Climate Change Vulnerability Assessment Methodology Workshop Proceedings

K.L. Hunter, J. Wade, C.H. Stortini, K.D. Hyatt, J.R. Christian, P. Pepin, I.A. Pearsall, M.W. Nelson, R.I. Perry, and N.L. Shackell

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CLIMATE CHANGE VULNERABILITY ASSESSMENT METHODOLOGY WORKSHOP PROCEEDINGS

by

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A standard framework is needed to assess commercially-important fisheries vulnerability to climate change across Fisheries and Oceans Canada's regions. A workshop was held in November 2014 at the Institute for Ocean Sciences in Sidney, British Columbia to build on the expertise and experience of several approaches to risk and vulnerability assessments developed by DFO Atlantic and Pacific Regions, as well as by NOAA Fisheries in the United States. Based on existing assessments and literature, participants discussed and agreed on a standard framework for DFO climate change vulnerability assessments (CCVA). Workshop participants emphasized that resource requirements that may be employed within a given framework, be they staff time or financial commitments, must be provided within the context of the methodology in order to make an informed choice of framework to employ. Ultimately, the goal of a CCVA is to provide science advice to fisheries managers to build resilience into fisheries management decisions. These proceedings provide recommendations for others developing fisheries vulnerability assessments, including an Aquatic Climate Change and Adaptation Services Program project in DFO's Pacific region *on Climate Vulnerability of Selected Species and Associated Capture Fisheries.*

RÉSUMÉ

Hunter, K.L., Wade, J., Stortini, C.H., Hyatt, K.D., Christian, J.R., Pepin, P., Pearsall, I.A., Nelson, M.W., Perry, R.I. and Shackell, N.L. 2015. .Compte rendu de l'atelier sur la méthode d'évaluation de la vulnérabilité aux changements climatiques. Rapp. manus. can. sci. halieut. aquat. 3086: v +20 p.

Un cadre normalisé est nécessaire pour évaluer la vulnérabilité aux changements climatiques des pêches importantes du point de vue commercial dans l'ensemble des régions de Pêches et Océans Canada. Un atelier a eu lieu en novembre 2014 à l'Institut des sciences de la mer à Sidney, en Colombie-Britannique, pour tirer parti de plusieurs méthodes d'évaluation des risques et des vulnérabilités établies par les régions de l'Atlantique et du Pacifique de Pêches et Océans Canada, ainsi que par les services des pêches de la National Oceanic and Atmospheric Administration des États-Unis. En se fondant sur les évaluations et les documents existants, les participants ont discuté et ont convenu d'un cadre normalisé d'évaluation de la vulnérabilité aux changements climatiques de Pêches et Océans Canada. Ils ont insisté sur le fait que les ressources nécessaires qui peuvent être employées dans un cadre donné, que ce soit des ressources humaines ou financières, doivent être affectées dans le contexte de la méthodologie afin de prendre une décision éclairée quant au cadre à utiliser. Au bout du compte, l'objectif d'une évaluation de la vulnérabilité aux changements climatiques est de fournir des avis scientifiques aux gestionnaires des pêches afin de renforcer la résilience des décisions en matière de gestion des pêches. Le présent compte rendu contient des recommandations à l'intention des autres intervenants qui élaborent des évaluations de la vulnérabilité des pêches, notamment aux responsables du projet de programme des services d'adaptation aux changements climatiques en milieu aquatique dans la région du Pacifique, qui porte sur la *vulnérabilité au climat de certaines espèces et de pêches de capture connexes*.

1.0 INTRODUCTION

Changes to the aquatic environment driven by anthropogenic carbon emissions present a growing risk and concern for fish and fisheries in Canada (Campbell et al. 2014; Hutchings et al. 2014). In 2011, Fisheries and Oceans Canada (DFO) initiated the Aquatic Climate Change and Adaptation Services Program (ACCASP) to improve understanding of climate change and prepare for climate-related impacts on the Department's business. Expected impacts of climate-induced changes fish and fisheries in Atlantic, Pacific, Freshwater, and Arctic Large Aquatic Basins demonstrate a need to systematically assess climate change risks to aquatic organisms and associated fisheries managed by the Department of Fisheries and Oceans Canada (DFO). Therefore, development of methodologies to address diversity of species and aquatic environments in fishing areas across Canada requires development of a unified approach within vulnerability assessments of fish and fisheries would benefit the Department in making decisions about where, when and why to invest in fisheries mitigation or adaptation options in the face of accelerating climate change.

Initiatives to build and apply integrated climate change planning tools for fisheries managers have recently emerged in both Canada and the Unites States. For example, Shackell and colleagues in Canada's Atlantic Region were funded through ACCASP to develop a vulnerability index for Atlantic species under climate change (Shackell et al. 2014; Stortini et al. 2015). Completed for the Scotian Shelf region in 2013-14, this marine species vulnerability index may be expanded to other DFO Atlantic regions. Similarly, the fisheries branch of United States National Oceanic and Atmospheric Administration (NOAA Fisheries) implemented a national climate change vulnerability assessment for commercially exploited species using a Delphic approach. In March 2014, this team completed an assessment of 79 fish species that contribute to fisheries in the north east Atlantic region of the USA (Morrison et al. 2015). A Delphic approach to risk assessment of Pacific salmon stocks to multiple stressors, including climate change, has also been undertaken in a pilot project under DFO's Wild Salmon Policy Strategy 4 implementation in Canada's Pacific Region. Last, a preliminary ranking of Pacific marine species sensitivity to climate change based on Pecl et al. (2011) was conducted for a sub-region of Pacific Region by Hunter et al. (2014). To move forward, convergence on a common methodology for planning, and later for decision-making within DFO, is warranted.

