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Climate Vulnerability Assessments in Marine Fisheries: Taking Stock and Looking Ahead

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Received: 28 March 2025 | **Revised:** 30 November 2025 | **Accepted:** 9 January 2026

Keywords: climate change | climate vulnerability assessment | climate-resilience | global fisheries | social-ecological systems

ABSTRACT

Climate Vulnerability Assessments (CVAs) are important tools for understanding and addressing the impacts of climate change on marine fisheries. Since their introduction in the 1990s, CVAs have evolved from theoretical frameworks to practical applications aimed at fostering climate-resilient fisheries management. This review synthesises recent advancements in CVAs, focusing on methodologies, geographic applications, stakeholder participation and their contributions to fisheries management. While many CVAs emphasise ecological or social dimensions, recent efforts have integrated these components, offering holistic insights into the vulnerabilities of fisheries as coupled socio-ecological systems. Key innovations include participatory approaches that incorporate expert knowledge and stakeholder input alongside advances in quantitative modelling and spatially explicit analyses. Our review highlights specific examples where CVAs have informed various management applications, such as species protection under the U.S. Endangered Species Act and the design of adaptive harvest strategies in Australia. However, barriers remain, including inconsistent methodological standards, limited uptake in nations with low-income economies and challenges translating CVA outputs into actionable policies. Looking ahead, developing generalised, integrated frameworks that bridge ecological and social dimensions, identifying ways to link CVA outputs to management guidance, and improving methodologies for data-limited contexts will all improve uptake and application of CVAs. Strengthening the connections between existing CVAs and climate-ready fisheries through adaptive management strategies can support fisheries management outcomes in a changing climate while balancing ecological sustainability and socio-economic equity.

Nima Farchadi, Daniel Crear, and Yunzhou Li shared lead author role.

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1 | Introduction

Climate change is altering marine ecosystems through long-term directional trends (i.e., presses) and episodic, extreme events (i.e., pulses), resulting in significant impacts on fisheries and associated economies (IPCC 2023; Pinsky et al. 2018; Samhouri et al. 2024). Globally, fisheries management agencies are encountering rapidly escalating challenges in already strained socio-ecological systems. Climate change has been linked to shifts in marine species distributions (Braun et al. 2023; Crear et al. 2023; Kleisner et al. 2016; Nye et al. 2009; Poloczanska et al. 2013) and associated declines in target species catch (Barbeaux et al. 2020; Klaer et al. 2015; Szuwalski et al. 2023; Wayte 2013), affecting fisheries-dependent communities (Farchadi et al. 2024; Rogers et al. 2019; Young et al. 2019). To support efforts to design and implement climate-resilient fisheries management frameworks (Holsman et al. 2019; Vogel et al. 2024), there is a concomitant need to assess the vulnerability of ecological and social systems to ongoing climatic changes.

Since the 1990s, climate vulnerability assessments (CVAs) have served as a valuable tool to evaluate the potential impacts of climate change on natural and human systems and to help prioritise management and conservation efforts that promote climate adaptation (Foden et al. 2019). Since their first application to marine fisheries in 2009 (Allison et al. 2009), CVAs have gained traction globally as tools for fisheries research (Figure 1; Li et al. 2023), supporting a new wave of climate-informed fisheries policy and management strategies (Holsman et al. 2019). While many fisheries-oriented CVAs focus on either ecological or social components, a growing number of CVAs have expanded to consider more integrated approaches that address both aspects of fishery systems (Dudley et al. 2021; Johnson and Welch 2009; Koehn et al. 2022; Li et al. 2024; Marshall et al. 2013; Pratchett et al. 2017).

A recent global analysis of the structural frameworks and methodologies used in fisheries CVAs highlighted the diversity of approaches used to assess climate impacts across fisheries of various scales and scopes (Li et al. 2023). As the literature on fisheries CVAs continues to proliferate and climate impacts in the oceans intensify, there is an opportunity to evaluate CVA applications in the broader context of climate-readiness and their use in building resilient fisheries systems. Here, we review recent CVA literature to identify fundamental features, innovations and achievements over the last 15 years, discussing the applications and 'real world' outcomes. Specifically, this review builds on previous global syntheses (e.g., Li et al. 2023) by focusing on how assessments have informed 'real-world' fisheries decision-making and policies, highlighting where barriers to implementation and application still persist, and identifying future directions for enhancing the utility of CVAs to support fisheries in a changing ocean.

