An Accounting of Integration of Environmental Variables in Fishery Stock Assessments in Canada

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By

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Kulka, D.W., Thompson, S., Cogliati, K., Olmstead, M., Austin, D., and Pepin, P. 2022. An Accounting of Integration of Environmental Variables in Fishery Stock Assessments in Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3473: viii + 79 p.

Within the context of developing a blueprint for the implementation of an ecosystem approach to fisheries management, this report details the finding of an in-depth evaluation of the use of environmental variables (EV; climatic, oceanographic and ecological factors) in the assessment of stock status and projections. The analysis also investigates the potential consequences to management recommendations resulting from the effects environmental change can have on population status and projections. The analyses are based on responses to a questionnaire distributed to fish stock leads responsible for the provision of advice and development of management recommendations. We received responses for 212 stocks. EVs were integrated either through model parameterization, implied ecosystem drivers that affect stock productivity, or linked via analyses outside the assessment model. Overall, 102 of current stock assessments (48%) made use of environmental data in stock assessments, with expectations that 65% of the remaining 110 stocks could incorporate ecosystem knowledge in future assessments if resources and funding are made available. Data quality and stock status had strong influences on the capacity of scientists to assess the impact of environmental change on stock dynamics. However, this analysis demonstrates that current approaches used in the assessment of Canadian fish stocks form an *ad hoc* collection of methods and procedures.

RÉSUMÉ

Kulka, D.W., Thompson, S., Cogliati, K., Olmstead, M., Austin, D., and Pepin, P. 2022. An Accounting of Integration of Environmental Variables in Fishery Stock Assessments in Canada. Can. Tech. Rep. Fish. Aquat. Sci. 3473: viii + 79p.

Dans le cadre de l'élaboration d'un schéma directeur pour la mise en œuvre d'une approche écosystémique de la gestion des pêches, ce rapport détaille le constat d'une évaluation approfondie de l'utilisation des variables environnementales (VE ; facteurs climatiques, océanographiques et écologiques) dans l'évaluation des stocks situation et projections. L'analyse étudie également les conséquences potentielles sur les recommandations de gestion résultant des effets des changements environnementaux peuvent avoir sur l'état et les projections de la population. Les analyses sont basées sur les réponses à un questionnaire distribué aux responsables des stocks halieutiques chargés de fournir des conseils et d'élaborer des recommandations de gestion. Nous avons reçu des réponses pour 212 stocks. Les VEs ont été intégrés soit par la paramétrisation du modèle, soit par des moteurs écosystémiques implicites qui affectent la productivité des stocks, soit liés via des analyses en dehors du modèle d'évaluation. Dans l'ensemble, 102 des évaluations de stocks actuelles (48 %) ont utilisé des données environnementales dans les évaluations de stocks, avec des attentes selon lesquelles 65 % des 110 stocks restants pourraient intégrer les connaissances écosystémiques dans les évaluations futures si des ressources et des financements sont mis à disposition. La qualité des données et l'état des stocks ont eu une forte influence sur la capacité des scientifiques à évaluer l'impact des changements environnementaux sur la dynamique des stocks. Cependant, cette analyse démontre que les approches actuelles utilisées dans l'évaluation des stocks de poissons canadiens forment un ensemble *ad hoc* de méthodes et de procédures.

INTRODUCTION

Perspective

Historically, the evaluation and management of fish stocks have focused on fishery-specific management objectives. Exploitation effects were the primary consideration and ecological factors driving productivity were unknown, poorly understood, or not considered relevant. Natural mortality (M) was treated incidentally as a (poorly estimated) constant or was not considered at all. It became clear that not factoring in complex and dynamic environmental influences resulted in a misperception of the state of the stock and the ecosystem in general, even in otherwise well-managed situations. The following extract from Skern-Mauritzen et al. (2016) elaborates on this point:

"*Fish stock productivity, and thereby sensitivity to harvesting, depends on physical (e.g. ocean climate) and biological (e.g. prey availability, competition and predation) processes in the ecosystem. The combined impacts of such ecosystem processes and fisheries have led to stock collapses across the world. While traditional fisheries management focuses on harvest rates and stock biomass, incorporating the impacts of such ecosystem processes are one of the main pillars of the ecosystem approach to fisheries management (EAFM).*"

Principles and conceptual elements of an Ecosystem Approach to Fisheries Management (EAFM) have been advocated for many years, from the Ramsar Convention in 1971 to the 1992 Convention on Biological Diversity (CBD) and the 1995 Jakarta Mandate on Marine and Coastal Biological Diversity (Garcia et *al*. 2003). The 1982 United Nations Convention on the Law of the Sea and the 1995 Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries and its corresponding International Plans of Action (IPOAs) laid out the principles of the ecosystem approach (EA). The FAO-Iceland Conference on Responsible Fisheries in the Marine Ecosystem, Reykjavik, October 2001 (Sinclair et al., 2003) brought the issue to the forefront.

However, implementation of an ecosystem approach has been a slow process and both Rice (2005) and Cowan et *al*. (2012) described the global challenges to acceptance and implementation of an EAFM. The science needed for its implementation was often considered to be overly complex in part given the difficulty in delineating coupled natural and human effects on populations. Poor understanding of the effect of the ecosystem on the stock often brings about resistance to approaches that go beyond integration of less complex fishery impacts.

Nonetheless, Canada and other countries, e.g., United States, several European countries, Australia, and New Zealand have recognized that the ecosystem plays a key role in stock productivity and survival. Therefore, environmental conditions should be considered when assessing stock status and applying fisheries management measures. As part of this recognition, Canada's modernized *Fisheries Act* gives prominence to an ecosystem approach, and to environmental influences on prescribed major fish stocks through the new Fish Stocks provisions (FSP) when making a decision, namely that:

- the Minister may consider … the application of a precautionary approach and an ecosystem (s2.5); and
- the Minister shall develop a plan … taking into account the biology of the fish and the environmental conditions affecting the stock (s6.1.1, 6.1.2 and 6.2.1).

In the provision of scientific advice, accounting for environmental effects provides a more complete understanding of stock status, and consequently, better management. This practise will also support the implementation of legal requirements to account for environmental conditions in fisheries management measures. "[Taking] into account … environmental conditions" includes scenarios where the influence of specific drivers is understood but can also include situations in which there is insufficient knowledge of the pathways of effect to allow an evaluation of anticipated conditions, in which case it would be treated as a source of uncertainty. However, it will likely become best practice to clearly state whether there is sufficient knowledge of the role of environmental conditions on population state in science advice. Fisheries managers may need to reflect this as well in their decision-making processes.

DFO's EAFM Initiative

Fisheries and Oceans Canada (DFO or the Department) is undertaking an initiative to evaluate and implement an EAFM through the work of a **national working group** of scientists and fishery managers supported by regional counterparts. The initial mandate of the working group is to develop a national framework for integrating ecosystem effects into single-species stock assessments and science advice for fisheries management. The long-term objective is for the implementation of an EAFM across most stocks currently assessed and managed by the Department. This will improve management of aquatic resources in Canada through a better understanding and consideration of ecosystem function and interactions with fishery effects, and on the risk associated with management decisions and will help meet the requirements of the new Fish Stocks Provisions (FSP) of the revised *Fisheries Act*.

Current Study

An objective of the EAFM initiative is to evaluate the current state of integration of Environmental Variables (EVs) in the stock assessments in Canada through a gap analysis. A study done in 2017 focused on quantifying the extent of application of climate, oceanographic and ecological factors on population dynamics and how these affected recommendations coming from stock assessments (Pepin et *al*. 2020). That study focused entirely on the science advisory reports and did not consider more details of the analyses and data nor the discussions that resulted in the consensus that led to the recommendations. The study also did not examine the application of that information in the decision-making process by Fisheries Management (FM).

Our study expands on the work of Pepin at al. (2020) by acquiring a broader range of information directly from the individuals involved in Departmental stock assessments. In particular, this study aims to:

- provide an inventory of EV data sources;
- delineate how EVs are integrated into the assessment;
- examine factors affecting EV integration;
- describe how EVs are being considered in decision-making processes; and
- examines future possibilities of enhancing integration of environmental variables.

This study also includes information on stocks where there is no integration of EVs, discussing limitations and reasons why EVs are not considered in those cases, which serves as a basis for some of the recommendations in the discussion. By evaluating the factors that affect EV integration, this study will provide a baseline (as of 2020) for the Department and going forward, will assist in prioritizing the implementation of an EAFM in the assessment process for most stocks managed by the Department.

METHODS/APPROACH

To determine the degree to which EVs are presently accounted for in Canada, we sought input from the Departmental fish stock leads (i.e., scientists, assessment biologists and resource managers) responsible for the provision of advice and development of management recommendations for individual stocks. A questionnaire (App. 1) was used to acquire that information to document EV integration and stock-specific opportunities and challenges related to EAFM implementation. This information was then compiled and categorized in a spreadsheet to facilitate analysis.

The Questionnaire

The survey was comprised of twelve questions intended to capture information on how EVs were used in stock assessments, plus instructions for how to fill out the form and other key background information (App. 1). The questions can be summarized as pertaining to:

a) Background information on the associated fishery or fisheries (Question 1),
b) Background information on surveys used to capture information on the stock (Question 2) and the associated assessment (Questions 3, 4, 5),
c) Integration of EVs into the stock assessment process (Question 6),
d) Effect of integration of EVs on the advice and recommendations to Fisheries Management (Question 7),
e) Information on future potential to include EVs (Question 8),
f) Limitations that would prevent consideration of EVs (Question 9),
g) Whether consideration or discussion of EVs occurred during the consultation process (Question 10),
h) Regional pressures that might limit consideration of EVs in the decision-making process by Fisheries Management (Question 11).

Data are available by contacting the corresponding author.

To summarize the information received, responses were classified into broad categories to partition how and to what degree EVs were integrated into the stock assessment and management processes. Responses to the 12 questions and their sub-categories amounted were categorized and compiled into an Excel spreadsheet comprising all information captured in the questionnaire plus baseline information including stock name, region, zone, fishery type, responsible scientist and resource manager, one line per stock.

Supplementary Interviews

Seventy-three supplementary interviews were carried out by phone or email for a random subset of the stocks. This exercise mainly focused on clarifying materials from the responses to the questionnaire. The interview elaborated barriers to EV integration (e.g., capacity restrictions, availability of data and models, stakeholder interest in an EAFM, known EVs not included in the assessment and plans for future assessments, etc.). For this analysis, there was insufficient time to conduct interviews with all DFO stock assessment leads.

Selected Stocks

There are approximately 281 stocks across all regions of DFO (Table 1) at the time of the analysis, depending on how stocks are defined or delineated, and including co-managed and internationally managed stocks. However, not all of stocks were evaluated in this analysis. The initial selection was based primarily on stocks listed in the 2018 Sustainability Survey for Fisheries (DFO 2020). Pepin et *al*. (2020) noted that for many Pacific salmon management units, numerous assessments exist that are not highly circulated or publicly accessible. Those units (mostly salmon) were excluded from the current study. As well, stocks deemed "not formally assessed" by the stock leads (i.e., 6 Pacific Groundfish stocks) were also excluded. In total, we excluded 53 stocks from this analysis. For the remaining 228 stocks, questionnaires (App. 1) were sent to assessment leads. The survey captures nearly all stocks for which DFO science advice is regularly provided (Table 1). Of the 228 questionnaires sent out, 212 were returned for an overall return rate of 93%.

Table 1. Count and rate of return of questionnaires. (NL – Newfoundland and Labrador Region, Gulf – Gulf Region, QC – Quebec Region, Mar - Maritimes Region, Arct –Arctic Region, Pac – Pacific Region, NCR – National Capital Region, ICCAT – International Commission for the Conservation of Atlantic Tunas. NAFO – Northwest Atlantic Fisheries Organization, IPHC – International Pacific Halibut Commission, ISC - International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean and TRAC – Transboundary Resource Management Committee in the Atlantic. Percent (%) analysed by region in this study (right column) refers to percent of total (281) Canadian stocks. See App. 2 for a stock by stock listing including co-managed stocks.

		Questionnaires			
Stocks	**Total Stocks**	**Sent**	**Percent Sent**	**Returned and Analysed**	**Percent Analysed**
Crustacean	**39**	**39**	**100%**	**39**	100%
Mar	8	8	**100%**	8	100%
Gulf	3	3	**100%**	3	100%
NCR	10	10	**100%**	10	100%
NL	2	2	**100%**	2	100%
Pac	3	3	**100%**	3	100%
QC	13	13	**100%**	13	100%
Groundfish	**92**	**92**	**100%**	**87**	95%
Mar (3 TRAC)	10	10	**100%**	10	100%
Arctic	2	2	**100%**	2	100%
Gulf	6	6	**100%**	6	100%
NL	11	11	**100%**	10	91%
NL (NAFO)	7	7	**100%**	7	100%
Pac	51	51	**100%**	47	92%
Pac (IPHC)	1	1	**100%**	1	100%
QC	4	4	**100%**	4	100%
Large pelagic	**9**	**9**	**100%**	**9**	100%
Mar	1	1	**100%**	1	100%
Mar (ICCAT)	6	6	**100%**	6	100%
NCR	1	1	**100%**	1	100%
Pac (ISC)	1	1	**100%**	1	100%
Marine Mammal	**17**	**17**	**100%**	**17**	100%

Arctic	14	14	**100%**	14	100%
QC	3	3	**100%**	3	100%
Mollusc	**20**	**20**	**100%**	**20**	100%
Mar	6	6	**100%**	6	100%
Gulf	1	1	**100%**	1	100%
NL	3	3	**100%**	3	100%
NAFO	1	1	**100%**	1	100%
Pac	5	5	**100%**	5	100%
QC	4	4	**100%**	4	100%
Other	**7**	**7**	**100%**	**7**	100%
Mar	2	2	**100%**	2	100%
Gulf	1	1	**100%**	1	100%
NL	1	1	**100%**	1	100%
Pac	3	3	**100%**	3	100%
Salmonid	**78**	**24**	**31%**	**13**	17%
Arctic	5	5	**100%**	5	100%
Gulf	1	1	**100%**	1	100%
NL	1	1	**100%**	1	100%
Pac	71	17	**24%**	6	8%
Small Pelagic	**20**	**20**	**100%**	**20**	100%
Mar	4	4	**100%**	4	100%
Gulf	2	2	**100%**	2	100%
NCR	1	1	**100%**	1	100%
NL	2	2	**100%**	2	100%
Pac	8	8	**100%**	8	100%
QC	3	3	**100%**	3	100%
Grand Total	**281**	**228**	**81%**	**212**	**75%**

Twelve Pacific and Arctic stocks included in this survey (App. 2) are co-managed by DFO and stakeholders, primarily Indigenous (Inuit, Métis, and First Nations) governments, communities and organizations (Indigenous groups). Those stocks have been included in this evaluation as they will also be required to adhere to the FSP in the revised *Fisheries Act*.

Twenty-two stocks overlap with external (international) jurisdictions, namely NAFO (North Atlantic Fisheries Organization), ICCAT (International Commission for the Conservation of Atlantic Tunas), IPHC (International Pacific Halibut Commission), ISC (International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean) and TRAC (Transboundary Resource Management Committee in the Atlantic). Under these circumstances, obligations to take into account environmental conditions may differ from Canadian stocks in terms of the legal requirements included in the FSP of the revised *Fisheries Act*. NAFO, with 13 contracting parties (signatories to the Convention) is responsible for the assessments and management of 20 fish and invertebrate stocks. ICCAT, with 53 contracting parties including Canada is collectively responsible for managing wide-ranging large pelagic species. In addition, the ISC, with 11 contracting parties, is the scientific body responsible for Pacific Albacore. Nonetheless, any member scientists involved in the assessment of these stocks can propose methods and undertake analyses that account for EVs.

For stocks that straddle the Atlantic Canada/USA border, the TRAC is responsible for the assessment of 5Zjm Haddock, 5Zjm Cod, and 5Z Yellowtail Flounder stocks; scientists from Canada and USA together undertake the assessment. In the case of the Spiny Dogfish stock that also straddles the Atlantic border, USA leads that assessment and presently, Canada's participation is minimal, providing only catch data. The American assessment does not evaluate EVs at this time although USA regulations may soon require a change to how the stock is assessed.

For the Pacific, there is Canada/USA or domestic co-management for Dungeness Crab, Pacific Hake – Offshore, Pacific Halibut, Eulachon, Intertidal Clams - Central Coast-Heiltsuk Manila and North Coast Haida Gwaii Razor, Pink Salmon – Fraser and Chinook Salmon – Yukon although at a less formal level than for Atlantic stocks (except for Albacore, see above). Refer to App. 2 and Pepin et *al*. (2020) for further details on these stocks.

Summarizing Questionnaires

Here we present a summary of the fundamental elements of the questionnaires to provide a perspective of the categories included in each of the major elements of the survey. Several aspects to emerge from the responses by assessment leads are included in the results but not detailed here because their provision and occurrence was not consistent among respondents.

EV Integration Definitions

The method and degree to which EVs were integrated into the stock evaluations were categorized as follows:

Parameterization – Environmental variables are included as parameters within the stock assessment model. This is the most direct approach to integrating environmental affects into the stock assessment.

Implied –This constitutes time varying M within the model, without clear knowledge of the specific environmental factors affecting the observed changes in M which is considered as an integration of environmental drivers but the assignation to specific factors is not always explicit.

Linked – The effects of environment on the stock were evaluated outside of the stock assessment model. This independent information was used to condition the assessment results and provide an assessment of the environmental drivers that are affecting stock status.

Not Used – There was no consideration of the environmental effects in the evaluation of stock status

Assessment Categories

Sixty-five assessment approaches identified for the 212 stocks examined were classified into 9 broad categories of the various methods used to facilitate an evaluation of the relationship between assessment methods and the integration of EVs (Appendix 3. Assessment Categories.). These include (1) counts, (2) state-space, (3) fishery dependent, (4) sequential population analyses, (5) survey indices, (6) surplus production, (7) statistical catch-at-age, (8) other, and (9) potential biological removal. As an example, Sequential Population Analyses (SPA) comprise a family of stock assessment models that include Virtual

Population Analysis, eXtended Survivorship Analysis (XSA), Cohort Analysis, Stock Synthesis, etc. with some employing Bayesian statistics or a spatial component. “Other” comprises a catchall of the remaining methods, observed with few instances.

Assessment Frequency and Timelines

Canadian stock assessments are carried out on varying schedules from annual to bi-annual, tri-annual and longer. For this study, any assessments that exceeded 3 years between assessments or were done on irregular basis were classified as episodic.

Quantitative fisheries assessment models may be either strategic (‘big picture’, direction-setting and contextual) or tactical (focused on management actions on short timescales), with some strategic models informing the development of tactical models (Plaganyi et *al*. 2011). For the purpose of this study, but keeping with the above description, Canadian assessments are defined temporally (Pepin et al. 2020) as:

- **Tactical** – if they represent advice of status and trends on timelines of 1-2 years.
- **Strategic** – if they represent advice for longer periods, 2-5+ years based on expectations based on population dynamics and/or long-term trends and/or projections of EVs.

Stock status

Stock status, classified as healthy, cautious, critical and uncertain, is determined by comparing stock size in relation to reference points (DFO 2020). The status of the stock affects management decisions, including harvest rates. This classification is used to inventory which stocks in each zone integrate EVs.

Data Quality

Integration of EVs in stock assessments is examined in terms of assessment (non-EV) data input. Canadian stock assessments are classified as Rich, Moderate or Poor, as follows:

Rich – Stocks for which there are fishery independent (i.e., from dedicated surveys) and fishery dependent (i.e., catch) indices of abundance, data on age and/or size structure, independent data to estimate rates of change in growth or mortality rates, and other biological data and/or knowledge that are used in conjunction with quantitative population models to estimate past and current population states and project the consequences of management measures under current and/or changing environmental conditions.

Moderate – Similar to data rich stocks (some fishery independent data along with fishery dependent data) but for which detailed biological knowledge is limited and for which models provide population aggregated estimates of the rates of change.

Poor – Stock for which assessments are reliant on fishery dependent indices of abundance, and with limited or no data on age or size structure.

EVs and Biological Processes

Following Pepin et *al*. (2020), EVs used in Canadian assessments are broadly classified as Climate Indicators, Ocean Conditions, Ecological Factors and Habitat Availability. Under each of these classifications, EVs specific to those classifications are listed along with corresponding stocks and affected biological processes for each stock (App. 7).

RESULTS

Questionnaires were completed by assessment leads for 93% (212 of 228) of regularly assessed stocks in Canada; Pacific Region with 74 stocks (35% of total), Maritimes 37 (17%), Quebec 27 (13%), Newfoundland and Labrador (NL) 27 (13%), Arctic 21 (10%), Gulf 14 (7%), National Capital Region (NCR) 12 (6%), and included 12 internationally managed stocks (NAFO [NL], ICCAT [Maritimes], ISC [Pacific] and IPHC [Pacific]) (Table 1 and Appendix 2. List of Stocks and EV Integration). The questionnaire return rate was 100% for Arctic stocks, 99% for the Atlantic regions (including international), 81% for the Pacific, with the missing stocks comprising mainly of salmonids (Table 1).

EV Integration by Region and Taxon

The highest degree of integration of EVs was observed for Quebec and NL at 85% and 74%, respectively. The lowest was observed for the Arctic (33%), Pacific (28%), and international stocks ICCAT (33%) and NAFO (25%) (Table 2, Fig. 1). However, if more salmonid assessments had been included, the Pacific proportion of stocks integrating EVs would be higher as river conditions were often taken into consideration in assessing population status.

For all regions combined, groundfish (41% of stocks) and crustaceans (18%) made up the majority of stocks examined in this analysis (Table 2, Fig. 1). The greatest proportion of stocks for which EVs were integrated included salmonids (85%), crustaceans (74%) and small pelagic fishes (70%) (Fig. 1). Use of EVs in assessments for marine mammals and groundfish were lowest at 31% and 24% of stocks. Had information been available for more Pacific salmon stocks, the proportion would likely have been higher for that taxon.

For all regions combined, groundfish (41% of stocks) and crustaceans (18%) made up the majority of stocks examined in this analysis (Fig. 1). Stocks for which EVs were integrated was highest for salmonids (85%), crustaceans (74%) and small pelagic fishes (70%), lowest for marine mammals and groundfish at 31% and 24% of stocks (Fig. 1). Had information been available for more Pacific salmon stocks, the proportion would likely have been higher for that taxon. Linked analyses were most frequently applied to crustaceans and groundfish stocks.

Integration of EVs by Method

Forty-eight percent of 212 stocks assessed in Canada integrated EVs either as model parameters (11%), linked analyses outside of the model (30%), or implied changes in M in the model (7%). Of the 101 stocks where EVs were used in the assessment, 63% constituted linked analyses, parameterized models comprised 23%, while implied made up 14%.

The highest proportion of stocks integrating EVs as parameters was in the Maritimes (59% of stocks), Pacific (29%) and NL (21%) (Fig. 1). ICCAT and NAFO did not parameterize EVs in any of their assessments. For linked analyses, the highest proportion was for ICCAT and NAFO stocks (100%), followed by Quebec (91%), Arctic (86%), NCR (83%), and NL (64%). Pacific (43%) and Maritimes (35%) had the lowest proportion of linked analyses for stocks in which EVs were considered. Finally, implied analyses were highest in the Gulf (44%), followed by Pacific (29%), NL (14%), Maritimes (6%) and Quebec (4%). Implied analyses were not used elsewhere.

EV integration varied substantially among taxa both in terms of degree and type of integration (Fig. 1). Across taxa, the highest proportion of stock assessments that parameterized EVs was observed for molluscs (67%). For linked analyses, the highest proportion was for "Other" taxa (100%); however, these were applied frequently to crustacean (86%) and groundfish (58%) stocks. Eleven of 13 salmon stocks assessments included river and oceanic EVs either as parameterized or linked in the analyses. Finally, of the stocks where EVs were used, implied analyses were used only for small pelagic fishes (35%) and groundfish (38%). Refer to App. 2 for stock by stock details.