The Pacific funded ACCASP project, *Climate Change Vulnerability Assessment (CCVA) for Selected Species and Associated Capture Fisheries,* is using a step-wise protocol and related "CCVA tool" to generate vulnerability indices for use at regional and possibly national scales by DFOs fisheries management sector. Building on existing expertise, lead researchers were invited to participate in a workshop to explore the potential development of a national approach for DFO. The aim of the workshop was to advance a common vulnerability assessment framework that could be put into practice by researchers and fisheries managers across DFO regions. At the workshop, participants reviewed methodologies and provided suggestions for developing the CCVA tool.

Since this workshop occurred, the Food and Agricultural Organization of the United Nations published a report on CCVAs for the fisheries and aquaculture sector (FAO 2015). The report recognized there is an array of CCVA approaches and some confusion in terminology in the sector. Similar to the objectives of the DFO workshop, the report reviewed several assessment methodologies with global to regional scales, including the NOAA Fisheries methodology, and discussed the similarities and differences in different approaches. The report documents several conclusions reached at the DFO workshop documented here including proposing a series of key steps required to complete CCVAs that support adaptation planning. Readers are recommended to review FAO (2015) for additional details.

2.0 ACKNOWLEDGEMENTS

The project leads would like to thank all the participants in this workshop. The presentations, contributions to thoughtful discussions, and comments were highly valuable. Much of the discussion from the workshop is being applied to the Pacific Region CCVA project. The Department of Fisheries and Oceans Canada provided financial support for the workshop via the Aquatic Climate Change and Adaptation Services Program, 2014-15.

3.0 PRESENTATIONS

3.1 ASSESSING MARINE SPECIES VULNERABILITY TO PROJECTED WARMING ON THE SCOTIAN SHELF, CANADA

Nancy Shackell[1] and Christine Stortini[2]

[1]Department of Fisheries and Oceans Canada, Maritimes Region

[2]Queen's University, Kingston, ON

Shackell and colleagues in Atlantic Region were funded under ACCASP to explore vulnerability indices to climate change for commercially important species. Additive models were used to quantify the realized thermal habitat of 46 temperate marine species using over 41 years of survey data from the Northwest Atlantic region. A "realized thermal habitat index" was estimated under both short term (2030) and long term (2060) warming scenarios (Shackell et al. 2014). This study determined if realized thermal habitat would remain the same, decrease or increase over time. Shackell et al. (2014) proposed that because fisheries agencies do not plan beyond 5 years, it is reasonable to use a realized thermal habitat index in stock assessment. Fisheries management decisions would therefore be influenced by the amount of suitable thermal habitat under gradual or extreme warming situation.

The second portion of the research, led by Stortini and Shackell, was to develop a vulnerability assessment by combining additional biological attributes with the thermal habitat model outputs developed by Shackell et al. (2014).

The vulnerability assessment was based on the following relationship:

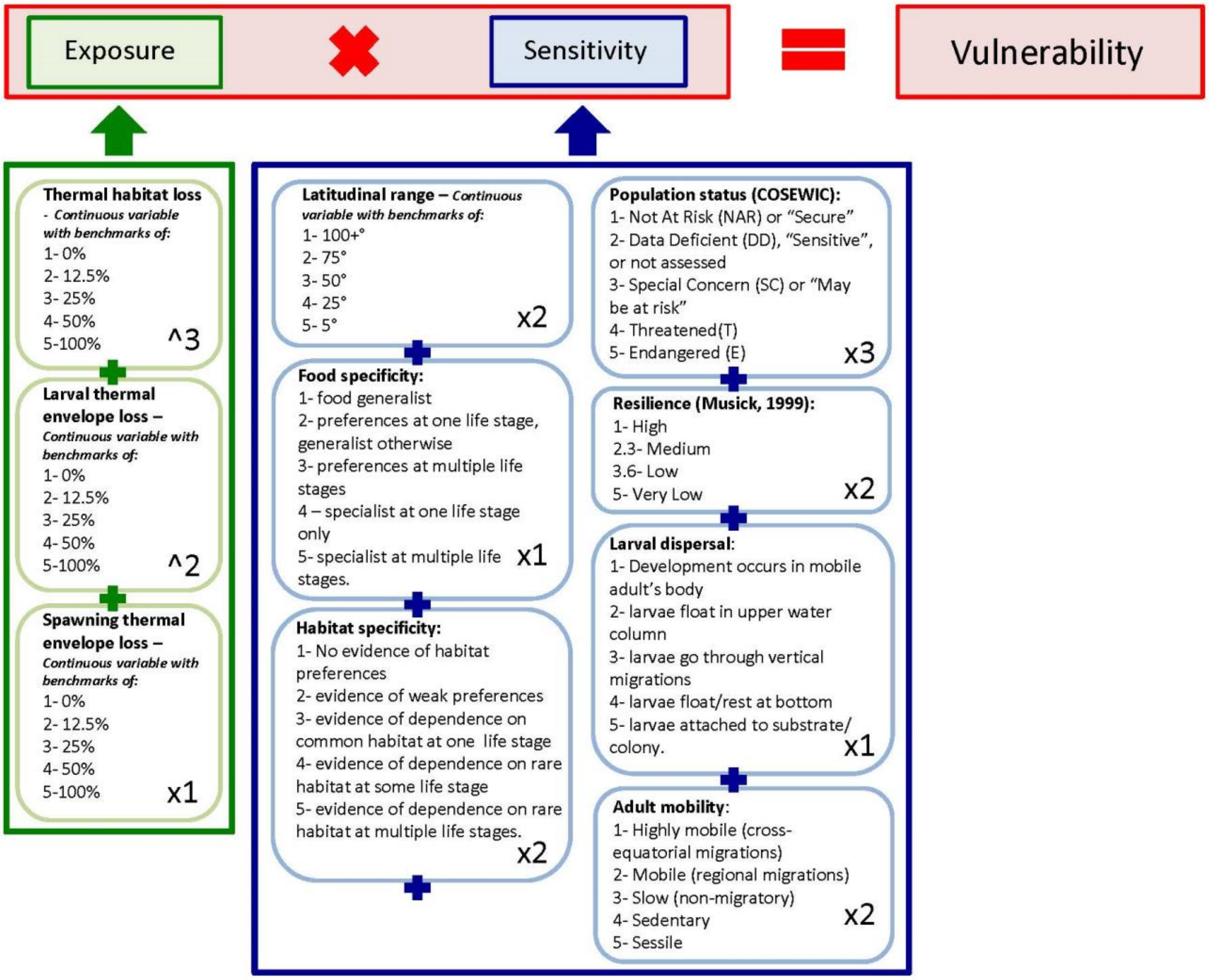

Figure 1. Vulnerability assessment framework from Stortini et al. (2015). Numbers in cells indicated weighting of the various attributes based on importance and data availability (either multiplicative or exponential; exponential weighting was used to reflect the likely sequence of events in nature: habitat is lost, then the species is forced to move, adapt, or perish). The results of this assessment provide relative ecological vulnerability scores for marine biota from Atlantic Region.

Particular to this assessment:

1) Basis was to use the index of thermal habitat change for the Scotian Shelf as a measure of exposure (Shackell et al. 2014).
2) Modeled thermal habitat change was combined with species-specific sensitivity attribute scores to determine vulnerability (Stortini et al. 2015).
3) Attributes of exposure and sensitivity were weighted based on importance as inferred from literature, and authors' confidence in the data gathered.

4) Expert opinion was not directly utilized as per NOAA Fisheries or DFO Pacific Salmon approaches. Rather, scores were assigned by a small project team using literature and with some species expert input.
5) Further analysis was performed on a small scale, assessing thermal habitat index and vulnerability of local populations on the eastern Scotian Shelf and western Scotian Shelf separately.

Discussion notes:

1) Long term and comprehensive biological and hydrographic data are available for Atlantic region, whereas these data are limited both spatially and temporally in other regions. In this study, species-specific information was linked to properties of the aquatic environment due to extensive fisheries and hydrographic survey coverage across the Region. A generalized CCVA should not demand this level of data availability.
2) Successful completion of the project was attributable to significant levels of cooperation and participation between regional species experts and the investigators throughout the project.
3) Authors suggest that future CCVAs incorporate knowledge of species interactions to evaluate cascading impacts of climate change on commercial species.
4) Until recently, environmental information at the scale of climate change has not been incorporated into population estimates within the management of the majority of commercial species or stock assessments in this region. The results of this analysis are currently being incorporated into stock assessment for some species.
5) Sea surface temperature (SST) is used as a key parameter to assess fish stock vulnerability to climate change. Further, these researchers concluded that it may have been more appropriate to incorporate seasonal temperature variation, as the seasonal variation was larger than the inter-annual variation. Researchers also concluded that inclusion of other climate drivers (i.e., oxygen depletion, acidification, etc.) would be beneficial.
6) Although this analysis weighted species attributes based on the literature, this was the only assessment presented that chose to use weighting, and researchers note that the choice in weighting scheme was subjective.
7) It was agreed, after some discussion, that a previously included component of this CCVA, adaptive capacity, should only be included when considering the human element of climate change vulnerability (i.e. social-ecological vulnerability). Therefore, those attributes considered under the adaptive capacity component of this CCVA were moved to the sensitivity component following the workshop, before the work was submitted for publication.
8) Hydrographic and biological data availability in Atlantic Region is relatively rich, thereby limiting the potential for this CCVA tool to be applied across DFO regions and species that range from data rich to extremely data poor. However, the basis of the method is transferrable.

3.2 NOAA FISH STOCK CLIMATE CHANGE VULNERABILITY ASSESSMENT

*Mark Nelson[1], Wendy Morrison[1], Roger Griffis[2], Jennifer Howard[2], Jon Hare[3], Eric Teeters[1], Mike Alexander[4], Jamie Scott[3]

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The goal of the Fish Stock Climate Change Vulnerability Assessment was to produce a practical and efficient tool for assessing the vulnerability of a wide range of stocks to a changing climate (Morrison et al. 2015). Individual species distribution models for US fish stocks used in this assessment were developed by NOAA Fisheries over several years and relied on substantial biological and hydrologic data resources. A CCVA was required because there are over 500 species to assess. If climate change risk were to be addressed on an individual species basis, vulnerability assessments for most would not be available in a timely fashion to inform management of sustainable fisheries in the face of rapidly accelerating climate change. More information on this project is available at: http://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/documents/Fish_Stock_Climate_Vulnerability_Assessment.pdf

A species' vulnerability is based on a combination of its sensitivity and exposure. Exposure was determined by experts by assessing the overlap of the species' modeled distribution and the magnitude of the expected climate change. Exposure factors used for the first full implementation are listed in Fig. 2. Twelve sensitivity attributes characterized life history characteristics believed to be indicative of how much a species may be affected by a changing climate. Detailed factor and attribute definitions were developed to assist expert scoring procedures.