2 | Fundamental Features of CVAs

Given the growing role of CVAs in assessing the impact of climate change on marine fisheries, we briefly review their progress in advancing climate-ready fisheries. Here, we define fundamental features of fisheries CVAs as key characteristics that have shaped their scope and focus, including the theoretical framework used, core methodology, participatory nature and geographical context.

2.1 | Theoretical Framework

As concerns about anthropogenic climate change intensified in the 1990s, efforts emerged to characterise the vulnerability of human and natural systems to climate change impacts (Brooks 2003; Füssel and Klein 2006). Early definitions of vulnerability differed by scientific discipline, hindering a shared vision for research and adaptation planning (Brooks 2003). For example, the vulnerability of a system could be defined either by the severity of specific climate change impacts or by

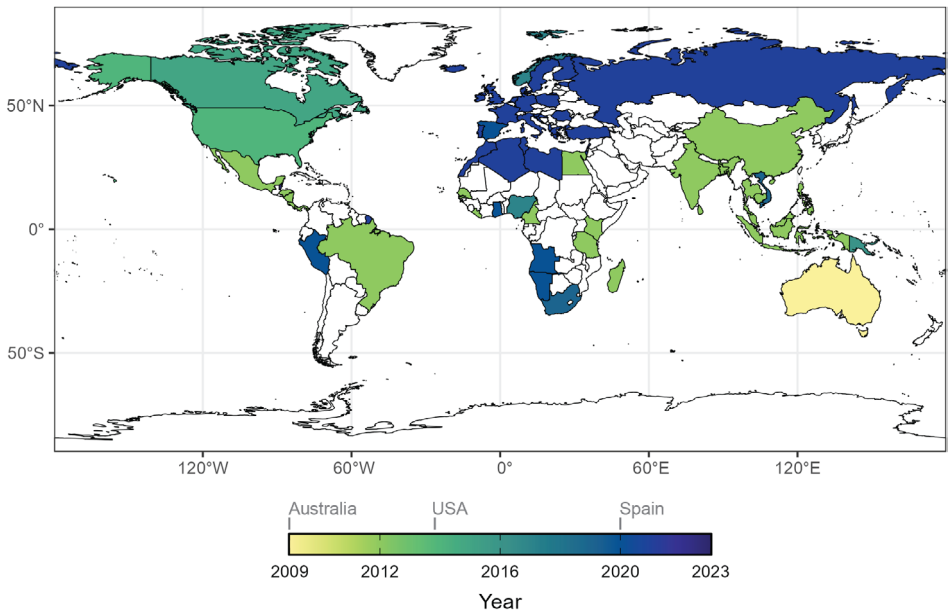

FIGURE 1 | Year of initial adoption of fishery CVAs. Starting in 2009 in Australia, fishery-oriented CVA applications have expanded globally. Colors indicate the first year in which a country completed or published a fishery CVA. Data sourced from Li et al. (2023) and updated to include 2009-2024, however the scale bar ends in 2023 as no additional countries adopted a fishery CVA in 2024.

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the intrinsic strengths and weaknesses of the system in the absence of any specific climate change impact (Brooks 2003). The Intergovernmental Panel on Climate Change (IPCC) harmonised these concepts in 1996, defining climate vulnerability as 'the extent to which climate change may damage or harm a system, depending not only on a system's sensitivity but also on its ability to adapt to new climatic conditions' (IPCC 1996). Assessments of climate vulnerability have largely adopted this definition by integrating assessments of the magnitude of external changes impacting a system ('exposure'), along with the internal susceptibilities of a system ('sensitivity') and its ability to adapt to change ('adaptive capacity') (Füssel and Klein 2006). Specifically, exposure represents the degree to which natural or human systems are subject to climate-related stressors (IPCC 2007). It can be measured by linking climate projections and species distribution maps and/or models (e.g., Boyce et al. 2022; Hare et al. 2016; Li et al. 2024), or by assessing environmental or target-species changes experienced by coastal communities (e.g., Allison et al. 2009; Li et al. 2024; Payne et al. 2021). Sensitivity reflects the extent to which a system could be affected once exposed (IPCC 2007). Common approaches include evaluating biological or ecological traits of species and habitats or assessing fishers' reliance on fisheries (Hare et al. 2016; Li et al. 2023). Adaptive capacity captures the positive attributes of a system that enable it to cope with or recover from the effects of climate change (IPCC 2007). This can be measured through indicators such as species fecundity, mobility and socio-economic flexibility (Cinner et al. 2018; Li et al. 2023).

