

Communicating Climate Vulnerability Assessments: Role of Expert Knowledge and
Applications to Fisheries Management

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Abstract

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Climate change poses a serious threat to marine organisms around the globe. Global ocean conditions are expected to change over the coming decades, putting fish and shellfish populations potentially at risk. Climate vulnerability assessments (CVAs) are an emerging tool to assess the vulnerability of fish and shellfish species to changes in climate. In 2015, the U.S. National Oceanic and Atmospheric Administration developed a standardized methodology for conducting CVAs. The methodology, published by Morrison et al. (2015), includes an expert elicitation process to score a species' sensitivity attributes and exposure factors, the two component parts that determine overall vulnerability. I aimed to better understand how experts were selected/what roles they played in these CVAs, how CVAs are used in management, and how the results are communicated once completed. To address the objectives, a literature review of existing CVAs that focused on fisheries and had used an expert elicitation process was completed and semi-structured interviews with CVA authors were conducted to fill in information gaps. Practitioners and developers of climate vulnerability assessments were asked questions about both the expert elicitation process and the application of climate vulnerability

assessments as a tool for management of marine species. I found that experts were primarily chosen based on species specific knowledge. The intended purpose of informing management was fulfilled in a handful of ways. Communication of results was varied and dependent upon the authors who completed the studies. More detailed and explicit methods and selection criteria will improve the trust, replicability, and utility of the CVAs. These CVAs are being used to inform management decisions, including supporting species listings on the U.S. Endangered Species Act; however, dedicated support for communicating CVA results may improve the utility of these assessments for decision-makers.

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Abstract

Climate change poses a serious threat to marine organisms around the globe. Global ocean conditions are expected to change over the coming decades, putting fish and shellfish populations potentially at risk. Climate vulnerability assessments (CVAs) are an emerging tool to assess the vulnerability of fish and shellfish species to changes in climate. In 2015, the U.S. National Oceanic and Atmospheric Administration developed a standardized methodology for conducting CVAs. The methodology, published by Morrison et al. (2015), includes an expert elicitation process to score a species' sensitivity attributes and exposure factors, the two component parts that determine overall vulnerability. I aimed to better understand how experts were selected/what roles they played in these CVAs, how CVAs are used in management, and how the results are communicated once completed. To address the objectives, a literature review of existing CVAs that focused on fisheries and had used an expert elicitation process was completed and semi-structured interviews with CVA authors were conducted to fill in information gaps. Practitioners and developers of climate vulnerability assessments were asked questions about both the expert elicitation process and the application of climate vulnerability assessments as a tool for management of marine species. I found that experts were primarily chosen based on species specific knowledge. The intended purpose of informing management was fulfilled in a handful of ways. Communication of results was varied and dependent upon the authors who completed the studies. More detailed and explicit methods and selection criteria will improve the trust, replicability, and utility of the CVAs. These CVAs are being used to inform management decisions, including supporting species listings on the U.S. Endangered Species

Act; however, dedicated support for communicating CVA results may improve the utility of these assessments for decision-makers.

Introduction

Oceans provide many ecosystem services globally, including food, carbon sequestration, fuel/energy sources, and cultural services (Arkema et al., 2015; Sanchirico & Mumby, 2009), that are threatened by climate change. Climate change poses serious risk to ecosystems and species around the world (NRC, 2010). Processes such as ocean acidification, ocean warming, and deoxygenation are often nested and exist within feedback loops that further contribute to their progression (Bijma et al., 2013; NRC, 2010). The impacts of climate change on marine species are well documented in the literature (Bijma et al., 2013; Hastings et al., 2020; Wang, 2022; Zunino et al., 2021). Changing ocean temperatures have led to range shifts and shrinking ranges for a variety of species (Hastings et al., 2020; Hattab et al., 2014; Mahanes & Sorte, 2019). Ocean acidification has impacted the size and physiological function of various species, including those that form essential habitats (Han et al., 2021; Sommer et al., 2015; Zunino et al., 2021). Deoxygenation of ocean waters causes dead zones and mass mortalities in concentrated areas (Diaz & Rosenberg, 2008; Watson et al., 2017).

These climate stressors impact commercial fisheries across the globe (Pentz & Klenk, 2017; Sumby et al., 2021). Management of commercial fisheries depends on knowledge about fish stocks, their dynamics, and future stock biomass projections (Pentz & Klenk, 2017; Sumby et al., 2021). This is made difficult with increasing frequency of climate shocks, such as marine heatwaves, and regime shifts (e.g., Hauri et al., 2024). Additionally, coastal communities that

rely on the ocean for sustenance, economic stability, and cultural practices are vulnerable to direct effects (e.g., sea level rise, increased storm frequency) and indirect effects (e.g., impacts on tourism, loss of culturally important species, loss of fishing) of climate change (Cinner et al., 2012; Ivanova Boncheva & Hernández-Morales, 2022).