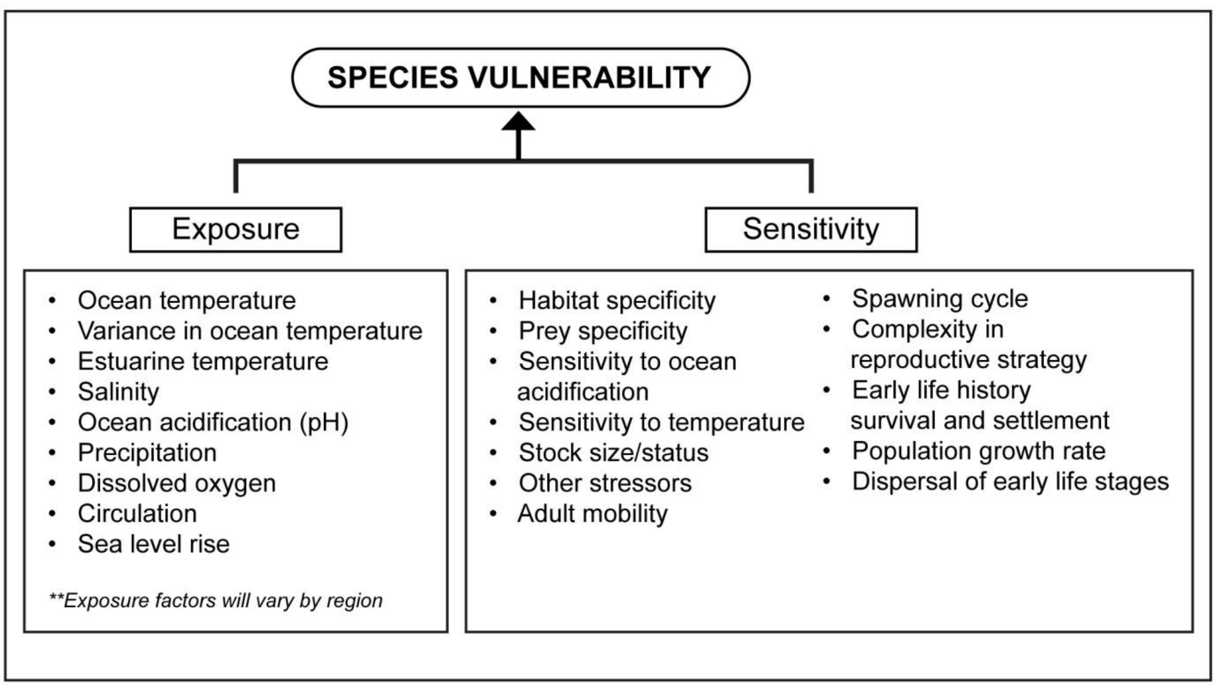

Figure 2. Exposure and sensitivity attributes applied to the NOAA Fisheries CCVA (Morrison et al. 2015).

Particular to this assessment:

1) Vulnerability is not equated to risk of extinction; it is identified as a decrease in abundance or productivity.
2) Biologically-oriented attributes were incorporated into the assessment using Williams (2011) as a guide.
3) The climate exposure used in the analysis is the overlap of the current species distribution and expected climate change (compared 2006-2055 to 1956-2005). Species distribution maps were available prior to undertaking this assessment and took considerable time and effort to produce.
4) For the assessment of sea surface temperature exposure, the standard deviation from the annual mean was used, not the seasonal mean.
5) Twelve sensitivity attributes (biological attributes indicative of a species' ability to respond to climate change) were used where each was scored as low/moderate/high/very high, and incorporated a method to assess uncertainty of each person scoring.
6) In order to be able to score uncertainty, a web enabled database was developed which took into account biases such as overconfidence and data availability.
7) This assessment relied on carefully chosen experts to score the information independently. Individual scores were assessed as a group in a subsequent workshop.
8) Responses were analysed using a logic model in order to identify what was driving vulnerability. This assessment did not use weighting.
9) The assessment has now been completed for 79 Northeast US fish stocks. A socio-economic assessment and a community vulnerability assessment now need to be undertaken to extend the assessment to fisheries associated with these stocks of fish.

Discussion notes:

1) Because a species may change distribution but the predator/prey relationship is not accounted for in this model, the ecosystem as a whole is not taken into account. This is acknowledged but is considered acceptable because there are poor data regarding ecosystem interactions.
2) Defining the 12 sensitivity attributes was the most time consuming part of the assessment, where each attribute involved a 1-3 page description.
3) It was very important to engage expert participants early on to establish trust and motivate them.
4) This approach may not be feasible where resources limitations (financial and human) hinder the ability of experts of participate. A generalized CCVA may require a mixed approach that can be adapted for regions lacking data and resources.

There was considerable discussion regarding the specifics of the analysis and how the CCVA developed in Atlantic Region could be refined to incorporate some of the strengths of the NOAA framework. In particular, it was suggested that the exposure component of the Atlantic Region CCVA could be generalized using the approach presented by NOAA, or some variation of this given region-specific environmental data availability. Further, weighting may not be appropriate given subjectivity, and a combination of literature and expert opinion may be optimal, since availability of published information varies from species to species.

3.3 RISK ASSESSMENT FOR PACIFIC SALMON

Isobel Pearsall[1], Kim Hyatt[2] and Wilf Luedke[2]

[1]Pearsall Ecological Consulting
[2]Department of Fisheries and Oceans Canada, Pacific Region

The Risk Assessment for Pacific Salmon was developed to address the integrated planning portion (Strategy 4) of DFO's Wild Salmon Policy, in accordance with DFO risk assessment guidelines, and is based on accepted methods (e.g. Forbes and Callow 2002, Hobday et al. 2007, Hobday et al. 2011, O et al. 2015).

The framework assesses current, and future, biological risks posed by various man-made and natural stressors and limiting factors on production of the salmon populations within a given salmon conservation unit (CU), including climate change (Fig. 3). The scoping and Level 1 Risk Assessment portion of this method have been applied at community-level workshops (with relevant science expertise in attendance) in several locations across British Columbia.