2.2 | Methodology

Fisheries CVAs have used a wide range of methodologies depending on the particular scope and focus of the assessment. Ecological CVAs primarily focus on the biophysical impacts of climate change on marine species, functional groups or ecosystems. These efforts often focus on functional categories of species of interest (e.g., benthic, demersal and pelagic) and typically involve expert and stakeholder input to score exposure, sensitivity and adaptive capacity based on scientific data, including climate projections, species life history and distribution maps (Hare et al. 2016; Kjesbu et al. 2022; Lettrich et al. 2023; Loughran et al. 2025; McClure et al. 2023). Social CVAs assess the vulnerability of social systems in the fisheries sector, using economic and social data, including surveys and secondary statistics, to characterise the vulnerability of communities, industries or national economies that depend on fisheries (Allison et al. 2009; Cinner et al. 2012; Dowd et al. 2025; Koehn et al. 2022). These assessments often focus on local or regional scales, using interviews and focus groups to gauge community perceptions of climate stressors and resilience strategies (Li et al. 2023).

A growing number of CVAs have begun to integrate assessments of social-ecological vulnerability in fisheries by combining climate exposure with traits describing the sensitivity and adaptive capacity of both ecological and social components of a system to assess the vulnerability of fishing fleets or coastal regions. These assessments provide a more holistic view of fisheries' vulnerability and support management decisions that are both ecologically sound and socially equitable (Greenan et al. 2019; Li et al. 2024; Marshall et al. 2013; Payne et al. 2021). For instance, Pita et al. (2021) merged species hazard assessments with fishing fleet data to estimate risk at both regional and fleet levels, highlighting the role of CVAs in identifying priority areas for adaptation and informing strategies that account for both ecological and social vulnerabilities.

Methods to assess fishery vulnerability can range from expert-driven, qualitative approaches to more data-intensive, quantitative ones, depending on available resources, scientific objectives and management needs (Foden et al. 2019; Pacifici et al. 2015). Assessments often rely on expert knowledge and stakeholder input to assess vulnerability qualitatively or semi-quantitatively (e.g., Morrison et al. 2015). Trait-based vulnerability assessments are a common participatory method adapted from ecological risk assessment (Chin et al. 2010; Hobday et al. 2006; Ramos et al. 2022; Walker et al. 2021). This approach involves experts and stakeholders to score species traits that characterise their sensitivity and adaptive capacity, usually on a qualitative scale such as 'low' to 'very high' (Hare et al. 2016). It can be helpful to conceptualise vulnerability as a system's exposure to climate change impacts moderated by the degree to which its intrinsic traits are likely to increase or decrease its susceptibility because it does not rely on resolving non-linear and uncertain numerical relationships between climate change and system responses. Trait-based approaches are relatively quick to implement, can be bolstered by traditional ecological knowledge, and enable the identification of traits that confer vulnerability, allowing system components (i.e., species) to be grouped and ranked to inform targeted policy development and adaptation planning. However, despite these advantages, these approaches often face challenges in defining vulnerability thresholds and characterising uncertainty, which can make them problematic to reliably reproduce and compare across study systems (Pacifici et al. 2015).

While participatory and largely qualitative trait-based approaches have formed our foundational understanding of climate vulnerability in fisheries, advances in data availability and modelling have facilitated the rapid growth of assessments that leverage statistical models and spatially explicit data streams (Boyce et al. 2022; Champion et al. 2023). For example, recent advances have incorporated climate model projections into fisheries CVAs, enabling probabilistic estimates of future vulnerability under different emissions scenarios or climate model frameworks by linking spatially explicit projections of oceanographic conditions (e.g., sea surface temperature, oxygen levels, pH) to species distribution models (e.g., Boyce et al. 2022, 2024). These advances reflect how the purpose and function of CVAs have evolved from conceptual models that provide relative risk assessments for strategic planning to quantitative evaluations that may lead to greater uptake into tactical fisheries management (Boyce et al. 2022; Champion et al. 2023). This shift coincides with the increasing availability, in some regions, of fine-scale oceanographic and climate models, along with more robust ecological models that describe species' responses to climate change, making their output suitable for use in CVA applications (Boyce et al. 2022; Champion et al. 2023).

