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WCPFC CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA) FRAMEWORK: TECHNICAL AND COMPLIANCE CONSIDERATIONS

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WCPFC CLIMATE CHANGE VULNERABILITY ASSESSMENT (CCVA) FRAMEWORK: TECHNICAL AND COMPLIANCE CONSIDERATIONS

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EXECUTIVE SUMMARY

This paper presents the Technical and Compliance Committee (TCC) with an overview of the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework and its specific relevance to technical implementation and compliance monitoring. The framework has been developed to systematically evaluate climate change risks to Conservation and Management Measures (CMMs) through assessment of hazard, exposure, sensitivity, and adaptive capacity.

From a TCC perspective, the framework provides crucial insights into:

- Operational feasibility of implementing climate-informed measures under changing conditions
- Monitoring, Control and Surveillance (MCS) data gaps and requirements for effective climate adaptation
- Fleet operational challenges under increasing extreme weather conditions
- Compliance implications when environmental conditions affect implementation capacity
- Technical infrastructure vulnerabilities to climate-related hazards.

In particular, the pilot assessment of CMM 2017-04 (Marine Pollution) demonstrates the framework's particular relevance to operational measures, revealing how climate change acts as a risk multiplier for vessel operations and waste management compliance during extreme weather events.

1. INTRODUCTION

1.1 Background

Following WCPFC21's adoption of Resolution 2019-01 and the Climate Change Workplan 2024-2027, the Commission commissioned development of a systematic framework to assess climate change vulnerability of CMMs. The CCVA Framework addresses the Commission's need to understand how climate change impacts might affect existing CMM provisions and implementation effectiveness.

1.2 TCC's Role in Climate Change Vulnerability Assessment

Convention Article 14.1(a) establishes TCC's core function to provide the Commission with information, technical advice and recommendations relating to the implementation of, and compliance with, conservation and management measures. In the context of climate change vulnerability assessment, TCC's expertise is essential for:

- Identifying MCS data and information gaps that climate change may exacerbate
- Evaluating operational feasibility of implementing climate-informed management measures
- Assessing technical infrastructure vulnerability to climate-related hazards
- Understanding fleet operational challenges under changing environmental conditions
- Determining compliance monitoring implications when climate impacts affect implementation capacity.

2. FRAMEWORK OVERVIEW

2.1 Conceptual Approach

The CCVA Framework adopts the IPCC AR6 risk-based assessment approach, defining climate risk as a function of:

Climate Risk = Hazard × Exposure × Vulnerability

Where:

- **Hazard**: Climate-related physical events or trends (e.g., ocean warming, acidification, sea-level rise)
- **Exposure**: Presence of systems, species, or assets that could be adversely affected
- **Vulnerability**: Propensity to be adversely affected, determined by **sensitivity** and **adaptive capacity.**

The framework has been designed as a rapid-assessment tool to enable quick identification of areas in need of attention, key drivers of climate risk, and rapid identification of information gaps. See Annex A for in-depth information about the framework, including its design and functionality.

2.2 Literature Review and Indicator Development

The framework development was informed by a comprehensive literature review conducted following PRISMA 2020 guidelines, examining over 500 studies globally and more than 130 operational vulnerability frameworks. The review searched multiple databases using terms including "climate change vulnerability," "adaptive capacity," "socioeconomic vulnerability," and "resilience to climate change."

Inclusion criteria focused on peer-reviewed articles and reputable institutional documents from the past 10 years, while exclusion criteria removed non-vulnerability climate topics and non-peer reviewed materials. The final sample of 536 sources provided the theoretical and practical foundation for developing WCPFC-specific climate change risk indicators.

Indicators are essential for identifying both the source and extent of climate risk. Without systematic indicators, it becomes impossible to quantify vulnerability levels, compare risks across different CMMs, track changes over time, or prioritize adaptation responses. The indicator-based approach enables the framework to move beyond qualitative assessments to provide measurable, comparable vulnerability scores that can inform decision-making. Importantly, while many of the indicators assigned to the Scientific Committee are drawn from examples in literature, the indicators posed for TCC are novel – few vulnerability assessments related to fisheries examined climate risk beyond the biophysical impacts on species.

2.3 Hazard Categories and TCC Relevance

Different climate hazards affect different components of the fisheries system. Some hazards primarily affect species biologically or behaviourally (such as ocean warming affecting tuna distribution or ocean acidification impacting coral reef ecosystems). However, for TCC, the most relevant hazards are those that impact vessel operations and technical infrastructure, as these directly affect the feasibility of implementing and monitoring compliance with CMMs.

2.4 TCC-Relevant Indicators

The framework includes specific indicators designed to capture technical and operational dimensions relevant to TCC's mandate:

Operations and Infrastructure Hazard Indicators

- Storms and Cyclones: Direct impacts on vessel operations, port infrastructure, and at-sea safety
- Wind Stress and Wave Height: Effects on vessel stability and operational safety
- Precipitation Extremes: Port infrastructure damage and access limitations
- Sea Level Rise: Long-term port infrastructure vulnerability.

Operational Exposure Indicators

- Fishing Fleet Exposure: How frequently fleets encounter climate hazards
- At-Sea Operations: Frequency of inadequate weather information for decision-making
- Financial Survivability: Percentage of operations unable to survive major weather events
- Crew Safety: Exposure to dangerous working conditions during extreme weather
- Search and Rescue Access: Proximity to emergency services during extreme events.

MCS and Compliance-Related Adaptive Capacity Indicators

- Observer Coverage: Likelihood of maintaining adequate monitoring levels during climate disruptions
- Vessel Monitoring Systems: Resilience of technical monitoring infrastructure
- Port Infrastructure: Ability of port facilities to maintain functionality under climate stress
- Fleet Operational Flexibility: Capacity to relocate operations due to climate-driven changes.

3. PILOT ASSESSMENT PROGRAM

3.1 2025 CMMs

The framework has been applied to five CMMs in the 2025 pilot assessment program:

- CMM 2024-07 (Cetaceans)
- CMM 2019-05 (Mobulid rays)
- CMM 2024-05 (Sharks)
- CMM 2017-04 (Marine pollution)
- CMM 2024-06 (NP Striped Marlin).

While all five assessments provide valuable insights, this paper draws particular attention to the marine pollution assessment due to its direct operational focus and high relevance to TCC's technical and compliance mandate[1]. See Annex A (Attachment D) for the individual report assessments for each CMM.

3.2 TCC-Specific Findings from Marine Pollution Assessment

The assessment of CMM 2017-04 provides the most relevant insights for TCC, as it focuses specifically on operational aspects of fisheries management.

[1] While our view is that the assessments provide valuable insights, consistent with our Assessment Report and presentation to Scientific Committee, we caution relying too heavily on the pilot assessments until the criteria are settled by WCPFC and procedures are agreed to safeguard the information and data the assessment is based on.

3.2.1 Key Findings

- **MEDIUM overall climate risk** driven primarily by high exposure to operational hazards
- **Operational vs. Biological Risk**: Climate change increases pollution risk primarily through extreme weather events that compromise operational systems rather than through direct environmental changes
- **Risk Multiplier Effect**: Climate change acts as a risk multiplier for marine pollution rather than a direct driver.

3.2.2 Specific Operational Impacts Identified

1. Vessel Operations: High winds, storms, and cyclones compromise waste management procedures and equipment functionality
2. Crew Safety Priority: During extreme weather, crew safety takes precedence which may compromise, for example, effective waste handling and disposal, or other environmental protocols.
3. Equipment Failure: Climate hazards damage waste storage systems and handling equipment
4. Port Infrastructure: Storm damage affects waste reception facilities and service availability.

3.2.3 MCS Implications

- Monitoring Challenges: Extreme weather events limit observer safety and monitoring effectiveness
- Compliance Verification: Difficulty verifying pollution prevention compliance during emergency conditions
- Data Collection: Vessel monitoring and reporting systems may be compromised during extreme weather

3.3 Cross-CMM Operational Challenges

Analysis across all pilot assessments reveals common technical and compliance challenges:

Fleet Operational Impacts

- Vessel Safety: Increased frequency of dangerous working conditions
- Operational Disruption: Higher rates of fishing ground relocation due to species shifts
- Equipment Stress: Climate hazards affecting vessel and monitoring equipment functionality
- Communication Systems: Extreme weather disrupting vessel-to-shore communications

Monitoring System Vulnerabilities

- Observer Program: Safety protocols during extreme weather limiting observation capacity
- Electronic Monitoring: Equipment vulnerability to harsh weather conditions

- VMS Systems: Potential for weather-related system failures or data gaps
- Port Infrastructure: Climate impacts on data transmission and vessel servicing facilities

3.4. Technical Implementation Considerations

3.4.1 MCS Data Requirements

The framework identifies critical MCS data elements for effective climate vulnerability assessment:

Existing WCPFC Data Assets

- Vessel monitoring system (VMS) data and its role in search and rescue
- Observer program data (including weather and operational condition reports)
- Compliance monitoring records
- Fleet characteristics and operational patterns.

Data Gaps Requiring Attention

Many of the TCC criteria were difficult to assess because the answers were not known to the assessors. However, the required information is likely to be obtainable and would particularly benefit from operator insights, including:

- Weather Impact Reporting: Systematic collection of data on how extreme weather affects operations
- Equipment Performance: Monitoring system functionality during adverse conditions
- Operational Decision-Making: Data on how climate conditions influence fishing operations
- Infrastructure Resilience: Port and support facility climate impact assessments.

Technical Infrastructure Vulnerability

Monitoring System Resilience

- Communication Systems: Vulnerability of satellite and radio communications during extreme weather
- Data Processing: Shore-based infrastructure resilience to climate impacts
- Power Systems: Backup power capacity for monitoring infrastructure during extreme events.

Vessel Technical Requirements

- Safety Equipment: Climate-resilient safety and emergency equipment standards
- Monitoring Equipment: Weather-hardened monitoring and reporting systems
- Waste Management Systems: Climate-resilient vessel waste storage and handling capabilities.

3.4.2 Implications

The framework highlights potential issues around:

- Safety vs. Compliance: Procedures when safety requirements conflict with compliance. If fishers are exposed to increasingly difficult weather and other events that impact operations, this may affect compliance – for example, a rise in force majeure claims.
- Emergency Reporting: Streamlined reporting for climate-related compliance challenges, as well as ensuring operational procedures are reviewed to account for extreme weather conditions – such as no interruption to search and rescue service.
- Weather Information Systems: Adequate weather forecasting for operational decision-making -this is increasingly important, but outside of WCPFC's control.

4. RECOMMENDATIONS

TCC is invited to:

1. Review the framework's technical and operational components for practical applicability
2. Identify improvements to the relevant TCC climate risk indicators
3. Provide further guidance on issues of interest to TCC.

5. CONCLUSION

The WCPFC CCVA Framework provides TCC with essential tools for understanding and addressing the technical and compliance implications of climate change on fisheries management. The framework's focus on operational aspects, demonstrated through the pilot assessment of five CMMs with particular emphasis on marine pollution, reveals how climate change acts as a risk multiplier for vessel operations and compliance systems.