As the threats climate change poses to both the environment and to people become more pressing, natural resource managers need strategies to consider and plan for climate impacts. Climate vulnerability assessments (CVAs) are an emerging tool being used to assess the risks of climate change for marine species and coastal communities (Hare et al., 2016; Spencer et al., 2019). The National Oceanic and Atmospheric Administration (NOAA) developed a climate science strategy in 2015 that identified conducting climate vulnerability analyses in each region as an immediate action (Link et al., 2015). CVAs are a structured approach to evaluating the relative vulnerability of harvested species to climate change and may be used to help inform management decisions, therefore contributing to meeting NOAA's climate goals.

Vulnerability assessments typically consist of two main components: sensitivity and exposure (Cheung et al., 2022; Hare et al., 2016; Spencer et al., 2019). Sensitivity is defined as a species' resilience to change, measured using several attributes that vary across studies (Hare et al., 2016; Morrison et al., 2015; Spencer et al., 2019). Sensitivity attributes can include both ecological and biological variables, such as prey specificity, population growth rate, and adult mobility (Hare et al., 2016). Exposure is defined by environmental factors that are expected to change given climate projections (Hare et al., 2016; Morrison et al., 2015; Spencer et al., 2019). Sensitivity and exposure vary among regions and life histories of the species being assessed (Cheung et al., 2022; Crozier et al., 2019). For example, "other stressors" is listed as a sensitivity attribute, which includes things such as habitat degradation and pollution that may vary between

regions. An additional component factored in for some CVAs is the adaptive capacity of the species being assessed, which is most often included within the sensitivity scoring by using sensitivity attributes that indicate a strong potential to adjust to environmental changes (Crozier et al., 2019). The characterization of adaptive capacity can be vague within the literature and difficult to assess broadly, however is generally considered to be the ability of a species to respond to environmental stressors and changing conditions (Crozier et al., 2019; Bueno-Pardo et al., 2021). Vulnerability of a species is therefore determined by the overall exposure of the species to climate variables, the general sensitivity of the species, and the ability of the species to adapt and respond to changing climate conditions.

A key component of vulnerability assessments is the reliance on expert elicitation for scoring of the species being assessed, particularly with respect to species' sensitivity (Hare et al., 2016; Spencer et al., 2019). Specifically, expert elicitation is often used to find people with specific knowledge who can provide direct insight about the study subjects, in this case different fish species. Experts are typically affiliated with government and academic institutions, and have expertise in the fields of ecology, oceanography, and fisheries (Hare et al., 2016; Spencer et al., 2019). However, many published vulnerability assessments lack a detailed description of how expertise is defined and by whom, how experts are identified and recruited, and what perspectives are represented. Because expertise is defined within social and cultural contexts (e.g., Hitomi and Loring, 2018), transparency regarding the expert elicitation process is important for identifying potential gaps in knowledge and perspectives that are included in CVAs and for improving reproducibility of methods used to assess fishery vulnerability to climate change. This study aimed to assess how CVAs in the past decade have described the expert elicitation process and what kinds of perspectives were represented across assessments.

Vulnerability assessments are designed as a qualitative tool to help inform resource management decisions (Comte, 2021); however, it is unclear to what extent these assessments are being applied in decision-making. Additionally, the accuracy and utility of vulnerability assessments may be eroded by unexpected climate events, such as marine heatwaves (P. Spencer, personal communication). As new CVAs continue to be developed, there is value in reviewing existing CVAs to understand the strengths and challenges of the approach, and how they are being used to address climate change impacts on marine fisheries. The objectives of this research are to (1) review the ways in which the expert elicitation process has been implemented within the CVA framework; (2) document practitioner perspectives on how vulnerability assessments are used and applied in management settings; (3) and understand how vulnerability assessments are communicated with audiences.

Methods

To address my objectives, I first reviewed published CVAs to synthesize their stated goals and methods, including the extent to which studies varied in how they applied a common CVA framework developed by Morrison et al. (2015). I then interviewed authors of a subset of these publications to better understand practitioner perspectives on the CVA process and its application to fisheries science and decision-making.

Overview of the CVA standard methodology

All of the CVAs reviewed in this study applied a standard methodology developed for marine fisheries by Morrison and coauthors (2015) for the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration. Foundational studies such as Chin et al

(2010) and Pecl et al (2014) laid the groundwork for assessing the vulnerability of marine species to climate change. Morrison et al (2015) drew heavily upon both papers to create a standardized methodology to assess the vulnerability of marine fish and shellfish stocks. Vulnerability is used to describe “a reduction in species’ productivity and or abundance associated with a changing climate, and includes both climate change and multidecadal climate variability” (Morrison et al., 2015, p. 1). Vulnerability is measured as a product of exposure and sensitivity. Exposure refers to the geographic distribution of a species and the overlap of that range with changing ocean-climate conditions (e.g., salinity, sea surface temperature, pH). Morrison et al. (2015, p. 4) describe sensitivity as “based on the current biological attributes that are indicative of a species’ ability/inability to respond to potential environmental changes” (e.g., habitat specificity or population growth rate).