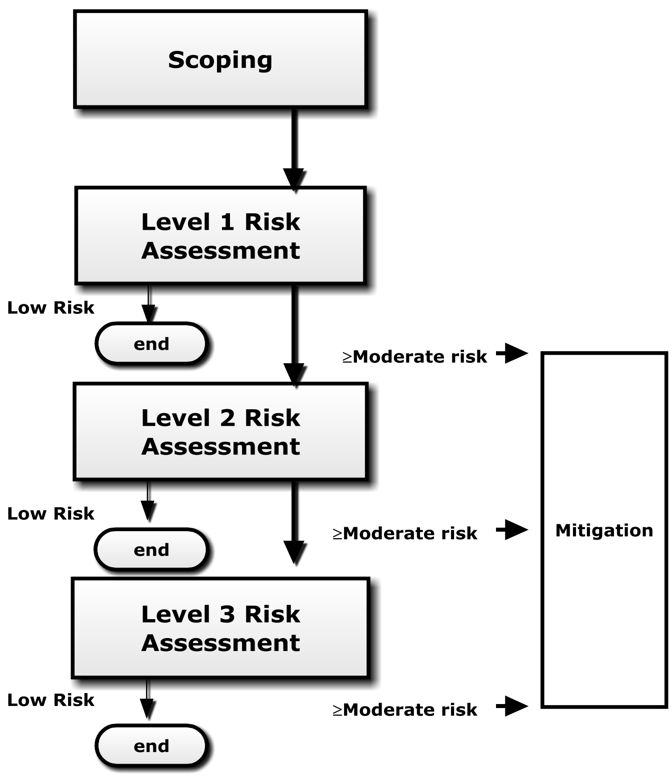

Figure 3. Risk assessment for Pacific Salmon framework from Hobday et al. (2007).

There were three steps to the assessment process:

1. Characterize the salmon population of interest and develop relevant life history tables.

2. Describe the biological characteristics and requirements of each life history stage from the literature. Utilize this information to determine the extent to which key requirements would be met given information from local and regional experts on the specific environmental context for each life stage of a particular salmon population and/or CU. Preliminary summaries were presented for review by local experts at workshops to produce limiting factors and risk rankings.
3. A generic life-history model was used in the workshop setting to help quantify limiting factor influences, including climate change, and to produce risk rankings for salmon populations and/or CUs.

Particular to this assessment:

1) Focused on Level 1 risk assessment, as per Hobday et al. (2007; 2011), to determine the factors limiting the productive capacity of Pacific salmon (sp.) in a population.
2) Risk rankings for selected wild salmon populations and CUs (Cowichan Chinook, Barkley Sockeye, Barkley Chinook salmon) were produced in consultation with a community of regional experts (principally biologists drawn from DFO) and local experts (drawn from First Nations, salmon restoration or fishing industry groups). Both types of experts provided detailed knowledge of when, where and how limiting factors might influence outcomes for the subject salmon populations within their specific environment.
3) Scoring was done twice, once with the initial summaries provided, then with the addition of information on climate change projections for the subject area and salmon population unit. Scoring was completed during a 1.5 day workshop.
4) The focus was on biological attributes of specific salmon populations principally within a freshwater context, although the Barkley Sockeye assessments also considered limiting factor interactions in both marine and freshwater ecosystems.

Discussion notes:

1) Discussion regarding spatial scale scoring descriptions and what magnitude of impact was included in the analysis.
2) The importance of preparing a short summary for management and stakeholders was discussed along the lines of the species profiles produced by NOAA Fisheries in their assessment.

The importance of accounting for bias was discussed briefly. It was noted that when biased rankings emerged as clear outliers from the distributions of rankings provided at the community meetings these were generally resolved through the presentation of additional data and discussion among the group of experts at the time.

4.0 DISCUSSION

4.1 CLIMATE CHANGE VULNERABILITY ASSESSMENT TOOL

Workshop discussions identified that a common approach for a CCVA tool would be needed for application of this type of assessment across DFO regions. Participants encouraged a more standard methodology which could be adapted to local species, divergent environmental conditions or management considerations as warranted.

A climate change vulnerability assessment tool should be able to:

- Identify the most vulnerable high value stocks/species/fisheries within a changing climate;
- Identify additional information needed to understand and address risks to these stocks/species and associated fisheries;
- Provide a basis for possible management actions to reduce vulnerability of species/stocks and associated fisheries;
- Identify where more information is needed to understand, track, and respond to fish stock vulnerability to help prioritize research, monitoring and modeling efforts;
- Provide ongoing science advice through iterative use of the Tool as climate models and projections improve and as biological changes occur;
- Incorporate an adaptive capacity component for the purpose of understanding fisheries social-ecological vulnerability.
- Be flexible enough to adapt to variation in data availability among regions (for example, measures of exposure used in Stortini et al. (2015) are not appropriate Pacific or Arctic regions because long-term, spatially broad data do not exist to evaluate changes in species thermal/climatic niches).

A climate change vulnerability assessment tool should be based on core elements, which include the framework, component definitions and assessment methodology. Data availability will determine how these core elements are used. Utility of CCVA results may be amplified when a comprehensive summary of each species' vulnerability is provided, as per Morrison et al. (2015).

4.1 CCVA FRAMEWORK

An essential element of a nationally applicable CCVA is to develop a flexible, adaptive approach with its key components defined. The framework must be relatively simple to allow for regional adaptation to area-specific vulnerabilities of fish and fisheries (i.e. unique life histories, local environments, temporal and spatial climate influences on biota, local fisheries infrastructure, community dependence, and data availability). The framework proposed below was derived from a number of CCVA studies (Williams et al. 2008; 2011; Pecl et al. 2011; Cinner et al. 2013; Morrison et al. 2015; O et al. 2015; Stortini et al. 2015), and the IPCC definition of vulnerability (IPCC 2014). Ecological and socio-ecological vulnerability related to climate change effects on marine ecosystems are key components of sustainable fisheries, and are therefore included in the CCVA tool framework (Fig. 4).