The TCC-relevant indicators represent the greatest unknowns in the current vulnerability assessment process. While considerable scientific knowledge exists about biological and ecological responses to climate change, far less is understood about:

- Operational system responses to extreme weather events
- Technical infrastructure vulnerability to climate hazards
- Fleet adaptive capacity under financial and operational stress
- MCS system resilience during climate disruptions
- Compliance effectiveness under changing environmental conditions

These knowledge gaps significantly limit the precision of CMM vulnerability assessments and highlights the critical importance of TCC's input in developing appropriate data collection systems and monitoring protocols.

TCC's expertise in technical implementation and compliance monitoring is crucial for ensuring the framework addresses real-world operational challenges so that it remains practical for fleet implementation. Through systematic assessment of climate vulnerabilities, TCC can help ensure that WCPFC's management measures remain effective and enforceable under changing environmental conditions.

The framework represents a proactive approach to climate adaptation, enabling WCPFC to anticipate and address technical challenges before they compromise management effectiveness. TCC's input and oversight will be essential for translating climate vulnerability assessments into practical, implementable management responses, particularly given that TCC-relevant indicators represent the greatest knowledge gaps in current understanding.

ANNEXES

Annex A: Draft WCPFC Climate Change Vulnerability Assessment Framework_FINAL REPORT

WCPFC CMM Climate Change Vulnerability Assessment

Literature Review

21 June 2025

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About this document

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EnviroSea Consulting

EnviroSea Consulting is an experienced service provider specializing in Fisheries Management, Strategy and Governance, Monitoring and Evaluation, Facilitation and Engagement, Project and Program design, and Policy and Regulation. Based in France, we are on a mission to provide focused, effective and practical services that have lasting impact to support our clients in meeting their goals and aspirations.

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Adira Consulting Ltd. brings extensive experience working for both senior management in developing and developed State government, and with and inside a range of multilateral organizations, including U.N bodies. Kerrie has experience in chairing multilateral bodies and Finance and Administration Committees, and she is also the current chair of the Independent Performance Review of the South Pacific Regional Fisheries Management Organization. She has also represented both the Australian Government and Cook Islands Government in a senior capacity at the WCPFC. ADIRA has extensive experience working with a range of international organizations, such as the Pacific Community, the ISSF and the Global Tuna Alliance to develop and implement strategic and operational plans to maximize strategic benefit and available resources.

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Overview

This report responds to the Terms of Reference from the WCPFC requesting a review of active WCPFC CMMs as defined by the Commission, to identify specific provisions that could benefit from additional discussions among CCMs as being vulnerable to climate change. The first step was to compile available advice through a targeted literature review and to identify a definition of vulnerability to be used for the assessment.

This report presents the findings and recommendations of a literature review focused on climate change vulnerability assessments both globally and in the context of the Pacific marine environment.

The literature review was conducted over April – June 2025, using a standardized methodology to source relevant literature and perform thematic analysis. The findings and recommendations in this report have directly informed the design approach of the WCPFC climate change vulnerability assessment framework.

Report structure

This document is presented in three parts:

List of figures

List of tables

Glossary

Acronym	Description
AI	Artificial intelligence
AR	Assessment Reports
CMM	Conservation and Management Measure
CPUE	Catch per unit effort
EEZ	Exclusive Economic Zone
HCVCA	Hazard and Climate Vulnerability and Capacity Assessment
FAO	United Nations Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
LVI	Livelihood Vulnerability Index
NbS	Nature-based solutions
NGO	Non-governmental organization
PICT	Pacific Island Countries and Territories
PIVA	Pacific Islands Vulnerability Assessment
PRISMA	Preferred Reporting Items for Systemic Reviews and Meta-Analyses
RVA	Rapid Vulnerability Assessment
SDG	Sustainable Development Goal
SPC	The Pacific Community
UNFCCC	United Nations Framework Convention on Climate Change
VA	Vulnerability assessment
WCPFC	Western and Central Pacific Fisheries Commission
WMO	World Meteorological Organization

Executive Summary

The Western and Central Pacific Fisheries Commission (WCPFC) is exploring the use of a vulnerability assessment framework to understand the vulnerability of its management framework (in particular its Conservation Management Measures (CMMs)), in response to the existential threat of global climate change. Climate change vulnerability assessments are an increasingly useful tool for understanding and adapting to climate change and reducing the vulnerability of people, systems and assets to its impacts.

This report outlines the findings of an extensive literature review undertaken between April and June 2025 on climate change vulnerability assessments across different contexts, to help inform the development of an appropriately framed and readily applicable WCPFC vulnerability assessment framework.

The review aimed to determine:

- a WCPFC-appropriate definition of 'vulnerability,'
- identify best practice approach(es) to inform the development of a WCPFC-specific framework for assessing climate change vulnerability, and
- key limitations and data gaps that arise in undertaking climate change vulnerability assessments.

The primary objective of the review was to explore how climate change vulnerability has been conceptualized, measured, and addressed across literature, with a particular emphasis on:

- Vulnerability definitions
- VA frameworks
- Assessment methodologies
- Indicators of and factors contributing to vulnerability
- Key insights to strengthen VA design.

This report reflects on 536 individual pieces of literature sourced from across the globe, and across sectors–e.g. fisheries, agriculture and river systems; and across disciplinary contexts such as natural resource management, urban planning and disaster risk reduction. It shows a wealth of literature and ideas, lessons and applications of vulnerability assessments. More specifically, our findings explore both the conceptual understanding of climate change vulnerability through the Intergovernmental Panel on Climate Change (IPCC) as well as its breadth across policy and academia.

Vulnerability definition

It is clear that there is no universally accepted definition of vulnerability, or the concepts and approaches used to define it. Although the IPCC definitions (a total of four with the most recent released in 2021) are widely used in vulnerability assessments, they are not always consistently applied, with either older version continuing to be utilized, or concepts and elements plucked and redefined / rearranged to suit individual case studies. It is also clear that that are many operational frameworks used in practice to assess vulnerability to climate change.

Despite this, we consider the AR6 definition provides the most up-to-date and holistic approach to determining vulnerability in recognition that vulnerability is not just in response to physical hazards, but also those framed around governance, justice and social equity.

Assessment framework design

It is common knowledge that the Western and Central Pacific Ocean (WCPO) and its inhabitants are some of the most at risk globally from the impacts of climate change. As a result, it is essential that an appropriate VA framework considers the overlapping complexities and unique operational realities associated with the WCPO region, but that also specifically considers the specific mandate of the WCPFC, along with its capacity and data availability.

Despite the wide array of different VA frameworks that have been designed globally, many existing methods rely on often very specific quantitative indices, large data sets and extensive scientific modelling capabilities, along with several year timeframes. In our view, these more complex versions are likely beyond the practical requirements of the WCPFC to not only readily apply through consensus-based decision making, or to regularly update and maintain as new information becomes available over time.

Other more pragmatic approaches such as rapid vulnerability assessments (RVAs) were identified. These approaches were centered around running higher level VAs to identify particular concepts or elements that require immediate attention (in cases where good information is available), and / or where further investigation is required as time and resources allow, to fill knowledge gaps.

In our view, the approach best suited for determining the climate vulnerability of individual CMMs is a framework that:

- Readily consolidates existing knowledge (including traditional and local expert knowledge)
- Identifies key climate risks and data gaps in the WCPO region
- Flags issues relevant to CMM revisions
- Is responsive to management
- Enables iterative and less resource intensive updates as and when new information becomes available.

General VA insights

Across the literature common themes were quickly identified. These are summarized in bullet form below.

- **Transparent, standardized methods** are essential to enable regular updating, replication, and to enable results to be integrated into other local, regional or global assessments as required (e.g., harmonization).
- **VAs must go beyond a single perspective**, integrating ecological, social, economic, cultural and political dimensions to ensure the full spectrum of influencing factors are considered.

- **Data gaps are common**. It is essential to readily incorporate all data sources (quantitative and qualitative) into assessments noting that often in cases where there are quantitative information gaps, there is available qualitative information from local communities and experts.
- **Suitable data management capacity** is required to ensure ongoing collection, analysis and storage of data records over time. This directly supports the ability to track vulnerability through monitoring and regular assessments.
- **Regular stakeholder engagement**, with a focus on **traditional and expert knowledge holders**, is essential. Early engagement with stakeholders and local communities should be factored into the design of a VA, to help identify those elements and information gaps that can be readily filled through locally held knowledge and traditional know-how / practices. Further, regular engagement pathways and channels should be implemented that enable regular reporting and information to be collected to update VAs on a regular basis. Not only does this approach ensure robust information sharing, but it also directly improves acceptance and social cohesiveness around adaptation activities resulting from VAs.
- **Capacity building and training** are essential to ensure VAs are both effectively designed and implemented, but that they are also effectively maintained over time. As mentioned in bullet one above, transparent and standardized methodologies, supported with standard operating procedures and guidance information, is considered best practice.

Pacific marine VA insights

In addition to the common themes outlined above, specific VA insights related to the Pacific marine environment were also identified and explored. The key specific themes included:

- **Ensuring gender-sensitive approaches** in the collection of traditional knowledge to inform a VA assessment is essential in the Pacific, recognizing that traditional knowledge is often differentiated by gender.
- **Funding is a very real barrier** to both establishing and maintaining VAs over time. VAs that require in-depth technical expertise and comprehensive analysis take more time and come with a higher cost, whereas low input, low-cost VAs may generate an oversimplified assessment that limits suitable adaptive actions to be generated. A balance must be struck, with the knowledge that effective VAs must be maintained over time.
- Pacific marine **VA frameworks need to be flexible** to be updated and adjusted regularly overtime as conditions and knowledge evolve. This is considered essential, noting climate change and the Pacific marine environment are in a relatively rapidly evolving state.

Key conclusions

1. The IPCC's AR6 vulnerability definition should be used

2. A pragmatic ‘rapid assessment’ approach is best suited to design a WCPFC VA framework that is focused on assessing CMM vulnerability, ensuring it meets those requirements set out in ‘Assessment framework design’ above
3. Key additional VA framework design considerations include:
    a. Transparent and standardized methodology
    b. Multi-faceted approach utilizing common fisheries indicators
    c. Enables the use of both quantitative and qualitative information
    d. Presents a low-cost option balanced against meaningful VA results
    e. Provides flexibility, enabling the addition / removal of indicators and information sources as understanding and knowledge evolves over time.

Part One: Introduction

1 Context

1.1 Global climate change

1.1.1 A warming earth

Global warming from human activities continues to increase with the global surface temperature estimated by the World Meteorological Organization (2025) to be 1.34°C to 1.41°C higher than pre-industrial levels (1850-1900). It is estimated that there is an 86% chance that global average temperatures will exceed 1.5°C above pre-industrial levels in at least one of the next five years and there is a 70% chance that the global five-year temperature average will exceed 1.5°C.

It is well documented that exceeding a global average temperature of 1.5°C will result in profound climate and weather-related impacts and that exceeding the critical threshold of 2°C will result in cascading and dangerous impacts across all global environments and ecosystems.

1.1.2 Climate change is an urgent, multi-faceted and interconnected threat

Human-induced climate change is widely recognized as an urgent, complex and accelerating crisis that continues to deliver more frequent and adverse impacts to global ecosystems, populations, settlements and infrastructure (UN 2021c; WMO 2025; Dasgupta et al. 2023a). Although a standalone threat, it is also deeply intertwined with non-climatic global challenges, such as biodiversity loss, overall unsustainable consumption of natural resources, ecosystem degradation, rapid urbanization, human demographic shifts, and social and economic inequalities and public health (UN 2021c; Dasgupta et al. 2023a; WCPFC Secretariat 2023; Bell 2016; WMO 2025). This makes it a multi-faceted and complex issue to understand, manage and adapt to.