The methodology described by Morrison et al. (2015) relies on expert elicitation to score the species based on each exposure factor and sensitivity attribute. Using expert opinion in combination with the published literature allows for scoring of both data-rich and data-poor species. Drawing from the EPA report on relative vulnerability of endangered species to climate change, “a good expert has technical knowledge of the subject, the ability to extrapolate information to new situations, and the capacity to clearly articulate the reasoning behind their decisions” (EPA, 2009). Experts are asked to score species’ sensitivity, exposure, or both. Scoring involves distributing tallies into different scoring bins (low, moderate, high, and very high). First they give scores individually, and then they are asked to score again in a group setting. The entire expert scoring process is created to minimize the potential biases. Uncertainty in expert scoring of exposure, sensitivity, and direction of effect is accounted for through a tally method of ranking. Experts who are sure of a score can place all five tallies in the bin they chose,

while those who are less certain can spread their tallies accordingly across the four bins. Additionally, the quality of the data used to score species is factored into the certainty around overall vulnerability rank. Morrison et al. (2015) emphasized the importance of communication and outreach in helping to create a useful product. The authors recommended using a vulnerability matrix with exposure scores and sensitivity scores multiplied to give overall vulnerability rank to easily display the vulnerability across all species in the assessment.

Review of published CVAs

To address the first objective, I used two databases (Web of Science, Google Scholar; searched April 2023) to identify all papers that cited Morrison et al. (2015). Additionally, two papers were found using NOAA's interactive web tool showing vulnerability assessments within the United States (NOAA, 2023). A total of 41 results were returned. Of these 41, only those meeting the following criteria were included in the review: (1) focused on marine and freshwater fisheries, and (2) included an expert elicitation process for sensitivity and/or exposure scoring. I chose these criteria to include only those CVAs that were focused on fisheries and to ensure that I would be able to study the expert elicitation process, as some CVAs do not use expert scoring. From the 41 results, 9 papers met all the requirements to be included in the study (Table 1); these papers are briefly summarized in the Results. Each paper was reviewed to document the sensitivity and exposure traits measured and attributes of the expert elicitation process, including the selection of experts and how scoring was done. For each paper, I also summarized the intended audience and purpose of the CVA, if stated.

Interviews with CVA authors

Published CVAs included relatively limited detail regarding expert elicitation methods and application of the CVA in a management context. To address these gaps, I conducted semi-structured interviews with researchers and agency officials who were listed as authors on the climate vulnerability assessments included in the literature review. An interview guide was developed with sections focused on background and experience with CVAs, methodology and implementation, communications and outcomes, and demographic information (Appendix A). Background and experience questions aimed to understand what kinds of organizations the participants work for and their specific roles in the CVAs. Methodology and implementation questions aimed to better understand the expert elicitation process and the role it played in the CVA. The communication and outcomes questions were intended to understand how CVAs are being communicated and subsequently utilized as tools for fisheries management.

Prospective interviewees included all authors of the 9 published CVAs that were reviewed. I initially contacted lead authors and followed up with additional coauthors as needed. Authors were contacted by email with a description of the study and an informed consent form. Additional contacts were identified through snowball sampling, where interviewees suggested potential participants with relevant experience and knowledge (Bernard, 2018). The research protocol and interview guide were reviewed and approved by the University of Washington Human Subjects Division (exempt protocol #00019013). Participants were informed about the goals of the study and procedures for ensuring interviewee confidentiality and provided an opportunity to ask questions before the interview. Interviews were audio recorded with permission of participants. Audio recordings were auto transcribed using a secure online program (Otter.ai), and transcriptions were manually reviewed and corrected for errors.

Thematic analysis of interviews

A thematic analysis of the interviews was conducted to draw out and organize common themes related to expert elicitation methods and CVA applications. I coded interviews using Atlas.ti software. The codebook was developed collaboratively with my advisor using primarily deductive methods (Creswell and Creswell, 2018) to link codes to specific research questions regarding the participant's background, the expert elicitation process within the CVA, and the purpose and communication of the CVA. While the main codes were linked to the research questions, sub-codes were used to reflect themes within answers to the initial interview questions. Sub-codes were developed inductively throughout the process to reflect commonalities across interviews.

Results

Summary of reviewed CVAs

The nine CVAs reviewed in this study cover a broad range of marine areas including regions along the coasts of the United States and Canada, South America, Europe, and Western Africa (Table 1). Fisheries in the geographic ranges of the studies are managed under national level fisheries management organizations, with the U.S. and Canada having regional management structures under the federal level. The CVAs that cover multiple species were often broken into different functional groups, such as pelagic fish, benthic fish, invertebrates, and elasmobranchs. The CVAs show that in general there are many species with moderate to high vulnerability across the studies, with only two studies showing lower levels of overall vulnerability. The CVAs showed that the factors driving vulnerability differ among geographic regions and functional groups, with little to no clear pattern across assessments. Some prominent

driving factors of exposure are ocean acidification and sea surface temperature, while drivers of sensitivity include habitat specificity, adaptive capacity, and adult mobility. Climate change is expected to shift species distribution ranges across multiple geographic areas.

Summary of interview participants

A total of 9 interviews were conducted with authors of CVAs or with those involved in the development of the methodology published by Morrison et al. (2015). Eight of the nine participants identified as white, and one as another race. Seven participants identified as male, and two as female. Seven participants were employed with government agencies at the time their CVA was conducted, the remaining two were employed at academic institutions. Of the interviewees, seven were from the United States, one was from Europe, and one was from South America. The interviewees ranged in age from thirty-two to sixty-three years old.