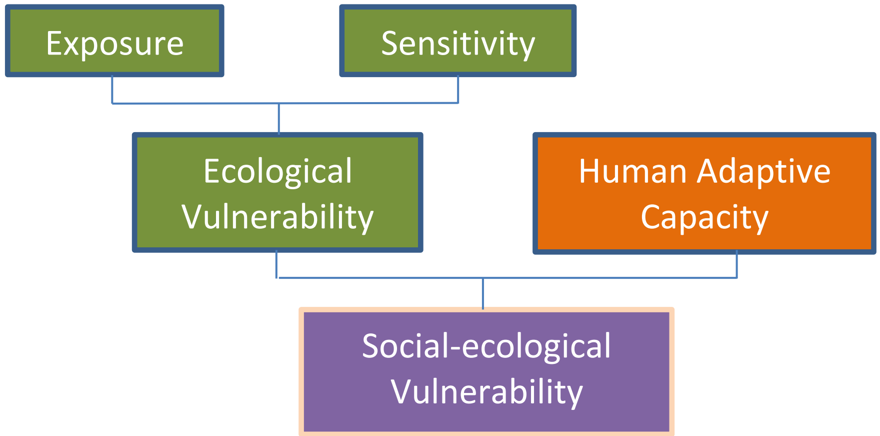

Figure 4. DFO Climate Change Vulnerability Assessment Framework for Fish and Fisheries. Attributes within each major component are developed regionally to allow for consideration of unique fisheries, environments, life histories, and temporal and spatial climate influences.

Component Definitions

Although not essential to the understanding of individual assessments, it is important if moving forward in the development of a common approach that terms are used consistently. Definitions of the framework components were derived from Williams et al. (2008, 2011) and IPCC (2014) and agreed upon by workshop participants.

Ecological vulnerability, as treated here, emerges from the interaction of two main components: exposure and sensitivity. Exposure (magnitude and duration) to altered environmental conditions is modified by the species' sensitivity to change. Several sensitivity attributes have been developed within existing methodologies, and are discussed below.

In some assessments, attributes that affect a species' capacity to adapt to changes in climate (e.g. propensity for movement at key life history stages, phenotypic plasticity) are included under the adaptive capacity component. Participants suggested attributes assessing species adaptive capacity should be considered as part of the sensitivity component because the term adaptive capacity applies to human systems attributes.

The human adaptive capacity component is presented here but is not discussed further as substantial work is required to establish relevant, science-based attributes to apply across fisheries-dependent regions. Social-ecological vulnerability depends on the relationship between ecological vulnerability and human adaptive capacity at specific spatial scales.

Key definitions therefore include:

Exposure: The extent and magnitude (absolute or relative) to which a species' or population's surroundings will be subjected to projected changes in climate drivers**.**

Sensitivity: The degree to which a species or population may be impacted, directly or indirectly, by projected changes in climate drivers.

Ecological vulnerability: The degree to which a system or species is susceptible to, or unable to cope with, effects of climate change, including variability and extremes. Vulnerability is not equated to risk of extinction, but rather is identified as a decrease in abundance or productivity.

Adaptive capacity: The ability of a human system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences of ecological vulnerability.

Social-ecological vulnerability: A function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

4.2 CCVA METHODOLOGY

The literature related to climate change risk and vulnerability assessment included for consideration by this workshop revealed a continuous evolution of methodologies. The review completed by FAO (2015) includes some additional examples for the fisheries and aquaculture sector that demonstrates the same. Generally, there are two major assessment routes: 1) data intensive/modelling approaches; and 2) processes to amass expert judgment. While there is commonality across many CCVA methodologies, we found important differences can emerge in terminology, data availability at spatial scales suitable for an assessment, and the degree to which an assessment relies on various forms of expert judgment (i.e. purely Delphic or 1-2 "decision-makers"), and mathematical aspects of attribute scoring such as whether to add or multiply scores to achieve a final score. Perhaps most importantly, different methodological approaches require different investments in time, and human and financial resources.

Three advanced CCVA methodologies were presented at the workshop to determine the importance of similarities and differences among them. It emerged that there are several common aspects of vulnerability indices developed and applied to date. These included the general framework, components and several different attributes. Differences among the methodologies were more informative and helped to tease out the best features of each assessment type. It was agreed that the development of the exposure component, scoring and weighting of attributes, and treatment of uncertainty are all important components of a CCVA.

The concept of combining both data intensive and expert judgment approaches was identified but not pursued at length. However, others are recommending a combined approach (Boldt et al. 2014).

Assessment Procedure

To achieve a defensible CCVA outcome, it was concluded that three assessment phases are needed: scoping, analysis including uncertainty and data quality assessments, and outputs.

Scoping

There was concurrence that there was no right or wrong way to conduct a CCVA. Rather it was deemed most important to use available data appropriately, and determine the best type assessment for the situation.

The first steps are to define the geographical area to be assessed and identify climate models and scenarios that will inform the CCVA. To maintain consistency across regions regarding exposure of areas to future climate change, it was recommended to use the “ensemble” climate predictions that represent essentially a median of 16 major global circulation models (GCMs), unless it is clear that one model works particularly well in an assessment area. It was suggested to use the medium (A1B) greenhouse gas emissions scenario wherever such scenarios are applied.

The scoping phase also defines the method to be used, for example, whether to use expert opinion and when. The importance of engaging the experts (if using them) early on to establish trust, and to motivate them, was emphasized. Engagement of experts, regardless of the method undertaken has the potential to accelerate the completion of wide ranging risk assessments. However, there are some limitations to relying on expert opinion, including but not exclusive to: no access or limited access to experts; varied support by managers to ensure expert participation; not all experts are equal; and nationally, some areas are highly limited in data and personnel. The choice of whether to include expert opinion in a CCVA, in large part, and outside of data limitations, depends on time, and financial and human resources available.