The observed rise in weather and climate extremes has already led to some irreversible impacts as natural and human systems continue to be pushed beyond their ability to adapt and respond (Dasgupta et al. 2023a). In addition to the increasing frequency and intensity of single extreme climate and weather events (e.g., droughts, heavy precipitation events, fires, typhoons, cyclones and hot extremes), slow onset changes (e.g., sea level rise, ocean warming and acidification, permafrost thaw, glacial retreat) continue to advance, delivering increased instances of irreversible change[1] and exacerbating the impact of single extreme weather events (Dasgupta et al. 2023a).

Marked changes in seasonal timings and environmental conditions have also led to widespread deterioration of ecosystems including their structure, function, resilience and adaptative capacity, driving significant changes in animal behavior, food webs, lifecycles and species distribution. In some cases, mass die-offs of species and localized extinction events have been observed (Vasilica et al. 2023; Anthony 2016; Savage et al. 2020; Foden et al. 2019). In fact, half of the terrestrial species assessed globally in the context of climate change, have shifted poleward or to habitats of higher elevation (IPCC 2023a). This trend is not unique to the terrestrial environment with species in the marine environment also demonstrating seasonal

[1] All ecosystems including those in terrestrial, freshwater, coastal and open-ocean marine environments

reproductive, lifecycle and distributional changes in response to warming temperatures and marine heatwaves and hotspots (Dasgupta et al. 2023a; Bell et al. 2021; Rosengren et al. 2020; Silva et al. 2022).

Collectively, the impacts of climate change are generating significant socioeconomic and global health problems for communities (particularly indigenous communities) and populations through acute food and water insecurity, increased disease, and trauma and health injuries (including death) suffered during extreme weather events. Further, vulnerable communities who have historically contributed the least to climate change are well-known to be disproportionately affected by these impacts (Dasgupta et al. 2023a; Campagnolo and Davide 2019; Retnowati et al. 2019).

1.2 Overview of the multilateral response to climate change

The multilateral response to climate change has been ongoing for four decades. As extreme weather and climate related events continue to occur on a more frequent and severe basis, the multilateral response continues to strengthen in recognition that a global effort is required to effectively manage it and that it is beyond the capability and responsibility of any singular nation.

1.2.1 International Panel on Climate Change (IPCC)

In 1988, the establishment of the IPCC was endorsed by the United National General Assembly to initially provide a review on the state of knowledge of climate change, including known social and economic impacts resulting from climate change, and recommendations on potential response strategies and elements to be included in a possible future international convention on climate, now known as the United Nations Framework Convention on Climate Change (UNFCCC). Its primary mission is to provide policymakers with regular, rigorous, and balanced scientific assessments on climate change, its impacts, potential future risks, and options for adaptation and mitigation.

Since that time, the IPCC has played a central role in shaping the global understanding of climate change. It is the leading international body for assessing science related to climate change. It is at the forefront of generating regular scientific assessments (Assessment Reports (AR)), methodology reports, special reports, technical papers and policy positions on the current state of climate change, future scenarios and pathways forward for governments and the UNFCCC Secretariat to use to navigate, minimize and prepare for climate change challenges as they become more exacerbated in the future.

The IPCC releases ARs every 5-7 years which are comprehensive evaluations of climate science. Each report considers the physical science basis, impacts, adaptation and vulnerability, and mitigation of climate change.

Six ARs in total have been generated by the IPCC, with the latest released in 2023 (AR6): "*Climate Change 2023 Synthesis Report*"(IPCC 2023a). The findings and recommendations in the report were directly informed by the Working Group II report "*Climate Change 2022: Impacts, Adaptation and Vulnerability*" (IPCC 2023a). Both reports are internationally recognized as best practice knowledge, including in how vulnerability is defined and categorized in the context of developing adaptation strategies.

IPCC reports serve several critical functions, both scientifically and politically: To synthesize scientific knowledge, to inform policy making, to establish scientific consensus and to educate and raise awareness.

1.2.2 United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC was established in 1992 and it has universal membership with 198 Parties. The UNFCCC is also the parent treaty of the Paris Agreement (2015) and the Kyoto Protocol (1997), which all have the ultimate objective of stabilizing greenhouse gas emissions in the atmosphere to prevent the ongoing human impact on the global climate system to ensure sustainability.

The 198 Parties meet annually at its Conference of the Parties to review, share and progress actions and commitments to continue global climate advancements in accordance with the objectives of the UNFCCC, the Paris Agreement and the Kyoto Protocol.

1.2.3 Food and Agriculture Organization of the United Nations (FAO)

The FAO promotes mainstreaming the adoption of climate change into global food and agriculture management and production, including fisheries and aquaculture management. It does this by providing a range of services to help countries effectively adapt to climate change. These include the provision of strategic guidance and best practice information (including for vulnerability assessments associated with different sectors), policy and adaptation planning support, and country support to access global climate change finance. As an example, the FAO has consistently provided and improved best practice guidance on assessing climate change vulnerability / risk assessments in the fisheries and aquaculture sectors (global or Pacific focused) since 2008 (See for example Comte (2021), Brugere and De Young (2015), Barange et al. (2018) De Young (2016) and Fellman (2012)).

1.3 Climate change in the Pacific region

Climate change is an existential threat to the Pacific region with impacts already seen and causing significant disruption (Dudley et al. 2021; Warrick et al. 2017). Some examples include Fiji and Tuvalu, where higher sea-levels coupled with frequent extreme weather events (cyclones and typhoons), has led to increased instances of severe flooding events and infrastructure damage (KIWA 2023). Further examples include the impacts on Pacific Island Countries and Territories (PICTs) more generally, including declining fish stocks as a result of habitat loss and redistribution of species, which threaten food security and local economies, health and livelihoods (Giddens et al. 2022; Bell et al. 2024).

Unchecked climate change poses a catastrophic threat to the Pacific region through:

1. physical environment changes such as extreme weather events (severe typhoons, droughts, flooding), sea level rise, ocean acidification and loss of habitat
2. health risks along with increased disease, and growing food and freshwater insecurity, and
3. social impacts on culture, traditional practices, gender equality and human rights, with a disproportionate effect on women, girls, the elderly and disabled groups (Pacific Community (SPC) 2023b.

The majority of PICTs are considered vulnerable and at high risk to the aforementioned impacts of climate change, due to their natural physical susceptibility coupled with a lack of coping and adaptive capacity (Saverimuttu 2021). In fact, at the current global warming rate, it has been predicted that some Pacific islands may be uninhabitable by the mid-21st century (Pacific Community (SPC) 2023b), despite the regions' minimal contribution to global greenhouse gas emissions (Pacific Community (SPC) 2023a).

1.3.1 Overview of climate change impacts on the Pacific marine environment

The Pacific marine environment is of paramount importance to PICTs as a primary food basket, economically, socially and culturally. However, it currently faces unprecedented stress from climate change impacts that threaten its ability to sustain current ecosystem functions that PICTs depend on for survival and economic stability (Bell et al. 2024).

Observed increases in sea temperature, ocean acidification, and frequency of marine heatwaves and violent topical weather events (e.g., cyclones), are causing the degradation of coastal marine ecosystems, including those reliant on coral reef, mangrove and seagrass habitats (Giddens et al. 2022; Bell et al. 2024). These impacts are directly impacting subsistence fishing productivity, local community fish supply and long-term food security, in addition to critical coastal protection that these habitats often provide (e.g., coral reef barriers protecting internal lagoons and communities from the open ocean (Giddens et al. 2022; Bell et al. 2024; WCPFC Secretariat 2023).

Marine fisheries, particularly tuna resources, are also experiencing significant changes from climate change impacts, including redistribution (both eastwards and polewards), stock biomass changes and changes in catch rates. These changes are directly affecting industrial tuna fisheries and also pose a serious threat to PICTs that generate significant revenue from license access fees to fish for tuna within national Exclusive Economic Zones (EEZs) (Bell et al. 2024; see also routine advice to the Commission e.g. FFA Secretariat and SPC-OFP Secretariat 2024).

Collectively, the impacts from climate change on the Pacific marine environment are already significant and readily observable. Integrated and holistic adaptation management approaches are considered essential to effectively manage the impacts of climate change in the region.

1.4 Western and Central Pacific Fisheries

1.4.1 Western and Central Pacific Fisheries Commission

The *Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific* Ocean (WCPF Convention) (2000) came into force on 19 June 2004, following six years of negotiations that began in 1994.

The Western and Central Pacific Fisheries Commission (WCPFC) was established by the WCPF Convention. The Commission serves as the decision-making forum responsible for setting Conservation Management Measures (CMMs) to effectively manage fishing activities, highly migratory Stocks, and associated species within the WCPO region.

The Commission meets annually and currently comprises 26 Members, eight Cooperating Non-members, and seven Participating Territories (a total of 41 CCMs). The Commission is supported by a dedicated Secretariat which is based in Kolonia, Pohnpei, Federated States of Micronesia (FSM).

The Commission supports three subsidiary bodies that develop and provide specialized advice and recommendations to support decision making by the Commission. These include:

1. The Scientific Committee (WCPFC-SC)
2. Technical and Compliance Committee (WCPFC-TCC)
3. Northern Committee (WCPFC-NC).

1.4.2 WCPFC response to climate change

The WCPFC and its subsidiary bodies have been actively discussing and progressing climate change related work since 2008 (WCPFC Secretariat 2023). Early discussions and advancements related mostly to the design and improvement of a Spatial Ecosystem and Population Dynamics Model (SEAPODYM) and related ecosystem indicators to help predict highly migratory species distributional changes (WCPFC Secretariat 2023).

In 2019, at the 16th Regular Session of the Commission (WCPFC16), the WCPFC held discussions that recognized the serious threats posed by climate change to highly migratory species and wider ecosystems of the WCPO region (refer). These discussions culminated in the adoption of *Resolution 2019-01 on Climate Change as it Relates to the WCPFC (WCPFC 2019)* .

In 2023, the Commission reaffirmed the resolution by agreeing to develop a dedicated workplan and support an assessment of the susceptibility of WCPFC CMMs to the impacts of climate change (WCPFC 2023).

In 2024, WCPFC21 adopted the WCPFC Climate Change Workplan 2024-2027 (see Attachment 13 WCPFC 2023), which outlines the specific activities and tasks to be taken by the Commission and its three subsidiary bodies to address climate change impacts on WCPFC fisheries.

2 Methodology

This literature review uses a structured and transparent methodology to synthesize current research on climate change vulnerability assessments. The review focuses on understanding the key concepts, assessment methods, definitions of vulnerability and adaptive responses associated with climate vulnerability.

While the WPCFC is interested in the fisheries/marine environment context, this review took an expansive approach to research climate change vulnerability assessments generally, and across other disciplines, in case there were lessons that can be readily applied in the WCPFC context.

2.1 Aim

The review aimed to determine a WCPFC-appropriate definition of 'vulnerability,' identify best practice approach(es) to inform the development of a WCPFC-specific framework for assessing climate change vulnerability and to identify key limitations and data gaps that arise in undertaking climate change vulnerability assessments.