The practitioners interviewed represented a primarily U.S. perspective. Since the majority of the interviewees were from the United States, the institutional background was governmental organizations under NOAA. The two interviewees from South America and Europe were conducting these CVAs at academic institutions.

Objective 1. Expert elicitation in CVAs

An important element of CVAs is expert scoring of species. Based on the review of published studies, experts were typically asked to score species according to their sensitivity to biological attributes as well as their exposure to environmental conditions. In all except one of the CVAs, experts were instructed to score the species individually first and then score a second time in a group scoring round. Answers could be changed between the two rounds, and a

consensus on the scores was not required. Expert scoring of sensitivity and exposure factors varied across studies (Table 2). Only two CVAs used different groups of experts to score sensitivity and exposure. These studies used a smaller subset of climate experts to score exposure factors.

The review of published CVAs revealed that experts were selected for attributes such as their academic degree (primarily PhD), taxonomic expertise, and organization type (government and academic). Based on the written methods, experts were chosen primarily for their knowledge of particular species, with a total of 6 studies choosing experts based on this criterion. Interviews with study authors confirmed this; interviewees largely described their approach as seeking experts with species-specific knowledge, as well as a broader ecosystem understanding so they were able to score multiple groups. One author from the United States explained their process, saying, “It’s sort of like there’s a sweet spot between a generalist and a specialist. We learned to avoid the person that knows one species really, really well and doesn’t care about anything else. That is less useful for our format because we needed people to not just score one species, we needed people to score a whole group of species” (Interview 08).

Some authors I interviewed noted that willingness to work collaboratively was another important consideration for identifying experts. CVAs require periodic commitment over an extended time frame and experts must be willing to score species in a group setting. Interviewees described the effort required to find people who are willing to work in this setting and potentially travel to work on the CVA. An author explained that “perhaps the most important thing is [that experts] had a good will to collaborate in this kind of process that took a lot of time and also, sometimes a lot of effort” (Interview 06). Additionally, trust and buying into the process is an important factor to consider when choosing experts. One interviewee said “I think we had a lot

of a lot of people in our study...kind of skeptical at first about whether this can be useful or not. I heard a lot of complaints and comments very directly about the utility of this... but those people kind of came around, I mean, some of the people when it was all said and done, they thought it was a worthwhile exercise, so I think there was at least some mindset change about it” (Interview 01). A different interviewee noted that proximity to the host office was a benefit they considered when choosing experts. Some species in the CVAs were considered data limited, so including experts with general knowledge of marine ecology and biology was considered beneficial by authors.

There was no direct mention of potential knowledge gaps among experts within any of the published papers. However, during interviews, authors identified gaps in the types of expertise included in the CVAs. One practitioner noted a lack of organizational diversity in experts, with a primary focus on government and intra-institutional recruiting. Many CVAs covered a large geographic extent, but some authors explained that finding experts who encompassed the entirety of the CVA range who were also willing and able to participate in the CVA was a challenge. A lack of geographic diversity among experts was noted by two out of nine interviewees. Multiple authors identified a lack of local and traditional ecological knowledge as a gap, some noting that at the time the methodology was being created, there was not as strong an emphasis on including local and traditional knowledge in these kinds of studies. One author noted that “with the benefit of science in hindsight, if I had to do it over again, I would work harder to get tribal involvement” (Interview 03).

Objective 2. Applications of CVAs

Within the publications, the main purposes of these CVAs are described as to help managers (broadly), to provide a broader look at vulnerability in a region, and to help prioritize future research on these species (Table 3). In a management context, the publications list CVAs as being helpful in an Ecosystem Based Fisheries Management (EBFM) context, in guiding “anticipatory and deliberate adaptive responses” for fisheries, and in helping incorporate climate change implications into harvest and allocation decisions. The main purposes of CVAs, as described by authors during the interviews, are to create “a tool to inform management”, create a broad scope overview of the species and their possible responses to climate change, and to support regional collaboration surrounding climate change. Interviewees described CVAs as a systematic approach to gaining an understanding of climate effects on marine species. Three authors mentioned using the CVA to look at broader vulnerability to climate impacts within a region or group of species. One of the authors who contributed to development of the CVA framework (Morrison et al. 2015) described the purpose of the CVA methodology as follows: “What managers needed now was...a quick glance of all the species that they were concerned about, and some sense of relative vulnerability. And with that, it might inform them about where to put some of their precious time and resources towards the ones that were most vulnerable, or at least be able to use that information, perhaps as a cautionary note in thinking about management strategies and management decisions going forward” (Interview 07).

While the intended goal of CVAs is often broadly characterized as “inform management”, this can take a wide variety of forms. Two interviewees described the use of CVAs in listing species for protection under the Endangered Species Act (ESA). Both the Northeast vulnerability assessment and the California Current vulnerability assessment were mentioned as being used to help list multiple species on the ESA (Hare et al., 2016; McClure et al., 2023). A co-developer of

the CVA methodology (Morrison et al., 2015) described CVAs as being used to inform the buffer set by fishery management councils for harvest specifications. For example, if a species is deemed to have high vulnerability, a larger buffer can be set between catch thresholds and catch limits. Both informing ESA listings and helping increase buffers around the acceptable biological catch are specific, targeted ways in which CVAs have been used in a management context.