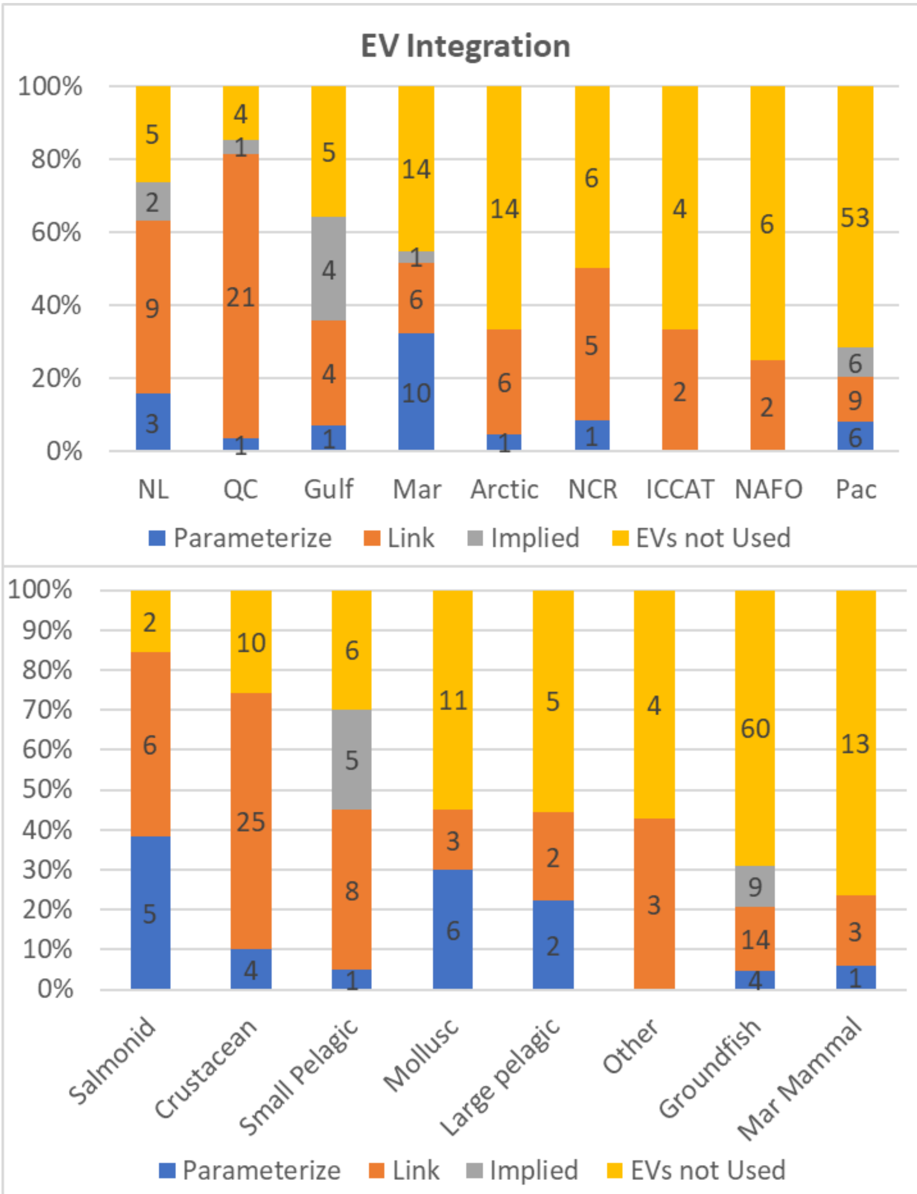

Figure 1. Integration of environmental variables into stock assessments in Canada, by Region (upper) and by Taxon (lower). note that ICCAT (Maritimes co-managed) and NAFO (NL co-managed) are shown separately.

EV Data Sources

There are many sources of EV data, often specific to particular regions/areas, sometimes specific to stocks. App. 6 lists the various sources of data on a stock basis for 78 (of the 101) stocks examined. The most important source noted was the Atlantic Zone Monitoring Program (AZMP, 12 mentions) which included oceanographic data, mainly temperature as well as zooplankton production. Another important source was DFO fishery independent surveys, for temperature, salinity, oxygen and habitat. In some cases EV data were collected during stock-specific surveys and in other cases, published data were used.

Assessment Categories

All six assessments employing counts integrated EVs (Fig. 2). The remainder, in descending order of degree of EV integration, were State-Space (STSP), fishery dependent, Sequential Population Analysis, survey indices, Surplus Production, Statistical Catch at Age, and Potential Biological Removal (PBR) assessment approaches. The "Other" category included assessments based on Acoustic Indices (EVs not used), two Delay Difference models (implied), Mark-Recapture (no EVs), a qualitative Management Strategy Evaluation (no EVs), a Principal Component Analysis (linked), a Traffic Light approach (linked) and for three stocks, there were no formal assessments and status was evaluated qualitatively. Refer to App. 3 for a categorized list of assessment methods used and their EV integration.

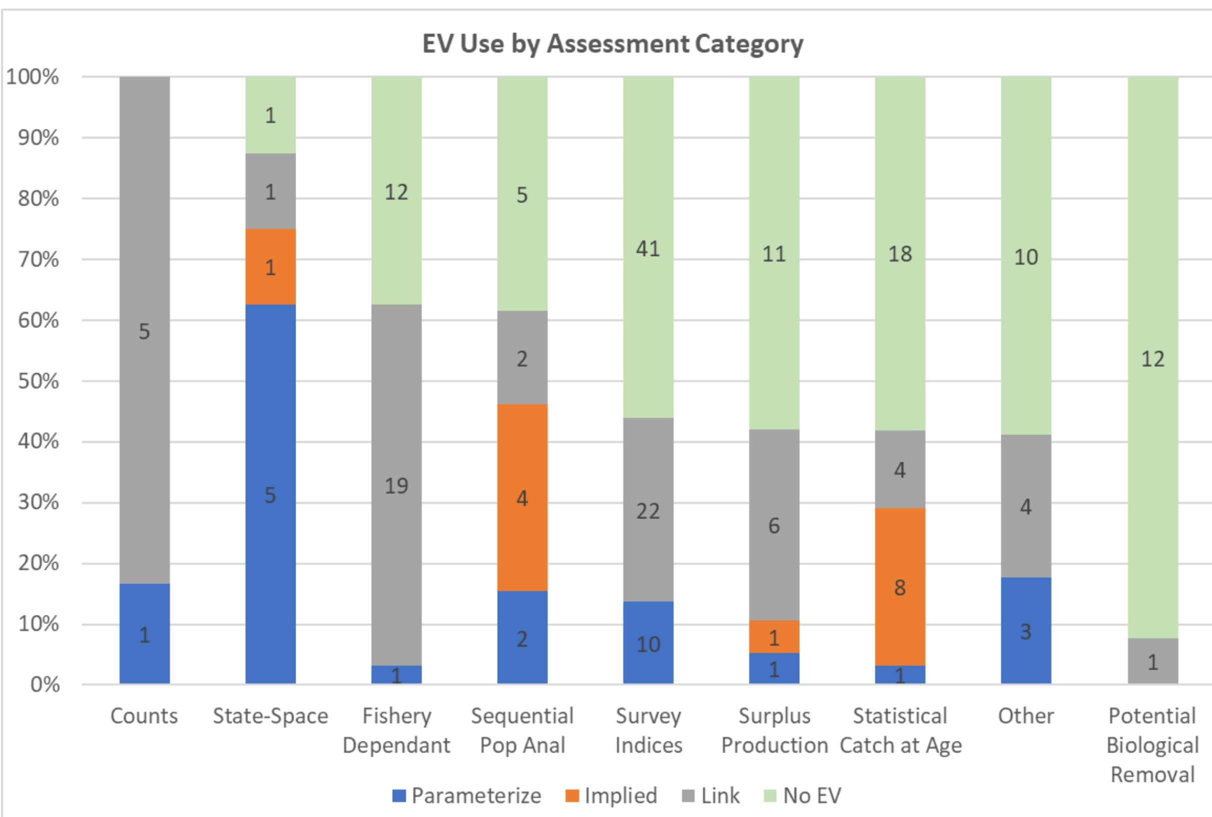

Figure 2. Integration of EVs into stock assessments. EVs used vs EVs not used including type of EV integration when EVs are used.

The highest number of stocks integrating EVs by assessment approach were using survey indices (32 stocks), followed by fishery dependent indices (20) and Statistical Catch at Age models (13) (Fig. 2, Table 2). All others assessment approaches had 8 stocks or fewer represented (Table 2).

Table 2. Summary of assessment methods and models used in relation to EV integration. Percentages represent assessment category totals shown in column 2.

Assessment Category	Count of Assessments where EVS were used	Percent Parameterized	Percent Implied	Percent Linked	Percent with EVs
Survey Indices	32	31%	0%	69%	44%
Fishery Dependent	20	5%	0%	95%	63%
Statistical Catch at Age	13	8%	62%	31%	42%
Sequential Population Analyses	8	25%	50%	25%	62%
Surplus Production	8	13%	13%	75%	42%
State-Space	7	71%	14%	14%	88%
Counts	7	17%	0%	83%	100%
Other	6	43%	0%	57%	41%
Potential Biological Removal	1	0%	0%	100%	8%
All Types	**102**	**22%**	**14%**	**63%**	**48%**

One approach stood out in terms of integrating EVs as model parameters; 71% of State-Space type assessments parameterized the effects of EVs in the assessments (Table 2). For the remainder, integration of EVs as model parameters was 31% for Survey Indices, 25% for Sequential Population Analysis, and 17% or less for all other categories. Implied approaches were used only for Statistical Catch at Age (62%), Sequential Population Analysis (50%), State-Space (14%) and Surplus Production (13%). All assessments categories incorporated EVs as linked analyses to a considerable degree with the highest at 95% for fishery dependent assessments, 83% for counts, 75% for Surplus Production, 69% for survey indices and 57% or less for all other categories.

The following provides examples of how EVs were integrated into the assessments as inventoried in Table 2 and detailed in App. 2, providing some insight into why certain methods were more likely to integrate EVs. Each bullet is an extraction of the questionnaire, in the (abridged) words of the respondent.

The highest counts for EV **parameterized** models pertained to analysis of survey indices (for 10 stocks) and State-Space (5 stocks) based approaches (Table 2). Examples of parameterized models from different model types are as follows:

- **Survey indices, Snow Crab Scotian Shelf** - Biomass estimates, the basis of harvest advice are based on current and historical states of environmental and ecosystem covariates.
- **Survey indices, Geoduck** - A spatial scuba survey-based index of habitat availability was used to estimate biomass on geoduck beds.
- **Statistical Catch at Age, Pacific Halibut** – Stock Synthesis (age-structured population dynamics model) integrate Pacific Decadal Oscillation as covariates for recruitment.

- **State-Space, Scallop, 4 Scotian Shelf/Bay of Fundy stocks** - The State-Space habitat-based model was fit to commercial catch, VMS (video monitoring system) effort and survey data. Habitat quality is explicitly included; advice is based primarily upon biomass density in high quality habitat regions.
- **Fishery dependent, Surf Clam Banquereau** - A spatial fishery-based index of habitat availability, a VMS proxy is used to estimate biomass.
- **Count, Grey Seal** - Ice cover has been incorporated into assessment models to provide an index of pup mortality.
- **Bayesian Surplus Production model, Swordfish Atlantic** – Trends in CPUE (catch per unit effort) were correlated with decadal cycling of the Atlantic Multi decadal Oscillation (AMO) and the North Atlantic Oscillation (NAO). Including the AMO as a covariate to area specific catchability in the model helped reduce conflicting directions of various CPUE trends.

The highest stock count for **implied** approaches pertained to Statistical Catch at Age (8) and Sequential Population Analysis (4). Following are examples of Implied application of EVs:

- **Sequential Population Analysis, Cod 4RS-3Pn** - Natural mortality relates to predation by gray seals and harp seals and fishing mortality not counted as recreational fishing, but their importance is unknown. Other groundfish stocks in the southern Gulf use a similar approach.
- **Statistical Catch at Age, Pacific Herring, Central Coast, Haida Gwaii, North Coast, Strait of Georgia, West Coast Vancouver Island** - Changes in predation pressure and/or food availability are accounted for indirectly in both the assessment model and MSE (Management Strategy Evaluation) simulations. Assessment model parameterization includes estimating time varying natural mortality (tactical approach), which is assumed to be a function of ecological or environmental drivers. Strategically, scenarios with changing trends in M are explored within the MSE process to identify management procedures robust to increasing M. Most recent work is in trying to attribute estimated trends in M to predator biomass via bioenergetics/ consumption rates.

The highest stock count for **linked** approaches pertained to survey indices (22), followed by fishery dependent approaches(19), Surplus Production (6) and counts (5). Examples of EV linked assessments:

- **Survey indices, Greenland Halibut Cumberland Sound** - Environmental variables were considered when reviewing the history of the fishery and when assessing the population model. Changes in location affected catch rates and fishery participation.
- **Survey indices, Capelin 4RST** - Environmental and biological variables thought to influence cohort strength and pre-spawning adult mortality were evaluated to more accurately estimate standardized CPUEs.
- **Survey indices, Iceland and Sea Scallop 3Ps** - Sea stars are the key predators of scallop and are accounted for in the survey catch data. The trends in the biomass indices of these predators are considered in the assessment. An increase in predators might explain a change in scallop distribution or mortality rates.
- **Fishery dependent, Lobster Fishing Area 22** - Temperature is considered semi-quantitatively to describe or explain general trends in other indicators. For example, a low catch rate at the beginning of the season may be associated with a low water temperature during this period.

It is not unusual that more than one EV is used in an assessment. These may be integrated within a single model or in more than one model estimating different parameters that reflect processes affecting the population (e.g., growth, mortality, recruitment, etc.). An example is the State-Space Scallop Scotian Shelf/Bay of Fundy stocks. In addition to the State-Space habitat-based assessment model, annual rates of natural mortality were modelled from trends in the clapper index (hinged empty shells). As another example, there were 4 models used for Atlantic Swordfish but only one model used EVs as parameters. For a complete description of assessments and EV integration, refer to App. 2 and App. 7 for details by stock.

Frequency of Assessments

EVs were used more frequently for assessments that were done every year (71% of cases) or every second year (54%), and less frequently for assessments that were done every third year (40% of cases) or episodically (35% of cases) (Fig.3).

EV parameterized models were used in 24% of annual assessments, none in bi-annual or tri-annual assessments. However, there were 9 instances of assessments using parameterized models that were episodically assessed, as needed, with more frequent assessments deemed unnecessary. EV implied models were observed for 13% of annual assessments, 8% for bi-annual, 4% for episodic while linked analyses were found in all assessments to varying degrees (35% annual, 46% bi-annual, 40% tri-annual 23% for episodic assessments).

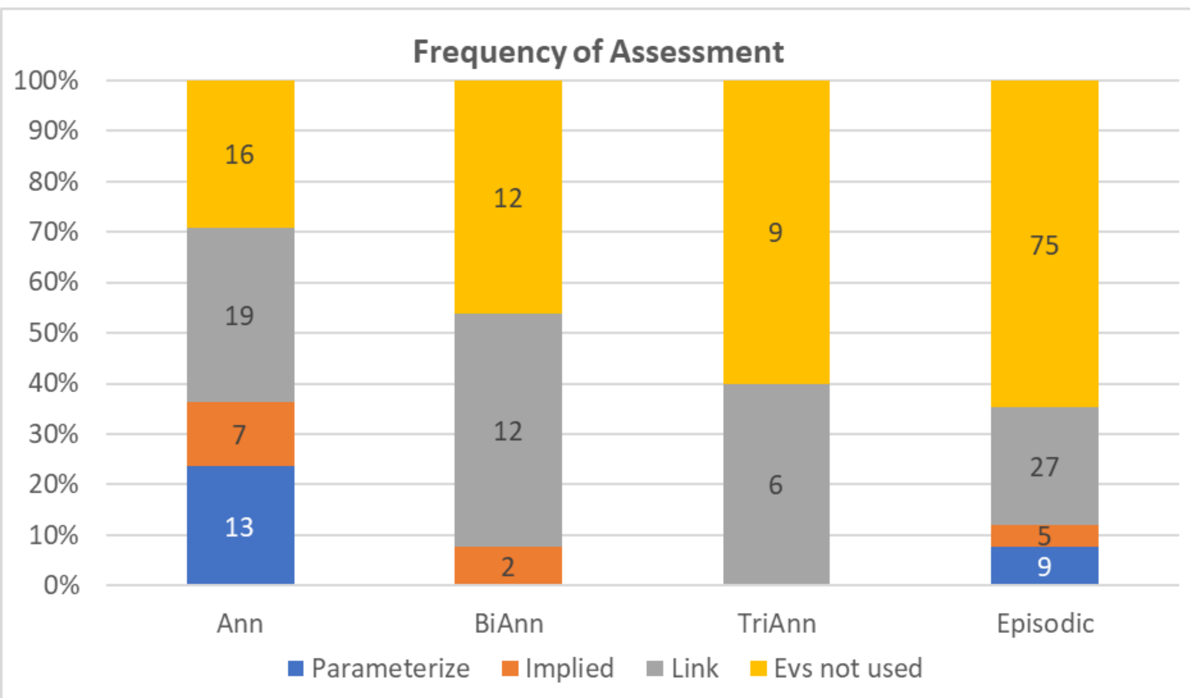

Figure 3. Integration of EVs by frequency of assessments.

Time Frame (Tactical or Strategic)

Where EVs were integrated, 48% of assessments were described as tactical, 37% as strategic and 15% designated as a mix of both. Parameterized models and linked analyses had a higher proportion of models that were tactical than those using implied models, but implied models were more often described as both strategic and tactical (Fig 4).

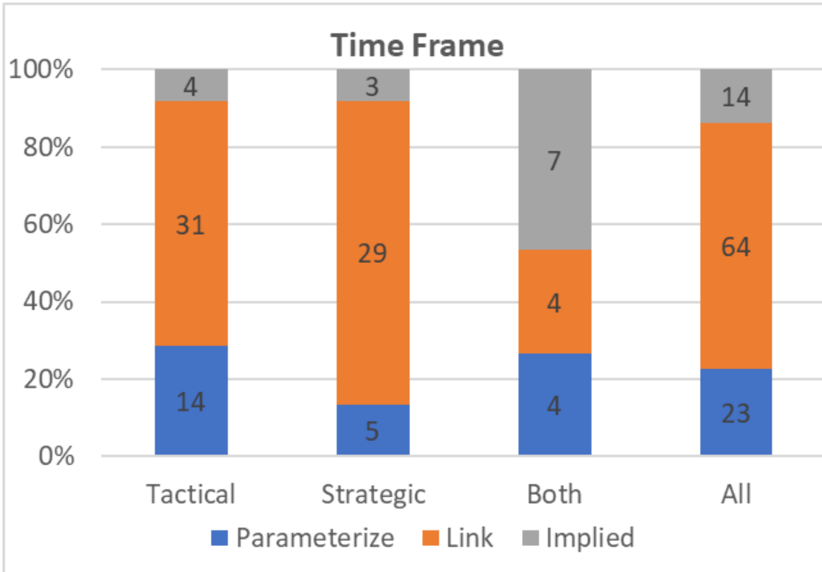

Figure 4. Mix of strategic and tactical models in terms of types of EV integration

Stock Status

Fifty-one percent of assessments of healthy stocks incorporated EVs. In cases in which EVs are integrated into assessments of healthy stocks, 37% incorporated EVs through model parameterization (Fig. 5). Implied analyses occurred in 8% of cases while linked analyses were most prominent at 55% of healthy stocks that applied EVs in the analyses. Many stocks that are in the healthy zone are primarily important directed fisheries designated as data rich (see Data Quality section below).

EV integration in stocks classified as cautious was slightly lower than for healthy stocks (48%). However, stocks designated as critical had the highest proportion of EV integration at 69%. For those that use EVs, linked analyses was the most common form of integration (50%). However, implied analyses were also important (32%) and in this case, 7 stocks were described as having elevated natural mortality which was thought to be causing these stocks to remain in the critical zone in spite of minimal fishing pressure. EVs are included in only 32% of assessments for stocks classified as uncertain, with linked analyses being the predominant approach.

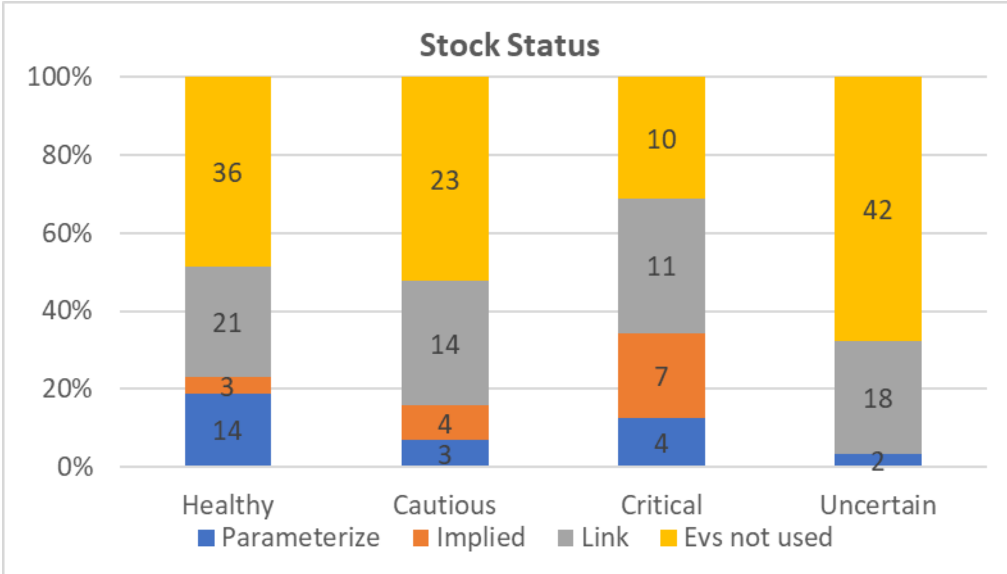

Figure 5. Assessment type as related to stock status

Stocks Evaluated by COSEWIC for Risk of Extinction

Seventy-two of 212 stocks examined have also been assessed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) for risk of extinction (Fig. 6). As none of the those COSEWIC assessed stocks are listed under SARA (*Species at Risk Act*) schedules and thus with no restriction under the *Fisheries Act*, DFO treats them the same as all stocks, performing regular assessments or Recovery Potential Assessments.

Only 29% of COSEWIC assessed stocks integrated EVs as opposed to 57% for non-COSEWIC assessed stocks (Fig. 6). For 16 Endangered designated stocks, DFO integrated EVs as parameterized, implied and linked analyses (19% each) and for the remaining 44%, EVs were not integrated. For the 16 stocks that were designated as Threatened, DFO integrated EVs as implied (6%) and linked analyses (25%), and for the remaining 69%, EVs were not integrated. For the 24 stocks that were designated as Special Concern, DFO integrated EVs as parameterized (4%) and linked analyses (4%), and for the remaining 92%, EVs were not integrated. For the 16 stocks designated as Not at Risk, DFO integrated EVs as parameterized (6%), and linked analyses (19%), and for the remaining 75%, EVs were not integrated (Fig. 6).

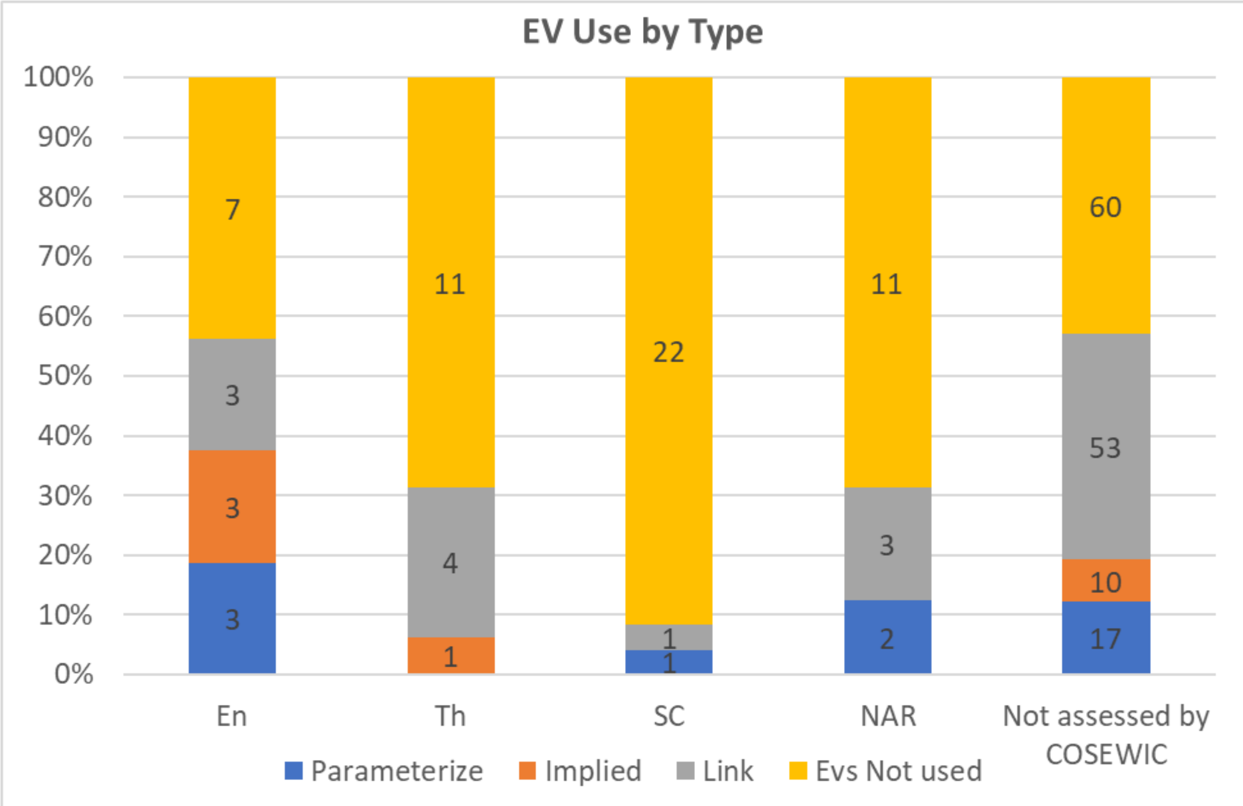

Figure 6. EV integration for stocks assessed by COSEWIC vs not assessed. Count of stocks shown on the bars. En – Endangered; Th – Threatened; SC – Special concern; NAR – Not at risk; or Not assessed by COSEWIC.

Environmental State Addressed Separately

Seventy-seven percent of Canadian assessments included a discussion of the state of the environment. Sixty-one percent of assessments included a discussion of the environmental state of the oceans when EVs were not used whereas 95% of Canadian stocks integrating EVs also included a discussion of the environmental state. The environment played no role in the assessment either as integration of EVs or a general discussion for 20% of all assessments examined.

Discussion of environmental state in the absence of EV integration (61% of stocks) did not affect the assessment outcomes but potential affects on the stock were noted (see App. 4 for stock specific examples). In some cases, it was noted that EVs would be integrated in the future based on indications of environmental influences on the stock observed from environmental state discussions.

Absence of environmental discussion during the assessment related to a paucity of environmental information for the region, such as for several stocks in the Arctic, or stocks that had not been assessed in recent years, such as some Pacific groundfish. Another key reason given was limited capacity and/or resources to undertake studies into the effects of the environment on population dynamics.

Integration of EVs into Advice and Management Decisions

Stock assessments that integrated EVs using parameterization or implied methods not only affected assessment results but also affected the science advice in all cases (Fig. 7). On the other hand, linked EV analyses were used to interpret and condition the assessment in 48% of cases and 26% of the time affected the advice (Fig. 7). The linked analysis, that does not directly impact the model output, allowed the assessor to choose whether to condition the assessment advice based on the linked findings. This choice was generally based on the statistical significance of EV effects.

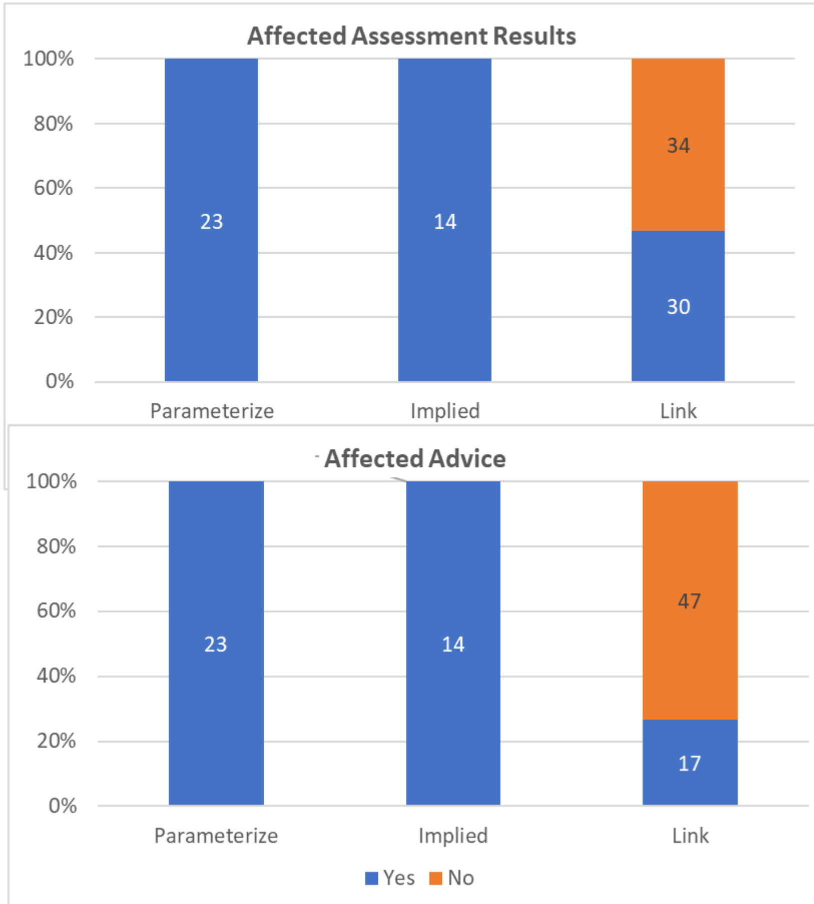

Figure 7. EV Integration as it affected assessment results and subsequent management advice.

Limitations Affecting EV Use

Several factors limited the use of EVs in stock assessments. For the majority of stocks that do not currently integrate EVs, multiple rather than single factors more commonly limit EV integration (Table 3). Availability of EV data and deficient mechanistic understanding are the leading factors limiting use of EVs in Canadian stock assessments. Deficient EV data was the lead cause of non-EV integration, in 64% of stocks, with deficient mechanistic understanding the second leading cause, in 24% of cases.

Table 3. Limitations preventing the use of EVs in Canadian assessments. Within the brackets are assessor responses to the question whether Ev integration is likely in the future.

Limitations (Future Integration Likely?)	Count of Stocks	Count Total	Percent of Total
Data (Yes, Possibly, Unlikely, No, Unknown)	**29**		
Data - Aging, Species/stock Differentiation (No, Unknown)	**8**		
Data - Incomplete Survey (Unknown)	**1**		
Data, Population Parameters (Yes, Unknown)	**7**		
Data, Mechanistic Understanding (Yes, Maybe [research needed], No)	**11**		
Data, Mechanistic Understanding, Model Code (No, Unknown)	**9**		

Data, Mechanistic understanding, Monitoring, Survey issues (Yes, Possibly)	**5**		
Data, Transboundary (No)	**1**	71	64%
Mechanistic Understanding (Possibly, No, Unknown)	**21**		
Mechanistic Understanding, Ecological Uncertainties, Monitoring (Possibly)	**3**		
Mechanistic Understanding, No surveys, Highly migratory, International barriers (Unknown)	**1**		
Mechanistic Understanding, Stock Dynamics, 2 Species (Unknown)	**1**		
Mechanistic Understanding, Resources (Possibly)	**1**	27	24%
Monitoring (Yes)	**1**		
Monitoring, Data (Yes)	**1**	2	2%
Resources (No, Possibly)	**5**		
Resources, Model Code (Yes)	**2**	7	6%
No assessment (Possibly)	**1**		
Time (Yes)	**1**		
No Interest (Yes)	**1**		
Lack of Value (No)	**1**	4	4%

Data Quality and Deficiencies

Quality of (non-EV) data used to assess stocks affected the degree of EV integration. Data rich and to a lesser extent, data moderate stocks were more likely to integrate EVs: 60% of data rich stocks, 44% of data moderate stocks and 35% of data poor stocks integrated EVs (Fig. 7). Thus, assessment data quality affects the degree of EV integration. This may reflect the economic or social importance of the stock but the quality of information will affect the likelihood of detecting the effect of changing environmental condition.

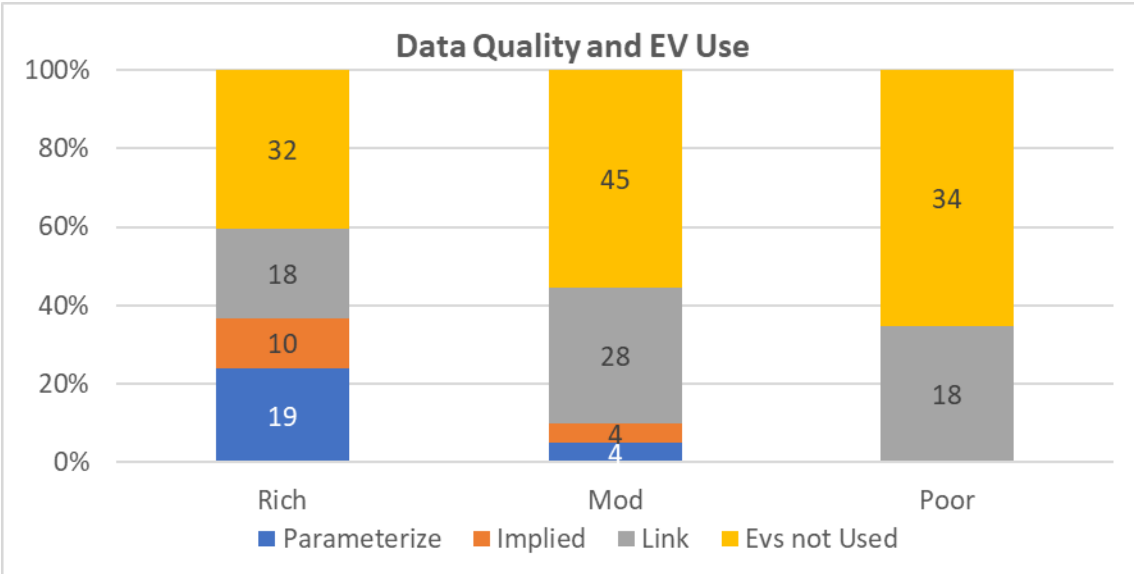

Figure 8. Integration of EVs with respect to quality of non-EV data used in the assessment. Numbers shown on the bar are stock count.

Assessment data quality also affected type of EV integration (Fig. 7). Data rich stocks integrated EV suing model parameterization most frequently (83%), followed by the remaining 17% applied to data moderate stocks. Of the stock assessments where EV integration was implied analyses were also more frequent for data rich stocks (71%) than in data moderate stocks. Neither model parameterization or implied analyses were used for data poor stocks. Of the stock assessments where EV integration was linked, this was lowest for both data rich and data poor stocks at 28% each, and the remaining 36% were attributed to data moderate stocks. Importantly, linked EV analyses was the only assessment type that was applied to data poor stocks. The 18 data poor stocks that used linked analyses were varied and included 5 crustaceans (lobster stocks), 4 salmonids, 3 small pelagic fish, 3 molluscs and 1 each of groundfish, marine mammal and other stocks. Key to their commonality was that when EV data were collected coincident with stock surveys or collections meant that environmental effects could be explored outside of the assessment model and may provide a foundation for substantive integration into the assessment. This indicates that even for data poor stocks, environmental affects can be integrated when appropriate data are available.

Quality of the data varied among the different categories of assessments (Fig. 8). When EVs were used, State-Space models and Statistical Catch at Age had the highest proportion of rich data as input, with88% and 74% of assessments, respectively, and only one data poor instance for Statistical Catch at Age. At the next level, Sequential Population Analyses and counts had data rich input for an average of 68% of cases and few (11%) data poor instances. Stocks with data rich input were low for survey indices, Surplus Production, fishery dependent and other categories averaging 23%. Potential Biological Removals had only data poor input. Acoustic index models (under the “other” category) comprised the data rich component for that category. All other assessment types, Delay Difference Model, mark-recapture, PCA and Traffic Light were applied to data moderate stocks.

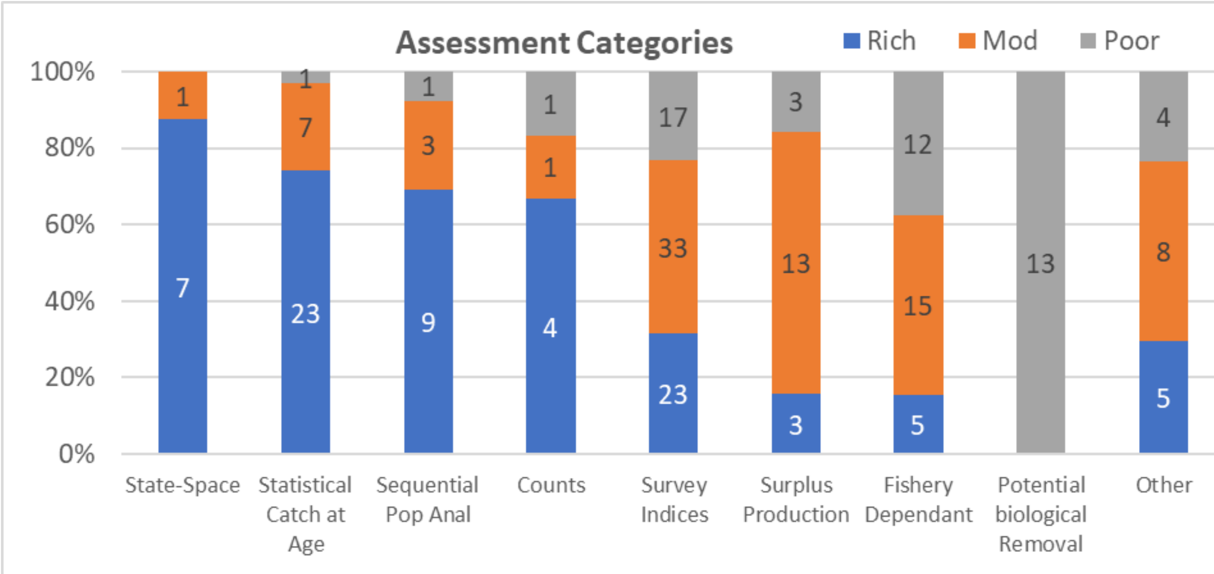

Figure 9. Data quality by stock assessment category

Comparing EV integration type by assessment category (Fig. 2) and data quality by assessment category (Fig. 8), reveal a strong relationship between the integration of EVs, the manner of their integration, and assessment methods. Model parameterization was most frequent for State-Space models corresponding to the highest proportion of data rich stocks and no data poor assessment input. Statistical Catch at Age, with a similar proportion of data rich stocks had the highest relative proportion of implied analyses and low model parameterization. Sequential Population Analysis, which is applied primarily to data rich and moderate stocks, has a similar mix of approaches to integration of EV types, but a higher proportion of stocks not using EVs than for State Space and Sequential Population analyses. At the other end of the spectrum, PBR stocks were all data poor and had only one linked analysis for this assessment category; the rest did not integrate EVs. Thus, there was a correlation between quality of input data used and the approach to EV integration, including the type of EVs used. Higher quality of assessment input data was associated more with EV integration and in particular, model parameterization and implied analyses; integrating EVs directly into the assessment model was done mostly for data rich stocks.

Data deficiencies were identified for 66% of the stocks as the key or secondary reasons for not including EVs (Table 3). For 6% of stocks, data deficiencies, namely inconsistent EV data series were cited as the exclusive reason for not integrating EVs. A significant number of respondents noted that accessing EV data was a challenge because the information was in format that was not readily accessible, making integration of environmental effects less likely. For the remaining 38% of assessments, data deficiencies coupled with other reasons, mainly mechanistic understanding, were cited as the limiting factors. Another reason given was that standard assessment models do not accommodate EV integration (Appendix 3. Assessment Categories.).

Mechanistic understanding

In addition to data quality issues, scientists involved in assessments that do not presently integrate EVs stated that lacking or deficient mechanistic understanding (unable to determine how EVs affected the stock status), monitoring, deficient understanding of stock dynamics (information on the stock's biological processes are poorly understood) and survey issues (insufficient information about population trends or fishing effects to allow differentiation from natural processes) played a part in the non-integration of EVs (Table 3). Remaining reasons cited were resource issues and insufficient time or expertise to undertake integration based on sound scientific principles. Limited interest in addressing environmental effects was rarely identified as a limiting factor, but noted in three cases: Grand Bank Redfish in 3LN and 3O, Atlantic Cod in 3NO and all NAFO managed stocks. In general, integration of EVs was largely regarded as useful. In only one case did an assessment scientist cite the lack of value to the past and current assessment's outcome (Sablefish) as the primary reason for not integrating EVs.

Capacity

For assessments not integrating EVs, 76% of respondents indicated that limited (37%) or lacking (39%) capacity, namely expertise, time and/or money to carry out the work, were the primary or secondary reasons why EVs were not integrated into their assessment.

Regional Pressures

In addition to data issues and capacity, other regional pressures affected the degree of EV integration in 45% of stocks that did not integrate EVs. Pressures included biological interactions between stocks leading to conflict of interest where trophic EV considerations for one stock might be detrimental to the other stock, and co-management where one of the parties chose not to consider environmental effects. Limited recognition of the potential role of environmental factors was rarely an issue that prevented EV integration into assessments.

Application to Other Stocks

In 84% of cases, the method or approach to incorporating EVs into the assessment could be applied to some other stocks: 100% for EV parameterized assessments, 93% for implied EVs in models and 78% for linked analyses. This potential application to other stocks pertained not only to related stocks such as the same or similar species in adjacent areas but also with wider, general application where EV data in sufficient quantity were available. This suggests that existing approaches could be adapted to stocks that do not currently integrate EVs and in fact, adaptation of EV integration from other assessments is already taking place for at least 10 stocks. Respondents indicated that both data and methods are presently available to incorporate EVs into about 66% of the 111 stocks where EVs are not presently used. There is sufficient scope in the science advisory process that an increase in the number of stock assessments integrating EVs is highly possible.

Whether EV integration into other stocks would significantly affect the assessment outcome would only become known by exploring their use. However, where EVs are currently used, respondents indicated for 11 assessments that other (linked) EVs were tried and discarded for various reasons, mainly that their integration was found to make little or no difference to the outcome of the assessment or the associated data were not robust enough. This is not to say that other EVs not yet examined might be observed to influence the population processes. For half of the stocks where EVs are not presently used, responses indicated that there were no previous attempts to integrate EVs but future attempts to integrate were not ruled out, but dependent on data quality and availability of EVs.

Future Possibilities

Stock assessment scientists for assessments where EVs are not presently being used indicated that future integration of EVs was likely or being considered in 41% of cases. Thus, in the short term, EV integration is likely to occur for 34 stocks that would increase EV integration to about 65% of the 212 stocks examined. Fifty percent of respondents indicated that it would be unlikely or not possible in the foreseeable future to integrate EVs into their assessments given the current state of knowledge and available data. The remaining 9% of respondents were uncertain. Refer to App. 5 for stock specific examples of potential future integration of EVs.

In a few cases, where EVs were already integrated, scientists indicated that further enhancements to EV integration were being considered. For example, for Gulf Lobster, it was noted that temperature is presently linked indirectly to stock indicators and efforts will be made to initiate parameterization of this EV in the stock assessment model by 2022.

EV Parameters and Population Biological Processes Affected

EVs used in Canadian assessments are classified as Climate Indicators, Ocean Conditions and Ecological (that includes Habitat Availability) Factors.

Predators and prey (Ecological Factors) constituted the largest contribution of EVs to stock assessments with 31 instances, for 9% of parameterized assessments, 50% implied, and 31% of linked analyses, and sometimes coupled with other EVs (Table 4). Plankton was the most common named prey including copepods, zooplankton in general, and unspecified ichthyoplankton. Predators were varied and when specifically named included a broad range of taxa: sea stars, capelin, redfish, cod, seals and otters and more general descriptions of trophic interactions.

Ocean Conditions, most often consisting of a metric of water temperature, was the next most commonly used EV for Canadian stock assessments, in most cases in conjunction with other types of EVs. It was used as a model parameter for 27% of EV parameterized stock assessments and 63% of linked analyses (Table 4). Temperature comprised sea surface readings (SST), midwater or bottom temperatures depending on the requirement and the species. For anadromous species, temperature was used both at sea and in rivers and lakes. Other ocean/water conditions, used at much lower rates, included salinity, pH, oxygen, conductivity, ocean chemistry, water level and colour and were mentioned for 6% of assessments. Ice melt and sea ice extent (either as area or volume) were also used in 6% of assessments that incorporated EVs.

Climate Indicators were used in 18 instances, in 18% of assessments that employed model parameters and 8% of linked analyses. The remaining EVs used pertained mainly to habitat and were only used occasionally (Table 4).

Table 4. List of EVs used separated by how they were used: Parameterization, Implied or Linked analyses.

EV	Count of Stocks	Percent
Parameterize	**22**	
Sea Surface Temperature, Salinity Pacific, Decadal Oscillation Timing Diversion Temperature Discharge	4	18%
Clapper proxy	3	14%
Temperature, Depth, Substrate, Species Composition	3	14%
North Atlantic Oscillation, Atlantic Multidecadal Oscillation	2	9%
Habitat	1	5%
Habitat Quality, Clapper Proxy	1	5%
Ice melt	1	5%
Pacific Decadal Oscillation	1	5%
Proxy Benthic Habitat	1	5%
Sea Ice Predators, Prey, Temperature	1	5%
Temperature, Condition (diet)	1	5%
Water level, colour, debris, Temperature	1	5%
North Atlantic Oscillation, Temperature Predation	1	5%
Predation	1	5%
Implied	**14**	
Predation, Prey	7	50%
Unspecified	7	50%
Link	**64**	
Temperature	20	31%
Predation, North Atlantic Oscillation	4	6%
Shore length	2	3%
Sea Surface Temperature Zooplankton prey	2	3%
Temperature, Plankton Predator Abundance	2	3%
Unspecified	2	3%
Larval Transport	2	3%
Arctic Oscillation latitude (temperature proxy)	1	2%
Biochemistry, Sea Ice Contaminants Predation	1	2%
Diet Capelin	1	2%
El Niño/Southern Oscillation	1	2%
Extent	1	2%
Habitat Co-occurrence, Trophic Interactions	1	2%
Ice	1	2%
Ice melt	1	2%
Predator	1	2%
Predators Starfish	1	2%
Prey	1	2%
Sea Otter, Sea Star Predation	1	2%

Sea Surface Temperature	1	2%
Sea Surface Temperature, Salinity, Plankton	1	2%
Sea Surface Temperature, Zooplankton Prey, Ice Retreat	1	2%
Temperature, Depth, Plankton Community Biomass	1	2%
Temperature, Oxygen, Ph, Competition	1	2%
Temperature, Plankton	1	2%
Temperature, Plankton Community Biomass	1	2%
Temperature, Predation	1	2%
Temperature, Predator Redfish, Abundance, Regime Shift	1	2%
Temperature, Prey, Community biomass	1	2%
Temperature Prey Nutrients Plankton Community change	1	2%
Temperature, Prey, Habitat	1	2%
Thermo-profiling, Water Chemistry, Primary Prod., Food Web	1	2%
Depth, Temperature, Dissolved Oxygen, pH, Turbidity and Conductivity	1	2%
Area	1	2%
E&N Pacific Index, sea level anomalies, max area Haida eddies, Aleut Low Press Index, N Pacific index, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, El Niño Index, Southern Oscillation Index	1	2%
PDO ONI, Sea Surface Temperature, Temperature, Salinity Copepods, Biol spring Transition, Ichthyoplankton	1	2%
Prey Depth	1	2%

A single EV was used in the assessment for 27% of parameterized models (Table 4, App. 7 for stock by stock details). Climate Indicators alone were used for the 4 assessments; North-Atlantic Oscillation (NAO) and Atlantic Multi-decadal Oscillation (AMO) data were included in analyses in relation to movements of highly migratory species, and one stock used Pacific Decadal Oscillation (PDO) in relation to recruitment.