Importantly, these quantitative approaches also offer improved capacity to capture and communicate uncertainty. While they do not inherently reduce uncertainty, their key advantage lies in

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their ability to make the sources and magnitude of uncertainty transparent and traceable. For example, as uncertainty in CVAs can arise from a variety of sources (Dietze 2017; Monnereau et al. 2017), such quantitative methods can help identify and address it by estimating the dominant sources and magnitude of uncertainty in climate model projections (Payne et al. 2021), attributing uncertainty to specific components of the CVA workflow (Goodman et al. 2024), and characterising how uncertainty varies across space and over time (Brodie et al. 2022; Davies et al. 2023; Jansen et al. 2022). The capacity from such quantitative approaches can help clarify where spatiotemporal predictions of future vulnerability are more or less reliable and how much confidence can be placed in the assessment, an area where qualitative approaches often lack systematic means for evaluation.

However, these computational solutions are primarily limited by algorithmic representations of species-environment relationships and estimates of vulnerability that are largely naive to traditional ecological and expert knowledge of climate impacts being observed 'on the water' that may not be well documented in existing data streams. Moreover, while Earth-system and lower-trophic-level models routinely use ensemble approaches to quantify spatiotemporal uncertainty, comparable tools for higher-trophic-level models remain less mature, though coordinated efforts such as FishMIP are helping advance this capacity (Blanchard et al. 2024). Ultimately, each CVA approach has different strengths and limitations, and the integration of these methods in fishery CVAs may offer a more comprehensive understanding of vulnerability in social-ecological fishery systems.

2.3 | The Participatory Nature of CVAs

Many ecological CVAs have used 'experts' (typically scientists) during the scoring process who can provide expert opinions on specific species, functional groups, ecosystems or habitats (Boyce et al. 2022; Farr et al. 2021; McClure et al. 2023). Experts typically use a synthesis of existing scientific literature on species' life history characteristics and ecological relationships, combined with their experience, to provide scores on species' sensitivity and adaptive capacity (Hare et al. 2016; Teck et al. 2010). Social CVAs often include participants from multiple sectors, such as the fishing industry, management and the nearby community. This is often done through specifically designed surveys to understand climate change stressors to those most affected and help promote climate resiliency of coastal communities (Martins and Gasalla 2020).

Despite the benefits of including the oceanographic and biological expertise of scientists in ecological CVAs and local and experiential knowledge from fisher and community members in social CVAs, assessments combining expert knowledge from these two groups have been limited (Carroll et al. 2023; Li et al. 2025). While fishers may not have formal scientific training, they have pragmatic knowledge about changes in their ecosystems, the behaviour and distribution of the species that they capture, and the policies and socio-economic structures that reduce or enhance their vulnerability (Gianelli et al. 2021). Integrating representatives from the fishing community into social-ecological CVAs alongside scientists and managers can help fill critical scientific gaps at local scales, build trust and improve buy-in of management interventions (Carroll et al. 2023; Daigle et al. 1996; Mills et al. 2023; Reyes-García et al. 2016). In some applications, the participatory processes follow an initial science-driven step. For example, Carroll et al. (2023) first developed an ecological CVA for Caribbean recreational fisheries through a literature-based desktop analysis that scored species' climate exposure and sensitivity. These preliminary vulnerability rankings were then refined through participatory workshops with recreational fishing guides, fishery managers and local scientists who contextualised the results and outlined key measures to increase climate resilience. This type of stepwise approach, where scientific assessments provide a foundation of subsequent participatory engagement, offers a promising model for integration of diverse knowledge systems. A recent study further integrated and compared three types of information—scientific data, local fishermen's knowledge and institutional expert knowledge—to examine their utility and limitations in informing climate vulnerability of fisheries social-ecological systems, cautioning the potential bias in each knowledge system and calling for a more collaborative approach to generate meaningful and actionable knowledge for CVAs (Li et al. 2025). Such collaborations across sectors can help increase the chances of developing effective strategies and policies that consider environmental justice and human well-being (Seara et al. 2020) while incorporating the best scientific information available to balance the inherent social-ecological tradeoffs in promoting climate-resilient fisheries and fishing communities.