During scoping, documenting all decisions and assumptions which are made was described as essential. For example, in NOAA Fisheries experience, a vulnerability assessment was required because there were over 500 species in need of assessment. Addressing each species individually would require inordinate resources. The compromise involved aggregating species by major characteristics and then assessing multiple species in groups. Decisions taken on which species belonged to which group and any assumptions were well documented for transparency. It must be made clear whether scoring of attributes will include weighting, and by what factor. Documentation of these decisions is critical to justifying the assessment methodology.

Different strengths and weaknesses of the two main approaches were discussed. When choosing an approach, the potential consequences (i.e. expectations, outcomes, shortcomings) should be discussed with fisheries management a priori. The inclusion of managers in the scoping phase was stressed by the participants as in their experience, buy-in from managers was essential for encouraging participation by other researchers.

Analysis

Attributes have been developed for a number of existing assessments (Pecl et al. 2011; Morrison et al. 2015; Stortini et al. 2015), along with a list of sensitivity attributes with accompanying definitions. The list of attribute definitions was recommended as a good starting place for developing a CCVA, particularly because decision-rules associated with the scoring of each attribute is well described. Recognizing that there are data gaps for many species, the methodology must be clear about which sensitivity attributes require data in order to be included in the index score. Exposure attributes seemed most dependent on available data and/or the support of experts to interpret information. This component is therefore unlikely to be applied consistently across regions.

Workshop participants discussed the option to recommend set attributes associated with the framework. The subsequent conclusion was not to assign specific attributes but to allow regional assessments to guide the development of their own attributes. Differences in data availability of the exposure component restrict the application of a standard methodology across DFO regions.

The downside to this approach is that results from different regional assessments may not be directly comparable.

There are important differences in the quality and quantity of species-specific and environmental data available in marine and freshwater zones on Canadian Atlantic, Arctic and Pacific coasts. To maintain an effort to apply a similar assessment across regions and manage data discrepancies it was suggested to first apply a CCVA to those species and locations for which the data are rich. Second, these “highest quality” data sources could be “degraded” to mimic other “lower quality” species or areas to determine what effect quality has on the overall result. This approach would assist decision-making regarding the applicability of an assessment method, as well as the interpretation of results in data poor situations.

An important difference among the assessments presented was weighting of attributes. Weighting results in attribute scores with greater influence on the overall vulnerability score. Where weighting is applied, the ability to observe which attribute(s) drive vulnerability scores is hindered. It was recommended that decisions be documented and clear justification be provided where attribute weighting is included in a CCVA scoring procedure.

Uncertainty and Data Quality

Uncertainty associated with scores must be captured at each level of scoring to provide transparency within the CCVA decision-making process. NOAA Fisheries provided a good model to capture uncertainty where individuals are providing attribute scores using literature sources, expert opinion, or a combination of both. In the NOAA model, attributes are scored by assigning 5 tallies to 4 scoring bins (Table 1). This gives the individual completing the assessment an ability to express uncertainty in the index score based on the quality of available information (Table 2).Paragraph on limitations of the methods

Table 1. Example of an uncertainty matrix after Morrison et al. (2015).

Low uncertainty (all tallies in one bin)			
Low	Moderate	High	Very High
	5		
Moderate uncertainty (tallies split among some bins)			
Low	Moderate	High	Very High
		3	2
High uncertainty (tallies split among many bins)			
Low	Moderate	High	Very High
1	1	2	1

Data quality is different than uncertainty; however, they can be related, especially in data poor situations. It was recommended that confidence in index scores should be documented by using an accepted data quality matrix (e.g. Table 2). A data quality score captures the quantity and consistency of information across literature sources used for scoring and should be taken into account when interpreting outputs.

Table 2. Example of a data quality evaluation template after Nelson et al. in prep.

Data Quality Score	Description
3	**Adequate Data.** The score is based on data which have been observed, modeled or empirically measured for the species in question and comes from a reputable source.
2	**Limited Data.** The score is based on data which has a higher degree of uncertainty. The data used to score the attribute may be based on related or similar species, come from outside the study area, or the reliability of the source may be limited.
1	**Expert Judgment.** The attribute score reflects the expert judgment of a reviewer and is based on their general knowledge of the species, or other related species, and their relative role in the ecosystem.
0	**No Data.** No information to base an attribute score on. Very little is known about the species or related species and there is no basis for forming an expert opinion (use judiciously).

Outputs

It was agreed that scientific outputs from CCVAs or other risk assessments are not always readily accessible to fisheries managers. In order for a CCVA to be meaningful, it was highly recommended, in addition to publishing in primary literature, to provide a succinct summary or report to managers, in a format that can be understood and utilized easily.

NOAA Fisheries devised a document to summarize key information and results of the Fish Stock Climate Change Vulnerability Assessment. This approach was taken up by workshop participants as an efficient way to communicate project outcomes to key individuals. It was suggested that summaries be tailored to individual species, stocks, species groups, or fisheries, as appropriate to the assessment noting all significant outcomes.

Climate change impacts are not just a management concern for the distant future. The expectation is for extreme events to occur over the short term with important consequences for fisheries management. It was strongly recommended for summary documents to highlight impacts that are expected in 10, 20, 30 years or more, that would be experienced when contemporary conditions in aquatic environments exceed the normal range of variability.

It was recognized that these types of assessments are one way of approaching very complex problems to assist with identifying risk and prioritizing action. Outputs generally produce a risk ranking and list potential threats for species associated with climate change. The results should be understood within context of the assessment and not reach outside the intended scope of the CCVA.

5.0 CONCLUSIONS

Vulnerability is complex and can be assessed using a variety of approaches. We discussed several approaches developed in the North American context that aim to provide multi-dimensional assessment of vulnerability of fish species to climate change. The results of these assessments apply to the geographic location and cannot be applied elsewhere. Rankings and scoring are expert-dependent and may vary depending on participation which can affect confidence in the results. Uncertainty is also impacted by issues of data quality and quantity over space and time. However, these weaknesses should not preclude the utility of the information compiled and assessed by a CCVA as long as good practices are implemented in the methodology (FAO 2015). It was acknowledged that CCVAs should go further to address social-ecological elements of vulnerability.