More commonly, multiple EVs were used for each assessment to assess drivers of stock status. For example, Climate Indicators, Ocean Conditions (NAO and temperature) and multispecies links (predators) were parameterized in the same model. The associated (affected) population processes were biomass and productivity (App. 7). Another example, climate indicators, ocean conditions and multispecies links were used together to examine EV effects on stock status, either in terms of biomass or productivity.

For the 14 implied EV analyses, associated environmental effects were uncertain. However, the likely effects were predators and prey (multispecies links) and were considered to be affecting natural mortality.

For linked analyses, EVs were not integrated directly into the assessment model. Thus, examination of environmental effects on the stocks could be carried out independently. EV use was complex with about 35-40 different EVs in all categories. Similar to model parameterization, linked analyses included single EV categories such as Climate Indicator (Arctic Oscillation, latitude as a temperature proxy affecting biomass for Arctic Char in Cambridge Bay) but also multiple EV categories (Climate Indicators, Ocean Conditions and multispecies links, temperature, predators (Redfish abundance) and regime shift affecting productivity, abundance, growth, reproduction, and trophic relationships, all to varying levels of complexity.

EVs were particularly important for several stocks in the Gulf of St. Lawrence, an area where a number of stocks have not only declined but recovery is being affected by a changing environment. Temperature is a dominant ecological factor that influences the biology of ectothermic or cold-blooded organisms that functionally have an optimal temperature window. Moderate differences in temperature can affect productivity and reduce resistance to environmental challenges such as hypoxia and ocean acidification. Furthermore, strong prey-predator interactions paired with low estimated biomass are currently having greater effects on populations than the current impacts of fishery harvests for a number of stocks.

DISCUSSION

This study summarizes the state of EV integration in Canadian stock assessments in 2020 and describes approaches and factors that affect integration. It constitutes a benchmark of the progress towards EV integration and will be useful for monitoring and planning activities going forward. In 2020, nearly half of Canadian assessments integrated climate, oceanographic, and/or ecological variables contrasting with circumstances in 2005 when EVs were rarely integrated (Pepin et *al*. 2020). Although the state of the environment was occasionally discussed at that time, that process played no role in the assessment outcome. In contrast, examination of the state of the environment is now common practise; environmental knowledge played a role either as direct integration into the assessment or as a separate description of the state of the environment for 80% of Canadian assessments in 2020.

EVs were integrated in three ways, as model parameters, as linked analyses that are done independent of the assessment model, or as implied changes in natural mortality. The prevalent approach (63% of cases) involved linked analyses where environmental effects were evaluated outside of the stock assessment model. More commonly used than the other approaches that parameterize the assessment model, independent information was used to condition the assessment results. It was more common as it was adaptable to a broader range of assessment approaches by not requiring modification of or integration into the assessment model. However, the assessors and the fishery managers did not always exercise the option of conditioning the assessment outcome and/or the management strategy, less so at the management advice stage. In the case of linked analyses results were often not integrated when it was thought not to significantly affect the projections of future population state or did not improve the confidence intervals of projections or, at the management stage, regional issues precluded integration of EVs. The decline in use of linked analyses from assessments results to management advice indicates there is an opportunity to better translate our understanding of the role of EV on population change and dynamics and their importance for their consideration in decision making. Lack of understanding of the underlying mechanisms affect stock dynamics is more often treated as a source of uncertainty rather than an indication of the unknown risk affecting the potential consequences of management actions. However, this may also reflect the difficulty in achieving consensus about the robustness of conclusions from consideration of commonalities in multiple time series. Furthermore, this may also reflect reluctance to accept multiple sources of information not combined in models without a clear understanding of the scientific process, or concerns by stakeholders about the implications of the findings to the advice when uncertainty in the conclusion.

The increase in EV integration in recent years highlights a positive response to increasing awareness that populations and ecosystems are not always at equilibrium, as well as growing recognition of the revised Canadian legislation that gives prominence to an ecosystem approach in evaluating stock status. Our findings are consistent with Marshal et *al.* (2021) in the USA and Skern-Mauritzen et al. (2016) globally who suggest that there are increasing opportunities and incentives to include and evaluate relationships between harvested species and their ecosystems moving forward. However, the impact on decision-making of knowing or considering environmental factors as part of the assessment remains limited.

Marshall et *al.* (2018) examined more than 200 USA stocks and determined that one quarter of the assessment models included at least one type of interaction between the assessed species and its ecosystem, especially physical drivers of habitat and climate. Many assessments included changes in environmental states as part of the background information for the evaluation of stock status and projections. In Canada, 18% of assessments integrated EVs directly (as model parameters and implied M) in the model in 2020. Marshall et *al.* (2018) indicated that interactions within the physical environment (habitat, climate) were included twice as often as interactions among species (predation). Many assessment reports included ecological interactions only as background or qualitative considerations, rather than incorporating them in the assessment model, equivalent in Canada to separate state of the environment presentations, done for 77% of assessments.

In comparing global rates of integration to Canada, Skern-Mauritzen et *al*. (2016) showed similar proportion of ecosystem drivers incorporated into assessments in NE Atlantic, higher in Barents Sea and NE Pacific (US), Southeast Atlantic (Africa) and lower in most other parts of the world ocean. They also noted that inclusion of environmental interactions has been primarily a bottom-up process, driven first by scientific support in the literature, then data availability, and then interest and inclusion in the assessment model. They also found that qualitative inclusion of ecosystem effects on stock productivity was more common than quantitative inclusion, although they did not quantify those differences. The same can be said for the Canadian state. No mention was made of legislative obligations for EV integration in different jurisdictions.

Following Pepin et *al*. (2020), EVs used in Canadian assessments were classified as Climate Indicators, Ocean Conditions, Ecological Factors and Habitat Availability. In this evaluation, applying these classes to EVs was diverse in formulation, often used in combination and were particular to individual assessments. The potential effect of predators or prey (Ecological Factors) on population dynamics, indicative of the potential importance of multispecies interactions, constituted the largest contribution to stock assessments. Plankton was the most common named prey including copepods, zooplankton in general, and unspecified ichthyoplankton. Predators were varied and when specifically named included a broad range of taxa. Temperature (Ocean Conditions) was the next most commonly used EV for Canadian stock assessments, in most cases in conjunction with other types of EVs. Temperature comprised sea surface readings (SST), midwater, or bottom temperatures depending on the species habitat. For anadromous species, temperature was used both at sea and in rivers and lakes. Other ocean/water conditions, used at much lower rates, included salinity, pH, oxygen, conductivity, ocean chemistry, water level and colour were mentioned

In terms of data sources, the AZMP (for the Atlantic) and fishery-independent multispecies surveys were the key sources of EV information.

While degree of integration of EVs into assessments in Canada varied across regions and taxa, those differences generally related to other factors, including:

- <u>Data availability and quality</u> – Quality and availability of data used to assess stocks, be it EVs or other (fishery and population) data to assess status influenced whether or not EVs were in incorporated into the assessment.

  When fishery independent data are available in the form of sustained surveys that yield change in abundance, biological information (e.g., age, growth, maturity) that can affect population dynamics, and evaluate reliability of the fisheries dependent data, it is easier to integrate EVs and assess the effects of the environment on the stock given that fishery removals can be differentiated. Data rich (referring to non-EV data) stocks incorporated EVs at almost twice the rate of data poor stocks.

Fisheries of high value or yield were more likely to have assessments that integrated EVs and this relates to a higher level of resources allocated to those key stocks. Almost all moderate and poor stocks used linked analyses where there has been more limited investment to understand the underlying fishery effects and population mechanisms for non-target or lesser valued species.

In terms of EV data, there were many sources, sometimes stock specific but the most commonly cited source was AZMP (Atlantic), a source for physical, chemical and biological data that included oceanographic data, mainly temperature and salinity as well as zooplankton production information gathered from a variety of surveys. Temperature, salinity, oxygen and habitat data collected during DFO abundance surveys were the other common source and that information was often integrated into the AZMP. For areas where AZMP data or annual research surveys exist, EV integration was more likely to occur.

Paucity or lack of easy access to EV data was cited as the most common reason for not integrating EVs. Another reason for not integrating EVs was that they were thought not to significantly affect the projections of future population state or did not improve the confidence of projections. This reasoning fails to recognize that uncertainty likely represents an unknown risk associated with possible management actions. A number of cases were cited where EV integration was undertaken but subsequently discarded, mainly because integration of those factors were found to make little or no difference to the outcome of the assessment or the data were not robust enough to use. The absence of EV data is often associated with stocks that are considered data poor, which may represent a major limitation about the factors that are driving the dynamics of some, possibly less dominant and non-target components of the ecosystem. Owing to the greater efforts to address data requirements of the *revised Fisheries Act*, new or enhanced sampling programs should ensure that essential ecosystem variables are considered in the survey planning process.

Integration was lower for transboundary/internationally managed stocks (NAFO, ICCAT, IPHC, ISC and TRAC). In those circumstances, any changes in assessment approaches, including EV integration require the agreement of all involved parties which limits the consideration of environmental effects in assessments. Whereas for Canadian stocks, legal requirements in the FSP of the revised *Fisheries Act* require that environmental effects be taken into account.

Type of assessment – The degree of EV integration and EV approaches varied greatly among assessment types. For counts (primarily linked analyses), State-Space (the majority as model parameters) Sequential Population Analyses (mixed categories) and fishery dependent approaches (linked analyses), the majority of assessments integrated EVs. Less than half of survey indices based assessments, (highest degree of implied integration), Statistical Catch at Age and Surplus Production models (mixed approaches) had the highest degree of implied integration. At the low end of the scale, only one case of EV integration was identified for the PBR approach.

Different assessment approaches are more amenable to EV integration than others given that certain models more easily accommodate EV parameters. For the more sophisticated models, the majority of State Space, Sequential Population Analyses models and fishery dependent analyses integrated EVs, with the majority of State Space models integrating EVs as parameters because this type of model can more easily accommodate any type of parameter, including EVs.

The most common way to evaluate environmental effects was outside of the assessment model using the linked approach; integration by that method was greater than parameterization and implied approaches combined. Linked analyses were used when model parameterization was not an option and thus facilitated a greater degree of EV integration.

In some cases, the assessment employed more than one assessment category, referred to as an ensemble approach (Stewart and Martel 2015), and for those multilayer assessments, EV integration was more likely to occur. Thus, all types of assessment methods in use in Canada can take EVs into account either within or external to the model, suggesting that broad integration of EVs into all types of assessment approaches is possible, and that regulatory requirements for EV integration in the revised Canadian legislation can be met.

However, even when some form of EV integration was mechanistically possible and usable EV data were available, it was noted that expertise to do so was not always available and for this reason, some assessments did not integrate EVs at this time. New resources, namely expertise and time, will be required in some situations.

<u>Frequency of Assessments</u> - Canadian stock assessments are carried out on varying schedules from annual to bi-annual, tri-annual and episodic (sporadically and more than three years between assessments). Assessment schedules varied depending on: value of the resource; species longevity (longer lived species requiring less frequent assessments) and availability of resources to carry out EV integration, often correlated with value of the resource.

More frequently assessed stocks had a higher degree of EV integration, reflecting the impetus to actively consider EVs for what are generally more valuable resources with higher quality data. Annual assessments not only had the highest rate of EV integration, but also had the greatest proportion with model parameterization. Tri-annually assessed stocks employed linked analyses only.

Some stocks were assessed episodically because they comprised longer lived species with stable population attributes, their abundance was at very low levels and unfished thus no need for more frequent assessments, or were less valuable commodities. Availability of resources (time, money) to monitor and evaluate those stocks limited the frequency of full assessments, and stock status updates were often limited in scope and often precluded EV integration.

<u>Stock Status</u> - Stock status affected the extent of EV integrations. DFO's Sustainability Survey for Fisheries (DFO 2020) categorizes stock status as being either healthy, cautious, critical or unknown. Stock in the healthy and cautious zones integrated EVs at a similar intermediate rate, with uncertain stocks integrating EVs at the lowest rate and critical stocks at the highest rate. It may be particularly useful for stocks that are depleted or in the cautious and critical zone to understand non-fishing effects that are causing stocks to decline or remain at depressed levels despite low fishing mortality, which may explain higher rate of EV integration for that category.

<u>Time Frame</u> - Quantitative fisheries assessment models may be either strategic ('big picture', direction-setting and contextual, 2-5 year time frame) or tactical (focused on management actions on short timescales, 1-2 years), with some strategic models informing the development of tactical models (Plaganyi et *al*. 2011). Time frame appeared to have little effect on EV integration rate or type of integration approach used.

<u>Limitations</u> - Integration of EVs was largely regarded as useful. In only one case did the respondent indicate that 'lack of value' was the primary reason for not integrating EVs. For assessments that do not presently integrate EVs, limited interest in addressing environmental effects was rarely expressed. Rather, lacking or deficient mechanistic understanding, insufficient monitoring, deficient understanding of stock dynamics, limited information about population trends or fishing effects to allow differentiation from natural processes co-played a part in the non-integration of EVs.

The integration of EVs over a relatively short period has become an increasingly common practise in Canadian stock assessments (compared to results from Pepin et al. 2020) and continues to expand to other stocks. Where EVs are being integrated, the methods used were often deemed adaptable to and available for assessments presently not integrating EVs, as long as the appropriate environmental data and analytical resources were available. This adaptability of established approaches to other stocks accommodates broader potential integration and EV integration is presently under development for more assessments. This could potentially bring the total to about 65% of Canadian stocks integrating EVs but will be dependent on availability of resources and data.

A significant factor affecting EV integration was limited capacity, namely expertise, human resources and funding to carry out the work. Inadequate capacity to undertake research and analysis about the effect of EVs was cited as one reason for most stocks where EVs were not being used. Thus, even if methods could be developed or adapted and EV data were available for those stocks, capacity was a constraint.

Regional pressures pertaining to specific stocks and interaction among stocks tend to constrain use of EVs in about half of assessments that do not integrate EVs. For example, biological interactions among commercial stocks affected how environmental effects were taken into consideration. For example, respondents noted that there is strong socio-economic pressure to be able to fish both capelin and cod. However, the presence and magnitude of a capelin fishery can influence considerations of capelin as a key food source for cod, and in turn negatively affect management recommendations for cod because of trophic and fishery interactions.

Another form of co-management of border straddling stocks, managed by more than one country present a different problem in terms of potential integration of EVs. Changes in assessment approaches require the agreement of all involved parties and this can and does limit the consideration of environmental effects in those international assessments; those stocks are not subject to Canadian policies or legislation. There is often reluctance to the integration of EVs in the development of fishery recommendations because of the potential need to adopt a more precautionary approach in setting allowable catches in order to reduce risk of management actions.

Increasing importance of environmental drivers on stock status have influenced incorporation in the advisory process. The perspective of First Nations, Indigenous groups , stakeholders and the willingness of decision-makers to act on the inferences about EVs can affect whether ecosystem considerations are included in the development of advice. In many instances, agreement on the certainty of pathways of effect or conflicts of interest (e.g., capelin vs. cod example) has implications for what management actions will factor into the decisions concerning future harvest rates.

CONCLUSIONS

In Canada, a long-term objective of the EAFM WG of DFO is for broad implementation of EV integration to better inform the state of the stock, ultimately leading to more informed management decisions. Globally, it is increasingly clearer that the environment plays a key role in productivity and survival of exploited freshwater and marine populations and that these natural ecosystem processes need to be taken into account when evaluating stock status and fisheries management. As such, Canadian assessments have progressed from no integration in the early 2000s to nearly half of the stocks in this study integrating EVs in the assessment and this proportion is expected to increase in the near future. Revisions to the *Fisheries Act*, in the form of Fish Stocks provisions (sections 6.1.1, 6.1.2), now place some constraints on the Minister to consider the effect of environmental conditions in implementing measures to maintain major fish stocks at or above the level necessary to promote the sustainability of the stock. However, this gap analysis demonstrates that current approaches used in the assessment of Canadian fish stocks form an *ad hoc* collection of methods and procedures. There is currently no foundational framework to provide a set of criteria that allow objective quantification of the degree of uncertainty about the consequences of variations in environmental conditions on stock status or their appropriateness for integration in each assessment.

An indirect benefit from this study is that direct contact with assessors and managers has stimulated some participants to think more about the possibilities of EV integration into stock assessments, thus enhancing the approaches already in place. This sentiment was noted by a number of the participants and will require commitment of resources and prioritization of the need for a more comprehensive approach to assessments from science and resource management sectors, which will necessitate leadership from senior management.

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Appendix 1. Questionnaire

Stock Assessment Gap Analysis

DFO is undertaking an initiative to evaluate and implement an Ecosystem Approach to Fisheries Management (EAFM). The EAFM initiative was developed partly from work done through the Aquatic Climate Change Adaptation Services Program (ACCASP) to evaluate the use of environmental information in Canadian led stock assessments (CSAS SAR 2019/029). The EAFM initiative is being led by a National Working Group of scientists and fishery managers supported by Regional counterparts responsible for the development of EAFM case studies. The Working Group has a three-year timeline to develop a national framework for integrating an ecosystem approach to single-species stock assessments and the provision of science advice for fisheries management decision making. The long-term objective is for the broad implementation of an EAFM across most of the stocks currently assessed and managed by the Department. The work will improve the management of aquatic resources in Canada through better understanding and consideration of ecosystem function and interactions, and will help meet the requirements of the new Fish Stocks Provisions of the revised *Fisheries Act*.

The EAFM is focused on single-species stock assessments in which knowledge about environmental variables is or can be incorporated into the assessment of stock status to inform management about past, current and potentially future states of the stock.

To provide an appropriate EAFM implementation plan, we seek input from the Departmental fish stock leads (scientists, assessment biologists and resource managers) responsible for the provision of advice and development of management recommendations for individual stocks to identify the feasibility and requirements of moving towards an EAFM. To achieve this, we have developed a questionnaire to be used to document the stock-specific opportunities and challenges related to EAFM implementation, and to serve as the basis for subsequent interviews with the stock leads.

Some of the questions in the questionnaire are similar in nature to the ones addressed in the aforementioned review by ACCASP, but given that the analyses for that review were based entirely on advisory documents from 2016 or earlier, this exercise will serve to update and cross-validate those results, in addition to identifying potential opportunities and challenges for the inclusion of environmental variables in stock assessments.

Instructions and Procedures for the Questionnaire Respondent

- **The Assessment Biologist (AB)** responsible for the stock identified will provide the responses to the questions below. Where appropriate, the AB should consult with other assessment team members and the **Resource Manager (RM)** responsible for the stock.
- Responses can be structured in paragraph or point form, whichever works best for the respondent.
- Please be brief but include all details that you think may be relevant to our understanding of the incorporation of **environmental variables** into the assessment.
    - **Environmental variables** can consist of climate change indicators, oceanographic variables (e.g., temperature, salinity, upwelling, current or transport indices), ecological

factors (e.g., abundance of potential prey, predators, competitors), metrics of physical or biological habitat availability, or other variables that can affect the productivity (e.g., growth, mortality, recruitment) or availability (e.g., distribution, catchability) of the stock being assessed. Other considerations may, for example, deal with information on predation on a particular targeted species that should be considered in assessing status and trends.

- Specify whether the environmental variables are considered to be useful from a tactical and/or strategical perspective.
  - Tactical represents advice of status and trends on timelines of 1-2 years.
  - Strategic advice concerns longer time periods (2-5+ years) and based on long-term trends and/or projections of environmental variables.
- Include any documentation that you think may enhance our understanding of the environmental variables used and their incorporation into the assessment.
- The deadline for submission of responses to this questionnaire is two weeks from when the questionnaire was sent to you. The completed questionnaire is to be returned to David Kulka (dave.kulka@dfo-mpo.gc.ca).
- Once you submit the completed questionnaire, Mr. Kulka will arrange a follow-up interview by teleconference with you. This teleconference session will be used to elaborate on the written responses and allow for clarification of points where appropriate.
- After the teleconference session, Mr. Kulka will make any subsequent additions or precisions to the responses to the questionnaire and will send you a final version for validation.

Questionnaire

Responsible scientist, biologist or analyst: Name
Stock identification: Stock
Region: Region
Due date for return of completed questionnaire: March x 2020

1 – Briefly describe the fishery (such, area, duration or seasonality, gear types used, vessels (e.g. inshore, middle distance), etc.)

Response:

2 – Length of survey and fishery time series for this stock used to examine stock trends (if more than one time series is used for each category then provide information for all series).

Response:

3 – Frequency of assessments and year of the last assessment

Response:

4 – Frequency of updates (if multi-annual advice is provided)

Response:

5 – Please describe the type of assessment (e.g., qualitative, quantitative, survey-based index, catch data only) that is used for this stock. Do you consider the stock to be data poor, data moderate or data rich?

Response:

6 – Have environmental variables (e.g., climate indicators, oceanographic conditions, ecological factors and/or multispecies links, habitat availability) been included in the assessment process? If yes, please describe which variables were included, and how they were considered in the assessment (e.g., retrospective analyses, model parameterization).

a) *Were the environmental effects viewed from a tactical (1-2 years) or strategic (3-5+ years) perspective?*

   Response:

b) *Is the approach applicable to other stocks? If yes, has it been used by others?*

   Response:

7 – Have changes in environmental variables affected the science advice and/or recommendations to Fisheries Management (e.g., affected the outcome of quantitative model(s), resulted in recommendations for changes in fishing levels and/or practices)? Please consult with the Resource Manager responsible for this stock in responding to this question.

Response:

8 – If changes in environmental state have ***NOT*** *been included in the assessments, do you believe there is sufficient knowledge about this stock to:*

a) *Provide an overview of the potential impact of changes in environmental variables on the stock's biology and productivity, or possibly develop a conceptual model of the major factors that may be affecting a stock?*

   Response:

b) *Undertake a preliminary, exploratory, or more in-depth analysis of the relationship or effect of those environmental changes on rate processes (e.g., recruitment, growth, mortality, distribution, catchability) that are important in providing advice on current and future states of the stock?*

   Response:

c) *Include environmental variables formally, either quantitatively or qualitatively, in the assessment process?*

   Response:

9 – What are the major limitations that would prevent consideration of environmental variables in the advisory process (e.g., data limitations, lack of monitoring information, survey issues, lack of mechanistic understanding)?

Response:

10 – Have changes in environmental state been discussed in general during assessment meetings, consultations with industry, ENGOs, Indigenous groups and rights holders, or other stakeholders? If yes, what concerns have been raised? If no, why was the ecosystem not discussed? Please consult with the Resource Manager responsible for this stock in responding to this question.

Response:

11 – Are there regional pressures, issues or policies that may limit the consideration of environmental variables in stock assessments and the development of recommendations for this stock? Please consult with the Resource Manager responsible for this stock in responding to this question.

Response:

12 – Any other comments or concerns you may have.