2.4 | CVA Implementation

Drawing from CVA reviews (e.g., Li et al. 2023) and our updated literature search through August 2024, which included both peer-reviewed studies and relevant grey-literature reports, we found a wide geographic range of fishery CVA applications, with a total of 77 assessments disproportionately distributed across 79 countries (Figure 2). These studies were identified and selected using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach (Moher et al. 2009), applying the search query 'TS = (vulnerability AND (fisheries OR fish OR fishing))' and subsequently screening for relevance to climate-related stressors and marine fisheries (Li et al. 2023). We adopted the IPCC (2007) definition of vulnerability for this review. The application of CVAs, which typically involve a comparison of multiple target species or fishing communities, has predominantly concentrated on relatively developed regions and relatively high-income countries where research infrastructure and capacity tend to be higher (Li et al. 2023). Most studies have focused on North America and Asia, whereas Africa and South America have had the fewest assessments conducted. A small fraction of CVAs have targeted European fisheries (6%), although they contribute over one-eighth of the world's marine fisheries catches (Payne et al. 2021). This uneven and unrepresentative distribution points to the opportunities to expand CVA applications supporting fisheries management.

CVA studies are often categorised by the fishery component on which they focus (Figure 2). Ecological CVAs, which examine multiple species, stocks and habitat vulnerability, are

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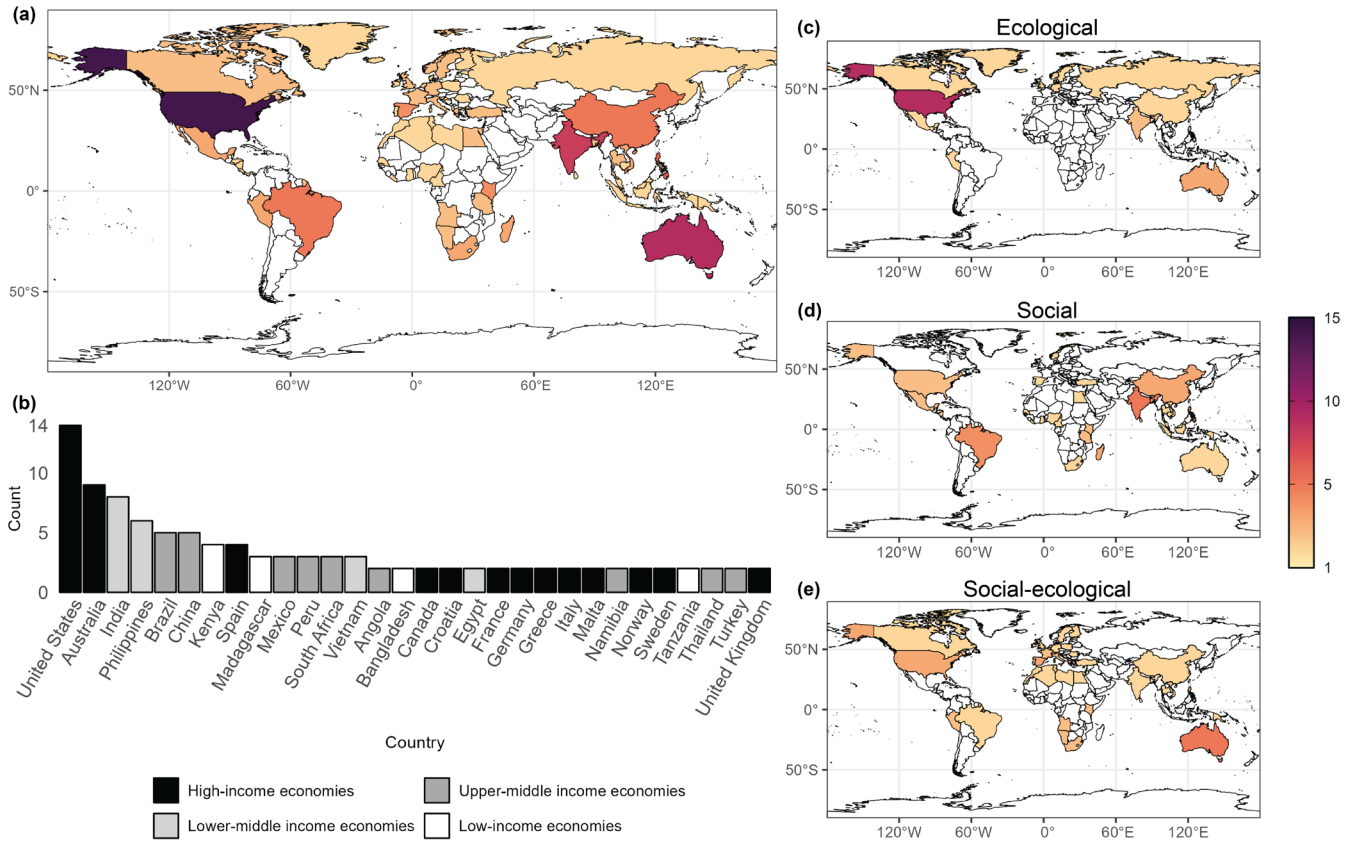

FIGURE 2 | Global distribution of fishery CVAs. (a) Geographic distribution of CVA studies (77 total), categorised by the number of studies covering each country. (b) Countries with more than one CVA application are classified by income categories based on World Bank country classification. (c–e) Geographic distribution of CVA studies focusing on fisheries' ecological, social and social-ecological components, respectively. See Appendix S1 for a list of studies.

primarily concentrated in temperate regions, notably the U.S. and Australia, but appear rare in the tropics (Figure 2). Socio-economic CVAs, which address fishing communities' and stakeholders' social and economic vulnerability, are more prevalent in tropical regions (Figure 2). The countries with the most social CVAs (with more than four studies) include the Philippines, India and Brazil. Social-ecological CVAs usually deal with complex interactions among fishery species, resource users and management (Pratchett et al. 2017) and are more commonly implemented in developed countries and regions with more experience in ecological or social CVAs, such as Australia, the U.S. and European countries (Figure 2).

On a country level, CVAs that assess the ecological components of a fishery, such as species and habitat vulnerability, have been most commonly employed in the U.S. and Australia. The early adoption of CVAs in these countries may be attributed to greater research capacity and well-developed national policies and investments, such as NOAA Fisheries Climate Science Strategy in the U.S. and Ecological Risk Assessment for the Effects of Fishing (ERAEF) in Australia (Hobday et al. 2006; NOAA 2015). These policies have supported, and in some cases mandated or incentivised, climate-related fisheries management and research strategies. The more extensive CVA development in the U.S. and Australia may also reflect their large, diverse coastal regions that require tailored assessments (Hare et al. 2016; Li et al. 2023; McClure et al. 2023).

Looking beyond country level CVAs, there has been a recent push for regional fisheries management organisations (RFMOs) to develop their own CVAs. The Western and Central Pacific Fisheries Commission (WCPFC) has conducted a comprehensive review of CVAs and has developed a climate change vulnerability assessment framework designed to evaluate climate change risk to conservation and management measures (Baird and Robertson 2025). Although CVA development at the RFMO-level has trailed behind that at the country level, many RFMOs have recognised the importance of taking into account climate impacts on their fisheries, many of which target species (e.g., tunas) that are transboundary.

Australia pioneered the expert-opinion, trait-based approach (Chin et al. 2010; Johnson and Welch 2009; Pecl et al. 2014) that was the basis for the U.S. CVA methodology initially implemented in the Northeast U.S. region (Hare et al. 2016; Morrison et al. 2015) and expanded to other coastal regions to provide comprehensive ecosystem-wide assessments of climate vulnerability (Farr et al. 2021; Lettrich et al. 2023; McClure et al. 2023; Quinlan et al. 2023; Spencer et al. 2019). Similarly, Australia has led quantitative and qualitative approaches to demonstrate climate vulnerability at both species and industry levels (Champion et al. 2023; Frusher et al. 2016; Pecl et al. 2014). This focus has a strong alignment with Australia's recognition of the impacts posed by climate change on fisheries across its waters (Hobday and Lough 2011; Lough and Hobday 2011). It is supported by

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authoritative legislation, as AFMA officially adopted a climate risk framework, which integrates climate-related risks into decision-making of Australia's fisheries (AFMA 2025; Fulton et al. 2021). The development of this framework was a multi-year effort in consultation with fisheries stakeholders. This resource investment in CVAs in the U.S. and Australia has facilitated the direct and indirect use of CVAs results in fishery management, as detailed in Section 3.

3 | CVA Applications in Fisheries Management

The development and deployment of CVAs have facilitated a deeper understanding of which species and/or fishery systems are vulnerable to climate stressors and helped identify where management efforts are most needed (Hare et al. 2016). While earlier reviews have summarised the methodology, expansion and dimensions of CVAs (e.g., Li et al. 2023), our focus here is how these assessments have been used in practice, highlighting examples of management uptake and remaining barriers to implementation. With the flexibility to use either qualitative or more quantitative approaches, CVAs are adaptable to various applications and resource constraints, such as varying data availability, research or management capacity and models of stakeholder engagement (Carroll et al. 2023). Ultimately, these approaches have the potential to inform management decisions and identify targeted actions aimed at addressing specific vulnerabilities, thereby fostering more effective and sustainable responses to climate-related challenges.

Although most CVA research in fisheries has emerged within the past decade and integrating new scientific assessments into management decisions may take time, emerging evidence already highlights their practical contributions. For example, CVAs have directly informed species protection under the U.S. Endangered Species Act (ESA), with vulnerability assessments for the Northeast and California Current serving as guidance for ESA listings to address climate change impacts (Hare et al. 2016; McClure et al. 2023; Somma 2023). Specifically, NOAA's ESA 5-year review on the Snake River spring/summer Chinook salmon distinct population segment (DPS) incorporated extensive results of the salmon CVA, noting that this DPS is expected to be highly vulnerable to climate change in the future, particularly during its marine stage (Crozier et al. 2019; NOAA Fisheries 2022). In the U.S., the Mid-Atlantic Fisheries Management Council uses the Northeast CVA vulnerability rankings and distribution shift potential (Hare et al. 2016) and the social indicators from the Northeast U.S. fishing communities CVA (Colburn et al. 2016) in their systematic risk assessment framework and decision table to prioritise resource allocation and inform strategic planning (Gaichas et al. 2018). Similarly, Australia's climate risk assessment framework employs CVAs, along with predictive models and ecosystem indicators, as the first step to evaluate whether existing stock assessments and harvest strategies address climate change effects on high-risk species. When gaps are identified, precautionary adjustments to total allowable catches or efforts are recommended (AFMA 2025).

In addition to direct management applications, the value of CVAs has also been demonstrated through indirect effects. The genesis of CVAs (Chin et al. 2010; Hare et al. 2016; Johnson and Welch 2009; Pecl et al. 2014) has advanced the conversation on climate impacts and fisheries in the U.S. Since the first U.S.-based ecological CVA (Hare et al. 2016) was published, more than seven regional ecological and multi-taxa CVAs have been developed in the U.S. In the U.S. Chesapeake Bay, information from the Northeast CVA and Habitat CVA is being applied to inform the synthesis of information on rising water temperatures and their effects on fisheries and habitat (Saba et al. 2023). CVAs are now widely recognised as valuable tools to raise awareness and guide research priorities. Nevertheless, to our knowledge, there has not been a systematic review and performance evaluation of the application of CVAs in fisheries management, which remains an important area for future research.

Despite the emergent applications of CVA in management, some notable gaps and limitations have hindered the ability of CVAs to catalyse larger actions to address climate change's global impacts on marine ecosystems and coastal communities. A critical limitation is the lack of comprehensive guidelines for those creating CVAs, including methodological and modelling protocols, stakeholder engagement and processes for producing knowledge in participatory CVAs. Additionally, there is a need for explicit information and guidance on effective pathways to implement CVA findings directly to fisheries management, often referred to as on-ramps (Mason et al. 2023). These gaps make it challenging for practitioners to effectively interpret CVA results, compare them across CVAs and translate scientific findings into actionable policies. Furthermore, with the recent development of numerous climate-related fisheries tools, including climate-informed stock assessments and reference points, species climate projections, ecosystem indicators and dynamic ocean management, strengthening the connections among these approaches and clarifying how CVAs complement them is an important step that could improve their application and eventual uptake in CVAs and fisheries management. For example, integrating the outputs of species distribution models (SDMs) into CVAs could improve their applicability as SDMs can capture spatial and temporal variability of climate exposure and sensitivity. These methodological and tool-based synergies may facilitate more targeted climate adaptation strategies or serve as an entry point for more detailed analyses, for example, scenario planning or management strategy evaluation. While integrating climate change considerations into fisheries management remains hindered by incomplete information and institutional inertia, processes such as CVAs can provide venues for sustained collaboration between scientists and managers, providing opportunities to translate climate impacts into adaptive and actionable management strategies (Vogel et al. 2024).

4 | Future Directions of CVAs

Despite the extensive and growing literature on CVAs, their full potential to enhance climate resilience in ocean systems remains underutilised. There are also substantial challenges in the uptake and implementation of CVA findings, particularly in less developed and Small Island Developing Countries where climate change impacts on fisheries are particularly rapid and severe (e.g., non-filled countries in Figure 1; Li et al. 2023), capacities may be limited, and the need for targeted adaptation efforts

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may be greatest. While our review focused on marine systems, freshwater and inland fisheries, which provide critical nutrition and livelihoods for many communities (Welcomme et al. 2010), remain largely absent from the CVA literature. Including these systems in future assessments would broaden the applicability of CVAs and address another commonly overlooked dimension of global fisheries vulnerability. Another challenge is that CVAs tend to be siloed, often focusing primarily on either ecological or social factors, which can limit their overall effectiveness in resolving the climate vulnerability of complex human-natural systems. However, recent applications are striving to create more generalizable frameworks that consider social and ecological dimensions (Dudley et al. 2021; Marshall et al. 2013). Addressing these limitations and removing barriers to their practical use will be essential to reduce capacity limitations for new CVA users and to maximise the effective applications of CVAs in the face of ongoing climate challenges.

To enhance the effectiveness and utility of fishery CVAs, pathways must be established to integrate CVA frameworks with climate-ready fisheries and adaptive management strategies. For example, stakeholders continue to emphasise the importance of generating assessments that are relevant for specific time horizons and spatial domains (Boyce et al. 2022), but many CVAs are not designed to be spatially or temporally explicit (Braun et al. 2026). As ecological and earth-system models progress, their integration into CVA frameworks can support fine-scale predictions and strengthen climate-smart spatial management. However, this shift may raise concerns about maintaining meaningful participatory input, particularly in large-scale assessments. Recent CVA applications have begun to adopt more holistic and flexible approaches that incorporate diverse types of data, including experiential, qualitative and quantitative, as well as varied knowledge systems (Boyce et al. 2024; Carroll et al. 2023). This pluralistic perspective can expand CVA implementation in underrepresented regions (Figure 1) by enabling the inclusion of Indigenous and local ecological knowledge (Carroll et al. 2023), which is often rooted in long-term, place-based observations (Gadgil et al. 1993), and by supporting assessments in data-poor contexts through the use of proxies or information from related systems or species. Advances in computational capacity and platforms now make it possible to integrate diverse knowledge sources in ways that preserve transparency, quantify uncertainty in vulnerability estimates and enhance reproducibility across spatial and temporal scales. Future CVA approaches should, therefore, seek to produce holistic assessments that identify vulnerabilities and guide actions to reduce exposure, mitigate sensitivity or enhance adaptive capacity across ecological and human dimensions (Pratchett et al. 2017), fostering resilience in socio-ecological systems under changing ocean conditions.

Acknowledgements

This manuscript is the product of the 'Merging CVA Science with Dynamic Ocean Management' workshop hosted by the Woods Hole Oceanographic Institution and the Northeast Regional Ocean Council (NROC). Funding was provided by NROC and the NASA Ecological Conservation Program (Grant 80NSSC23K1538). MCA was supported by the WHOI President's Innovation Fund. The authors are particularly grateful to W. Morrison, J. Hare, J. Cudney, S. Lucey and M. Jacox for their thoughtful input on these ideas and earlier versions of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

A reference list of all studies synthesised in this review is available in the Appendix S1.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** faf70064-sup-0001-AppendixS1.xlsx.

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