2.2 Objective

The primary objective of this review is to explore how climate change vulnerability has been conceptualized, measured, and addressed in scholarship and policy. Emphasis was placed on identifying:

- How vulnerability is conceptualized and defined
- VA frameworks
- Methods for assessing vulnerability
- Case studies illustrating real-world applications to assess climate change vulnerability
- Indicators of and factors contributing to vulnerability
- Key insights to strengthen VA design

2.3 Scope

The review covers literature published between 2015 and 2025, focusing on peer-reviewed journal articles, book chapters, guidance and relevant information sources available in the English language.

Key vulnerability themes explored were:

Physical vulnerability

Impact on infrastructure (e.g. coastal villages, port infrastructure), land (coastal degradation, encroachment etc.) operations

Environmental vulnerability

Impacts on habitats and ecosystems (species distribution, food-web impacts, life-cycle impacts, invasive species, die-offs) as a result of changes in sea-level, tides, currents, surface temperatures, gradient shifts, ocean acidification, more frequent severe natural events (cyclones, typhoons, floods, fires etc.)

Social vulnerabilities

Impact on marginalized communities, impact on people and communities in general, health and food availability

Economic vulnerability

Impact on industries and coastal communities / livelihoods

Cultural vulnerability

Impact on indigenous communities, traditions, practices, beliefs and cultural identity

Adaptation

How systems (communities, ecosystems, environments) can adapt or mitigate climate change impacts

2.4 Approach

2.4.1 Search Strategy

A comprehensive search was conducted using Scopus, which was selected because of its broad literature base relevant to this field. Google Scholar was used as a supplement to Scopus because it casts a wider net and includes many documents in its results (including relevant grey literature) that Scopus deliberately filters out.

The following terms were searched in both Scopus and Google Scholar.

- Climate change vulnerability
- Climate change impact
- Socioeconomic vulnerability
- Physical vulnerability
- Adaptive capacity
- Resilience to climate change (Marine)
- Climate change and inequity
- Sustainable development and vulnerability
- Socio-economic vulnerability

Boolean operators and truncation were used to refine results. Filters were applied for publication date (2015–2025), language (English), document type (articles, books, reports) and topic area relevance (i.e., journals from environment and biological sciences and policy, earth and planetary science; and not from disciplines such as energy, medicine, computer science, chemical engineering). Where a search returned significant results (+500), the first 500 records for each search term were reviewed.

2.4.2 Inclusion and Exclusion Criteria

Inclusion Criteria

- Peer-reviewed articles and reputable institutional documents (e.g. international organizations such as IPCC, WCPFC, SPC, FAO, UNFCCC) not more than 10 years old[2]
- Studies that explore theoretical frameworks, case studies, empirical research on climate vulnerability
- Country reports and relevant policy / information papers
- Studies published in English

Exclusion Criteria

- Articles on non-vulnerability climate change topics (e.g. mitigation)
- Non-peer reviewed articles
- Gray literature not specifically relevant

[2] Notwithstanding this, many case studies applied operational frameworks developed prior to 2015. Given this, and particularly as they are referenced in Annex B, we have referenced them in full.

2.4.3 Screening and Selection Process

A literature review was conducted following the PRISMA 2020 guidelines (Page et al. 2021) to ensure transparent and replicable reporting. The identification, screening, eligibility, and inclusion of studies were documented in a PRISMA flow diagram (see Figure 1), which outlines the number of records retrieved, screened, excluded, and included in the final synthesis. All identified records were extracted for reference management. The final sample consisted of 536 sources deemed directly relevant to the review objectives.

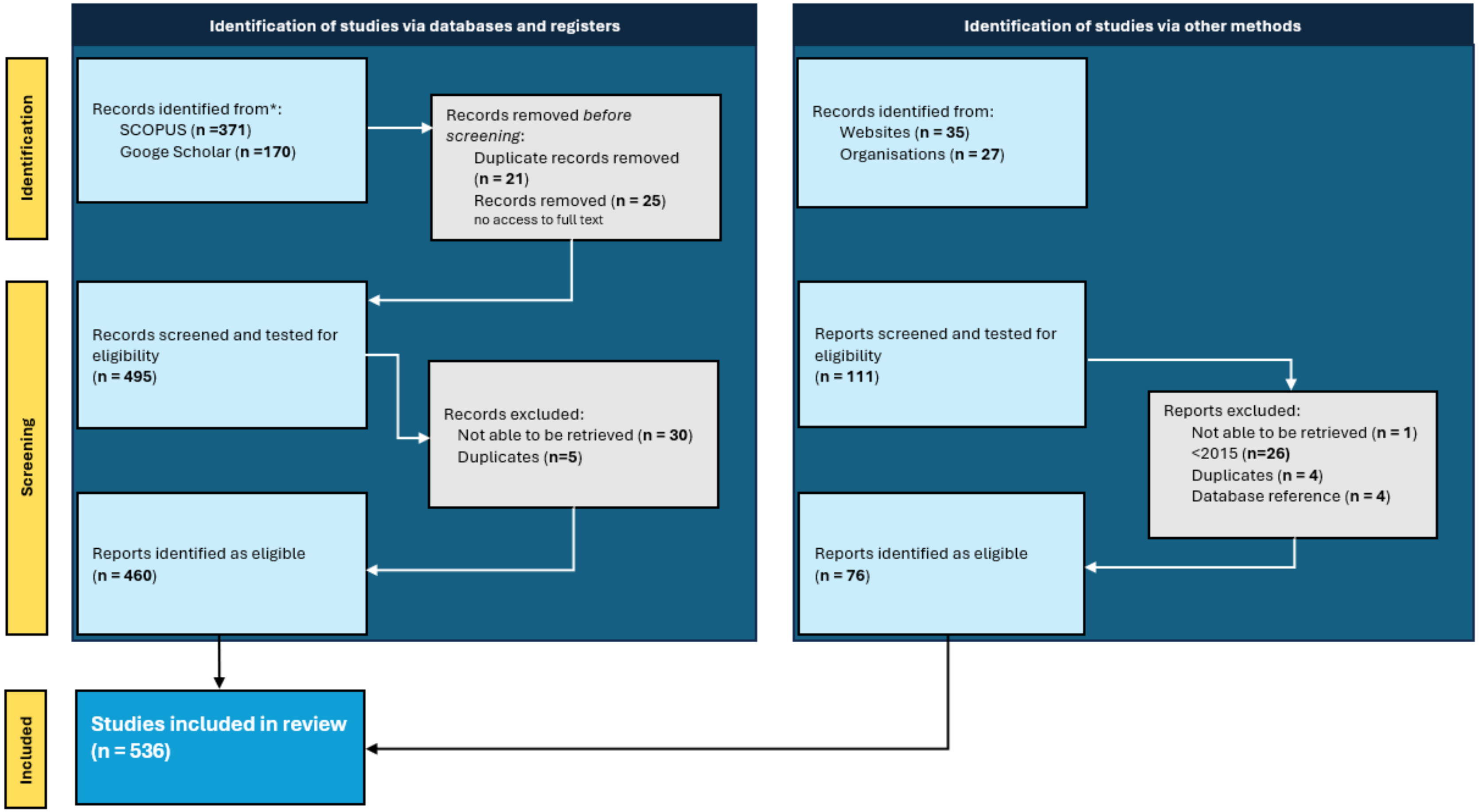

Figure 1. *PRISMA 2020 flow diagram illustrating the study selection process for climate change vulnerability literature*

2.4.4 Data Extraction and Thematic Analysis

A data extraction template was developed consisting of nine categories with a sub-set of information categories used to help summarize the required information elements from each identified information source. The nine categories and associated sub-categories are presented in Table 1 below.

Table 1. *Categories and sub-categories used to summarize identified information sources*

Category	Sub-category
Reference information	• Title • Authors • Year • Filename
Themes	• Region / location • Application (terrestrial, marine or both) • Types of climate change vulnerability identified
Summary	• Study objective and research question • Type of methodology used • Description of the methodology • Key findings • Gaps and proposed solutions
Definitions	• Climate change definition • Climate change vulnerability definition • The concept of climate change described • Vulnerability criteria specified
Contributing factors	• General factors contributing to climate change vulnerability • Specific contributing factors to climate change vulnerability • WCPFC relevant climate vulnerability factors
Framework	• The name of the vulnerability framework used • Description of the vulnerability framework • Approach to incorporate traditional knowledge into the vulnerability assessment framework • Future-proofing features found in the vulnerability assessment framework
Key takeaways	• Identified challenges with assessing climate change vulnerability • Identified solutions to the challenges with assessing climate change vulnerability • Lessons learnt from climate the change vulnerability assessment
Supporting rationale	• Supporting information to justify the findings of the above categories

To support the data extraction and thematic analysis process, the AI research assistant tool Elicit (developed by Ought) was used to assist with initial screening, summarizing abstracts, and identifying thematic similarities across studies. Further, the AI research assistant tool Julius (developed by Caeser Labs Inc.), was also used to help synthesize commonalities and cross-cutting themes across the categories. All final decisions regarding inclusion of findings, interpretation, and synthesis were made by the author(s) following suitable cross-checking and validation exercises.

2.4.5 Limitations

The results of this review are largely reliant on the search terms used, which are focused on climate-related vulnerability assessment. The non-inclusion of other related terms such as hazard, exposure, risk, and disaster, among others, narrowed the scope of the review to the field of climate-related vulnerability assessment.

Part Two: Our findings

3 Overview

Adaptation to climate change and its associated variability is one of today's most pressing global societal challenges. In the cyclical planning process of adapting or adjusting to the actual or expected climate and its effects, climate-related vulnerability and risk assessments are an important phase because they are designed to help in the identification of adaptation options and measures.

Climate change vulnerability is a key component of both Disaster Risk Reduction and Climate Change Adaptation (Kelman, Mercer, and Gaillard 2017). Vulnerabilities arise from social, economic, physical, and environmental factors (Jeevamani et al. 2021).

Climate change vulnerability assessments identify which species or populations are threatened and where, when, why, and to what degree they are vulnerable (Glicket et al, 2022, as cited in Thurman et al. 2022). Importantly, climate change vulnerability assessments are not about the impacts of resource mismanagement; it is important to distinguish between mismanagement and climate change impacts (Froese, Papaioannou, and Scotti 2022).

According to the IPCC, 'a vulnerability assessment' is the integration of sensitivity to climatic variations, adverse climate change, and adaptive capacity which is dependent on sensitivity, exposure and adaptive capacity" (IPCC 2023a; Oloyede, Benson, and Williams 2021). A vulnerability assessment involves the process of identifying a problem, quantifying it and assessing the risk rate encompassing the formulation of development approaches to reduce the risk and level of susceptibility.

We reviewed 500+ articles relating to climate change vulnerability assessments, including some 300+ case studies with a vulnerability assessment and a further 160+ exploring climate change vulnerability frameworks across a range of marine and terrestrial contexts, including fisheries, and across a range of geographies (see Figure 2). In doing so, we sought to find a common or practical definition that could be adopted by the WCPFC and readily applied to its own vulnerability assessment framework.