Response:

Appendix 2. List of Stocks and EV Integration

List of stocks examined by type of EV used, Taxon, Region and Fishery Type indicating type of EV integration. Co-managed and internationally managed stocks are indicated in the Region column. NL – Newfoundland and Labrador Region, Gulf – Gulf Region, QC – Quebec Region, Mar - Maritimes Region, Arct – Arctic Region, Pac – Pacific Region, NCR – National Capital Region, ICCAT – International Commission for the Conservation of Atlantic Tunas. NAFO – Northwest Atlantic Fisheries Organization, IPHC – International Pacific halibut Commission and ISC - International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean.

Stock	Region	Fishery Type	Taxon	EVs used
Dolly Varden North Slope - 4 stocks	Arct (Co-managed)	Other	Salmonid	Parameterize
Cod - Southern Gulf of St. Lawrence (4TVn)	Gulf	Moratorium	Groundfish	Parameterize
Snow Crab - Scotian Shelf (4X)	Mar	Dir	Crustacean	Parameterize
Snow Crab - Scotian Shelf (ENS-N)	Mar	Dir	Crustacean	Parameterize
Snow Crab - Scotian Shelf (ENS-S)	Mar	Dir	Crustacean	Parameterize
Atlantic Halibut - 3NOPs4VWX+5	Mar	Dir	Groundfish	Parameterize
Swordfish - North Atlantic	Mar	Dir	Large pelagic	Parameterize
Sea Scallop - Inshore SFA 28 (Bay of Fundy)	Mar	Dir	Mollusc	Parameterize
Sea Scallop - Inshore SFA 29W	Mar	Dir	Mollusc	Parameterize
Sea Scallop - Offshore SFA 26 German, Browns	Mar	Dir	Mollusc	Parameterize
Sea Scallop - Offshore SFA 27, Georges	Mar	Dir	Mollusc	Parameterize
Surf Clam - Banquereau	Mar	Dir	Mollusc	Parameterize
Tuna Bluefin - Western Atlantic	NCR	Dir	Large Pelagic	Parameterize
Snow Crab - CFA 1-12 2HJ3KLNOP4R	NL	Dir	Crustacean	Parameterize
Cod - Atlantic (3Ps)	NL	Dir	Groundfish	Parameterize
Capelin - SA2+3KL	NL	Dir	Small Pelagic	Parameterize
Geoduck	Pac	Dir	Mollusc	Parameterize
Salmon Sockeye - Fraser (Early Stuart)	Pac	Other	Salmonid	Parameterize
Salmon Sockeye - Fraser (Early Summer)	Pac	Other	Salmonid	Parameterize
Salmon Sockeye - Fraser (Late)	Pac	Other	Salmonid	Parameterize
Salmon Sockeye - Fraser (Summer)	Pac	Other	Salmonid	Parameterize
Halibut Pacific	Pac (IPHC)	Dir	Groundfish	Parameterize
Seal Grey	QC	Dir	Marine Mammal	Parameterize
Greenland Halibut - Cumberland Sound	Arct	Dir	Groundfish	Link
Whale Bowhead - E Canada - W. Greenland (ECWG)	Arct	Other	Marine Mammal	Link
Lake Trout - Great Slave Lake	Arct	Bycatch	Salmonid	Link
Arctic Char - Cambridge Bay	Arct	Dir	Salmonid	Link
Arctic Char - Cumberland Sound	Arct	Dir	Salmonid	Link
Lake Whitefish - Great Slave Lake	Arct	Other	Salmonid	Link

Snow Crab - CFA 12 (12, 18, 25, 26), 12E, 12F, 19	Gulf	Dir	Crustacean	Link
Witch Flounder - 4RST	Gulf	Dir	Groundfish	Link
Herring - 4T (Fall Spawner)	Gulf	Dir	Small Pelagic	Link
Herring - 4T (Spring Spawner)	Gulf	Dir	Small Pelagic	Link
Lobster - Inshore LFA 27-33	Mar	Dir	Crustacean	Link
Lobster - Inshore LFA 34	Mar	Dir	Crustacean	Link
Lobster - Inshore LFA 35-38	Mar	Dir	Crustacean	Link
Lobster - Offshore LFA 41	Mar	Dir	Crustacean	Link
Shrimp Northern - Eastern Scotian Shelf (SFA 13-15)	Mar	Dir	Crustacean	Link
Gaspereau	Mar	Other	Small Pelagic	Link
Tuna Bigeye	Mar (ICCAT)	Dir	Large pelagic	Link
Tuna Yellowfin Atlantic	Mar (ICCAT)	Dir	Large pelagic	Link
Shrimp Northern (Borealis) - SFA 4	NCR	Dir	Crustacean	Link
Shrimp Northern (Borealis) - SFA 5	NCR	Dir	Crustacean	Link
Shrimp Northern (Borealis) - SFA 6	NCR	Dir	Crustacean	Link
Shrimp Northern (Borealis) - SFA 7	NCR	Dir	Crustacean	Link
Mackerel - Atlantic (NAFO 3-4)	NCR	Dir	Small Pelagic	Link
Lobster - LFA 3-14c	NL	Dir	Crustacean	Link
Plaice American 3Ps	NL	Bycatch	Groundfish	Link
Witch Flounder - 3Ps	NL	Dir	Groundfish	Link
Haddock 3Ps	NL	Moratorium	Groundfish	Link
Plaice American 2+3K	NL	Moratorium	Groundfish	Link
Iceland Scallop 3Ps	NL	Dir	Mollusc	Link
Sea Scallop 3Ps	NL	Dir	Mollusc	Link
Salmon Atlantic - NL	NL	Dir	Salmonid	Link
Herring - 2J3IKLPs	NL	Dir	Small Pelagic	Link
Plaice American 3LNO	NL (NAFO)	Moratorium	Groundfish	Link
Witch Flounder 2J3KL	NL (NAFO)	Moratorium	Groundfish	Link
Shrimp Trawl	Pac	Dir	Crustacean	Link
Rockfish Bocaccio	Pac	Bycatch	Groundfish	Link
Cod Pacific - 5A/B/C/D	Pac	Dir	Groundfish	Link
Cod Pacific 3C/D	Pac	Dir	Groundfish	Link
Pacific Ocean Perch - PMFC 5ABC-QCS	Pac	Dir	Groundfish	Link
Cucumber Giant Red Sea	Pac	Dir	Other	Link
Red Sea Urchin	Pac	Dir	Other	Link
Green Sea Urchin	Pac	Dir Other	Other	Link
Salmon Chinook Okanagan	Pac	Dir	Salmonid	Link
Lobster - 17	QC	Dir	Crustacean	Link
Lobster - Areas 19-20-21 (Gaspé)	QC	Dir	Crustacean	Link

Lobster - Zone 22 (MI)	QC	Dir	Crustacean	Link
Shrimp Northern (Borealis) Gulf	QC	Dir	Crustacean	Link
Snow Crab - 12A (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 12B (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 12C (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 13 (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 14 (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 15 (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 16 (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 16A (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Snow Crab - 17 (Estuary and N Gulf)	QC	Dir	Crustacean	Link
Greenland Halibut - 4RST	QC	Dir	Groundfish	Link
Redfish - Unit 1	QC	Index	Groundfish	Link
Seal Hooded - Northwest Atlantic	QC	Dir	Marine Mammal	Link
Beluga - Northern Quebec (Nunavik)	QC	Other	Marine Mammal	Link
Clam Stimpson's Surfclam	QC	Dir	Mollusc	Link
Capelin - 4RST	QC	Dir	Small Pelagic	Link
Herring - 4R (Fall Spawner) / (Spring Spawner)	QC	Dir	Small Pelagic	Link
Herring - 4S (Fall Spawner) / (Spring Spawner)	QC	Dir	Small Pelagic	Link
Winter Flounder - 4T	Gulf	Dir	Groundfish	Implied
Yellowtail Flounder 4T	Gulf	Dir	Groundfish	Implied
American Plaice - Southern Gulf of St. Lawrence (4T)	Gulf	Moratorium	Groundfish	Implied
White Hake - 4T	Gulf	Moratorium	Groundfish	Implied
Haddock - 4X5Y	Mar	Dir	Groundfish	Implied
Cod - Northern (2J3KL)	NL	Dir	Groundfish	Implied
Witch Flounder - 3NO	NL	Dir	Groundfish	Implied
Herring - Central Coast (Pacific)	Pac	Dir	Small Pelagic	Implied
Herring - Prince Rupert District (North Coast / Pacific)	Pac	Dir	Small Pelagic	Implied
Herring - Strait of Georgia (Pacific)	Pac	Dir	Small Pelagic	Implied
Herring - WCVI	Pac	Dir	Small Pelagic	Implied
Herring - Haida Gwaii (Pacific)	Pac	Moratorium	Small Pelagic	Implied
Hake Pacific – Offshore	Pac (Co-manage)	Dir	Groundfish	Implied
Cod - 4RS-3Pn	QC	Dir	Groundfish	Implied
Greenland Halibut - NAFO 0A and 0B	Arct	Dir	Groundfish	No
Atl Walrus - Baffin Bay (High Arctic)	Arct	Other	Marine Mammal	No
Atl Walrus - Foxe Basin (Central Arctic)	Arct	Other	Marine Mammal	No

AtlWalrus - Hudson Bay-Davis Strait (Central Arctic)	Arct	Other	Marine Mammal	No
Atl Walrus - Penny Str-Lancaster Sound (High Arctic)	Arct	Other	Marine Mammal	No
Atl Walrus - South and East Hudson Bay	Arct	Other	Marine Mammal	No
Atl Walrus - West Jones Sound (High Arctic)	Arct	Other	Marine Mammal	No
Narwhal - (EHA BB) Admiralty Inlet	Arct	Other	Marine Mammal	No
Narwhal - East Baffin	Arct	Other	Marine Mammal	No
Narwhal - Eclipse Sound	Arct	Other	Marine Mammal	No
Narwhal - Northern Hudson Bay	Arct	Other	Marine Mammal	No
Narwhal - Smith/Jones/Parry	Arct	Other	Marine Mammal	No
Narwhal - Somerset	Arct	Other	Marine Mammal	No
Beluga - Cumberland Sound	Arct (Co-manage)	Other	Marine Mammal	No
Lobster - Southern Gulf (LFA 23, 24, 25, 26A, 26B)	Gulf	Dir	Crustacean	No
Rock Crab - LFA 23, 24, 25, 26A	Gulf	Dir	Crustacean	No
Scallop - S Gulf of St. Lawrence (SFA 21a, b, c, 22, 23, 24)	Gulf	Dir	Mollusc	No
Striped Bass - South Gulf of St Lawrence	Gulf	Other	Other	No
Atlantic Salmon - Gulf	Gulf	Other	Salmonid	No
Atlantic Cod - 4X5Y	Mar	Bycatch	Groundfish	No
Pollock - 4X5 (Western Component)	Mar	Dir	Groundfish	No
Redfish - Unit 3	Mar	Dir	Groundfish	No
Silver Hake - 4VWX	Mar	Dir	Groundfish	No
Surf Clam - Grand Bank	Mar	Dir	Mollusc	No
Eel (Large)	Mar	Dir	Other	No
Elvers	Mar	Dir	Other	No
Herring - 4VWX	Mar	Dir	Small Pelagic	No
Herring - 5Y, 5Z (weirs)	Mar	Dir	Small Pelagic	No
Striped Bass - Bay of Fundy	Mar	Other	Small Pelagic	No
Shark Atlantic Blue	Mar (ICCAT)	Bycatch	Large pelagic	No
Shark Shortfin Mako Atlantic	Mar (ICCAT)	Bycatch	Large pelagic	No
Tuna Albacore Atlantic	Mar (ICCAT)	Dir	Large pelagic	No
Shark Porbeagle	Mar (ICCAT)	Moratorium	Large pelagic	No
Yellowtail Flounder - 5Z	Mar (TRAC)	Bycatch	Groundfish	No
Atlantic Cod - 5Zjm	Mar (TRAC)	Dir	Groundfish	No
Haddock - 5Zjm	Mar (TRAC)	Dir	Groundfish	No

Shark Dogfish, Atlantic - 4VWNX - 5	Mar (USA led)	Bycatch	Groundfish	No
Shrimp Northern (Borealis) - Eastern Assessment Zone	NCR	Dir	Crustacean	No
Shrimp Northern (Borealis) - SFA 1	NCR	Dir	Crustacean	No
Shrimp Northern (Borealis) - WAZ	NCR	Dir	Crustacean	No
Shrimp Striped (Montagui) – Eastern Assessment Zone	NCR	Dir	Crustacean	No
Shrimp Striped (Montagui) – SFA 4	NCR	Dir	Crustacean	No
Shrimp Striped (Montagui) - Western Assessment Zone	NCR	Dir	Crustacean	No
Greenland Halibut (Turbot) - 2-3KLMNO	NL	Dir	Groundfish	No
Haddock 3LNO	NL	Moratorium	Groundfish	No
Whelk - 3PS	NL	Dir	Mollusc	No
Cucumber Sea - 3Ps	NL	Dir	Other	No
Cod 3NO	NL (NAFO)	Bycatch	Groundfish	No
Redfish - 3LN	NL (NAFO)	Dir	Groundfish	No
Redfish - 3O	NL (NAFO)	Dir	Groundfish	No
Skate Thorny - 3LNOPs	NL (NAFO)	Dir	Groundfish	No
White Hake - 3NOPs	NL (NAFO)	Dir	Groundfish	No
Yellowtail Flounder - 3LNO	NL (NAFO)	Dir	Groundfish	No
Squid 3+4	NL (NAFO)	Dir	Mollusc	No
Prawn Trap	Pac	Dir	Crustacean	No
Big Skate 3C/D	Pac	Bycatch	Groundfish	No
Big Skate 5A/B	Pac	Bycatch	Groundfish	No
Big Skate 5C/D	Pac	Bycatch	Groundfish	No
Longnose Skate 3C/D	Pac	Bycatch	Groundfish	No
Longnose Skate 5A/B	Pac	Bycatch	Groundfish	No
Longnose Skate 5C/D	Pac	Bycatch	Groundfish	No
Rockfish Quillback – Inside	Pac	Bycatch	Groundfish	No
Rockfish Quillback – Outside	Pac	Bycatch	Groundfish	No
Rockfish Yelloweye - Inside Population	Pac	Bycatch	Groundfish	No
Rockfish Yelloweye - Outside Population	Pac	Bycatch	Groundfish	No
Arrowtooth Flounder - Coastwide	Pac	Dir	Groundfish	No
Dover Sole 3C/D	Pac	Dir	Groundfish	No
Dover Sole 5A/B	Pac	Dir	Groundfish	No
Dover sole 5C/D/E	Pac	Dir	Groundfish	No
English (lemon) Sole 3C/D, 5A/B	Pac	Dir	Groundfish	No
English (lemon) Sole 5C/D	Pac	Dir	Groundfish	No
Lingcod – Outside - 3C	Pac	Dir	Groundfish	No
Lingcod – Outside - 3D	Pac	Dir	Groundfish	No
Lingcod – Outside - 5A B	Pac	Dir	Groundfish	No
Lingcod – Outside - 5C D E	Pac	Dir	Groundfish	No

Longspine Thornyhead	Pac	Dir	Groundfish	No
Pacific Ocean Perch - PMFC 3CD-WCVI	Pac	Dir	Groundfish	No
Pacific Ocean Perch - PMFC 5DE-HS/DE/WHG	Pac	Dir	Groundfish	No
Petrale Sole	Pac	Dir	Groundfish	No
Rockfish Canary	Pac	Dir	Groundfish	No
Rockfish Copper, China and Tiger - Inside and Outside	Pac	Dir	Groundfish	No
Rockfish Redbanded	Pac	Dir	Groundfish	No
Rockfish Redstripe	Pac	Dir	Groundfish	No
Rockfish Rougheye/Blackspot	Pac	Dir	Groundfish	No
Rockfish Shortraker	Pac	Dir	Groundfish	No
Rockfish Silvergray	Pac	Dir	Groundfish	No
Rockfish Widow	Pac	Dir	Groundfish	No
Rockfish Yellowmouth	Pac	Dir	Groundfish	No
Rockfish Yellowtail	Pac	Dir	Groundfish	No
Rocksole 3C/D	Pac	Dir	Groundfish	No
Rocksole 5A/B	Pac	Dir	Groundfish	No
Rocksole 5C/D	Pac	Dir	Groundfish	No
Sablefish	Pac	Dir	Groundfish	No
Shark Dogfish - Inside	Pac	Dir	Groundfish	No
Shark Dogfish - Outside	Pac	Dir	Groundfish	No
Shortspine Thornyhead.	Pac	Dir	Groundfish	No
Lingcod – Inside - Strait of Georgia	Pac	Other	Groundfish	No
Pink and Spiny Scallop	Pac	Dir	Mollusc	No
Intertidal Clams - South Coast-Vancouver Island	Pac	Other	Mollusc	No
Salmon Sockeye - Stikine	Pac	Dir	Salmonid	No
Tuna Albacore - North Pacific	Pac (ISC)	Dir	Large Pelagic	No
Dungeness Crab	Pac (Co-manage)	Dir	Crustacean	No
Intertidal Clams - Central Coast-Heiltsuk Manila	Pac (Co-manage)	Other	Mollusc	No
Intertidal Clams - North Coast Haida Gwaii Razor	Pac (Co-manage)	Other	Mollusc	No
Eulachon - Central Coast	Pac (Co-manage)	Other	Small Pelagic	No
Eulachon - Fraser River	Pac (Co-manage)	Other	Small Pelagic	No
Eulachon - Skeena Nass	Pac (Co-manage)	Other	Small Pelagic	No
Atlantic Halibut - 4RST	QC	Dir	Groundfish	No
Clam Softshell Common	QC	Dir	Mollusc	No
Icelandic Scallop - 16EF-18A	QC	Dir	Mollusc	No
Sea Scallop - Area 20	QC	Dir	Mollusc	No

Appendix 3. Assessment Categories.

Assessment	Parameterize	Implied	Link	No EV	Total
Counts	**1**	**0**	**5**		**6**
Count			4		4
PA Counts			1		1
Pup Count	1				1
State-Space	**5**	**1**	**1**	**1**	**8**
Bayes STSP	4				4
JABBA MPB Synthesis			1		1
State Space CaA		1			1
StSP	1				1
StSp Age Structure				1	1
Fishery Dependent	**1**	**0**	**19**	**12**	**32**
Commercial CPUE			10	1	11
Fishery Dependent	1		4	6	11
CPUE Exploitation Rates			2		2
A&G M, EV association			1		1
Catch				1	1
Catch curve				1	1
Data Poor DBSRA MSY			1		1
Data Poor DCAC MSY			1		1
Fishery Index				1	1
Spawner Abundance Index				1	1
Stock Synthesis				1	1
Sequential Population Analysis	**2**	**4**	**2**	**5**	**13**
VPA		2	2	3	7
ASM VPA	1				1
Multifan-CL Synthesis VPA ASPIC				1	1
RPA VPA SCA		1			1
SCA	1				1
SPA		1			1
VPA, DLM				1	1
Survey Indices	**10**		**22**	**41**	**73**
Survey Index	6		20	21	47
Biomass Est				11	11
MSY Survey Index				6	6
Abundance	4				4
Eight Indicators				1	1
CPUE Index			1		1
Quantitative			1		1
Ratio Based Estimator				1	1
Spawner Index model				1	1

Surplus Production	**1**	**1**	**6**	**11**	**19**
Bayes SPM	1	1	2	6	10
Bayes SPM MSE				2	2
SPM				2	2
SPM Biomass spatial			2		2
ASPIC				1	1
EFA Productivity model			1		1
SPM Stock Synthesis			1		1
Logistic Biomass Model				1	1
Statistical Catch at Age	**1**	**8**	**4**	**18**	**31**
Bayes CaA		1	2	14	17
SCA	1	2	2		5
SCA MSE		5			5
ISCAM CaA				3	3
Closed Loop age struc				1	1
Other	**3**	**0**	**4**	**10**	**16**
No formal Assessment				3	3
Acoustic index				2	2
Delay Difference model			2		2
Closed loop simulation	1				1
Abundance Mark-Recapture	1				1
Tag Recapture				1	1
Management Strategy Evaluation				1	1
HCR Management Strategy Eval				1	1
Principal Component Analysis			1		1
Qualitative				1	1
TLA Traffic Light			1		1
Harvest Advice				1	1
Potential Biological Removal	**0**	**0**	**1**	**12**	**13**
Abundance PBR				6	6
PBR			1	6	7
Grand Total	**22**	**14**	**64**	**110**	**212**

Appendix 4. List of Stocks that do not Integrate EVs.

For the 111 stocks where EVs are not used in the assessment, 60% of respondents indicated that it was apparent that environmental factors affected the stock. The remainder were uncertain, because there is no clear understanding of mechanisms of EV effects, or environmental data were insufficient to examine the relationships between environmental effects and population parameters.

Stock (Potential Impact of EVs on the stock) Limitations to EV Integration (Possible to Include)
Crustacean
Dungeness Crab (Yes) Mechanistic understanding (Yes)
Lobster - Southern Gulf (LFA 23, 24, 25, 26A, 26B) (Yes) Data, Monitoring, Survey issues, Mechanistic understanding (Maybe)
Prawn Trap (pH, O2 reduction) Monitoring Biological Data (Yes)
Rock Crab - LFA 23, 24, 25, 26A (Unknown) Data, Monitoring, Survey issues, Mechanistic understanding, Limited Capacity (Yes)
Shrimp Northern (borealis) - Eastern Assessment Zone (Unknown) Data (No)
Shrimp Northern (borealis) - SFA 1 (Yes) Mechanistic understanding (Yes)
Shrimp Northern (borealis) - WAZ (Unknown) Data, Limited Capacity (No)
Shrimp Striped (montagui) – Eastern Assessment Zone (Yes) Data, Mechanistic Understanding, No Capacity (No)
Shrimp Striped (montagui) – SFA 4 (Yes) Data, No Capacity (Yes)
Shrimp Striped (montagui) - Western Assessment Zone (Yes) Data, Mechanistic Understanding, Limited Capacity (No)
Groundfish
Arrowtooth Flounder - Coastwide (Unknown) Mechanistic understanding, Data, No Capacity (Unknown)
Atlantic Cod - 4X5Y (Yes) Data, Limited Capacity (Yes)
Atlantic Cod - 5Zjm (Yes) Data, Limited Capacity (Yes)
Atlantic Halibut - 4RST (Unknown) Mechanistic understanding (Unknown)
Big Skate 3C/D (Unknown) Data, Species ID, No Capacity (No)
Big Skate 5A/B Unknown) Data, Species ID, No Capacity (No)
Big Skate 5C/D (Unknown)

Data, Species ID, No Capacity (No)
Cod 3NO (Yes)
No Interest, Limited Capacity (Maybe)
Dover Sole 3C/D (Unknown)
Data, Mechanistic Understanding, No Capacity (No)
Dover Sole 5A/B (Unknown)
Data, Mechanistic Understanding, No Capacity (No)
Dover Sole 5C/D/E (Unknown)
Data, Mechanistic Understanding, No Capacity (No)
English (lemon) Sole 3C/D, 5A/B (Unknown)
Data, Mechanistic Understanding, No Capacity (No)
English (lemon) Sole 5C/D (Unknown)
Mechanistic understanding, No Capacity (No)
Greenland Halibut - NAFO 0A and 0B (Yes)
Data, No Capacity (Maybe)
Greenland Halibut (Turbot) - 2-3KLMNO (Yes)
Aging, Limited Capacity (No)
Haddock - 5Zjm (Unknown)
Monitoring (Yes)
Haddock 3LNO (Unknown)
Mechanistic understanding, Limited Capacity (Maybe)
Lingcod – Inside - Strait of Georgia (Unknown)
Mechanistic understanding, No Capacity (No)
Lingcod – Outside - 3C (Unknown)
Mechanistic understanding, No Capacity (No)
Lingcod – Outside - 3D (Unknown)
Mechanistic understanding, No Capacity (No)
Lingcod – Outside - 5A B (Unknown)
Mechanistic understanding, No Capacity (No)
Lingcod – Outside - 5CDE (Unknown)
Mechanistic understanding, No Capacity (No)
Longnose Skate 3C/D (Unknown)
Data, Species ID, No Capacity (No)
Longnose Skate 5A/B (Unknown)
Data Species ID, No Capacity (No)
Longnose Skate 5CD (Unknown)
Data Species ID, No Capacity (No)
Pacific Ocean Perch - PMFC 3CD-WCVI (Yes)
Resources Code, Limited Capacity (Yes)
Pacific Ocean Perch - PMFC 5DE-HS/DE/WHG (Yes)
Resources Code, Limited Capacity (Yes)
Shortspine Thornyhead (Yes)
Data, Model code, Limited Capacity (Yes)

Resources Code (Yes)

Longspine Thornyhead (Yes)

Data, Model code, Limited Capacity (Yes)

Pollock - 4X5 (Western Component) (Yes)

Data Incomplete Survey (Yes)

Redfish - 3LN (Maybe)

Mechanistic understanding, Stock dynamics, 2 species pelagic component, Limited Capacity (Maybe)

Redfish - 3O (Maybe)

Aging, 2 species, stock issues, Limited Capacity (Maybe)

Redfish - Unit 3 (Maybe)

Data (Maybe)

Rockfish Canary (Yes)

Mechanistic understanding, No Capacity (No)

Rockfish Copper, China and Tiger - Inside and Outside (Yes)

Data, Mechanistic Understanding, No Capacity (Yes)

Rockfish Quillback – Inside (Unknown)

Mechanistic understanding, Limited Capacity (No)

Rockfish Quillback – Outside (Unknown)

Mechanistic understanding, Limited Capacity (No)

Rockfish Redbanded (Yes)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Redstripe (Yes)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Shortraker (Unknown)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Silvergray (Yes)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Widow (Yes)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Yelloweye - Inside Population (Unknown)

Mechanistic understanding, Limited Capacity (No)

Rockfish Yelloweye - Outside Population (Unknown)

Mechanistic understanding, Limited Capacity (No)

Rockfish Yellowmouth (Yes)

Data, Mechanistic Understanding, No Capacity (No)

Rockfish Yellowtail (Yes)

Data, Mechanistic understanding, Code, No Capacity (No)

Rockfish Rougheye/Blackspot (Yes)

Data Mechanistic understanding Code, No Capacity (No)

Rocksole 3C/D (Maybe)

Resources, Limited Capacity (Yes)

Rocksole 5A/B (Maybe)

Resources, Limited Capacity (Yes)
Rocksole 5C/D (Maybe)
Resources, Limited Capacity (Yes)
Petrale Sole (Unknown)
Mechanistic understanding Resources, No Capacity (Maybe)
Sablefish (Maybe)
Lack of Value, Limited Capacity (Yes)
Shark Dogfish - Inside (Unknown)
Mechanistic understanding, Limited Capacity (No)
Shark Dogfish - Outside (Unknown)
Mechanistic understanding, Limited Capacity (No)
Shark Dogfish, Atlantic - 4VWNX - 5 (Yes)
Data, Transboundary, No Capacity (Yes)
Silver Hake - 4VWX (Yes)
Data, Limited Capacity (Yes)
Skate Thorny - 3LNOPs (Yes)
Data, No Capacity (Yes)
White Hake - 3NOPs (Yes)
Data, No Capacity (Yes)
Yellowtail Flounder - 3LNO (Yes)
Data, Limited Capacity (No)
Yellowtail Flounder - 5Z (Yes)
Data Mechanistic Understanding, Limited Capacity (Yes)

Large Pelagic

Shark Atlantic Blue (Yes)
Data, No Capacity (No)
Shark Porbeagle (Yes)
Data (No)
Shark Shortfin Mako Atlantic (Yes)
Data, No Capacity (No)
Tuna Albacore - North Pacific (Maybe)
Mechanistic understanding, No surveys, extensive distribution, highly migratory international barriers, (No)
Tuna Albacore Atlantic (Yes)
Data, Limited Capacity (Yes)

Marine Mammal

Atlantic Walrus - Baffin Bay (High Arctic) (Yes)
Data, Limited Capacity (Yes)
Atlantic Walrus - Foxe Basin (Central Arctic) (Yes)
Data, Limited Capacity (Yes)
Atlantic Walrus - Hudson Bay-Davis Strait (Central Arctic) (Yes)
Data, Limited Capacity (Yes)

Atlantic Walrus - Penny Strait-Lancaster Sound (High Arctic) (Yes)
Data, Limited Capacity (Yes)
Atlantic Walrus - South and East Hudson Bay (Yes)
Data, Limited Capacity (Yes)
Atlantic Walrus - West Jones Sound (High Arctic) (Yes)
Data, Limited Capacity (Yes)
Beluga - Cumberland Sound (Yes)
Data, No Capacity (Yes)
Narwhal - (EHA BB) Admiralty Inlet (Yes)
Data, Population parameters (No)
Narwhal - East Baffin (Yes)
Data, Population parameters (No)
Narwhal - Eclipse Sound (Yes)
Data, Population parameters (No)
Narwhal - Northern Hudson Bay (Yes)
Data, Population parameters (No)
Narwhal - Smith/Jones/Parry (Yes)
Data, Population parameters (No)
Narwhal - Somerset (Yes)
Data, Population parameters (No)

Mollusc

Clam Softshell Common (Unknown)
Data, Limited Capacity (No)
Icelandic Scallop - 16EF-18A (Yes)
Data (Yes)
Intertidal Clams - Central Coast-Heiltsuk Manila (Unknown)
Data, No Capacity (No)
Intertidal Clams - North Coast Haida Gwaii Razor (Unknown)
Data, No Capacity (No)
Intertidal Clams - South Coast-Vancouver Island (Unknown)
Data, No Capacity (No)
Pink and Spiny Scallop (Unknown)
Data, No capacity (No)
Scallop - Southern Gulf of St. Lawrence (SFA 21a, b, c, 22, 23, 24) (Yes)
Population data (Yes)
Sea Scallop - Area 20 (Yes)
Time (Yes)
Squid 3+4 (Yes)
Data, No capacity (No)
Surf Clam - Grand Bank (Unknown)
Data, Mechanistic Understanding, Limited Capacity (Unknown)
Whelk - 3PS (Maybe)

Mechanistic Understanding, No survey, Poor LF info, , Limited Capacity (No)

Other

Cucumber Sea - 3Ps (Unknown)

Mechanistic understanding No survey series Poor LF info, Limited Capacity (No)

Eel (Large) (Yes)

Resources (Yes)

Elvers (Yes)

Resources (Yes)

Striped Bass - South Gulf of St Lawrence (Maybe)

Data Mechanistic Understanding, Limited Capacity (No)

Salmonid

Atlantic Salmon - Gulf (Yes)

Mechanistic understanding, No Capacity (Yes)

Salmon Sockeye - Stikine (Yes)

Monitoring, Mechanistic understanding (Yes)

Small Pelagic Fishes

Eulachon - Central Coast (Maybe)

Mechanistic understanding, Ecological uncertainties, Data, deficient monitoring, Limited Capacity (Yes)

Eulachon - Fraser River (Maybe)

Mechanistic understanding Ecological uncertainties, Data, deficient monitoring, Limited Capacity (Yes)

Eulachon - Skeena Nass (Maybe)

Mechanistic understanding Ecological uncertainties data limitations deficient monitoring, Limited Capacity (Yes)

Herring - 4VWX (Yes)

Mechanistic understanding (Yes)

Herring - 5Y, 5Z (weirs) (Yes)

Mechanistic understanding (Yes)

Striped Bass - Bay of Fundy (Yes)

No assessment (Yes)

Appendix 5. Future EV Integration - Stock Specific Examples of Potential Impacts of EVs, Exploratory Analyses and likelihood of EV Integration

Following are stock specific descriptions of EV Exploratory Analyses or other knowledge linking environmental effects to population processes. These include instances where EVs were known or thought to affect the stock but these effects were not yet formally integrated into the assessment process, including likelihood of EV integration in the near future, or with no specific timeline. Those stocks where questionnaire respondents indicated that EV integration is likely in the near future are annotated with "[Integration likely]", possible integration but with no timeline with "[Possible Integration]".

Refer also Appendix 3. Assessment Categories. for a complete list of stocks showing whether Potential Impacts were discussed (Yes or No) as well as Limitations for all stocks.

Crustaceans

- Northern Shrimp SFA 1 [Possible Integration] - EV integration used in other areas for shrimp are being considered (Weiland and Siegstad 2012 and Brosset et al 2018).
- Shrimp, Northern and Striped SFA 4 - Through the production model it has been determined that NAO and predation are drivers or shrimp productivity changes (determined on the level of Voronoi polygons). Some further exploration is planned using different predators (i.e., skates) and the effects of the Arctic oscillation (AO) rather than NAO. Research on the effects of environmental changes on rate processes has not revealed any conclusive relationship. This is intended to be done with the model such that the environmental/ecosystem components will determine future productivity, and subsequently inform on fisheries management decision making. Once the model, incorporating predation and NAO, is fully implemented into the stock assessment process, then a 1-year projection will be provided.
- Maritime Shrimp (SFA 13-15) [Integration likely] – A negative correlation between temperature and recruitment (high temperatures – low recruitment or low temperatures – high recruitment) has been observed. Through the Maritime Shrimp case study, an assessment framework to provide biomass estimates that incorporates the temperature relationship is being developed.
- Prawn Trap [Possible Integration]- Incorporating climate and oceanographic indices into the stock-recruitment estimation would allow scaling of future projections with changes in ocean productivity. Climate and oceanographic indices could be obtained for Strait of Georgia and Howe Sound areas. Ocean productivity estimates could be obtained via Oregon State University's Ocean Productivity Index, which is derived from a Vertically Generalized Production Model calibrated to MODIS and SeaWiFs satellite chlorophyll imagery (Behrenfeld and Falkowski 1997).
  Several physical and biological factors that could potentially impact the productivity of stocks. For example, Sweetman et al 2017 suggests that the bathyal depths worldwide will undergo significant reductions in pH by the year 2100 (0.29 to 0.37 pH units), which in turn will affect the viability of crustaceans. O2 concentrations will also decline in the bathyal NE Pacific and Southern Oceans at intermediate depths. The flux of particulate organic matter to the seafloor is likely to decline significantly in most oceans, which may change the food availability for crustaceans and bottom dwelling taxa.
- Lobster Southern Gulf [Possible Integration] - If a habitat suitability index under development is robust, it may be included as a contextual indicator of stock status in future sGSL lobster stock assessments. Similarly, if the link between rock crab availability and lobster productivity can be

sufficiently established, rock crab density (or abundance) could be included formally as a quantitative indicator within the lobster stock assessment.

- Rock Crab - LFA 23, 24, 25, 26A [Possible Integration] - If ongoing analyses of the impacts of changes in lobster abundance on rock crab recruitment, mortality and distribution is robust, it could be included as a contextual indicator of stock status in future sGSL rock crab stock assessments.
- Dungeness Crab [Possible Integration] - Preliminary work sought to include environmental variables, but the effects of numerous confounding environmental factors have proved difficult to tease apart quantitatively. Further investigation may allow environmental variables to be included in the assessment process once it has been developed. Information exists on the potential effects of temperature, salinity, hypoxia, ocean acidification, and currents on aspects of recruitment, growth, mortality, distribution, and catchability.

Groundfish

- Silver Hake 4VWX - [Integration likely] More predictive ability and a better understanding of stock dynamics is expected to increase confidence in the Advice provided to Resource Management. The current assessment model is driven by a survey index, with recruitment signals (age 1) detected in the year the age 1 fish are harvested by the fishery. Consequently, incorporating ecosystem indicators into the assessment model would add predictive capacity for effective management of this fishery by anticipating recruitment signals a year ahead and develop a more robust understanding of climate change implications to stock status.
- Rockfish (various species) - [Integration likely] - Rockfish show some synchrony in recruitment events, possibly due to similar timing of larval release or hatch. For example, 1999 seemed to be a good year for many rockfish species, likewise 2010 and 2016 where years of strong recruitment for several species. However, given the late age of recruitment to fisheries of rockfish in general one may not detect a recruitment event for a decade or more. Models that incorporate EVs usually hypothesize that productivity will be affected. For example:
    - offshore currents and presumably upwelling of cold, nutrient-rich water should enhance juvenile survival (recruitment success) (Zabel et al. 2011);
    - basin-scale atmospheric circulation that creates southward coastal winds and westward moving eddies may influence the transport of larvae from marine canyons up into shelf waters where juvenile habitat is favourable (Haigh et al. 2018).

Other studies have speculated that EV can affect biology:

- Redstripe Rockfish, BC North (BCN) and BC South (BCS) - advection of oxygen-rich water to females at depth during gestation during large marine heatwaves and/or El Niño events at the surface facilitates metabolic processes (Schroeder et al. 2019).
- For some data-limited Pacific groundfish stocks, namely Redstripe Rockfish Rougheye/Blackspotted Rockfish, 5DE and 3CD5AB, Widow rockfish Longspine and shortspine thornyhead, closed-loop simulation models have been developed and will be used increasingly. These can incorporate environmental changes indirectly by assuming that natural mortality increases as environmental conditions deteriorate.
- Greenland Halibut 4RST [Integration likely] – Work that considers climate change in the stock assessment advice is under way. Environmental variables that have a known potential impact on

Greenland halibut were qualitatively presented at the most recent assessment (Duplisea et al. 2019, Duplisea et al. 2020). Conclusions of ongoing lab studies on the effect of temperature, oxygen and pH will be presented at the next assessment for consideration as part of the assessment. As well, the R package, developed to provide E conditioned stock assessment advice for Greenland halibut could be applied to any species with a survey or CPUE and catch time series (https://github.com/duplisea/ccca).

- Greenland Halibut 0+1 - A conceptual model might be possible, processes related to recruitment, e.g. transport of eggs and larvae by currents, could be factors in stock distribution and abundance.
- Greenland Halibut 2+3KL - There has been work done on changes in distribution related to changing climate (Wheeland, L.J. and M.J. Morgan. 2019).
- Thornyhead, Longspine and Shortspine [Possible Integration] - If clear responses to ecosystem conditions can be proven (e.g., recruitment success vs. downwelling, mortality rates vs. predator density, survival rates vs. prey density, etc.) then equations might be able to incorporate this information; however, this requires that data on the independent factors are available as consistent time series. Tailored stock assessment models, such as iSCAM (integrated Statistical Catch-Age Model), could include EV effects but are prone to bugs and have not been fully tested against credible model systems.
- Sablefish [Integration likely] - The US sablefish assessment uses a sea level recruitment relationship modeled in the assessment via the internal population dynamics as a direct offset to the expected value for recruitment and as a survey index of age-0 recruitment deviations (Haltuch et al. 2019). The Gulf of Alaska assessment qualitatively incorporates environmental information via an Ecosystem and Socioeconomic Profile (Hanselman et al. 2019). Steps to prepare for Canadian EV integration include: (1) development of conceptual model of influence of environmental processes on population dynamics, (2) derivation of EV for those hypotheses, (3) retrospective analyses of relationships between EVs and Sablefish population processes (e.g., recruitment), (4) derivation of EV projections into the future for those EVs with statistical support, and (5) prospective simulations of the management system under scenarios with and without EV forcing to determine if performance of current management procedure could be improved with EV consideration.
- Cod 4TVn [Possible Integration] - Population productivity (i.e. rates of recruitment, individual growth and natural mortality) depend on the ecosystem/environment. If this variation can be estimated, then the effects of ecosystem/environmental change would be accounted for in the assessment and advice. However, causal factors are not identified and reasons for productivity change are not yet understood.
- Atlantic Cod 4X5Y [Possible Integration] - Trends in broader species groups across the region should still be considered, albeit qualitatively, when discussing changes in Cod abundance. Despite recent increases in abundance of some demersal species, the productivity, trophic interactions and structure of the Scotian Shelf ecosystem has changed since the early 1990s (DFO 2015). Increases in bottom water temperatures are accompanied by changes in groundfish landings, increases in landings of invertebrates and decreases in mean fish length from the RV surveys for many stocks (DFO 2018; DFO 2017a; DFO 2015). A dominance shift towards smaller zooplankton taxa away from large, energy-rich copepods like Calanus finmarchicus, has been observed since 2010, and may indicate less productive conditions for planktivorous fish (Johnson et al. 2017). In addition to these broad changes along the lower and mid-trophic groups, the

abundance of grey seals has increased substantially on the Scotian Shelf, likely increasing the predation pressure on Cod and, consequently, contributing to higher natural mortality (DFO 2017b). Future assessments should continue considering these and other over-arching trends along the Scotian Shelf and Bay of Fundy regions, even if they cannot be accounted for quantitatively.

- Cod 4X5Y - A wide range of indicators should be considered when looking at the 4X5Y Cod stock components in an ecosystem context. To date, some progress has been made in showing that spatio-temporal dynamics of Cod are partially driven by bottom temperature and depth (Irvine et al. unpublished report). Despite this positive step, availability of existing data sources and substantial data gaps for key prey species continue to hinder the progress.
- Atlantic Cod 5Zjm [Possible Integration] - Environmental factors could be incorporated into the assessment. Environmental data collected during RV surveys could be examined on an annual basis to examine the relationship between environmental data and changes to the stock. In addition, the US surveys collect stomachs from haddock that could be examined to explore changes in diet.
- Pollock - 4X5 (Western Component) - Studies in other nearby areas showed effects of large scale environmental change on 5Z cod productivity and have been implicated in contributing to declines in the Gulf of Maine fish stocks (e.g., Pershing et al. 2015). Species distribution has shifted for cod to increasing depths and distance from the shelf and available thermal habitat available to cod is expected to decline with global warming projections (2018 State of the Ecosystem - Gulf of Maine and Georges Bank). Unfavorable environmental conditions are thought in part to cause high natural mortality. Lower condition and productivity of cod suggest shifts to lower quality prey items and a decline in some species of zooplankton with increasing temperatures may also result in impacts on survival of early stages of cod.

  White Hake 3NOPs [Possible Integration] - There are opportunities for including environmental variables into the assessment in a quantitative way if a model could be developed. Modelling work is ongoing and recent aging work has the potential to open the door to an age based model. White hake is concentrated mainly on the southwest Grand Banks where water temperatures are warmest. Dispersion patterns and survival potential of eggs, larvae and juveniles are impacted by the strength of the Labrador current where a weak along-slope current and strong on-bank flow contributed to stronger recruitment.
- Skate Thorny 3LNOPs [Possible Integration] - There are opportunities for including environmental variables into the assessment in a quantitative way if a model could be developed. Modelling work is ongoing and recent aging work using vertebrae has the potential to open the door to an age based model.
- Pollock4X5 [Possible Integration] - Environmental factors could be incorporated in the assessments. The RV surveys used in the update on the stock collects environmental data that could be examined on an annual basis to examine the relationship between environmental data and changes to the stock.

  Increased natural mortality and shifts in distribution may be related to changes in environmental conditions and increased predation. Tagging studies could be used to investigate transboundary movements but would require several years before tagged fish were recruited into the fishery. Also, predominant prey for pollock diets have changed over time with prey items like krill being more important in the 1960s to 1980s. Another consideration could be the spatio-temporal patterns of pollock body size as a factor of temperature and population density. CTD data from the RV Survey provides geo-referenced environmental data such as temperature, depth, salinity, and dissolved oxygen. Plankton data is available from the AZMP survey.

- Yellowtail Flounder 5Z [Possible Integration] - The analytical assessment exhibits a strong retrospective pattern suggesting increased natural mortality possibly due to seal predation, disease (*Ichthyophonus*), or climate change, along with fishery effects. However, strong supporting evidence for any of these ideas has not been found to date and there could be multiple factors working together.
- Pacific Ocean Perch [Possible Integration] - If clear responses to ecosystem conditions can be proven (e.g., recruitment success vs. downwelling, mortality rates vs. predator density, survival rates vs. prey density, etc.) then equations might be able to incorporate this information; however, this requires that data on the independent factors are available as consistent time series.

  Previous correlations included that between sea height and Pacific Cod recruitment: high sea levels during January-March were associated with high transport through the Hecate Strait area and reduced recruitment for the stock (Sinclair et al. 2001).

Salmonids

- Char Cambridge Bay - [Integration likely] Arctic Oscillation was correlated to CPUE. In Lachlan River science special response (In press) one data limited model had an adjustment that was based on latitude as a proxy for temperature.
- Sockeye Salmon Stikine [Integration likely] - Escapement goal reviews for both the Tahltan Lake stock and the Mainstem stock aggregate is pending and it is likely that environmental variables will be considered in this process. Linkage of in-river mortality to flow and adjustment of in season CPUE model to reflect flow may be possible.

Other

- Red Sea Urchins [Possible Integration] - Water temperature, salinity, nutrients appear to affect recruitment success. High algae abundance has the potential to be favourable to growth rates. Ocean acidification may negatively impact red sea urchins in a variety of ways (growth, larval survival). The absence of predators, such as sunflower sea stars, may increase abundance or change behaviour of smaller urchins. The presence of sea otters dramatically affects the abundance of red sea urchins as these are an important part of their diet. It may be possible to include a conceptual discussion of environmental variables affecting this stock.

Mammals

- Beluga Cumberland Sound [Possible Integration] – A case study examining how ice dynamics may increase risk of entrapment, how increased predation may impact the population, and how changes in preferred prey might reduce or boost reproductive output.

  Changes in ice dynamics are being examined: increased risk of entrapment, how increased predation may impact the population, and how changes in preferred prey might reduce or boost reproductive output.
- Scallop [Possible Integration] - Southern Gulf of St. Lawrence (SFA 21a, b, c, 22, 23, 24) – There is access to geodata from the temperature probes deployed on buoys (Ouellet et al. 2019) and from the AZMP on physical oceanographic conditions in the Gulf of St. Lawrence (Galbraith et al. 2019; Chassé et al. 2014). This can be used to explore EV integration.

- Walrus 6 stocks - There is sufficient general knowledge to provide a speculative overview of the potential impacts of EVs on productivity. For example, sea ice mediates access to benthic food sources in shallow (< 80 m depth) waters. On one hand, sea ice may provide a platform from which walrus dive to access shallow bivalve beds much further offshore than they could swim (i.e. not accessible from terrestrial haulout sites). Variation in sea ice impacts walrus access to food (i.e. good ice years = access to food; poor ice years = resort to terrestrial or other sites far from preferred foraging areas). On the other hand, walrus may also have preferred feeding sites along coastlines, which would largely be inaccessible during much of the year when land fast ice is present. The impact of ice reductions in this scenario could be beneficial by providing longer seasonal access to preferred foraging areas (unlike in the previous scenario in which sea ice reductions would be harmful). So, we could walk through the list of potentially important variables (another, for e.g., is water temperature and overall impacts on productivity, and how productivity is compartmentalized – e.g. potentially shifting from sea ice algae-benthic system to more pelagic system). We could then outline possible mechanisms for each variable that would lead either to increased or decreased walrus productivity, but data to even model such impacts conceptually (e.g. select between scenario 1 and 2, or some mix of both – e.g. depending on the season, and seasonal shifts in distribution) is lacking.

Molluscs

- Sea Scallop Area 20 [Possible Integration] - If the AZMP buoy is close enough to fishing areas, environmental variables could be included in the next stock assessment.
- Scallop Southern Gulf - Knowledge of impacts of environmental changes on other scallop stocks (US - see Cooley et al. 2015 and Rheuban et al. 2018, Bay of Fundy, Magdalen Islands) could probably be applied to this stock.
- Scallops Area 20 - There is a buoy from the Atlantic Zone Monitoring Program (AZMP) located in this area and EVs are monitored. Data are used in the lobster stock assessment and may be useful for the scallop assessment. A research project to detect environmental cues recorded in scallop shells, which will inform on variables such as temperature variation and phytoplankton blooms is under way. There is a shell collection which will enable us to determine some environmental variables since 1990. We've also partnered with physicists who will inform us on currents and get some environmental variable estimates.
- Icelandic Scallop 16EF-18A [Possible Integration] – A stock assessment model is under development and acquisition of environmental data has commenced this year with aim of including them in the 2023 assessment.

Pelagic fishes

- Porbeagle Shark – Trophic and temperature interactions are conceptually understood. There is information on trophic relationships from stomach sampling from the commercial fishery. There is information that links porbeagle catches as well as movement tracks to temperature or other oceanic variables which could be used to evaluate distribution, habitat or changes in habitat. In terms of correlating environmental variables with abundance or trends in abundance. Currently, mechanisms (to estimate abundance) are not understood.
- Mako shark - Distribution seem to be associated with areas of high mixing (warm/cool water) and show relatively strong temperature preferences. However, available environmental indices (e.g. SST) may not be strongly related to abundance and distribution, due to the species' ability to use

vertical position in the water column to modify the environments they experience (similar to porbeagle). This complicates the choice of biologically-relevant environmental predictors.

- Shortfin mako and Blue Shark - Blue shark seem to be associated with areas of high mixing (warm/cool water) and show relatively strong temperature preferences. However, available environmental indices (e.g. SST) may not be strongly related to abundance and distribution, due to the species' ability to use vertical position in the water column to modify the environments they experience (similar to porbeagle). This complicates the choice of biologically-relevant environmental predictors. Productivity in shark populations is thought to be relatively fixed and dependent on life history not on environmental variability. Short-term changes in productivity (e.g. recruitment, growth, mortality) are not expected to occur.
- Yellowfin Tuna – This is a case where environmental change affects perception of stock health. Climate-induced changes in catchability and/or availability that are not included in the development of indices of abundance can lead to false conclusions about population abundance trends. Hence the need to explore this relationship.
- Albacore Tuna Atlantic [Possible Integration] - The need to incorporate environmental variables is recognized for albacore and other species assessments. New information suggests that the mixed layer depth might impact catchability of surface fisheries, research required to confirm this and to inspect sources of environmental information that might help integrate this information in CPUE standardization.

Appendix 6. Data Sources for Environmental Variables for Model Parameterization in Canadian Stock Assessments.

EV Data Sources

Parameterize (49 Stocks)

Capelin - SA2+3KL

Current

- Timing of sea ice retreat is calculated from ice coverage chart sourced from Environment Canada
- Zooplankton production come from the AZMP (Atlantic Zone Monitoring Program lines and Stn. 27)
- Physical oceanography also comes from the AZMP program (lines and Stn. 27)
- Diet of capelin comes from our own work
- Ecosystem composition (predator trends etc.) from annual NAFO report.
- Capelin consumption estimates from DFO stomach sampling program combined with predator abundance trends.

Future – NA

Geoduck (Pacific)

Current

- Geo-referenced positions of fishing events from harvester's logbooks are mapped and used to identify where geoducks are harvested and define bed areas (habitat availability).
- Between 2000 and 2017 hydro-acoustic back-scatter analysis was used to map out substrate types and help refine bed areas (Geoducks are only found in soft substrates).
- Since 2018, multi-beam 3D mapping has been used to refine estimates of bed areas before conducting density dive surveys.
- Bed areas are further refined using data from fishery-independent density dive surveys, specifically substrate and Geoduck density data observed by the divers are mapped out in GIS and used to refine bed area estimates for surveyed beds.

Future - It would be interesting to include the potential impacts of Sea Otters on Geoduck stocks in the assessments in the future. Data or results from modelling on Sea Otter range expansion and expected areas of occupation could be investigated for future inclusion in the assessments.

Sea Scallop - Inshore SFA 28 (Bay of Fundy), Inshore SFA 29W, Offshore SFA 26 German, Browns, Offshore SFA 27, Georges

Current

- Multibeam surveys Optical (camera) surveys with VMS data to develop habitat suitability maps
- Scallop surveys (clapper index for M)

Future - Expansion of habitat suitability map development to several new areas (using multibeam and optical surveys along with oceanographic modelling). Satellite remote sensing data, oceanographic model output and larval transport models are considered. Laboratory studies of climate impacts (e.g. Ocean acidification) may ramp up in the future to provide information to enable some long term (50 years+) simulation work.

Snow Crab - CFA 1-12 2HJ3KLNOP4R

Current

- Lagged NAO is the EV that we use in the evaluation of stock status, specifically in the proposed PA Framework. It is retrieved from the NOAA website where monthly mean NAO index are posted from 1950-present.

Future – Potential sources include oceanographic information from the Atlantic Zonal Monitoring Program (AZMP) surveys (bottom temperature, zooplankton abundance and biomass) and sea ice information from the National Snow and Ice Data Center (NSIDC).

Snow Crab - Scotian Shelf (4X), Scotian Shelf (ENS-N), Scotian Shelf (ENS-S)

Current

- DFO single species assessment surveys (snow crab, shrimp, scallop, lobster)
- Ocean Tracking Network- moored receiver arrays DFO Ecosystem Surveys ("Groundfish" surveys)
- Atlantic Zonal Monitoring Program (AZMP) -
- Fishermen's and Scientist Research Society (FSRS) recruitment trap survey

Future- NA

Surf Clam – Banquereau

Current

- Fishery footprint is used as a proxy for habitat.

Future - Bottom temperature, but not where to get that data within and outside of my Region.

Linked Analyses (29 Stocks)

Clam Stimpson's Surfclam

Current

- Logbook positions defining habitat

Future - Data from the Atlantic Zone Monitoring Program (AZMP)

Atlantic Cod - 4X5Y

Current – NA

Future - Spatio-temporal dynamics of Cod are partially driven by bottom temperature and depth (Irvine et al. unpublished report).

Greenland Halibut - 4RST

Current

- Blais, M., Galbraith, P.S., Plourde, S., Scarratt, M., Devine, L., and Lehoux, C. 2019. Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St. Lawrence during 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/059. iv + 64 p. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2019/2019_059-eng.pdf
- Galbraith, P.S., Chassé, J., Caverhill, C., Nicot, P., Gilbert, D., Lefaivre, D., and Lafleur, C. 2019. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/046. v + 79 p. http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2019/2019_046-eng.pdf
- Peter Galbraith and his colleagues produce annual time series of multiple EV. This is part of the information that Daniel Duplisea entered in https://github.com/duplisea/ccca

Future - NA

Greenland Halibut - Cumberland Sound

Current

- Canadian Ice Service (https://iceweb1.cis.ec.gc.ca/CISWebApps/page1.xhtml?lang=en).
- CTD casts and fishing gear mounted instruments but the data were not consistently available and were not used in the provision of advice.

Future - Data from oceanographic instruments in addition to sea ice data.

Greenland Halibut – 0+1

Current – NA

Future - Pending modeling approaches or other methods to help link EV with stock status, Arctic Oscillation Index (AOI), temperature (sea surface and/or bottom), currents could be considered.

Haddock 3Ps, Plaice American 2+3K, 3LNO Witch Flounder - 3Ps, 3NO

Current

- Trawl mounted CTD during DFO RV surveys
- Oceanographic data (contact Fred Cyr, David Belanger for details)
- AZMP sampling
- Satellite sea surface temp and plankton bloom data

Future - NA

Pollock 4X5

Current – NA

Future

Predominant prey for pollock diets have changed over time with prey items like krill being more important in the 1960s to 1980s. Plankton data is available from the AZMP survey. Another consideration could be the spatio-temporal patterns of pollock body size as a factor of temperature and population density. CTD data from the RV Survey provides geo-referenced environmental data such as temperature, depth, salinity, and dissolved oxygen.

Herring, 2J3KLPs

Current – NA

Future – There is no larval herring survey in the region and plankton data is limited. Reimplementation of acoustic surveys and potential development of absolute biomass estimates may facilitate the development of more robust models that incorporate available environmental data (from regional AZMP program).

Most of the environmental data are from the AZMP program (1999-present for one station in 4X – Prince 5 station). There is a lack of mechanistic understanding of the influence of individual environmental variables, and changes are most likely due to multiple factors with many interactions among factors.

Herring – 4R (Fall Spawner) / (Spring Spawner), 4S (Fall Spawner) / (Spring Spawner)

Current

- Krill and copepods (food for Atlantic Herring)
- Water temperatures, etc. from the AZMP, https://www.dfo-mpo.gc.ca/science/data-donnees/azmp-pmza/index-eng.htmlhttps://www.dfo-mpo.gc.ca/science/data-donnees/azmp-pmza/index-eng.html

Future – AZMP data. Possibly data from the ecosystem approach data synthesis matrix (https://github.com/duplisea/gslea for more information).

Herring – 4T (Fall Spawner), 4T (Spring Spawner)

- Neuenhoff, R.D., Swain, D.P., Cox, S.P., Mcallister, M.K., Trites, A.W., Walters, C.J., and Hammill, M.O. 2019. Continued decline of a collapsed population of Atlantic cod. Can. J. Fish. Aquat. Sci. 76: 168–184. Atlantic cod SSB (5+) and Grey seal abundance (seal-years).
- Atlantic Bluefin tuna rod and reel CPUE index of abundance from (Maritimes region) :
- ICCAT. 2017. Report of the 2017 ICCAT Bluefin stock assessment meeting. Collect. Vol. Sci. Pap. ICCAT, (Madrid, Spain).
- IML https://github.com/duplisea/gslea) : Temperature data
- Galbraith, P.S., Chassé, J., Caverhill, C., Nicot, P., Gilbert, D., Lefaivre, D. and Lafleur, C. 2019. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/046. Iv + 79 p. – ecosystem matrix Temperature data
- Blais, M., Galbraith, P.S., Plourde, S., Scarratt, M., Devine, L. and Lehoux, C. 2019. Chemical and Biological Oceanographic Conditions in the Estuary and Gulf of St.

Lawrence during 2018. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/059. Iv + 64 pp. (Zooplankton abundance and species composition)

Future – Benoît, H.P., and Rail, J. 2016. Principal predators and consumption of juvenile and adult Atlantic Herring (*Clupea harengus*) in the southern Gulf of St . Lawrence. (September).

Iceland Scallop 3Ps, Sea Scallop 3Ps

Current – NA

Future – Temperature data is collected during each scallop survey, and temperature data is also collected during the annual spring multispecies surveys in this NAFO division.

Lobster – LFA 23, 24, 25, 26a, 26b; Inshore LFA 27-33; Inshore LFA 34; Inshore LFA 35-38; LFA 3-14c; Offshore LFA 41

Current

- Bottom temperature – use the raw data collected during surveys. For simulation modelling, temperature time series incorporating as much of the regional data as possible was modelled.

Future – Evaluating different bottom temperature models and climate projects into analyses.

NL Lobster stock (LFAs 3-14C)

Present

- The only available source used is temperature data collected by FFAW index fishers with modified traps during the lobster season since 2006.

Future – NA

Redfish – Unit 1

Current

- Environmental variables collected on our annual survey in August (O2, salinity, temperature) and from the Atlantic Zone Monitoring Program.

Future – NA

Shrimp Northern – Eastern Scotian Shelf (SFA 13-15)

- Ecosystem Surveys
- Snow crab survey
- NOAA satellite temperature database.

Future – BNAM (David Brinkman's temperature model data), and the shrimp bycatch data from other fisheries (especially snow crab). I am also exploring the availability of internal sources for zooplankton, currents, salinity, dissolved oxygen, and pH data for the eastern Scotian Shelf.

Shrimp Northern (Borealis) – Eastern Assessment Zone, - SFA 1
Shrimp Striped (Montagui) – Eastern Assessment Zone, SFA 4 Western Assessment Zone
Present – NA

Future – CTD mounted on the trawl. Not used, however, as an explanatory variable in the stock status but were rather used as a background information. Potential to use satellite derived data for the primary production assessments, but needs to be evaluated - ocean climate index (a composite temperature index), Total production of the spring bloom (magnitude), Spring bloom initiation date

Snow Crab – CFA 12 (12, 18, 25, 26), 12E, 12F, 19

Present

- Lagged NAO is the environmental variable that we use in the evaluation of stock status, specifically in the proposed PA Framework. It is retrieved from the NOAA website where monthly mean NAO index are posted from 1950-present.

Future – Other sources that we might consider include oceanographic information from the DFO oceanography section's Atlantic Zonal Monitoring Program (AZMP) surveys (bottom temperature, zooplankton abundance and biomass) and sea ice information from the National Snow and Ice Data Center (NSIDC).

Snow Crab 4T Gulf

Current

The data on annual bottom water temperatures are provided from the snow crab survey (CTD and star Oddi probes attached to the trawl) and the research vessel ground fish survey (CTD).

Future – Since 2015, the snow crab group is getting annual daily bottom water temperatures at tree different locations in the southern Gulf (Chaleur Bay, Bradelle bank and in Cape-Breton corridor) from Star Oddi and Minilog probes attached to a line of anchors. Preliminary data showed that the bottom water temperatures in Bradelle bank were cooler than for Chaleur Bay and the Cape Breton Corridor). The effects of the bottom water temperature on eggs development are still under investigations but it appeared that in the Cape Breton Corridor where the bottom water temperatures are few degrees higher, the eggs development takes only one year compared to other parts of the southern Gulf.
The snow crab group is also working of accessing bottom water acidity in the southern Gulf with samples taken from the snow crab survey, the research vessel ground fish survey and other field surveys with the Perley.

Rock Crab

Present – NA
Future- Lobster Predator Prey relationships. (Rondeau et al., 2014), Northumberland Strait Multi-Species survey (e.g. lobster abundance)
Generally, any other relevant and available data sources (e.g. water temperature data, traditional knowledge studies, local knowledge studies).

Beluga

Current – NA
Future
With earlier breakup and later freezing, the beluga have shifted the timing of their migration by about 10 days over a decade. So, spring migration to summering grounds now occurring 10 days earlier, and return to overwintering area now occurring 10 days later.

Whale Bowhead – Eastern Canada – West Greenland (ECWG)

Current

- Habitat that minimizes risk of predation to vulnerable segments of the population – nursing calves and juveniles. This would be sea ice and coastline together and they are not static variables. For example, as we continue to loose summer sea ice the distribution of this critical habitat shifts over time towards the Arctic Archipelago and poleward – both habitats that are limited and will eventually become scarce.

- Access to high quality lipid-rich food. Although large-bodied copepods will continue to be available as the ocean warms, their relative accessibility to bowhead whales will change over time. In particular, natural undersea landscape features and ocean currents create conditions necessary to force prey towards the surface during upwelling events at the time of year that zooplankton are diapausing near the bottom during life-history stages that concentrate food quality (high lipid content of gonads). Currently, the coming together of these two events – oceanographic features and lipid-rich prey – occurs in autumn (ca Sept.-Nov.) along the east coast of Baffin Island. As oceans warm the distribution and timing of maximum prey availability likely will shift towards the Arctic Archipelago and poleward requiring modeling to identify. Similar to (1), these habitats may become limiting.

Future
Other possible useful data sources would include measures of SST, primary productivity (e.g., Chlorophyll) from satellite imagery, seasonal sea ice conditions (distribution, thickness, pan size, coverage), distance to coastlines and key oceanographic features such as trenches, sills, canyons. From ocean surveys, direct measures of zooplankton abundance categorized by life stages and distribution of killer whales, seasonal movements, and ecotypes.

Atlantic Salmon NL

Present

Temperature loggers are used at most Atlantic salmon monitoring facilities. Water temperature data has been used occasionally to address concerns from stakeholder groups or resource managers about the potential effects of angling on salmon during the summer months. In addition, water level loggers recently purchased to add to the environmental data collected starting in 2020.

The exact process in which environmental variables at sea drives marine survival of Atlantic salmon is still poorly understood despite being a research focus for salmon scientists in North America and Europe for several decades. Environmental data that is presented at our Atlantic salmon stock assessments is usually included in the science advice given to resource managers.

Future - NA

Dolly Varden

Current

- A community-based monitoring program is undertaken by local aboriginals since 1996. Environmental variables collected include qualitative rankings of date of year, water color, content of debris, water level, and clarity of water. Because of nature of qualitative rankings, it is hard to directly apply for evaluation of stock status. Alternatively, we used generalized linear mixed effect models to standardize CPUE of Dolly Varden. Plugged into a set of quantitative assessment models, CPUE is a key abundance index for assessing stock status under environmental changes.
- We incorporated weather data of air temperature and precipitation in the nearby weather observation station. Data analysis indicated the existence of collinearity between date of year as well as between water level and water color, we remove variables of air temperature and water level.

Future

Dedicated staff would be needed to 1) compile data not collected directly by the department (i.e., large scale information collected by other agencies such as: air temperature, sea surface temperature, Arctic Oscillation Index, marine weather, marine ice breakup/ extent, hydrology data available from certain rivers such as the Firth and Mackenzie) ; 2) manage environmental data collected by the population assessment program (i.e., grater effort would be made to deploy multi-parameter data loggers to measure temperature, turbidity, etc. in both marine and freshwater in concert with fisheries-dependent monitoring programs); and 3) model (e.g., to evaluate environmental effects on a) stock vital rates such as birth/growth/death and other important life history aspects, and b) the fishery).

Lake Whitefish

Current

- Through implementation of long-term community-based field survey programs, limnology and lower trophic production data were collected along with species richness, species-specific abundance and biomass. There are no specific analysis relating environmental variables to abundance and production,

Future - it is future work to probe quantitative, qualitative and mixed effects on the path of changes of LKWF production. Future plan is to apply ecosystem modeling approach to incorporate food web connection with changing LKWF production and cumulative effects from human activities in GSL. We will develop a mass-balanced food-web models for GSL ecosystem and will apply it to ecological simulation given different scenarios of exploitation and management policy.

Implied Analyses

Witch Flounder - 3NO

Southern Gulf Groundfish and Herring

Present

For sGSL cod and other groundfish, the main ecosystem effect considered in the models is the effect of predation by grey seals. This can be incorporated indirectly by estimating time-varying natural mortality. To incorporate it directly via a functional response requires information on seal abundance, geographic distribution and diet composition. This is obtained from the marine mammal research and assessment programs. Seal abundance by herd comes from their assessments and diet information comes from their research projects. The latter can be very challenging because diet can vary substantially between areas, seasons, the sexes and individuals. So a carefully planned sampling plane is needed to avoid serious bias in estimated diet composition. Finally satellite tag data and aerial surveys of haul out sites are needed to estimate seal abundance in the study area (e.g., the sGSL).

For Atlantic herring, there are also important ecosystem effects of predation on natural mortality. However, it is more complicated than it is for cod. Herring have many predators, though recent increases in natural mortality appear to be strongly linked to the abundance of grey seals and tuna.
We are also modelling recruitment of herring as a function of biological and physical oceanographic conditions. These factors are monitored by the AZMP (Atlantic Zonal Monitoring Program).

Future - NA

Appendix 7. Enumeration of EV Affected Population Processes

Table A71a. Affected population processes by EV types used to Parameterize the Model. In the left column, the bolded text is the EV category (Climate Indicators, Ocean Conditions, Multispecies Links, Habitat Availability). Directly below is a list of the EVs and in brackets are the biological processes affected by the EV. In the right column is listed the corresponding stocks.

Classified EVs Used in Parameterized Models N=23 and affected population process (in brackets)	Stock Name/Count
Climate Indicators	**4**
NAO, AMO (Movements)	Swordfish, BF Tuna
Pacific Decadal Oscillation (Recruitment)	Pacific Halibut
Ice Melt (Pup mortality)	Grey Seal
Climate Indicators, Ocean Conditions, Multispecies Links	**1**
North Atlantic Oscillation, Temperature, Predators (Biomass, Productivity)	Snow Crab 1-12
Ecological Factors	**4**
Clapper Proxy (Natural Mortality)	Sea Scallops
Predation (Productivity, Mortality)	Scotian Shelf, B Fundy Gulf Cod
Ecological Factors, Habitat Availability	**1**
Habitat Quality, Clapper Proxy (Natural Mortality)	Sea Scallops Scotian Shelf Inshore
Habitat Availability	**3**
Proxy Benthic Habitat (Biomass)	Surf Clam Banquereau
Habitat Quality (Productivity)	Geoduck
Water level, colour, debris, temperature (CPUE Abundance)	Dolly Varden
Ocean Conditions, Habitat Availability	**5**
SST, Salinity, PDO timing, temperature, discharge (Natural Mortality Productivity)	Sockeye Fraser (4) Atlantic halibut SS
Ocean Conditions, Habitat Availability, Ecological Factors	**1**
Temperature (Catchability), Diet (Natural Mortality)	Cod 3Ps
Ocean Conditions, Multispecies Link	**1**
Temperature, Sea Ice, Predators, Prey (Biomass)	Capelin SA 2+3KL
Ocean Conditions, Habitat Availability, Multispecies Links	**3**
Temperature, Depth, Substrate, Species Composition (Biomass)	Snow Crab Scotian Shelf EN, 4X

Table A71b. Affected population processes by EV types used in Implied Analyses

Classified EVs Used in Implied n=14 and affected population process (in brackets)	14
Multispecies Links	**5**
Predation, Prey (Natural Mortality)	Pacific Herring

Unspecified	**9**
(Natural mortality, Recruitment, Growth)	Cod 4RS3Pn, 2J3KL
(Natural Mortality, Habitat Loss)	White Hake 4T
(Productivity)	Witch 3NO
(Weight at Age)	Pacific hake
(Natural Mortality)	Yellowtail, Winter Flounder Plaice 4T, Haddock 4X5Y

Table A71c. Affected population processes by EV types used in Linked Analyses

Classified EVs Used in Linked Analyses N=64 and affected population process (in brackets)	Stock Count
Climate Indicator	**4**
Arctic Oscillation, Latitude [temperature proxy] (Biomass)	Char Cambridge Bay
El Nino Southern Oscillation (Distribution, Catch)	Tuna Yellowfin Atl
Ice melt (Migration)	Beluga N QC, Greenland Halibut Cumberland
Climate Indicator Ocean Conditions Multispecies Links	**2**
Temperature Predator Redfish Abundance Regime shift (Productivity, Abundance, Growth, Reproduction, Trophic Relationships)	Shrimp Northern Gulf
PDO, ONI, SST, Temperature, Salinity, Copepods, Biol Spring Transition, Ichthyoplankton (Survival)	Chinook Okanogan
Ecosystem Factors	**1**
Diet capelin (Growth)	Char Cumberland
Ecosystem Factors Climate Indicator	**4**
Predators, NAO (Productivity)	Shrimp SFA 4-7
Ecosystem Factors Habitat Availability	**1**
Prey Depth (Diet)	Redfish U 1
Habitat Availability	**4**
Extent (Productivity)	Stimpsons Surf Clam N Gulf
Shore length (Biomass, Density)	Red Cucumber Red Sea Urchin Pac
Area (Habitat)	Gaspereau Fundy
Multispecies Links	**3**
Predators (Mortality, Distribution)	Sea Scallop 3Ps
Predators Starfish, Sea Otters (Biomass)	Iceland Scallop 3Ps
Sea Otter Sea Star Predation (Biomass)	Green sea Urchin
Ocean Conditions	**26**

Biochemistry, Sea Ice, Contaminants, Predation (Population)	Bowhead Whale
Sea Surface Temperature (Catch Rate)	Tuna Bigeye
Temperature (Abundance 1, Productivity 19)	20 stocks – Shrimp Pac, Snow Crab Gulf, Lobster Gulf and Mar, Plaice 3Ps
Temperature Oxygen Ph Competition (Productivity)	Greenland Halibut 4RST
Depth, Temperature, Oxygen, pH, Turbidity, Conductivity (Productivity)	Lake Trout Gt Slave Lk
Larval Transport (Recruitment)	Pac Cod 3 and 5
Ocean Conditions Ecosystem Factors	**7**
Prey (Productivity)	Plaice 3LNO
SST, Salinity. Plankton (Biomass)	Salmon Atl NL
SST Zooplankton. Prey, Ice Retreat (Growth, Diet)	Capelin 4RST
Temperature Depth Plankton Community Biomass (Productivity, Recruitment)	Haddock 3Ps
Temperature, Plankton, Community Biomass (Productivity)	Witch Flounder 3Ps
Temperature, Prey, Community Biomass (Productivity)	Plaice 2+3K
Temperature, Predation (Productivity, Recruitment)	Shrimp NE Scotian Shelf
Ocean Conditions Climate Indicator	**1**
E&NPac Index, Sea Level Anomalies, Max Area Haida Eddies, Aleut Low Press Index, N Pacific Index, Pacific Decadal Osc, N Pac Gyre Osc, El Niño Index, S Osc Index (Recruitment)	Pac Ocean Perch
Ocean Conditions Multispecies Links	**2**
Temperature, Plankton (Recruitment)	Herring 2J3KLPs
Thermoprofiling, Water Chemistry, Primary Prod, Food Web (Productivity, Diet)	Lk Whitefish Great Slave Lake
Ocean Conditions Ecosystem Factors Habitat Availability	**1**
Temperature, Prey, Habitat (Para- Egg Production, Link-Spawning Recruitment, Condition)	Mackerel
Ocean Conditions Ecosystem Factors Multispecies Links	**5**
SST, Zooplankton, Prey (Recruitment)	Herring 4R 4S
Temperature, Prey, Nutrients, Plankton, Community Change (Productivity)	Witch Fl 2J3KL
Temperature, Plankton, Predator Abundance (Recruitment, Natural Mortality)	Herring 4T Spring Fall Spawners
Ocean Conditions Habitat Availability Multispecies Links	**1**
Habitat, Co-occurrence, Trophic interactions (Unspecified)	Boccaccio
Unspecified	**2**
Unspecified (Productivity, Reproduction)	Witch Fl 4RST Hooded Seal Atl

Annex 1 – Fisheries and EV Integration

Beyond the issues related to factors affecting the integration of EVs in the advisory and decision making process, the nature of the fishery itself may have implications for the capacity of DFO to integrate knowledge and understanding of the impacts of environmental change on stock status and productivity. This section, details information related to the types and location of fisheries on current patterns of use of EVs in the assessment and management processes. This is peripheral to the general objectives of the analyses presented in the body of this report but may provide insights that can indicate the need for further consideration in development of an ecosystem approach to fisheries.