CVAs were also identified as a tool for prioritizing research goals. A CVA provides a broad overview of the relative vulnerability of different species to climate change effects in the coming decades. Three interviewed authors noted that CVAs are a potential way to guide future research priorities in their institutions, although it is unclear if they are actually being used in this way. The information produced can be used to identify specific knowledge gaps related to highly vulnerable species or those for which limited data are available. CVAs may be used to help allocate resources for new research efforts. Both developers and authors state that they use these CVAs as a tool to understand future research needs.

Objective 3. Audience, outreach, and communication

A few interviewees noted that the information from the CVAs was not always communicated efficiently or to a broader audience beyond scientists with access to the published results. A lack of intentional and strategic communication can cause information to be “trapped” within the organization or institution that generated it. Some CVAs were communicated using media rollouts on the science centers’ websites (NOAA, 2023). Strategies of communication included engaging the regional fishery management councils with presentations about the vulnerability of stocks in their jurisdiction, interviews with newspapers or other publications

about the completion of the vulnerability assessment, and occasionally the creation of web content to share the information more broadly with the public.

Communication of the CVA was typically left for the individual authors or government science centers to handle. Some interviewees suggested that this approach leads to a lack of consistency in communication across studies. One co-developer of the CVA methodology (Morrison et al., 2015) described the communication challenge as follows: “[Communicating results] was usually left up to the regional leads, working with their folks. And sometimes those regional leads did a good job. Sometimes, that job was lacking. You know, good scientists often aren’t great communicators. Good scientists often don’t have a clue what happens at a council level, and they don’t want to know” (Interview 08).

Differing levels of capacity across the project teams can lead to variability in the timelines for publication and communication to audience members and stakeholders. One participant from the United States referenced the lack of ability to publish in a timely manner, stating: “I think they were originally called RVAs...rapid assessment or rapid vulnerability assessment. At some point in time, I realized we probably shouldn’t be calling it that...because it’s taken us years to get this done” (Interview 04).

Media strategies varied by institution type, with the CVAs produced by government institutions taking a more targeted approach to try and communicate results. All studies in the United States were undertaken by government organizations that fall under NOAA. Studies in other countries were completed by individuals primarily from academic institutions, rather than from government agencies. These CVAs completed by authors in academic institutions did not have a media rollout, or the support of a large government agency to help disseminate information.

Discussion

This project contributes to the understanding of expert elicitation within CVA methodology as well as application and efficacy as a tool to inform fisheries management. Overall, I found that within the expert elicitation process, experts were primarily selected based on knowledge of specific species and there was limited additional detail about criteria used in choosing experts. I also found that CVAs overall have been used in the ways they were originally intended, mostly as broad scope overviews of climate vulnerability in a region and also as tools to inform management (e.g., for ESA-listing process). Potential interviewees were limited to authors of the nine studies meeting inclusion criteria, thereby limiting the scope of information drawn from interviews. Of nine authors interviewed, the majority were from the United States, biasing these results towards U.S. institutions and applications of CVAs. Other countries have differing fishery management institutions and structures that could affect how these CVAs are used.

Expert elicitation in CVAs

In published studies, the descriptions of the expert elicitation process often included limited detail on the experts themselves, including their social identities (e.g., age, gender, race), career stages, and organizational affiliations. A lack of diversity can lead to expert panels with limited perspectives and knowledge bases. Only one of the nine studies was explicit in stating that they tried to include a diverse range of career stages and genders, which was helpful in thinking about what expertise means to the authors. The usefulness of a tool like a CVA depends upon trust in the methodology and products at the end of the study. A deep understanding of

what kind of expertise is being used is important in fostering a sense of trust in the process and its outcomes. Transparency in methodology and expert selection also ensure that there are certain standards of replicability within these studies. A systematic approach to identifying expertise and experts will allow for a stronger understanding of what is being represented in the outcomes of the study, and additionally how to replicate those outcomes in different contexts or studies (Davis and Wagner, 2003).

Expert scoring of sensitivity is a constant across studies, however, not all studies use the same experts to score exposure or even use experts to score exposure at all. It may be important to consider approaches to differentiating how various experts play a role in each step of the CVA. For instance, those with expertise in species biology may not have the same proficiency in climate modeling and prediction. Alternatively, including participants with only modeling expertise may limit inclusion of empirical knowledge.

The lack of consideration of traditional or local ecological knowledge when selecting experts constrains what “expertise” means in these studies. The Morrison et al (2015) methodology’s requirements for expertise only involve “technical knowledge” of the subject, an ability to apply knowledge to new scenarios, and an ability to justify and explain their reasonings. Recent papers have conducted climate vulnerability assessments that include experts with local “on the water” knowledge (Carroll et al., 2023). Practitioners and authors of CVAs mentioned when interviewed that they would have liked to better include Indigenous perspectives. This opens an opportunity for co-production of knowledge that broadens the diversity of expertise informing vulnerability of fisheries systems to climate change. The value of traditional and local knowledge and perspectives has been shown to be important in terrestrial and aquatic resource management (Ballard et al., 2008; Stead, Daw, and Gray, 2006).