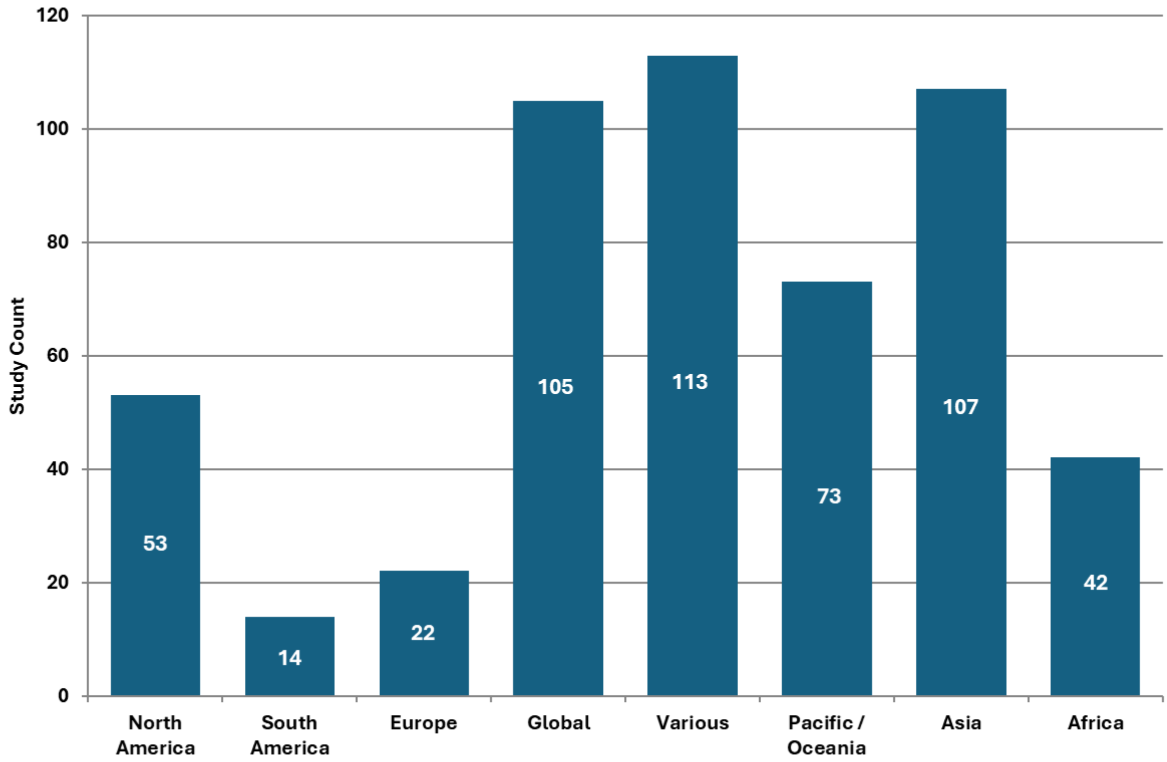

Figure 2. *Number of literature sources by region (Various = more than one regional application but not global; Total n=529 (7 studies cross-referenced without determining the study focus)*

4 Definition of vulnerability

4.1 Introduction to the high-level concepts

The concepts of hazard, sensitivity, and adaptive capacity have long been foundational in understanding how societies and systems respond to environmental and climate-related challenges.

Generally, now, a hazard refers to a potentially damaging physical event or trend; exposure describes who or what is affected by the hazard; sensitivity describes how significantly a system is affected by such disturbances; and adaptive capacity reflects the ability to adjust, cope, or recover.

Over time, and with growing experience in both research and practice, the meanings and applications of these concepts have evolved. This evolution laid the groundwork for more integrated frameworks of vulnerability, which came to represent not only susceptibility to harm but also the underlying social and economic conditions that shape responses. As climate and disaster risk discourses advanced, the concept of risk was introduced to combine the probability of hazardous events with the potential consequences, emphasizing the dynamic interaction between hazard, exposure, and vulnerability. In this way, as is demonstrated below, vulnerability is no longer seen as an isolated concept, but as embedded within complex systems influenced by governance, inequality, and historical context.

These concepts, now highly nuanced, are discussed in detail below and are essential components of a vulnerability framework.

4.2 The evolution of the IPCC definition(s) of vulnerability

The IPCC's definition of climate change vulnerability has undergone significant transformation over the past two decades. Earlier assessment reports primarily conceptualized vulnerability as a technical or biophysical issue—one grounded in the physical exposure of systems to climate hazards and their inherent ecological sensitivity. However, more recent reports, particularly the Sixth Assessment Report (AR6) (Dasgupta et al. 2023b), reflect a deeper, more integrated understanding that vulnerability is not merely ecological or physical, but profoundly social, political, and inequitable. This progression has helped shift marine and fisheries policy toward more inclusive, justice-oriented adaptation strategies.

Many of the reviewed studies drew directly from IPCC definitions of vulnerability or at least reference them implicitly. However, they do not always align with the definitions most contemporary to the time of the study's publication. This discrepancy underlines the value of first outlining the evolution of IPCC definitions before turning to how climate change vulnerability is presently framed in research and policy.

To date, the IPCC has released six comprehensive Assessment Reports, four of which—TAR (2001)(IPCC 2001), AR4 (2007) (IPCC 2007, 200), AR5 (2014) (IPCC 2014), and AR6 (2021–2022) (IPCC 2023b) have explicitly addressed the concept of vulnerability, though the framing of 'vulnerability' has developed over time (Table 2).

The early reports (TAR and AR4) were hazard-centered, with a strong emphasis on biophysical vulnerability, which is how exposure to climate hazards and ecological sensitivity shaped a system's susceptibility. In this framing, vulnerability was largely defined as a function of exposure, sensitivity, and adaptive capacity. For example, in TAR, vulnerability was conceptualized as the outcome of how much a system is exposed to climate stimuli, how sensitive it is to those stimuli, and how well it can adapt.

AR4 expanded on this by integrating socio-economic factors and emphasizing the role of governance and institutional context. In AR4, vulnerability referred to both the vulnerable system itself and the impacts upon it, and adaptive capacity was understood as something that modulates both exposure and sensitivity. While exposure and vulnerability were key terms in both AR4 and AR5, their meanings shifted significantly between the two (Figure 3). In AR4, exposure was internal to the vulnerability framework; in AR5, it became external, defined alongside hazard and vulnerability as a component of climate risk.

Table 2. *Summary overview of the focus and approach of the IPCC VA frameworks*

Assessment Framework	Focus	Impact on assessment approach
TAR & AR4	Focus Biophysical vulnerability + adaptive capacity	Emphasis on stock resilience, fisher adaptation tools (e.g. gear, livelihoods)
AR5	Risk framing (hazard × exposure × vulnerability)	Integrated ecosystem–human system risk assessments, early warning systems, spatial planning
AR6	Social vulnerability, justice, equity	Policies addressing inequality, governance reform, inclusive adaptation, recognizing Indigenous and local knowledge

AR5 introduced a more explicit risk-based framework, redefining vulnerability as the propensity or predisposition to be adversely affected. It included sensitivity and adaptive capacity but positioned exposure and hazard as distinct components of risk. It consciously uses terms that embrace uncertainties in simulations of future climate impacts.

Hazards—previously embedded in the concept of exposure—were now recognized as separate, climate-related events or trends (e.g., extreme weather), while exposure referred to the presence of people, ecosystems, or assets in places that could be adversely affected. This reconceptualization aligned the IPCC more closely with international disaster risk reduction frameworks and emphasized that vulnerability is shaped not only by biophysical factors, but also by systemic attributes and the capacity to cope and adapt. It recognizes that interconnected systems can amplify vulnerabilities.

In AR5 and AR6, a key distinction emerged: both reports treat climate risk as a combination of hazard, exposure, and vulnerability, but AR6 goes further by framing vulnerability within broader systems of inequality, governance, historical marginalization, and power dynamics. It places vulnerability in direct conversation with global development goals, notably the Sustainable Development Goals (SDGs, UN 2015) highlighting the interdependence of climate adaptation, social equity, and sustainable development. AR6 also calls for more data-driven vulnerability assessments, encouraging the use of quantitative indicators and metrics to inform planning and policy.

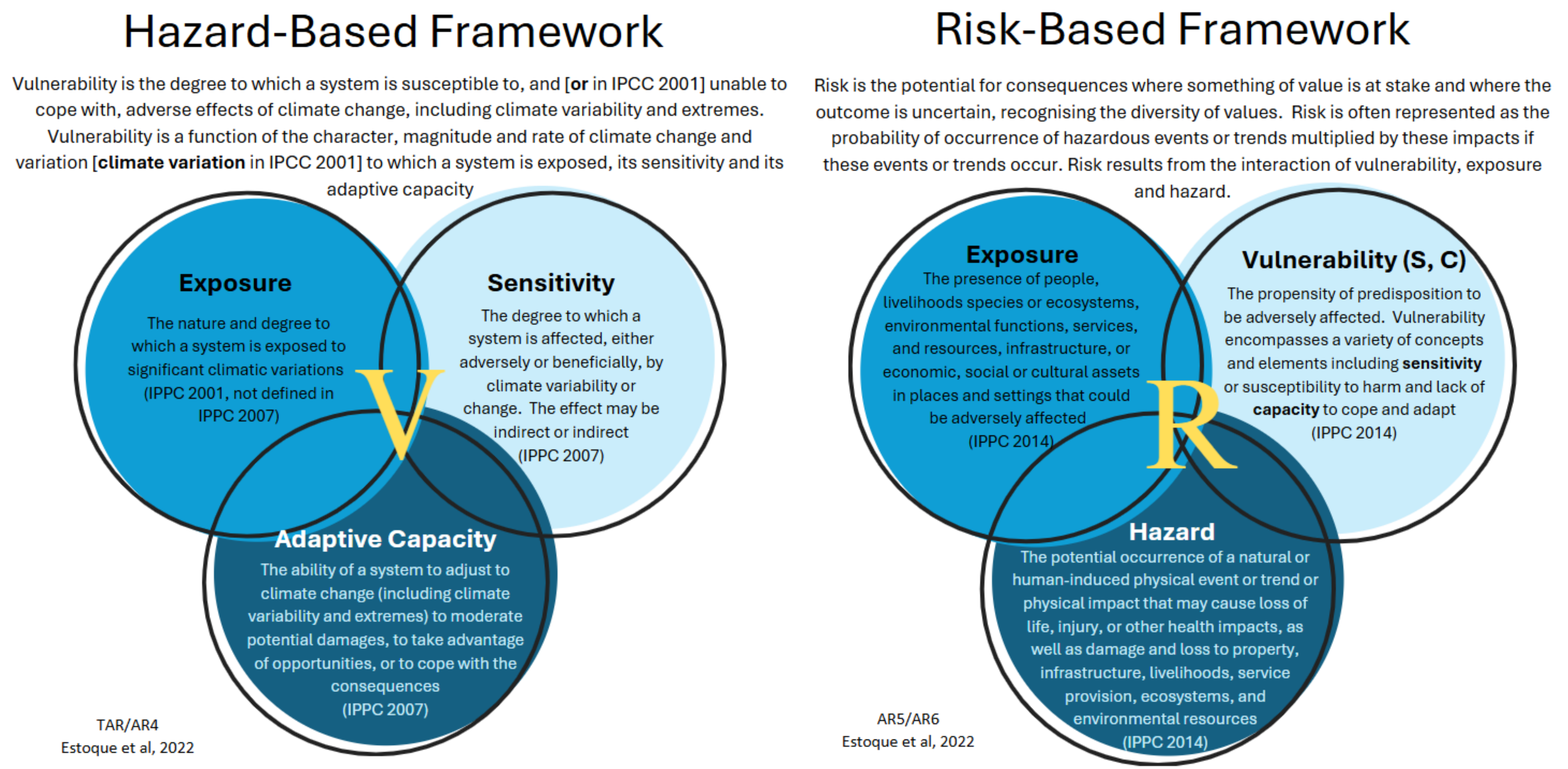

Figure 3. *VENN diagrams by Estoque et al (2022) of the hazard-based approach and risk-centered approach*

Despite these conceptual advancements, AR5 and AR6 definitions have not been widely adopted in practice. A study by Estoque et al (2023) examined how well the AR5 definition of vulnerability had been adopted in vulnerability assessments published between 2017 and 2020 across disciplines, including fisheries. It was found that most studies continued to use TAR or AR4 frameworks, with only limited uptake of the AR5 conceptualization. Some studies used entirely alternative definitions. Estoque et al theorized the reasons for this limited adoption are likely multifaceted, including researcher preference, potential confusion or misunderstanding, and a lack of awareness of newer frameworks. Practical constraints, such as data limitations or institutional inertia, may also play a role.

Importantly, it remains unclear whether the newer conceptualizations invalidate or replace earlier definitions. While frameworks have evolved, many of the foundational elements—such as sensitivity and adaptive capacity—remain relevant, even if their positioning within the overall framework has changed. In our view, the shift from a vulnerability-based model (TAR/AR4) to a risk-based model (AR5/AR6) (refer Figure 2) represents a broadening of scope rather than a complete rejection of previous approaches

A summary comparison of these reports and their approach to assessing vulnerability is attached as Annex A.

4.3 Vulnerability definitions across academic discourse

A significant body of case study research has developed over the last decade focusing on complex interactions between climate change and society in specific locations (Debortoli et al. 2019a). Across the literature within this review, it is clear that there is no single or uniform definition of "climate change vulnerability". This is, in part, because the conceptualization of climate change vulnerability and adaptation has changed over time from the biophysical aspects of vulnerability to a view that includes more social aspects (Bertilsson 2023). Consistent with the findings in Estoque et al 2022, many studies in the literature review adopted their own definition, or specifically limited the definition to physical factors specific to their assessment ((See, for e.g Closset et al. 2018).

Many authors comment that the definition of 'climate change vulnerability' is dynamic (e.g Adraoui and Jaafar 2023), context-dependent (e.g Silva et al. 2022; A. Thomas et al. 2020), scale-dependent (e.g A. Thomas et al. 2020) and deeply multi-faceted (e.g Ludeña and Yoon 2015). It depends on who is being assessed, on what scale, and data availability (Savage, McIver, and Schubert 2020)). The term 'vulnerability', more generally, has been used with various meanings and by many researchers in food security, natural hazards, disaster risk, public health, global environment, climate change or development economics, which includes the orientation of the vulnerability analysis (Closset et al. 2018)). This explains the many definitions and perspectives across literature.

Some researchers have used multiple definitions of vulnerability in a single study: be it early and late IPCC definitions (Vo and Tran 2022), IPCC definitions and alternative definitions (Jeevamani et al. 2021; Bedeke 2023; Otto et al. 2017), or explicitly comparing the impact of the hazard-based and risk-based IPCC definition within the same assessment (e.g Shouvik Das et al. 2020). Most authors did not explain their rationale for the adoption of implementation of a particular vulnerability definition. Few (such as Rouleau et al. 2022a; Valera and Sharifi 2025; Cangüzel and Coşkun Hepcan 2024) explicitly drew on the AR6 approach, despite 54 Articles within the review being published after its release.

There are more than 80 unique definitions of climate change vulnerability across the literature reviewed. Notably, of the ~500 records reviewed, definitions not modelled on the IPCC definitions were very different – some were very specific to a situation (i.e. to assessing social aspects of climate change vulnerability; and some (particularly ecologically-related definitions) had no resemblance to IPCC definitions (e.g Bedeke 2023; Lapola et al. 2020). The remaining records did not propose a definition of climate change vulnerability. It was outside the scope of this review to determine whether that affected the merit of the assessment.

Rather than list all of these out, we broadly grouped these definitions firstly to determine whether there was a common approach taken across studies; and secondly to determine which, if any, IPCC definition was most widely used (Table 3).

These results show that the IPCC TAR/AR4 definitions continue to be the most popular definitions, despite two substantive updates from the IPCC, and notwithstanding that all the literature within this review was published after the adoption of AR5 (Figure 3) (Figure 4). It is hard to determine the reason for this, but it is possible that the TAR/AR4 definition persists because it was well established for a long period and there are a wealth of assessments to turn to for guidance; and it may also be because the data needs and assessment and invariably more complex under the AR5 and AR6 framework. This fact is particularly important for the WCPFC in determining how it will proceed.

Table 3. *Number of references related to individual vulnerability assessment definitions (n=262)*

Definition premise	**Number of references**
Based on, or very similar to IPPC TAR / AR4	**128** (49%)
Based on, or very similar to IPPC AR5	**30** (11%)
Based on, or very similar to IPPC AR6	**4** (2%)
Author's Own - -Susceptibility to a physical factor *Expressed in terms of the mere exposure to physical factors or a susceptibility to a climate event occurring e.g a cyclone or flood.* *(Similar to the AR5 definition of exposure, a component of risk).*	**23** (9%)
Author's Own - -Susceptibility of a system to a climate change impact *Expressed in terms of an impact on an ecological system arising from climate-related impacts such as sea surface temperature increases and habitat changes*	**27** (10%)
Author's Own – Other *This is a catch all category for author-developed definitions that do not neatly fit into the categories above. This also includes definitions blend IPCC definitions in a way that confuses their different concepts or which only refer to one component of climate vulnerability/risk as given by the IPCC*	**50** (19%)

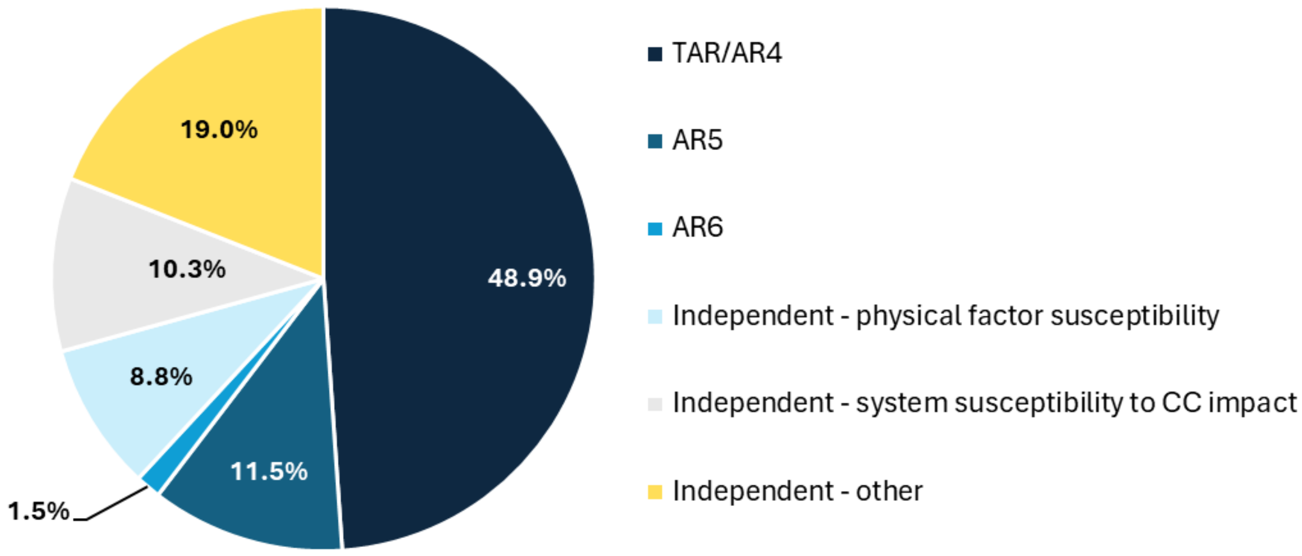

Figure 4. *Breakdown of reviewed information sources by identified vulnerability assessment category*

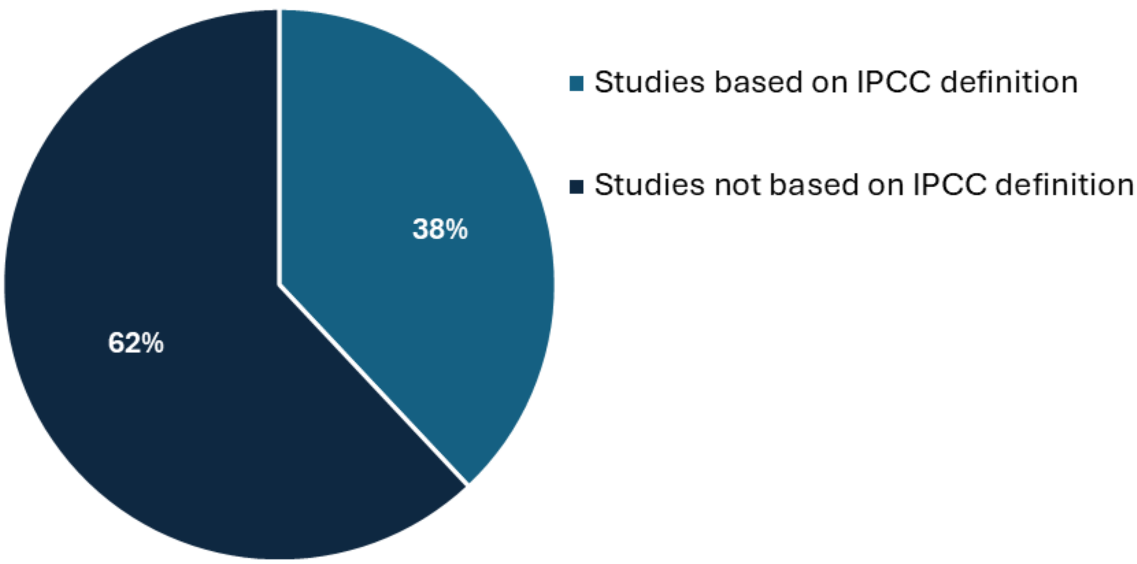

Figure 5. *Percentage of reviewed studies using and not using an IPCC vulnerability assessment definition*

4.4 Definition of vulnerability concepts

It is clear that exposure, sensitivity and adaptive capacity are fundamental components of a vulnerability assessment, and are the central parts of the 'risk' equation. Risk is focused on the likelihood that an event will happen and the consequences if that event were to occur. As noted above, the role of 'exposure' changed within the IPCC framework between the AR4 and AR5 assessments from being a component of vulnerability to a separate function.

Many studies draw on these components – certainly those who follow the IPCC assessment models, but also some authors who used their own definition of vulnerability, but who assessed to some extent one or more of these components. For example, the American lobster vulnerability assessment that investigated the susceptibility of the fishery to negative impacts from future temperature increases (Le Bris et al. 2018).

In this respect, it is also useful to explore how those components are defined (as distinct from how they are measured) across literature. There is a significant variation across literature, depending on the context.

4.4.1 Exposure

Exposure is a foundational concept in vulnerability assessment frameworks, representing the degree to which a system, community, or resource is subjected to environmental hazards or stressors. For example, coastal regions are often exposed to sea-level rise and storm surges (KIWA 2023; Heck et al. 2020), while arid zones face heightened exposure to drought (Y. Li et al. 2023; Meybeck, Rose, and Gitz 2019). UNEP (2017) and Il Choi (2019) highlight that the spatial and temporal dimensions of exposure are critical since the frequency and intensity of hazards can vary widely across locations and over time.

Exposure is variously defined across the literature as:

- The extent of exposure to climate change (Xue Yang et al. 2021)
- physical changes in the environment (Giddens et al. 2022)
- the magnitude and rate of climate variations (Jeevamani et al. 2021) to physical environment conditions affecting the system (Licuanan et al. 2015)
- globally modelled estimations of recent changes in climate change stressors (Okey, Agbayani, and Alidina 2015)
- the degree to which a system is exposed to climatic variations, specifically focusing on seawater temperatures (M.-J. Kim et al. 2023)
- exposure to changing environment (NOAA 2019)
- degree of risk from natural disasters (Thurman et al. 2022)
- the potential magnitude, frequency, duration and areal extent of climate-related changes (A. P. Fischer and Frazier 2018)
- the nature and degree to which a system experiences environmental or socio-political stress (Hélène et al. 2022)
- climate-influenced stress-factors like drought or sea level risk (Herrick 2021) and

- the degree a livelihood is adversely affected by climate change das (Shibu Das and Sharma 2024).

Some authors also directly use old IPCC definitions (i.e. those used in TAR and AR4, or earlier).

Generally, while exposure is an element of the previous and current IPCC frameworks, these definitions do not accord with the contemporary definitions. In the IPCC AR6 framework, hazards are defined as climate-related physical events or trends—such as marine heatwaves, ocean acidification, or sea-level rise—that have the potential to cause harm to human or ecological systems. These hazards are considered independently of who or what is affected; they are the external climate drivers. In contrast, exposure refers to the presence of people, species, ecosystems, or assets in locations where they could be adversely affected by these hazards. It is a spatial concept that highlights what is in harm's way but does not imply sensitivity or capacity to cope—that is the role of vulnerability.

This tripartite structure—hazard, exposure, and vulnerability—interacts to determine overall climate risk. This represents a refinement from the IPCC AR4 framework, which many studies used as their conceptual basis, in which risk was often defined primarily as a function of vulnerability and exposure, and climate hazards were not consistently treated as a separate, explicit component. AR6 clarifies these distinctions, allowing for more precise identification of what drives risk and enabling more targeted adaptation strategies.

Come (2021) demonstrates that quantifying exposure requires robust data collection and analysis, often leveraging geographic information systems (GIS) and climate models in. These tools help map hazard-prone areas and estimate the likelihood of future events, as shown in Bell et al (2024) . The integration of spatial data, such as in Y. Li et al (2023) and the UN Habitat Community Assessment Guides (2020) allows for the identification of risk hotspots, which is essential for targeted adaptation planning. Exposure assessments may also consider the distribution of critical infrastructure and population density to ensure that the most vulnerable areas receive appropriate attention (Brownbridge and Canagarajah 2024).

In practice, exposure analysis guides the prioritization of adaptation and risk reduction efforts. Policymakers and practitioners use exposure maps, like those referenced in Brugere and De Young (2015) and Bell and Bahri (2018), to inform the placement of early warning systems and the development of evacuation plans. The allocation of resources for infrastructure upgrades in high-risk zones, as seen in CRIDF (n.d.) and UNFCCC (2021), is often based on detailed exposure assessments. This targeted approach ensures that interventions are both efficient and effective, maximizing the impact of limited resources.

4.4.2 Sensitivity

Sensitivity is a critical component of vulnerability assessment frameworks, reflecting how susceptible a system, community, or resource is to harm when exposed to hazards. For instance, the studies in Tsao and Ni (2016), Subiyanto et al (2020) and Pirasteh et al (2024) highlight how agricultural communities are particularly sensitive to drought and temperature fluctuations due to their reliance on consistent rainfall and fertile soils. Similarly, Rosengren et al (2020)and Silva et al (2022) discuss the heightened sensitivity of coastal fisheries to ocean acidification and warming waters, which can disrupt breeding cycles and reduce fish stocks. Sensitivity is not uniform; it varies based on ecological, economic, and social factors, where different regions and sectors exhibit unique vulnerabilities (Payus, Herman, and Sentian 2022; Rouleau et al. 2022a; Robert Blasiak et al. 2017).

Sensitivity is variously defined as:

- the degree to which a system is affected by climate change impacts (Xue Yang et al. 2021)
- biological traits (Nicotra et al. 2015), degree affected by climate-related stimuli (Jeevamani et al. 2021),
- how the system responds to these conditions (Licuanan et al. 2015),
- potential loss of distribution due to climate change (Valencia et al. 2020),
- expert-derived ratings of habitat sensitivities to climate stressors (Okey, Agbayani, and Alidina 2015),
- degree to which a system is affected by climate-related stimuli, and it includes biological traits such as abundance, distribution, and phenology (M.-J. Kim et al. 2023)
- sensitivities to changes (NOAA 2019),
- ability to defend against disasters (Thurman et al. 2022),
- the degree to which people and communities could be affected or harmed by climate-related changes (A. P. Fischer and Frazier 2018),
- the degree of coastal region's/society's dependence on marine fisheries (Hélène et al. 2022),
- the degree to which a system is affected by climate changes (Herrick 2021), and
- natural susceptibility to natural hazards (Shibu Das and Sharma 2024).

These definitions are, more or less, on track with current approaches, though some definitions are arguably more useful as the criteria for determining a given variable's <u>degree</u> of sensitivity.

Assessing sensitivity involves a detailed examination of both biophysical and socioeconomic characteristics. For example, Rabiei -Dastjerdi (2025) and Park and Xu (2022) explore how the age structure of populations and the diversity of income sources can influence a community's ability to withstand shocks. In Ojea, Lester and Salugeiro (2020), and Reid et al ((2022) the focus shifts to ecological sensitivity, examining how species with narrow habitat ranges or specialized diets are more vulnerable to environmental changes. The integration of social data, such as in Mathews, Smith and Madrigano (2025) and Mizrahi et al (2020), allows for a more nuanced understanding of how factors like poverty, education, and health status contribute to overall sensitivity.

The practical implications of sensitivity analysis are significant for adaptation planning. By identifying which groups or systems are most sensitive, as demonstrated in Closset et al (2018), Ojea et al (2017) and C. Li Yang and Yang (2025) decision-makers can prioritize interventions that address underlying vulnerabilities. For example, targeted support for smallholder farmers can help build resilience to climate variability (Koutroulis et al. 2019; Beroya-Eitner 2016), while investments in healthcare and education can reduce social sensitivity to disasters (He, Shen, and Zhang 2018; Licuanan et al. 2015). Sensitivity assessments also inform the design of early warning systems and social safety nets, ensuring that the most at-risk populations receive timely and effective support.

4.4.3 Adaptive Capacity

Adaptive capacity is the ability of systems, communities, or species to adjust, respond, or recover from the impacts of hazards or environmental changes. This element is central to reducing vulnerability, as highlighted in Guillamont (2015) Birkmann et al (2015) and Battamo et al (2022), where strong governance and institutional frameworks enable effective adaptation. In Scott, Hall and Gössling (2019)and De Bortoli et al (2019b), adaptive capacity is linked to access to resources, knowledge, and technology, which empower communities to implement resilience-building measures. The presence of social networks and community organizations, as seen in (Eriksen et al. 2020; Gumel 2022; Contreras, Chamorro, and Wilkinson 2020), further enhances adaptive capacity by facilitating information sharing and collective action.

Adaptive capacity is the most widely defined across the literature as:

- The ability to cope with climate change impacts (Licuanan et al. 2015; Xue Yang et al. 2021; Jeevamani et al. 2021; Shibu Das and Sharma 2024)
- enhancing factors limiting factors (Valencia et al. 2020)
- inverse of cumulative impacts of non-climate human stressors (Okey, Agbayani, and Alidina 2015)
- the ability to recover from extreme events (Thurman et al. 2022)
- the ability to modify social norms, behaviors and policies to anticipate or reduce risk (A. P. Fischer and Frazier 2018)
- the ability of the community to maintain its level of well-being, income and cultural attachment (Hélène et al. 2022)
- the ability to modify or adjust fisheries and livelihoods in order to cope with the negative impacts of climate change and pursue any emerging opportunities (R. Blasiak et al. 2020)
- the ability to reduce impacts through constructive changes (Herrick 2021), and
- the ability to cope with stressors (Pike, Jiddawi, and De La Torre-Castro 2022)

These definitions borrow concepts from across disciplines – adaptability (as used in biology and natural resources management research), capacity, capability and coping capacity (as used in hazards and disasters research), and resilience (as used in ecology and socio-ecological systems research)(Warrick et al. 2017).

Adaptive capacity is central to reducing vulnerability, as highlighted in Guillaumont (2015), Birkmann et al (2015) and Battamo et al (2022), where strong governance and institutional frameworks enable effective adaptation. In Scott, Hall and Gössling (2019) and De Bortoli et al (2019a), adaptive capacity is linked to access to resources, knowledge, and technology, which empower communities to implement resilience-building measures. The presence of social networks and community organizations, as seen in Eriksen et al (2020), Gumel and Contreras (2022), Chamorro and Wilkinson (2020) further enhances adaptive capacity by facilitating information sharing and collective action.

In practice, assessing adaptive capacity involves evaluating a range of factors, including governance structures, institutional strength, and the availability of financial, human, and social capital. For example, Ludeña and Yoon (2015) and Champion et al (2023) examine how local governments and NGOs play a pivotal role in supporting adaptation initiatives, while Beccari (2016) and Berrouet, Machado and Villegas-Palacio (2018) focus on the importance of education and capacity-building programs. The integration of traditional knowledge and innovative technologies, as discussed in Wade et al (2017), Nicotra et al (2015) and Acconcia et al (2020), can also boost adaptive capacity by providing context-specific solutions to emerging challenges.

It is clear that building adaptive capacity requires targeted investments in infrastructure, education, and social services. Studies like Blasiak et al (2020) and Reggiani, Nijkamp and Lanzi (2015) demonstrate how improving access to healthcare and early warning systems can enhance community resilience to climate shocks. The development of flexible policies and adaptive management strategies, as seen in Tsao and Ni (2016), and Sibiyanto et al (2020), allows for continuous learning and adjustment in response to new information or changing conditions. Partnerships between governments, civil society, and the private sector, as highlighted in Pirasteh et al (2024) and Rosengren (2020), are also essential for scaling up successful adaptation measures.

5 Vulnerability Assessment Framework Design

From the literature, we identified 132 different operational vulnerability assessment frameworks, highlighting the vast diversity of methodological approaches used to assess climate change vulnerability. They included both theoretical frameworks and applied case studies, ranging from local, qualitative assessments to highly quantitative, global-scale analyses.