EV use is enumerated by fishing sector, gear used, type of fishing activity i.e., directed, targeting a particular stock; formerly a directed fishery now under Moratorium; taken as Bycatch in other fisheries; or Other, comprising sustenance, aboriginal, recreational, ceremonial or bait fisheries. EV integration generally relates to a common thread, quality of data.

EV Integration by Fisheries Sector

Of the 212 stocks examined, 39% were prosecuted as Inshore fisheries, 40% as Offshore, the remainder 21% were Midshore or Mixed sector fisheries (Table Ann1). Inshore-Midshore, Midshore-Offshore, Inshore-Offshore and All Sectors comprise Mixed Sectors.

Different Regions comprised different mixes of sectors fished. There was a mix of all taxa in the Inshore fisheries and a majority subset in the remaining sectors. In all Canadian Regions, the industry fished a varying mix of near, mid and offshore areas.

Table Ann1. Stock count for fisheries examined classified by Sector, Region and Taxon.

Sector/Taxon	NL	Gulf	QC	Arct	Mar	NCR	ICCAT	NAFO	Pac	All	Percent of Tot
Offshore	**7**	**2**	**10**	**1**	**11**	**10**	**5**	**5**	**34**	**85**	**40%**
Crustacean			9		1	10				**20**	9%
Groundfish	5	2	1	1	8			5	34	**56**	26%
Large pelagic							5			**5**	2%
Mollusc	2				2					**4**	2%
Inshore	**6**	**8**	**10**	**20**	**11**				**27**	**82**	**39%**
Crustacean	1	2	3		7				1	**14**	7%
Groundfish		1	1	1					4	**7**	3%
Mar Mammal			3	14						**17**	8%
Mollusc	1	1	3						5	**10**	5%
Other	1	1			2				3	**7**	3%
Salmonid	1	1		5					6	**13**	6%
Small Pelagic	2	2			2				8	**14**	7%
Midshore		**3**	**5**							**8**	**4%**
Crustacean		1								**1**	0%
Groundfish		2	1							**3**	1%
Mollusc			1							**1**	0%
Small Pelagic			3							**3**	1%

Mixed Sectors	**6**	**1**	**2**	**0**	**9**	**2**	**1**	**3**	**13**	**37**	**17%**
Crustacean	1		1						2	**4**	2%
Groundfish	5	1	1		2			2	10	**21**	10%
Mollusc					4			1		**5**	2%
Large pelagic					1	1	1		1	**4**	2%
Small Pelagic					2	1				**3**	1%
Grand Total	**19**	**14**	**27**	**21**	**31**	**12**	**6**	**8**	**74**	**212**	

Integration of EVs as a proportion of total stocks assessed was highest for Midshore and Mixed fisheries (Fig. Ann1). EVs were used in stock assessments pertaining to fisheries across all sectors, application slightly higher in offshore and inshore sectors varying from 75% of stocks integrating EVs in assessments of Mixed (widespread) fisheries, Midshore fisheries 74%, Inshore fisheries, 53% and Offshore fisheries, 40% (Fig. Ann1).

In terms of how EVs were integrated, Midshore fishery assessments had the highest degree of integration at 75%, Mixed at 57%, Inshore at 54% and Offshore lowest at 36% (Fig. Ann1). Assessments with EV-parameterized models was highest for Mixed sector fisheries at 27% of total mixed sector assessments, much lower for other sectors, 13% for Inshore fisheries, 2% for Offshore fisheries, none for Midshore fisheries. Implied EV integration was highest for stock assessments pertaining to Midshore sector fisheries 25% of total Midshore sector stocks, 5% for Mixed fisheries, 7% for Inshore fisheries and 5% for Offshore fisheries. Use of Linked analyses was similar across sectors, highest for stock assessments pertaining to Midshore sector fisheries at 50% of total Midshore sector stocks, 29% for Offshore fisheries, 33% for Inshore fisheries and 27% for Mixed fisheries (Fig. Ann1).

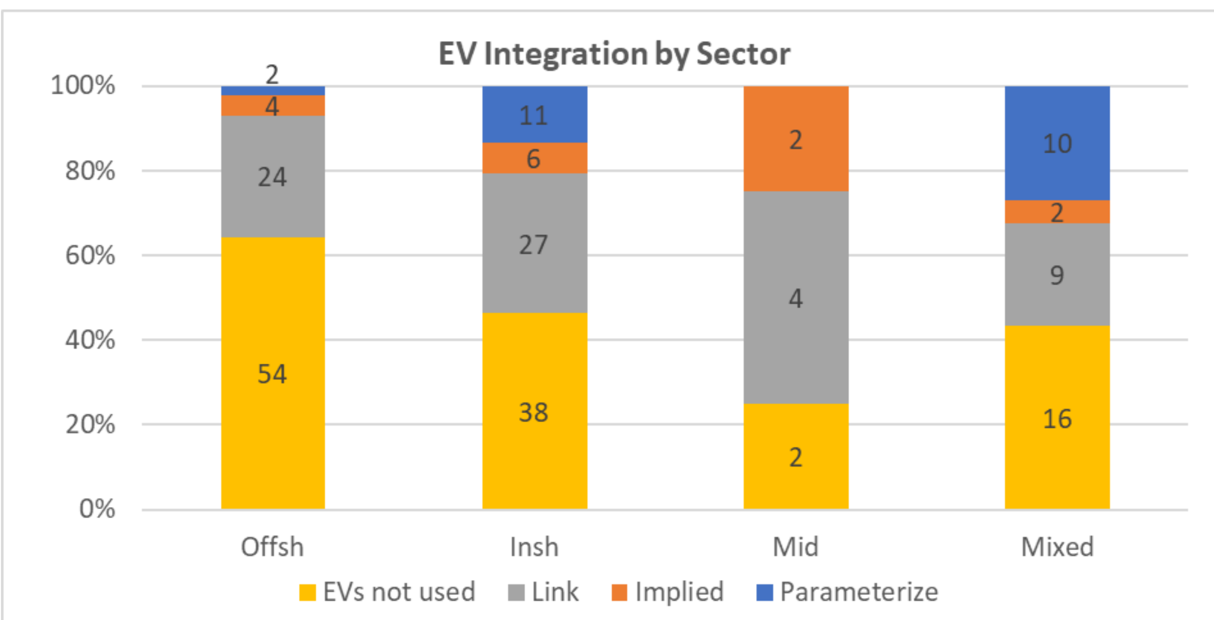

Figure Ann1. EV types integrated into assessments by fisheries sector.

EV Integration by Gears, Season

Gears used for the 212 fisheries examined were diverse and generally specific to the taxon (Table Ann2). The main gears used were: Traps for crabs, Trawls for shrimp, Mixed gears for groundfish (generally a combination of Trawls, Gillnets or Longlines) and small pelagic fishes, Longlines for large pelagic fish, Weapons (mainly rifles) for marine mammals, Dredges for molluscs and Rod and Gillnets for salmonids. Fishing generally occurred during spring through fall with some winter offshore activity. Season was stock specific. The gears associated with the highest degree of EV integration were Scuba, Rake, Kelp, MWT weapons and Danish Seine (at 100%), Trap at 85% GN at 75% ands Dredge at 67%. However, Neither fishing gear or fishery season (or sector) related to whether EVs comprised part of the assessment process, or not (Table Ann2). Certain gears were associated with a higher degree of integration but this observation relates to taxon and other factors such as data quality**.** For example, 85% of stocks that were fished with Traps have EVs incorporated into the assessment. Traps were used primarily to capture crustaceans and for this taxon, the stocks generally data rich and thus integration was high. See sections on **Integration of Environmental Variables and Data Quality** and **Fisheries and Data Quality** for further explanations of why Trap, Gillnet and Dredge fisheries were associated with above average use of EVs in associated assessments.

Table Ann2. Stock count by fishing gears and EV Integration.

Fishing Gears	Count of Stock	Percent Used EVs
Scuba	**4**	100%
Parameterize	1	
Link	3	
Rake	**3**	100%
No	3	
Kelp (Herring eggs)	**1**	100%
Implied	1	
MWT	**1**	100%
Implied	1	
Weapons	**17**	100%
Parameterize	1	
Link	3	
No	13	
Danish Seine	**1**	100%
Link	1	
Trap	**26**	85%
Parameterize	4	
Link	18	
No	4	
GN	**4**	75%
Link	3	
No	1	
Dredge	**12**	67%
Parameterize	5	
Link	3	
No	4	
Mixed	**95**	46%
Parameterize	10	
Implied	11	
Link	22	
No	51	
LL	**6**	33%
Parameterize	1	
Link	1	
No	4	
Trawl	**35**	29%
Implied	1	
Link	9	
No	25	
Rod	**4**	25%
Link	1	
No	3	
Pots	**1**	0%
No	1	
Drag	**1**	0%
No	1	
Hook	**1**	0%
No	1	
Grand Total	**212**	

EV integration by Fishery Types

Directed fisheries made up 71% of fishery types examined, bycatch 9%, fisheries under moratorium 5%, other fishery types (sustenance, aboriginal, recreational, ceremonial, bait) 15%. There were different degrees of EV integration among fishery types with respect in corresponding assessments. EVs were used more frequently in assessments pertaining to directed (53%) and moratorium (80%) fisheries much less in bycatch (16%) and other (30%) fisheries (Fig. Ann2). These differences in EV integration likely relates to higher quality of data used to assess stocks pertaining to Directed and Moratorium fisheries, making integration of EVs more feasible. As well, stocks under Moratorium are at low abundance and their productivity is more greatly affected by environmental affects. To better understand these effects, EV integration is necessary.

When EVs were integrated into corresponding assessments, EV category (Parameterize, Implied, Link) degree of integration varied by fishery type as well. As a percent of total stocks, assessments for Directed fisheries, those under Moratorium, Bycatch and "Other" fisheries, incorporated EVs as parameters in the assessment models in 11%, 10%, 0% and 15% of the corresponding assessments, respectively, (Fig. Ann2). Implied parameterization, for corresponding fishery types was 7% and 30% for Directed and Moratorium, 0% Bycatch and Other. For Linked analyses, EVs were incorporated into the assessments at a rate of 35% for Directed, 40% for Moratorium, 16% for Bycatch and 15% for "Other" fisheries (Fig Ann2).

Assessments for two of three bycatch fisheries that Linked EVs, Pacific Rockfish Bocaccio and NL Plaice American 3Ps are both commercially desirable species but are presently restricted to bycatch. The third bycatch species integrating EVs was a salmonid (lake trout) and that group generally integrated water conditions in the assessment. All five assessments that used EVs as model parameters under "Other" fisheries and one of five Linked analyses were for salmonids in river. Deeply depleted groundfish fisheries under Moratorium (Cod, Yellowtail, Winter Flounder and White Hake) in the Gulf of St Lawrence used an Implied EV integration approach where M was allowed to vary. This was done because environmental affects, reflected in high natural mortality rates were preventing recovery of those depleted stocks even at very low exploitation levels. Hence the high degree of Implied integration for that category.

In summary, more commercially important marine species, those tending to have richer data i.e., directed and formerly important fisheries now under moratorium, taken as bycatch only, or salmonids in freshwater had a higher rate of integration of EVs than for less important stocks taken historically only as bycatch or as "other" fisheries. Implied analyses occurred only for directed and moratorium fisheries and there were no EV parameterized bycatch assessments.

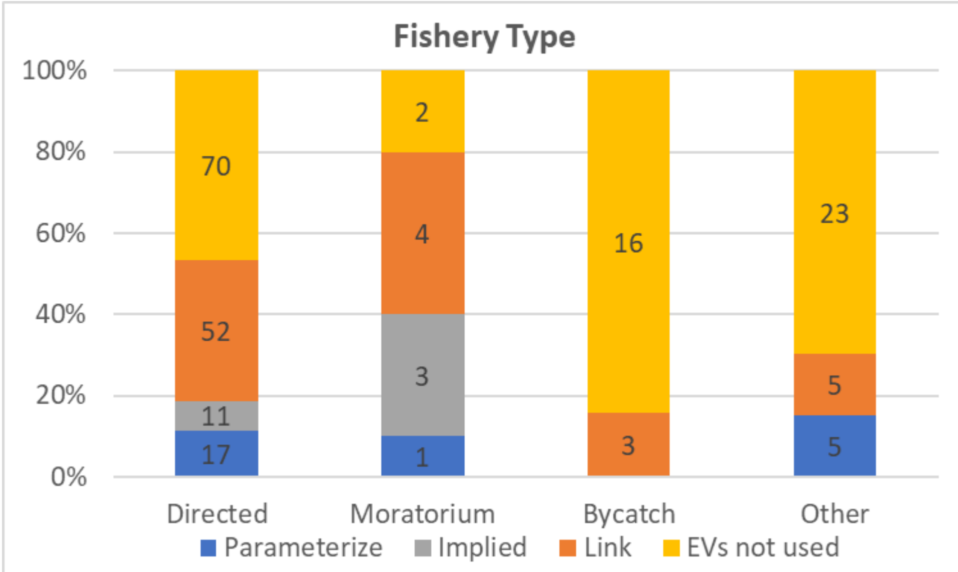

Figure Ann2. Integration of EVs by fishery type.

EV Integration by Fishery type and data richness

Quality of data used to assess stocks is classified as Rich, Moderate, or Poor and refers to quality of assessment input, not quality of EV data. Quality of data differed by fishery type: Directed, Moratorium and Bycatch fisheries compared to Other fisheries generally have higher quality input data for assessments (refer to section on **Integration of Environmental Variables and Data Quality**), thus providing more opportunity to integrate EVs into the assessment irrespective of fishery category.

Fishery types refer to whether the fishery Directed for a particular species, whether fishery is presently under Moratorium, where a particular stock was taken exclusively as Bycatch or, Other (sustenance, aboriginal, recreational, ceremonial, bait) types of fisheries

Table Ann3 shows EV integration by fishery type with respect to data quality. For directed fisheries, use of EVs (as a proportion of directed fishery stocks) was similar with respect to data quality, 57% of rich stocks, 48% moderate and 58% poor. For fisheries under moratorium, use of EVs quite different with respect to data quality, 100% of rich stocks, 80% moderate and 0% poor. For bycatch stocks use was 14% of rich stocks, 11% moderate and 33% poor. For ”Other” fisheries , use was 100% of rich stocks, 25% moderate and 9% poor. Data quality and integration of EVs is discussed in relation to taxon and Region under the section Integration of Environmental Variables and Data Quality.

Table Ann3. EV Integration by Fishery type and data quality

Data Richness	Directed	Moratorium	Bycatch	Other	Total
Rich	**61**	**4**	**7**	**7**	**79**
Parameterize	14	1		4	19
Implied	8	2			10
Link	13	1	1	3	18
Percent using EVs	57%	100%	14%	100%	59%
No	26		6		32
Moderate	**62**	**5**	**9**	**4**	**81**
Parameterize	3			1	4
Implied	3	1			4
Link	24	3	1		28
Percent using EVs	48%	80%	11%	25%	44%
No	33	1	8	3	45
Poor	**26**	**1**	**3**	**22**	**52**
Link	15		1	2	18
Percent using EVs	58%	0%	33%	9%	35%
No	11	1	2	20	34
Total	**149**	**10**	**19**	**33**	**212**

Stakeholder Interest and Use of EVs

In recent years not only has there been increasing interest in environmental affects on exploited stocks in the scientific community but also with other stakeholders. stakeholders outside of Science expressed concern and interest in understanding environmental affects on the stock for 42% of the 212 stocks examined. Stakeholders expressed interest in environmental effects for 30% of stocks where EV integration was not occurring. Overall, changes due to rising temperature was the single greatest concern among stakeholders.

Stakeholder interest was highest for Crustacean stocks. For Dungeness crab, effects of temperature, salinity, hypoxia, ocean acidification, and currents on aspects of recruitment, growth, mortality, distribution, and catchability are regularly discussed by industry, ENGOs, and Indigenous groups. Availability of Atlantic rock crab as prey for lobster came up frequently as a topic of discussion at both lobster and crab meetings with industry. For northern shrimp, buy-in from industry and stakeholders to integrate EV effects into the assessment is limited for stocks presently in an unfavorable environmental space and where the fishery is believed to only have limited impacts on the stock. Harvesters acknowledged that environment can affect productivity suggesting that Pacific Pink Shrimp avoid warm waters and thus, climate change might have an impact on their distribution (and thus accessibility) and abundance. The Pacific Prawn Fisherman Association (PPFA) submitted a proposal for researchers to perform population dynamics modelling which include environmental variables to help us meet the new Fish Stocks provisions of the *revised Fisheries Act*. For snow crab, ocean warming and negative affect on abundance is discussed regularly, as well as qualitive discussion of potential predation.

For Groundfish stocks, increased predation by seals and to a lesser extent, warming is of particular concern to industry and Indigenous groups particularly with respect to cod stocks on the Scotian Shelf, Gulf of St Lawrence and southern Grand Banks. Environmental affects of uncertain origin are of concern to the stakeholders in the Gulf, not only for cod but other groundfish species such as White Hake and Winter Flounder. For pollock, the Integrated Fisheries Management Plan was developed with stakeholders and includes an ecosystem approach. For Greenland Halibut in the Gulf, there is concern by stakeholders that predation and other environmental affects will result in increased M as occurred for the gadoids affecting abundance even in the absence of fishing. In Cumberland Sounds, the key issue for stakeholders is shrinking ice cover affecting where they can fish for Greenland Halibut. For Redfish, stake holders have expressed interest in shrimp consumption and the impacts of water warming and lack of oxygen in the Gulf on Redfish productivity. For Pacific groundfish, interest is limited because affects are generally poorly understood. Exceptions are Pacific Ocean Perch (increased fish mortality due to the expansion of oxygen-depleted 'dead' zones and conservation groups are more likely interested for the purpose of ameliorating environmental effects on ecosystems) and Canary Rockfish (stakeholders expressed interest in knowing future stock status for both harvest management and business planning).

For Marine mammals, Inuit groups often mention sea ice reduction as a factor altering Arctic marine mammal distributions. With respect to walrus, Inuit have voiced concerns that significant sea ice loss in areas such as Foxe Basin may have resulted in shifts to other areas such as norther Hudson Bay or Hudson Strait. For Beluga, the concern is that ice is affecting the timing of migration. Inuit groups have mentioned changes in distribution, body condition and behaviour of narwhals related to changes in the environment as well as increase pressure from industrial development and tourism. For Grey seal, ice conditions have been discussed as it affects pup survival and access by harvesters to the resource.

For Mollusc stocks, sea otter predation affecting Geoduck abundance is a concern for both industry and first nations. For Intertidal Clams, Indigenous communities and other stakeholders have raised anecdotal concerns about the observed declines in abundance, most attributed to fishing pressure, but some questioned the impacts of climate change (i.e. ocean acidification). For southern Gulf Scallop, impacts of increasing bottom water temperature has been raised by industry members, presently being investigated at a physiological/biochemical level in collaboration with fishery managers and industry. For Scotian Shelf/Bay of Fundy Scallops, environmental relationships have been discussed at advisory, assessment, and industry meetings including a) the impact of interactions between oceanography and bottom habitat on scallop productivity, b) effects of temperature and primary productivity on scallop condition, c) influence of predators on natural mortality, d) the impact of oceanographic conditions on scallop health, e) oceanographic influences on larval transport and survival, and f) longer term impact of directed environmental change (e.g. temperature and acidification) on scallop population dynamics.

For Salmonids, climate change effects on habitat, population dynamics, and fisheries for Dolly Varden are an important driver of discussions in annual co-management meetings, There are also several traditional knowledge reports on how environmental change are influencing stocks and their fisheries. For Lake Tout, concerns have been expressed about changing river flows and water levels, habitats alteration and resultant changes in catch trends as discussed during the advisory committee meetings and consultancy meeting with local communities. For Fraser and Stikine Sockeye, impact on productivity are discussed. For Atlantic Salmon, high temperatures, low food availability which may have negative impacts on salmon while at sea are regularly discussed with stakeholders.

For Pelagic fish, a shift in in 2J3IKLPs Herring recruitment during the 2000s from predominantly spring to fall spawners is linked to temperature/climate change and this was presented and accepted by stakeholders. For Herring - 4R, 4S (Fall Spawner) / (Spring Spawner), stakeholders reported deeper herring schools in the fall and are unable to catch the fish with purse seines at that time. For the Herring 4T Fall/Spring Spawner stocks, stakeholders have been asking for the incorporation of predation in the assessment, as they felt the grey seal and more recently Bluefin tuna populations were an increasing threat to the herring stocks. Participants from all groups felt that the ecosystem information for both recruitment and natural mortality was beneficial to the assessment. For Pacific Herring, Indigenous groups often identify the need for consideration of climate change into harvest decisions and there is continued pressure from environmental groups to incorporate changing predator needs. There is some resistance from industry given an unclear understanding how environmental variables would impact harvest opportunities. For Eulachon, concerns raised stakeholders were largely around what benefit changes to management measures could have given the uncertainty associated with marine survival being a key threat.

For Pacific Cucumbers, environmental changes have been discussed with Indigenous groups and other stakeholders relating to increase in water temperature, possibly be a main factor in a trophic cascade in rocky reef habitats. Discussion has occurred on sea star wasting disease, which virtually eliminated one of the giant red sea cucumber’s predators, the sunflower sea star, and how the disappearance of this predator may have contributed to the high abundances of juvenile giant red sea cucumbers. The recolonization of sea otters along the BC coast are also a concern. Predators of giant red sea cucumbers and red sea urchin abundance and distribution in BC. For Pacific Urchins, changing (reduced) algal abundance, sea water temperature, sea star and sea otter presence/absence, are regularly discussed with industry and Indigenous groups.