Applications of CVAs

Vulnerability assessments have been implemented for decades to assess population, community, or ecosystem level vulnerability to different factors (such as chemical exposure; De Lange et al., 2010). The threat climate change poses to ecosystems globally is well documented at this point (NRC, 2010; Bijma et al., 2013; Hastings et al., 2020; Wang, 2022; Zunino et al., 2021). While vulnerability assessments have typically been used in the past to assess the vulnerability of marine habitats or ecosystems to oil spills or other pollution (De Lange et al., 2010; Tortell, 1992; Halpern et al., 2007), there were few studies prior to 2015 that considered climate change.

CVAs as a tool have the potential to be useful in helping inform management of fish stocks or management of marine regions in general. However, both those participating in the study and those using the outcome need to “buy into” the process and results. If participants are unsure about the usefulness of the project they are working on, this can lead to a lack of trust from the managers and scientists who will be using the information. In addition, trade-offs exist between the utility of CVAs as a snapshot of species vulnerability in a region and the time and effort required to produce these large-scale studies.

CVAs can be useful in providing an overview of climate factors driving vulnerability of species groups. As noted by interview participants, they have also been used for prioritizing future research projects, allocating research funding, and directing climate resiliency strategies. As noted in Morrison et al (2015), this methodology does not account for ecosystem level changes that could affect all species in an area. Currently, climate information is included in management tools such as ecosystem status reports, risk tables, and occasionally in stock

assessments (Dorn & Zador, 2020; Siddon, 2023). These other tools primarily look to address what a changing climate looks like in a certain area or how that might impact the ecosystem and in turn the stock. However, CVAs allow for managers to look at proposed climate impacts on the different stocks specifically. They can help account for information that may be missing from the risk tables and ecosystem status reports about how different species will be impacted in different ways. CVAs can be used in conjunction with other climate planning tools and approaches (such as EBFM plans) to maximize their utility.

Audience, outreach, and communication

Communication and outreach are necessary for CVAs to be useful as a tool to inform and guide management. Leaving communication up to those who conducted the CVAs puts the burden on people who are often tied up with other projects and ongoing work. It also leads to a lack of consistency in communication and outreach among NOAA regions (in the U.S.), the quality of which is dependent upon capacity within the organization that completed the CVA. To make this information more digestible and useful, targeting communications towards the specific audiences and end users may improve the utility of CVAs. Multiple interviewees mentioned the idea of creating a policy brief after completing a CVA. This is a good example of how providing managers and policy makers with a product they are familiar with might make outreach more successful. As stated in Morrison et al. (2015), it is important to maximize the usefulness to the end users and limit misinterpretation. A good example of a well-developed communication strategy is the NOAA CVA dashboard (<https://www.fisheries.noaa.gov/data-tools/climate-vulnerability-assessment-tool>), which compiles the results of all NOAA CVAs in one place. This tool provides menus to look up the

vulnerability of any species that has been assessed, making it easier to integrate into planning and management strategies. The website describes the tool as being useful for academia, scientists, and decision makers to find information on more than 400 species (NOAA, 2023). By tailoring communication methods to better serve non-scientists, the results will be more readily used in management and policy making decisions.

Conclusions

Climate vulnerability assessments are a useful tool. However, increasing the detail and description of the expert elicitation process will only serve to increase their utility. A detailed methods section allows for more replicability across studies and standardizes how experts are selected and therefore what kind of expertise is represented. This increase in detail will also build trust for the results produced from these assessments. Currently, CVAs are being used to inform management in a variety of ways, some of which were not necessarily the original intention. However, as some interview participants shared, CVAs become even more useful when paired with a social vulnerability assessment of people and communities. The NOAA equitable climate services action plan emphasizes the need to address climate impacts on underserved communities (NOAA, 2024), and a social vulnerability assessment can help bridge the gap between climate stressors on marine organisms and the potential impacts on communities.

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Table 1. Summary of 9 climate vulnerability assessments reviewed in this study.

Study	Region	Management authority	Focal species	Key findings
Bueno-Pardo et al. 2021	North, Central, and Southern Portugal	Directorate General of Fisheries and Aquaculture (Federal Management Structure)	74 species in twenty functional groups (e.g. pelagics, demersals, flatfishes)	Less than half of species have moderate or greater vulnerability (n=15). Adaptive capacity and overall vulnerability have a strong relationship, with low adaptive capacity leading to much higher vulnerability.
Gianelli et al. 2023	Southern Brazil, Uruguay, Northern Argentina	Transboundary management among federal agencies	28 species in four functional groups (bony fishes, chondrichthyans, mollusks, and crustaceans)	Distribution shifts are expected, with poleward shifts regardless of climate change scenario.
Giddens et al. 2022	Pacific Islands Region, United States	National Marine Fisheries Service (Western Pacific Fishery Management Council)	83 species in six functional groups (pelagics, sharks, deep slope, coastal, coral reef, and invertebrates)	Vulnerability shows a functional group dependent pattern, with large pelagics being less vulnerable and small and or sessile organisms being more vulnerable.
Hare et al. 2016	Northeast Shelf, United States	National Marine Fisheries Service (New England Fishery Management Council)	82 species in six functional groups (coastal fish, diadromous fish, elasmobranchs, groundfish, benthic invertebrates, and pelagic fish and cephalopods)	61 of the total species scored moderate or higher for climate vulnerability. Approximately half of the species assessed are predicted to be negatively impacted by climate change, rather than neutral or positively affected.