It was concluded that there are significant limitations or impediments to a successful assessment. These include data, time, and human and financial resources limitations. In order to mitigate some of these limitations and address methodological issues that affect all DFO regions, this workshop developed a standardized national Climate Change Vulnerability Assessment Framework. This framework could be subsequently adapted and applied to assess climate vulnerability of species supporting a diversity of commercial fisheries in other regions of Canada.

It is proposed that, going forward, the Climate Change Vulnerability Assessment Tool take into account the following conclusions:

- Determine the scoring process with emphasis on uncertainty and reducing subjectivity;
- Identify refinements to components and attributes to suit DFO purposes (regional);
- Continue conversations among DFO-Atlantic, DFO-Pacific and NOAA Fisheries CCVA experts to complement and refine ongoing efforts to assess vulnerability of commercially important aquatic taxa to climate change impacts.
- Acknowledge the importance of receiving support from management.
- DFO-Atlantic, DFO-Pacific and NOAA Fisheries partners are willing to continue collaborating by way of sharing methodologies and outcomes of assessment processes completed to date.

6.0 REFERENCES

Boldt, J.L., Martone, R., Samhouri, J., Perry, R.I., Itoh, S., Chung, I.K., Takahashi, M., and Yoshie, N. 2014. Developing ecosystem indicators for responses to multiple stressors. Oceanography 27(4):116–133, http://dx.doi.org/10.5670/oceanog.2014.91.

Campbell, I., Durant, D., Hunter, K.L., and Hyatt, K.D. 2014. Food Production; *in* Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, edited by F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.

Cinner, J.E., Huchery, C., Darling, E.S., Humphries, A.T., Graham, N.A.J., Hicks, C.C., Marshall, N., and McClanahan, T.R. 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PLoS ONE 8(9): e74321. DOI:10.1371/journal.pone. 0074321.

FAO. 2015. Assessing climate change vulnerability in fisheries and aquaculture: Available methodologies and their relevance for the sector, by Cecile Brugère and Cassandra De Young. FAO Fisheries and Aquaculture Technical Paper No. 597. Rome, Italy.

Forbes, V.E., and Callow, P. 2002. Population growth rate as a basis for ecological risk assessment of toxic chemicals. Philosophical Transactions of the Royal Society, London, B: Biological Sciences 357: 1299-1306.

Hobday, A.J., Smith, A.D., Stobtzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S., and Zhou, S. 2011. Ecological risk assessment for the effects of fishing. Fisheries Research 108:372-384.

Hobday, A.J., Smith, A., Webb, H., Daley, R., Wayte, S., Bulman, C., Dowdney, J., Williams, A., Sporcic, M., Dambacher, J., Fuller, M., and Walker, T. 2007. Ecological risk assessment for the effects of fishing: Methodology. Australian Fisheries Management Authority, Canberra. No. R04/1072.

Holt, K.R., Ackerman, B., Flemming, R., Forrest, R.E., Kronlund, A.R., Lacko, L., Olsen, N., Rutherford, K., Stanley, R.D., Taylor, N.G., and Workman, G. 2012. Ecological risk assessment for the effects of fishing: A pilot study for British Columbia groundfish fisheries. Can. Tech. Rep. Fish. Aquat. Sci. 2990.

Hunter, K. L., Gillespie, K.M., Brydges, T. M., and Irvine, J. R. 2014. Preliminary assessment of the sensitivity of West Coast Vancouver Island marine species to climate change. Can. Manuscr. Rep. Fish. Aquat. Sci. 3036: xi + 87 p.

IPCC. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132 pp.

Morrison, W.E., Nelson, M.W., Howard, J.F., Teeters, E.J., Hare, J.A., Griffis, R.B., Scott, J.D., and Alexander, M.A. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-3, 48 p.

O, M., Martone, R., Hannah, L., Greig, L., Boutillier, J., and Patton, S. 2015. An Ecological Risk Assessment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/072.vii + 59 p.

Pecl, G.T., Ward, T., Doubleday, Z., Clarke, C., Day, J., Dixon, C., Frusher, S., Gibbs, P., Hobday, A., Hutchinson, N., Jennings, S., Jones, K., Li, X., Spooner, D., and Stoklosa, R. 2011. Risk assessment of impacts of climate change for key marine species in south eastern Australia. Part 1: Fisheries and Aquaculture Risk Assessment. Fisheries Research and Development Corporation, Project 2009/070.

Shackell, N.L., Ricard, D., and Stortini, C. 2014. Thermal habitat index of many northwest Atlantic temperate species stays neutral under warming projected for 2030 but changes radically by 2060. PLOS ONE 9: e90662

Stortini, C.H., Shackell, N.L., Tyedmers, P., and Beazley, K. 2015. Assessing marine species vulnerability to projected warming on the Scotian Shelf, Canada. ICES Journal of Marine Science 72: 1731-1743.

Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffman, A.A., Langham, G. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. Plos Biol. 12:e325. DOI: 10.1371/journal.pbio.0060325

Williams, A., Dowdney, J., Smith, A.D.M., Hobday, A.J., and Fuller, M. 2011. Evaluating impacts of fishing on benthic habitats: A risk assessment framework applied to Australian fisheries. Fisheries Research 112:154-167.

7.0 APPENDICES

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7.2 ACRONYMS

Acronym	Description
ACCASP	Aquatic Climate Change Adaptation Services Program
CCVA	Climate Change Vulnerability Assessment
CU	Conservation Unit
DFO	Department of Fisheries and Oceans Canada
GCM	Global Circulation Models
IPCC	International Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration