin condition, and capelin larval abundance. Additional work will further test and refine the forecast model, and inform the development of LRPs. Comparative analysis between NL and GSL were initially considered, but progress on this front has been limited.

Why was method selected

This case study was built upon prior and ongoing research, so the methods used are in part a legacy of this prior work. The Bayesian model used is an evolution from the original analysis linking sea ice timing and capelin biomass, as well as studies on capelin larval survival and condition. While the Bayesian framework provides the ability of naturally integrating prior information, its main advantage here is the flexibility for implementing nonstandard model formulations.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
NL	SFA 4-7 Northern Shrimp	NAO, Predation	M	intermediate	Invertebrate	yes	2020	yes	yearly	maybe	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- Can we reasonably forecast future stock status of Northern shrimp based on trends in two main environmental variables - the North Atlantic Oscillation (NAO), and predation by cod?
- How does the model inform the LRP and PA framework for shrimp?

Methods (describe purpose, methods, and expected outcomes)

Spatially-explicit surplus production model with NAO and cod density as covariates. The model also includes predation by redfish and Greenland halibut. Additional work will explore the feasibility of developing ecosystem-informed LRPs and PA framework.

Why was method selected

This case study was built upon prior and ongoing research, so the methods used are in part a legacy of this prior work. The surplus-production structure is a standard formulation for simple stock dynamic models, but its simplicity is also well suited for linearization, incorporation of covariates, and the spatially explicitly fitting of the model using generalized additive models (GAMs).

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
NL	NL Snow Crab	NAO/AO, Ice	M	intermediate	Invertebrate	yes	2020	maybe	yearly	maybe	yes	part	tactical

Fisheries management questions (what FM questions will the case study answer)

- Can we reasonably forecast exploitable biomass of Snow crab based on large-scale climate forcing and exploitation rates?
- How does the model inform the PA framework and Harvest Control Rues for Snow crab?

Methods (describe purpose, methods, and expected outcomes)

Statistical ecosystem-informed model of exploitable biomass using lagged NAO/AO and exploitation rate as drivers. This model will inform the PA and HCRs as appropriate.

Why was method selected

This case study was built upon prior and ongoing research, so the methods used are in part a legacy of this prior work. Lagged relationships between snow crab and environmental indicators had been long recognized in NL, and had been explored using correlation and multiple regression analyses in the past. The advent of modern, more flexible tools like generalized linear and additive model (GLMs and GAMs) makes these statistical models a natural choice for modelling these relationships in snow crab.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
NL	Harp Seal	Ice, NL Climate Index, Prey	M	rich	Mammal	yes	2019	yes	multiyear	no	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- Can the estimates of present and projected harp seal abundance in NL Region be improved by expanding or refining the environmental variables incorporated into the age-structured population model?
- Additional question in conjunction with 2J3KL Cod Case Study: What is the likely impact of harp seal predation on 2J3KL Cod?

Methods (describe purpose, methods, and expected outcomes)

Ecosystem-informed age structured population model, with ice-related pup mortality, and environmentally-driven carrying capacity. Drivers explored/to be explored (direct and/or indirect through effects on fecundity, abortion rates, etc.) include Composite Environmental Index, sea ice metrics, prey availability (e.g., capelin), and harp seal condition. This work is applicable to other stocks; although DFO NL Region is trying to incorporate it into grey and hooded seal assessments/advice and the basic principles can be applied to a number of this stock assessments.

Why was method selected

This case study was built upon prior and ongoing research, so the methods used are in part a legacy of this prior work. The general structure of the harp seal assessment model has been fairly stable in recent years, including the inclusion of environmental covariates. It is in the details on how these covariates are included, and which alternative covariates may be more informative, where the focus of the research has been and continues to be. The original assessment model was developed using a frequentist (likelihood) framework, and part of the work in this case study is its migration into a Bayesian framework to allow for a more transparent treatment of prior information and model parameterization.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
GULF	Southern Gulf Cod	Predation	M	rich	Groundfish	yes	2019	yes	multiyear	yes	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- Why is the Southern Gulf Cod stock not rebuilding despite the moratorium on fishing? Environmental variables have to be included in assessments for this stock given that they are the main reason for its decline;
- Science advice from this case study also informs rebuilding plan components (e.g., targets, modeling);
- Provides outcomes for seal management;
- Case study supports regional and departmental priorities.

Methods (describe purpose, methods, and expected outcomes)

Two statistical Catch at Age models: Time-varying components of productivity; Incorporation of seal predation in the natural mortality of adult cod.

Why was method selected

These models have been in development and refinement through time to capture the population level of cod in the Gulf. Given that there has been a moratorium and there is no commercial harvest yet the population of cod has yet to rebuild, examining changes through time of natural mortality (primarily seals) was the recent iteration of the ongoing work for cod stock assessment.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
GULF	4T Herring	Prey, Predator	Both	rich	Pelagic	yes	2022	yes	biennial	maybe	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- Why is the stock declining? What factors other than the fishery are impacting the stock?
- Science advice from this case study also informs rebuilding plan components (e.g., targets, modeling);
- Case study supports regional and departmental priorities.

Methods (describe purpose, methods, and expected outcomes)

SCA for spring and fall spawners. Time-varying natural mortality was estimated. Key predator information (e.g., diets) presented. Ecosystem data-based covariates explaining time varying recruitment were incorporated.

Why was method selected

This method builds generally on the cod stock assessment model and the important role of time varying natural mortality and other EVs in the outcomes to help understand why the stock continues to decline.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
GULF	sGSL Snow Crab	Thermal Habitat	M	rich	Pelagic	yes	2022	yes	yearly	maybe	yes	part	S/T

Fisheries management questions (what FM questions will the case study answer)

- What are the linkages between environmental variables and this stock's health (currently in the precautionary approach's healthy zone)?
- How can climate change impact the stock's health (climate variables have a significant influence on this stock, including temperature which regulates terminal molt)?
- Science advice from this case study also informs rebuilding plan components (e.g., targets, modeling);
- Case study supports regional and departmental priorities.

Methods (describe purpose, methods, and expected outcomes)

Spatial-temporal variability in female snow crab size at terminal molt, with temperature as an important contributing factor.

Why was method selected

Females are less mobile and the important brooders potentially more vulnerable to temperature changes. This work should be able to be applied to males once established and for further work.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
GULF	Atlantic Salmon Miramichi	Temperature, Predation	Both	intermediate	Anadromous	yes	Unknown	no	multiyear	yes	yes	unfunded	S/T

Fisheries management questions (what FM questions will the case study answer)

- Is the warm water protocol helping the Miramichi Atlantic Salmon population recover (it is currently in the critical zone of the PA framework)?
- The warm water protocol helped build consensus around the management approach for the Miramichi salmon.
- Case study supports regional and departmental priorities.

Many specific questions would need to be explored, such as:

- Future research could look into benefits of closures of tributaries vs. pools;
- Are temperature thresholds adequate and what factors come into play.

Methods (describe purpose, methods, and expected outcomes)

Review of warm water protocol (WWP) management.

Why was method selected

There is no commercial harvest. It is not clear whether the warm water protocol is helping the Miramichi salmon population, however it is likely not harming those recreationally angled. The review demonstrated the different stakeholder groups, First Nations, and science, and how the WWP was developed and implemented.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
O&P	Lake Sturgeon	River Flow	M	intermediate	Freshwater	no	2019 RPA	no	multiyear	yes	no	funded	strategic

Fisheries management questions (what FM questions will the case study answer)

- How does the incorporation of river flow mediated recruitment affect outputs from a Recovery potential assessment (RPA)?
- Are population viability measures altered with the incorporation of EVs?
- Does advice from the RPA change with the incorporation of EVs?

Methods (describe purpose, methods, and expected outcomes)

- Known relationship between recruitment and river flow; exploring other potential relationships.
- Analysis of catch, mark-recapture, growth, recruitment, and environmental variables.
- Stage-based matrix population model.
- Will compare: allowable harm, extinction risk, minimum viable population (MVP).

Why was method selected

No information provided.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
O&P/ ARC	Cumberland Sound Beluga	Ice, Prey, Predator	Both	rich	Mammal	yes	2024	yes	multiyear	yes	yes	part	strategic

Fisheries management questions (what FM questions will the case study answer)

- Are EVs (ice cover and sea surface temperature) affecting the CSB stock?
- Are EVs suspected of affecting the stock's reproductive rate?
- Would consideration of EVs change the recovery factor (Fr) used for calculating PBR? If yes, how so?
- Would the Rmax used to calculate the PBR change? If yes, how so?
- How does the data-rich model-based assessment change with incorporation of EVs, including effects on maximum growth rate or stochastic process error?
- Historically, would incorporation of EVs have altered the resulting SAR? If so, would this have changed advice from FM?

Methods (describe purpose, methods, and expected outcomes)

Ice cover and sea surface temperature have been added quantitatively to a density dependent population model. Because there is little known about the direct relationship between ice cover and reproductive output/population growth, the climate variables have been added in as a process error and the model predicts whether impacts are positive or negative in any given year. Prey and predator impacts, as a result of changes in ice cover and temperature, are discussed in the case study but only qualitatively. Simulations using this updated model are currently being run, and we anticipate that the recommended landed catch will change as a result of incorporation of environmental variables, but the degree of change is not yet known. New advice will not be generated from this case study presently; however, a new assessment is pending in 2024 and so the updated model may be considered at that time.

Why was method selected

No information provided.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
O&P/ ARC	Dolly Varden	Climate	Both	rich	Anadromous	no	2021	yes	multiyear	yes	yes	part	strategic

Fisheries management questions (what FM questions will the case study answer)

- How do EVs affect Dolly Varden populations in Great Slave Lake? EVs have previously been incorporated into current model.
- If EVs considered in previous analyses were removed (analysis performed without EV), how would the output be affected? Would the science advice?
- If additional EVs are added to the previous analyses, how would the output be affected? Would the science advice change?
- How did FM consider the current EV inputs used; did this influence their management?

Methods (describe purpose, methods, and expected outcomes)

Climate variables will be incorporated quantitatively into the previous assessment. The case study will evaluate if/how Resource Management considered the climate variables when making management decisions. A retrospective analysis to see how the advice might have differed if these climate variables had not been included will be conducted.

Why was method selected

No information provided.

REGION	STOCK	ENVIRONMENTAL VARIABLE(S)	ASSESSMENT quantitative (M) qualitative (Q) or both	DATA AVAILABILITY	TAXONOMY	MULTISPECIES LINKS	ASSESSMENT YEAR	RESTROSPECTIVE ANALYSIS	FREQUENCY	APPLICABLE TO OTHER STOCKS	FISH STOCKS PROVISIONS (BILL C68)	FUNDING STATUS	TACTICAL vs STRATEGIC
O&P/ ARC	Atlantic Walrus	Ice, Prey, Primary production	Q (and limited at that)	poor (most stocks)	Mammal	yes (via prey, primary production)	2023	no	multiyear	maybe	yes	part	strategic

Fisheries management questions (what FM questions will the case study answer)

- Are ecosystem changes in the Arctic affecting Atlantic walrus population dynamics by influencing abundance/availability of food resources?
- Can EVs be quantitatively or semi-qualitatively analyzed in relation to Atlantic walrus stocks (data poor)?
- Do changes in the extent of land fast ice influence food availability, predation, other? If so, can these factors affect population dynamics? Can a driving factor be identified?
- Can it be determined if sea surface temperature influences this stock independent of ice-coverage? (i.e., when sea ice is absent). If so, in what way?

Methods (describe purpose, methods, and expected outcomes)

Extent of land-fast ice could be used to estimate/monitor access to or exclusion from benthic feeding areas around walrus haul-out sites used during spring, summer and fall. Similarly in winter, availability of sea ice as a resting platform over or adjacent to feeding areas if terrestrial haul-out sites are not available nearby could be used as predictor of food availability. Presumably, increased accessibility to food could be assumed to result in increases in reproductive success and population size of unknown magnitude, with some unknown lag following the environmental variation. While this could be modeled, the relationship between sea ice and walrus population dynamics is not known (e.g., while ice loss may provide access to benthic food, it could be detrimental in some other way, such as increasing predation risk, changing primary productivity with negative impacts on benthic prey, or ice loss itself could reduce access to prey, as might be expected of reduced winter ice platforms). So, it is difficult to even assess this qualitatively (i.e., direction, magnitude of impact not known).

Why was method selected

No information provided.

APPENDIX B

Case Study Report – 30 October 2020

The purpose of the Ecosystem Approach to Fisheries Management (EAFM) Case Study Report is to track how available information about Environmental Variables (EVs) and changes in the state of the ecosystem can influence the development and provision of DFO Scientific advice and the subsequent decision-making process in fisheries management. The aim of the report is to identify the key points required to describe the outcome of each case study considered under the National EAFM initiative.

There are six principal sections to the report. Sections A and C-F provide opportunities for all case studies to report using a common approach but Section B is focused on the majority of case studies that are designed to provide advice in the foreseeable future. Throughout development of the report, Science and Management sectors (e.g., Resource Management, Species at Risk, Marine Spatial Planning) are required to provide their combined (or differing) perspectives on the process; e.g., what was learned, what did/did not work, and what improvements to the decision-making cycle could provide evidence that the state of the environment affects the past, current and future state of the stock and management decisions.

Some case studies may not include the provision of ecosystem-informed advice through a typical peer-review process (e.g., CSAS), but should still provide a basis from which to evaluate what management options could or should have been considered in light of any new understanding about the environmental drivers affecting stock status. Reports from such case studies should also consider experience gained from prior or similar circumstances in which ecosystem-informed advice and management decisions did go through the Science-Management decision-making cycle.

The synthesis of the entire suite of EAFM case studies will follow recommendations developed by the National EAFM WG and will be modified as discussions evolve within the Case Study Synthesis subgroup. The synthesis of case studies will consider the level of complexity of the analysis (e.g., conceptual, empirical or mechanistic models) and the available decision tools (e.g., full Precautionary Approach (PA) framework, Reference Points, Harvest Control Rules, etc.).

Currently, the elements to be considered in the synthesis include:

- the stock assessment and how EVs were incorporated,
- the decision framework, if available (e.g., PA framework, Integrated Fisheries Management Plan (IFMP),
- the integration of scientific advice into management recommendations, and
- the decision.

Some variation is expected among case study narratives because of differences in subject matter and/or regional circumstances (e.g., pressures, policies, management agreements). As a result, the questions in the Case Study Report to be addressed by the National EAFM Working Group and Case Study leads were intentionally kept fairly general. The National EAFM Working Group will complete a final overall synthesis that will integrate the breadth of experiences encountered during the case studies. Responses to the questions should provide a foundation to better understand how EVs affect our understanding of the drivers of stock status and, in turn, how this may affect the management decisions needed to ensure sustainable fisheries.

Some questions may not have documented sources to consult, so simply state that it was not possible to address a particular point if that is the case. However, it is important to understand in some manner how the final outcome, from a management perspective, was achieved so that the flow of knowledge from the advisory process to the

Questions to Address:

A. Overview

1. Describe the Environmental Variables (EVs) included in the case study and their hypothesized importance in contributing to an improved understanding of the stock's dynamics.

2. a. What were the reasons to consider EVs in the development of the Case study?

    b. Had EVs been included in previous assessments for this stock?

    c. Were they included in the scientific advice or not?

    d. Did they influence the understanding of the stock's dynamics or did they affect the nature of the recommendation or scientific advice in previous assessments?

3. What methods or approaches were used to assess the influence of the EVs in the case study? Did this involve the application of novel approaches used in their evaluation?

4. Describe the difference (e.g., magnitude of change, trend) in the state of the stock and the state of the environment (or EVs) in the case study.

5. Does the case study provide an opportunity to better our understanding of the dynamics of multiple stocks? If so, how do you see this as an opportunity to move from single species management towards Ecosystem Based Management in which the interaction among many factors (e.g., environmental and anthropogenic)?

B. Did the case study involve the development of Scientific advice? (if no, go to C but you may still be able to answer some points in B)

6. a. Did the development of advice involve a peer-review process?

    b. What was the nature of the advice being requested?

    c. How were Terms of Reference developed and did they include EVs? Were there changes relative to previous assessments? If EVs were excluded, what were the reasons? Were the possible implications of including EVs on the nature of the advice and how it could be incorporated in decision-making made explicit and considered in development of the TOR.

    d. What Departmental Sectors or other agencies were involved in the process?

7. Describe how the inclusion of EVs altered our understanding of the state of the stock:

a. Did EVs alter the projections and/or the confidence in the range of projections?

b. How was the nature of the advice related to management decisions altered? (e.g., changes in (proposed) reference points or probabilities associated with projected stock dynamics or productivity)?

c. Any other changes/effects to the scientific advice related to the inclusion of EVs to note?

8. Describe the discussion related to the influence of EVs consultation with Indigenous nations and the stakeholders.

   a. Were EVs discussed during consultations?

   b. Was there general agreement among Indigenous nations and stakeholders that changes in environmental conditions were affecting the state of the stock? If not, what was the basis of the arguments presented by stakeholders?

   c. Were there differences in the perspectives of different groups (e.g., Indigenous groups and rights holders, industry [e.g., large vs. small enterprises], ENGOs)?

9. Describe how the inclusion of EVs in the Scientific advice affected the management recommendations.

   a. Were EVs considered in the development of recommendations by Management Sectors? If so, how?

   b. Did the current or anticipated (projected) state of EVs and their effect on stock status affect the nature of the recommendations during the fisheries management process for decisions (e.g., changes to TACs or HCRs)?

   c. Were there policy tools (e.g., PA framework, IFMP, Limit Reference Points, HCRs, Policy of New Fisheries for Forage Species, rebuilding plans) that guided the development of management recommendations and, if so how, and did they include consideration of EVs?

   d. Did the socio-economic assessment consider EVs in management scenario development? If so, how?

10. Provide an overview of the changes related to the EVs that may have occurred to the original recommendations in the fisheries management process throughout the approvals process, and the discussions that may have taken place as a result.

    a. Was there general acceptance or rejection of the findings with regard to the inclusion of EVs? Any particular discussion points to note?

    b. Did the decisions differ from previous years? If yes, were the differences a reflection of EVs and/or other (non-EV) factors?

c. If EVs were excluded in development of the management recommendations as a result of discussions throughout the approvals process, was a rationale provided in the analytical (science) portion of the memo or documented elsewhere?

d. Did the final decisions differ from the recommendations through fisheries management process? If yes, how did the final decisions differ from the recommendations, and what discussions may have taken place during the approvals process as a result?

C. Did the case study provide a novel approach for providing scientific advice or management practices in the future? If so then how?

11. Describe how the inclusion of EVs could affect the manner in which DFO approaches either the assessment of the stock or the management practices and whether that would likely improve sustainability.

    a. How did inclusion of EVs alter understanding of the processes affecting the stock?

    b. How could the information about EVs serve to change the nature of the advice or the manner in which advice could be provided in the future?

    c. How could information about EVs affect the future management practices to ensure sustainability and how would that differ from past practices?

    d. Did the case study provide insight into how different management practices or decisions could have altered the present state of the resource?

    e. Are there implications of the case study that go beyond the initial goals or scope that formed the foundation of the work?

D. Did the case study quantitatively evaluate the performance of new approaches (i.e., assess whether and/or how the advice differed from an approach that did not incorporate EVs)? If so how? Which uncertainties were considered?

If not, how do would you value how the new understanding or information is likely to affect Science and Management practices in the future?

E. Are there any best practices or recommendations related to the inclusion of EVs arising from the case study? That could be in the development of approaches to ensuring that EVs are properly evaluated or in the development of advice and the advice-to-decision process.

F. Add any additional outcomes or comments the case study contributors feel appropriate.

APPENDIX C

Questions used to assess the outcomes of the case studies by the Case Study Synthesis subgroup. There are four major categories of questions (3 detail contextual information; 6 detail the outcome of the case study; 9 detail the outcome of the CSAS Advisory Process; 5 detail the use of environmental variables (EVs) in fishery management Recommendations).

Questions	Categories	Rationale	Scoring criteria
Is there a descriptive historical scoping and contextual summary?	**1. Historical context-EVs in stock assessment**	Level of background EVs information	No = 1, partial= 2, Full = 3
Are there direct/clear mechanisms affecting stock productivity linked to EVs?	**1. Historical context-EVs in stock assessment**	A priori potential for positive outcomes of the case study	None = 1, relationship with general EVs or time-varying parameters with no hypothesis = 2, explicit relationship with EVs = 3
Are EVs effect/variables linked to Env overviews?	**1. Historical context-EVs in stock assessment**		No = 1, intermediate = 2, Yes/full = 3
What approach is used for EV consideration	**2. EAFM Case study**	Descriptive indicators, empirical relationships, time-varying fully incorporated parameters	Descriptive = 1, empirical = 2, fully incorporated = 3
What is the progress level of the Case study ?	**2. EAFM Case study**	Important regarding its uptake by FM	starting= 1, on-going= 2, fully developed= 3
Why EVs are considered?	**2. EAFM Case study**	Sciences initiative only, FM question, Sciences/FM	Science only = 1, FM question= 2, both = 3
What is the relevance to the management approach?	**2. EAFM Case study**	EVs may be needed for analysis and scenario setting (risks), but they may be irrelevant for the decision making process.	No = 1, risk analysis/strategic = 2, FM decision making = 3
Were diagnostics used in evaluating the effect of the EVs?	**2. EAFM Case study**		No = 1 ; qualitatively =2; quantitative = 3;

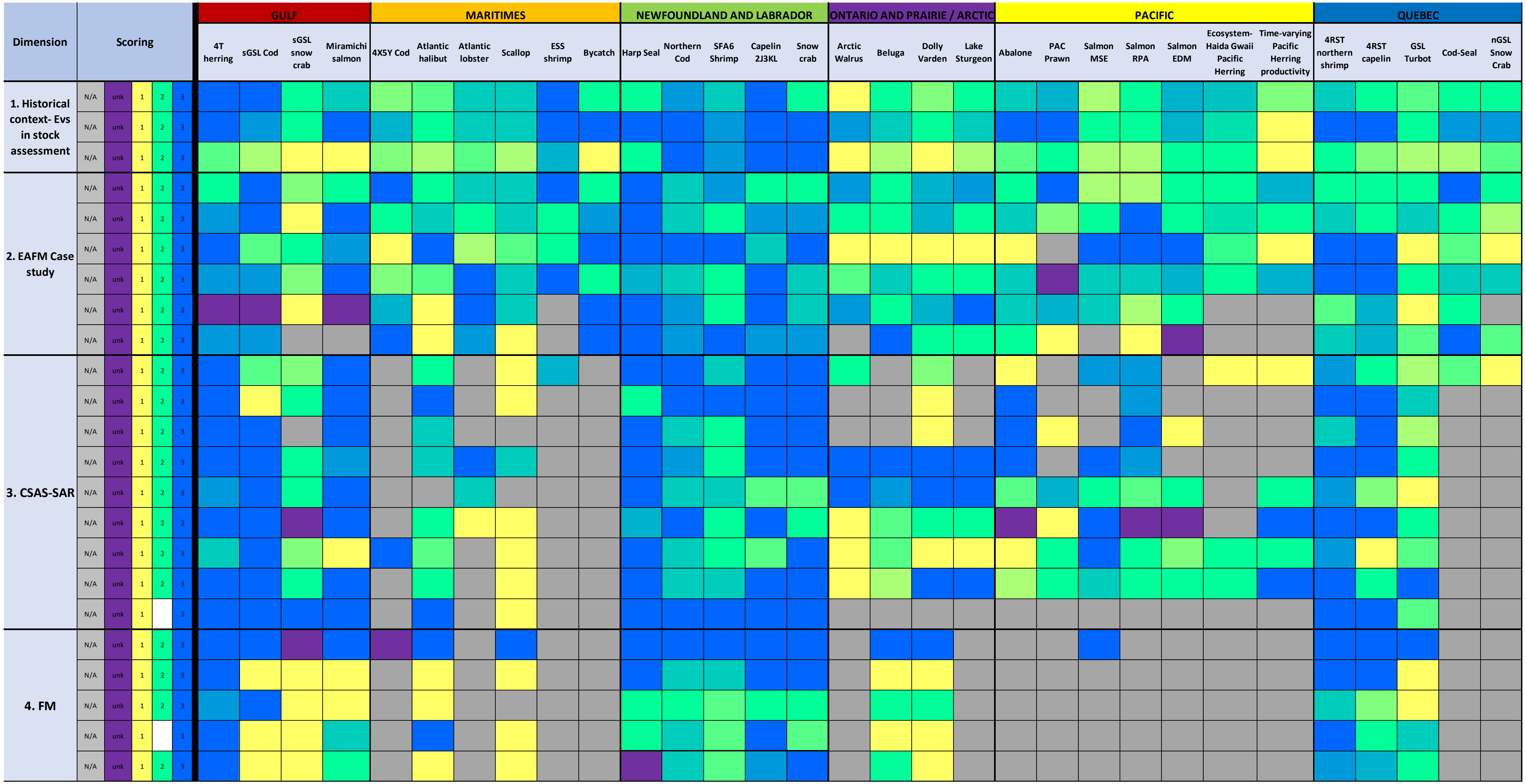
Questions	Categories	Rationale	Scoring criteria
What was the impact of the EVs on the outcome of the study?	**2. EAFM Case study**		Limited = 1 (confidence only); moderate = 2 (trajectory or confidence); large = 3 (trajectory and confidence)
What was the level of discussion between Science and FM about EVs	**3. CSAS-SAR**	None, low = just in the context of the case study, medium = on-going since few years, high = occurred over several years	No or Low = 1, medium = 2, high = 3
Were EVs in the Science advice request's Terms of Reference?	**3. CSAS-SAR**		No = 1, planned= 2, yes = 3
Was the case study presented for peer-review (PR)?	**3. CSAS-SAR**	Presented just for information, PR/rejected, PR/accepted	No = N/A, Information only = 1, PR/rejected = 2, PR/accepted = 3
How were EVs considered in the assessment?	**3. CSAS-SAR**	The role of EVs in the assessment and their level of utilization	Not considered = 1, Background only = 2, EVs had a qualitative/quantitative role in informing stock status/prospects = 3
How were EVs incorporated into evaluation of stock status and/or projections?	**3. CSAS-SAR**	parameterized into model; implied (no attributed driver; linked (empirical or inferred)	Linked = 1; Implied = 2; parameterized = 3
How important is the effect of EVs on the population status or population dynamics?	**3. CSAS-SAR**	Harvest is greatest source of loss; EVs affecting productivity; EVs are critical driver of stock status	Not critical = 1; Important or equal to harvest = 2; Substantial driver of dynamics = 3
Do EVs affect recruitment / productivity?	**3. CSAS-SAR**	EVs affecting recruitment / productivity?	unknown = N/A; No = 1; Yes = 3
Do EVs affect distribution / catchability?	**3. CSAS-SAR**	EVs affecting distribution / catchability	unknown = N/A; No = 1; Yes = 3

Questions	Categories	Rationale	Scoring criteria
Was there consideration of anticipated ecosystem state on future stock status (beyond the short term)?	**3. CSAS-SAR**		No = 1; Planned = 2; Yes = 3
Are there implications for PA, LRPs, IFMPs?	**3. CSAS-SAR**		No = 1; Maybe = 2; Yes = 3
Were EVs included in SAR recommendations/bullets?	**3. CSAS-SAR**		No = 1, yes = 3
Were EVs discussed at the advisory meeting?	**4. FM recommendations for decision-making**		No = 1; absence noted = 2; yes = 3
Were EVs and ecosystem effects an element discussed between Science and Managers in the construction of the recommendation (e.g., Memo)?	**4. FM recommendations for decision-making**		No = 1; absence noted = 2; yes = 3
How was the role of EVs incorporated into post-assessment discussion between Sciences and FM?	**4. FM recommendations for decision-making**	Taken directly from SAR; included in the narrative of potential implications for resource management; evaluation of potential scenarios;	SAR = 1; implications = 2; scenarios = 3
Were socio-economic factors included discussions or recommendations	**4. FM recommendations for decision-making**		No = 1; Yes = 3
Were EVs considered in memo to RDG or Minister?	**4. FM recommendations for decision-making**		No = 1; background = 2; yes = 3

APPENDIX D

Illustrative summary of average case study scores used in the development of scoring synthesis. Questions, dimension of the evaluation, rationale, and scoring description appear in Appendix C. Cell color and shading illustrates proximity to the highest score (3 – blue) or the lowest score (1 – yellow), with grey cells indicating N/A and purple cells indicating unknown. Case studies, in sequence from left to right are; Gulf Region: 4T herring; sGSL Cod; sGSL snow crab; Miramichi salmon. Maritimes Region: 4X5Y Cod; Atlantic halibut; Atlantic lobster; WSS Scallop; ESS shrimp; SS Bycatch. Newfoundland and Labrador Region: Harp Seal; Northern Cod; SFA6 Shrimp; Capelin 2J3KL; NL Snow crab. Arctic, Prairies and Ontario Regions: Arctic Walrus; Beluga; Dolly Varden; Lake Sturgeon. Pacific Region: Abalone; PAC Prawn; Sockeye Salmon MSE; Sockeye Salmon RPA; Sockeye Salmon EDM; Ecosystem - Haida Gwaii Pacific Herring; Time-varying Pacific Herring productivity. Quebec Region: 4RST northern shrimp; 4RST capelin; GSL Turbot Cod-Seal; northern GSL Snow Crab. Scale bar:

1	**1.33**	**1.67**	**2**	**2.33**	**2.67**	**3**


Dimension
Scoring
GULF
MARITIMES
NEWFOUNDLAND AND LABRADOR
ONTARIO AND PRAIRIE / ARCTIC
PACIFIC
QUEBEC
4T herring
sGSL Cod
sGSL snow crab
Miramichi salmon
4X5Y Cod
Atlantic halibut
Atlantic lobster
Scallop
ESS shrimp
Bycatch
Harp Seal
Northern Cod
SFA6 Shrimp
Capelin 2J3KL
Snow crab
Arctic Walrus
Beluga
Dolly Varden
Lake Sturgeon
Abalone
PAC Prawn
Salmon MSE
Salmon RPA
Salmon EDM
Ecosystem-Haida Gwaii Pacific Herring
Time-varying Pacific Herring productivity
4RST northern shrimp
4RST capelin
GSL Turbot
Cod-Seal
nGSL Snow Crab
1. Historical context- Evs in stock assessment
2. EAFM Case study
3. CSAS-SAR
4. FM
N/A
unk
1
2
3
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