Mahu et al. 2022	Western African Coast, from Senegal to Angola	Transboundary management among federal agencies	1 species (<i>Crassostrea tulipa</i> , West African Mangrove Oyster)	<i>C. tulipa</i> ranked as very highly vulnerable to climate change. The driving factors behind high vulnerability were early life history survival and settlement, adult mobility, and sensitivity to salinity.
McClure et al. 2023	California Current, United States	National Marine Fisheries Service (Pacific Fishery Management Council)	64 species in four functional groups (coastal and pelagic, highly migratory, anadromous, groundfish)	Majority of species have moderate or greater vulnerability to climate change; Ocean acidification and temperature increase contributed most to high exposure
Olusanya & van Zyll de Jong, 2018	Newfoundland and Labrador	Department of Fisheries and Oceans (Newfoundland and Labrador Regional Office)	7 species in four different Genuses (<i>Salmo</i> , <i>Salvenius</i> , <i>Esox</i> , and <i>Oncorhynchus</i>)	All seven species were ranked moderate vulnerability or greater. Inherent resilience, gene plasticity, dispersive capability, and exposure to temperatures were the biggest factors driving vulnerability in these species.
Ramos et al. 2022	Northern Humboldt Current System, Peru	Ministry of Production (Federal Management Structure)	28 species in three functional groups (benthic, demersal, and pelagic)	All but two species have a medium or higher vulnerability score. Benthic species are considered most vulnerable.
Spencer et al. 2019	Eastern Bering Sea, United States	National Marine Fisheries Service (North Pacific Fishery Management Council)	36 species in eleven functional groups (e.g. rockfish, salmon, crab)	8 species have a moderate vulnerability score, with the rest being ranked as low vulnerability. Even though many species had a high sensitivity score, the overall exposure score of the majority of species was low.

Table 2. Description of expertise and role of experts in CVA studies. Expertise was summarized from the publication (columns 1-4) and additional context from interviews with authors was summarized where available (column 5).

Publication	Number of experts per species	Role of experts in scoring	Description of expertise from publication	Additional context from interview (if applicable)
Bueno-Pardo et al., 2021	3-4	Both Sensitivity and Exposure	No description	Primarily proximity, within the same university because it's easier to communicate Seeking people with broad ecological knowledge on the species and species expertise
Gianelli et al., 2023	4-6	Sensitivity Only	Experts including senior researchers, early career researchers, and Ph.D and masters students in their respective fields	Nomination process in which five or six colleagues suggested names Selection criteria was expertise on the specific taxonomic group, availability to conduct the assessment, and good will to collaborate
Giddens et al., 2022	5	Sensitivity Only	No description of how experts were chosen, only stating that they picked 15 people to score the species	Focused on scientists, fish and invertebrate biologists who are knowledgeable in the species that we were targeting, and especially trying to tap a broader geographic perspective Tried to include experts from different geographies, and

				organizations
Hare et al., 2016	2	Separate Sensitivity and Exposure	<p>Expert group consisted of the core development team for the methodology</p> <p>Regional experts from NOAA NMFS including stock assessment scientists, fisheries scientists, ecologists, and oceanographers</p>	<p>Specifically looking within NMFS and NOAA employees</p> <p>Looked across each of the species groups for experts in those specific species</p> <p>Brought in climate experts to look at the exposure portion of the study</p>
Mahu et al., 2022	9 total (all for one species)	Both Sensitivity and Exposure	<p>Experience in shellfish research was considered the #1 priority</p> <p>Also considered “inclusivity”</p> <p>Expert group carefully formulated to satisfy both gender and generational diversity</p>	N/A
McClure et al., 2023	4	Both Sensitivity and Exposure	Not well described	<p>People who worked on the organisms specifically</p> <p>Geography, covering the whole study range</p> <p>Some stock assessors, oriented on population dynamics</p> <p>Tried to get other people who had a more ecological bent or who worked on habitat</p>

Olusanya & van Zyll de Jong, 2018	8 overall (supposed to be 26 total but most did not respond)	Both Sensitivity and Exposure	<p>Freshwater fisheries scientists from government research agencies, conservation groups, and academia</p> <p>Need extensive research experience with freshwater fishes and PhD or its equivalent</p> <p>The ability to articulate the justification for their scores</p>	N/A
Ramos et al., 2022	4	Both Sensitivity and Exposure	12 regional experts recruited from the Peruvian Marine Research Institute	N/A
Spencer et al., 2019	3-5	Separate Sensitivity and Exposure	<p>34 analysts from seven separate academic and government institutions</p> <p>Subgroups of 3 to 5, divided by taxonomic expertise</p>	Tried to be inclusive of different organization types

Table 3. Comparison between stated purpose of the CVA in the literature and in the interviews

Publication	Stated purpose (publication)	Stated purpose (interview)	Actual use
Bueno-Pardo et al, 2021	Set the basis for the assessment of the vulnerability of Portuguese fisheries	Intended for management	Cited by researchers trying to recreate this kind of methodology in other places Not necessarily being used in management
Gianelli et al, 2023	Useful for developing more refined and holistic future assessments Helpful for fishery managers, decision-makers, and researchers for identifying highly sensitive species and to guide potential anticipatory and deliberate adaptive responses in local and regional fisheries	Form a network of researchers working on climate change and fisheries in the Southwest Not primarily directed for informing management, but hopefully would do that regardless	Not yet seeing it being used in management, however only published a year ago
Giddens et al, 2022	Evaluate multiple impacts to ecosystems to assess climate vulnerability in an EBM context Tool for bringing the best available science into a usable format for timely, science-based management Identify data gaps and inform future research priorities	Single source of information for stakeholders that have to make decisions broader than single species level	Not sure where or how it is being used

Hare et al, 2016	<p>Inform research and management activities related to understanding and adapting marine fisheries management and conservation to climate change and decadal variability</p> <p>Provide a system-wide perspective for the Northeast U.S. Shelf</p>	<p>To take a broad look at the species and how climate might affect them moving forward</p> <p>Try and bring information to managers</p>	<p>Used in ESA listings</p> <p>Considered when planning for climate change impacts on fisheries</p>
McClure et al, 2023	<p>Provide foundational information for the future management of fish species in this system</p> <p>Identify key areas of future research</p>	<p>Aimed it at people making management decisions about particular species</p>	<p>Used in ESA listings</p> <p>Used as a prioritization tool for the North Pacific Fishery Management Council in general harvest and management discussions</p> <p>Used for consideration of ecosystem based fishery management plans at the council level</p>
Olusanya et al, 2018	<p>Provide insight into factors that drive vulnerability of freshwater fishes in the region</p> <p>Use for decision-makers and other stakeholders engaged in managing freshwater fish resources</p>	<p>N/A</p>	<p>N/A</p>

Ramos et al, 2022	<p>Help fishery managers incorporate climate change into harvest level and allocation decisions</p> <p>Assist stakeholders plan for and adapt to a changing future</p>	N/A	N/A
Spencer et al, 2019	<p>Conduct an assessment of the vulnerability of fish and invertebrate stocks in the EBS shelf to climate change</p>	<p>Used for management, as a prioritization tool, or a ranking tool</p>	<p>Used more qualitatively or informally</p> <p>Used to prioritize further research of species</p>

Appendix A

Interview Guide

Interview ID:

Interview Date:

This interview protocol is a guide for the interviewer, who will conduct verbal, in-person or remote interviews with participants in a semi-structured format. Participants will not have to provide written answers to questions.

Reminders for interviewer: Summarize the consent form for the participant and allow time to look it over (includes project overview, confidentiality information, and how long the interview should take). Allow time for questions. Ask them for oral consent. Ask for consent to audio record. If yes, start audio recorder and state date and interview #.

Note: Sub Questions in each section denoted with an “a” attached were developed to be asked to those who participated in the Morrison et al. (2015) development.

Part 1: Background

- 1) What type of organization do you currently work for?
- 2) What kind of organization did you work for at the time of the climate vulnerability assessment (CVA)?
or
2a) What kind of organization did you work for at the time you contributed to climate vulnerability assessments (CVA)?
- 3) How would you describe your role in carrying out the CVA?
or
3a) How would you describe your role in the development process or carrying out the CVA?

Part 2: Methods and Expert Elicitation

- 1) You cited Morrison et al. 2015 in your methods section, did you adapt anything from the original methods? If so, why did you adapt it?
or
1a) You developed the methodology for the existing CVAs in the US, what was the motivation behind creating this framework? And did you draw upon any existing frameworks?
- 2) Now I'd like to learn more about how the expert elicitation process worked within the CVA.
 - a. How did you go about choosing your experts?
 - b. What types of expertise or perspectives did you seek to include?
 - c. Did you pay any attention to aspects such as gender, career stage, ethnicity, etc.?
 - d. Were there any gaps in terms of knowledge, experience, or perspectives?

or

- 2a) Now I'd like to learn more about how the expert elicitation process works within the CVA framework.
- a. How did you envision those conducting this would go about choosing their experts?
 - b. What types of expertise or perspectives would you suggest they include?
 - c. In developing the framework, did you discuss w/ coauthors how aspects such as gender, career stage, ethnicity, etc might be considered?
 - d. In seeing how these have been applied, are there any gaps in terms of knowledge, experience, or perspectives?

Part 3: Application of CVA

- 1) A common theme across CVAs is the intention of using it in the management of fisheries and marine resources. What was the intended purpose of your CVA?
 - a. Who was the intended audience of the CVA?
 - b. How did you share results with the intended audience?
- 2) Since the publication of your CVA, has it been used in a way that you intended?
 - a. Do you think there are ways to improve how the CVA is being communicated and used in management?
- 3) Since the publication of your CVA, has anything happened to the stocks/species you looked at that you would not have predicted (in other words has anything surprised you)?

Part 4: Demographic Information

- 1) In what city or town do you live?
- 2) In what year were you born?
- 3) What is your gender?
- 4) What is your race, ethnicity, or cultural background?