5.1 Types of frameworks

The IPCC’s conceptual framework (especially as refined in AR5 and AR6) is widely referenced but inconsistently applied. Translating its high-level concepts (hazard, exposure, vulnerability, and adaptive capacity) into operational methods to assess climate risk, remains a challenge. There is no single standard methodology, reflecting the diversity of objectives, data availability, and system contexts.

Many of the case studies we reviewed, including recent case studies, continue to adopt the AR4-style vulnerability structure, possibly because more operational examples exist using that framework. This is despite AR5 and AR6 introducing significant conceptual changes—particularly in the treatment of exposure and adaptive capacity.

Some methods, such as the Livelihood Vulnerability Index (LVI), are relatively standardized and widely used. Others are bespoke frameworks developed by authors to fit specific fisheries, ecosystems, or social contexts. Most assessments fall along a spectrum of qualitative to quantitative approaches and address varying aspects of vulnerability—whether social, ecological, economic, or integrated socio-ecological systems.

Despite variation, several common themes and methodological patterns emerge:

- Trait-based approaches which emphasize biological or life history characteristics, such as mobility or thermal tolerance.

- Trend-based approaches which focus on empirical changes, such as to in distribution, abundance, or productivity over time.
- The choice of method often depends on data availability.
- Many assessments combine indicators in unique ways, some statistically, others through expert judgement or stakeholder input.
- Most frameworks use proxy indicators to identify determinants of vulnerability for targeting interventions and programs, but there are a diversity of approaches to determine the indicators, weight and score indicators.
- The lack of empirical data in some cases necessitates use of expert scoring or literature-based proxies.

Overall, the literature shows a high degree of methodological diversity, with frameworks selected and adapted according to data, purpose, and policy context. We categorized these into 4 broad, imperfect categories to distinguish between unique 'author's own' frameworks, those applying standardized frameworks, those applying another author's work and those applying mixed or comparative methods (*Figure 6*). This highlights the range of different methodological approaches that could be available to the WCPFC.

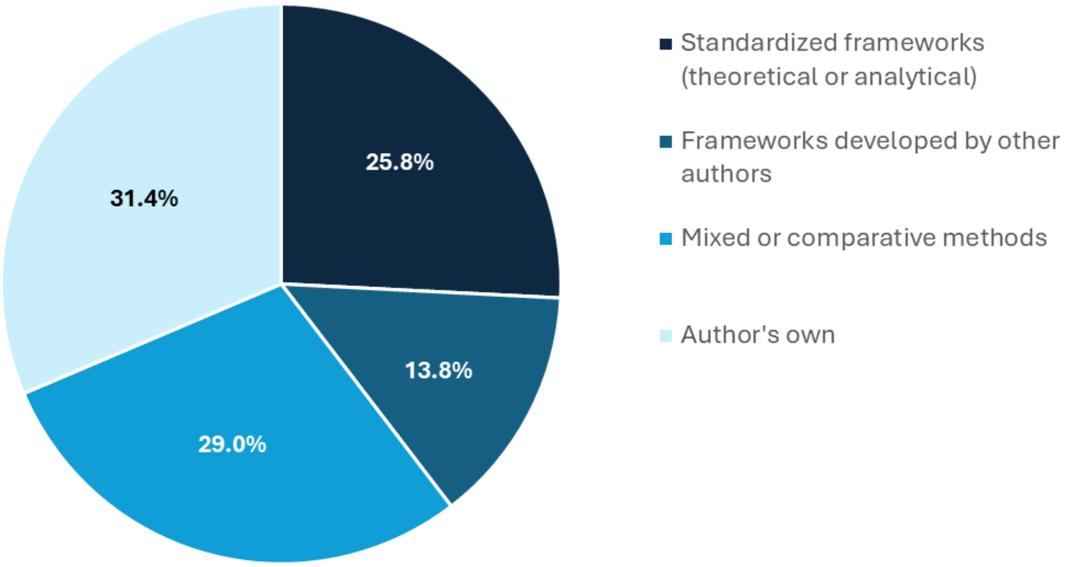

Figure 6. *Breakdown of VA frameworks by broad method categories found across the reviewed case studies (n =132)*

For the four categories of VA frameworks identified above, the application of these in a marine / fisheries context ranged from 15% to 25%.

See Annex B for a complete summary overview of the methodological approaches to climate change vulnerability in the reviewed literature.

5.2 Indicator selection

Methodological development typically involves three judgement steps:

1. **Selecting a general framework** – This may be top-down (data-driven, quantitative) or bottom-up (contextual, participatory)

2. **Choosing indicators** – These can be theoretically derived (deductive) or statistically identified ((inductive, e.g. Neil Adger, Arnell, and Tompkins 2005). Indicators vary widely but are intended to capture the state and vulnerability of the system. There is limited guidance for AR5/AR6-aligned assessments, there are well established, high impact operational frameworks applied across a range of the studies reviewed, such as Allison et al (2009), Marshall et al (2013), Hare et al (2016), Cinner et al (2013) and Chin et al (2010)

3. **Balancing biological and social dimensions** – Some assessments are biophysical only, others are social, and many aim for socio-ecological integration (Y. Li et al. 2023)

As Wheatley et al (2017) shows, even among academic assessments there is low agreement on which input variables best define sensitivity and exposure, and large variation exists between trait- and trend-based approaches. This supports the case for a customized framework tailored to WCPFC's needs.

Across the literature, there are a range of indicators used for assessing hazards, exposure, sensitivity and adaptive capacity. in some local studies biophysical factors are emphasized (Heck et al. 2020), while in some global studies, socio-economic or institutional dimensions are prioritized (Y. Li et al. 2023).

5.2.1 Fisheries specific indicators

Across reviewed fisheries studies, species and species/population stock level traits such as reproduction and recruitment, habitats specificity and environmental tolerance, mobility and physiology were among the most common groups of identified indicators. However, non-ecological indicators, such as fish price and distance to fishing ground, were also used.

To assist in identifying how indicators are grouped by vulnerability concept (Hazard, sensitivity and adaptive capacity), a set of most common indicators throughout the literature are presented below.

Hazard

The most commonly used indicators of hazard (or exposure, if earlier conceptual definitions of exposure were used) are set out in Table 4 below.

Table 4. *Most common fisheries specific 'hazard' indicators*

Criteria	Sub-criteria
Atmospheric	Temperature extreme
	Cyclones
	Storms
	Precipitation extremes
Marine	Sea level rise
	Sea surface temperature
	Ocean acidification
	Salinity
	Wind stress
	Currents
	Deoxygenation

Sensitivity

Most commonly used indicators of sensitivity across fisheries studies are set out in Table 5 below.

Table 5. *Most common fisheries specific 'sensitivity' indicators*

Criteria	Sub-criteria
Ecological and biological	
Early Life Stage	Early life history survival and settlement requirements
	Larval duration
	Early life history food availability
	Temperate stress in early life stages
Physiology	Cumulative life cycle effects
	Reliance on environmental cues or triggers
	Temperature sensitivity
	Rarity
	Dispersal capacity
	Life history and population structure
	Physical tolerance to environmental changes
Reproduction and Recruitment	Fecundity
	Spawning season
	Age/size at maturity
Stock status	Assessed status
	Abundance/CPUE
	Exploitation level
	Catch volume/rate
	Spatial concentration of catch
	Threat level
	Distance to fishing region
	Population growth rate
	Population viability
Food Web and Species interaction	Prey Specificity
	Trophic level
	Changes in ecosystem component species
	Adult Mobility

Criteria	Sub-criteria
Mobility	Seasonal migration
Habitats	Habitat specificity
	Environmental tolerance
	Temperate range
	Changes in species range
	Latitudinal range
	Range size
	Habitat Condition/suitability/extent/quality and occupancy
	Seasonality in distribution
	Acidification
Other Stressors	Susceptibility to disease
	Population decline
	Level of IUU
	Other
Socio-economic	
Economic Dependence	Economic rent from fishing and processing
	Price
	Fisheries export value as a proportion of export value
Food dependence	Dependent on fishery as protein and nutrition
	Food sufficiency
Compliance	Performance of MCS
Demographics	Number of vessels
	Age of vessels
	Number of processors
	Historical participation in the fishery
	Number of fishers
	Fleet power
	Fleet age
Livelihood dependence	Livelihood diversity and alternatives
	Gear dependence on habitats
Awareness of perception	Access to information and resources on climate change
	Climate change or environmental awareness
	Local ecological knowledge
Social and cultural dependence	Cultural importance of fishing
	Attachment to place
Infrastructure	Fisheries Infrastructure

Adaptive capacity

Most commonly used indicators of adaptive capacity across fisheries studies are set out in Table 6 below.

Table 6. *Most common fisheries specific adaptive capacity indicators*

Criteria	Sub Criteria
Biological adaptative capacity	Thermal range
	Mobility
	Stock status
	Range
	Distribution
	Spawning
	Dispersal capacity
	Generation time
	Reproductive rate
	Genetic variation
Ecological adaptive capacity	Habitat health, extent and diversity
	Presence of adjacent habitats
	Grazing and functional diversity
	Recreational corridors
	Diversity, plasticity, life history and population structure of other component species
	Reliance on environment cues for reproduction, hibernation and migration
	Diet/Abundance of food sources
Governance and Management adaptive capacity	Exploitation level
	Effectiveness of management framework
	Use of technology
	Knowledge creation and research input
	Gear diversity
	Flexibility to charge target species
	Livelihood diversification
	Economic diversification
	Flexibility to move areas or change fishing time
	Resource dependence
	Institutional support
	Strength of leadership
	Cooperative membership
	Presence/number of social, environmental and fishery organizations
	Capacity to anticipate and respond to change
	Participation and quality of decision-making processes
	Increased funding, or other resources and support

5.3 Traditional knowledge considerations

Utilizing and incorporating traditional and indigenous knowledge into assessing climate change vulnerability was highlighted as of paramount importance throughout the majority (~400) of the reviewed literature sources. Four recurring themes were identified that showcased how traditional knowledge enriches climate change vulnerability assessments and adaptation planning:

1. **Ecosystem and ecological insight** – Traditional knowledge systems are built upon generations of close observation and interaction with the environment, providing a keen awareness of subtle changes before they are detected or forecast by scientific monitoring. Examples include Micronesian fishers who can detect altered spawning runs before modelling (KIWA 2023) and Fulani herders who are able to detect the health in grass phenology long before satellites detect drought (Meybeck, Rose, and Gitz 2019).
2. **Holistic view** – vulnerability assessments become more holistic, adopting environment-stewardship lenses that merge spiritual, social and ecological duties. Examples include sacred-grove rules in the Caribbean (Heck et al. 2020), "tabu" forest closures in Hawai'i (SPREP, n.d.-b), and subsistence technologies and community structures in the Pacific (SPREP 2021), which impose culture-based limits that maintain ecosystem function and help create buffers to climate change related shocks.
3. **Bridging** – co-production of assessment frameworks helps to bridge place-based customary insights with scientific modelling, often enabling data gaps to be filled to provide more robust modelling to inform an assessment. Examples of this include Afghanistan's HCVCA toolkit (UNEP 2017) that blends elders' hazard rankings with GIS layers, and Y. Li et al's global fisheries synthesis (2023) which shows local–expert knowledge filling data gaps in stock assessments.
4. **Strengthened policy** – formally advancing traditional knowledge from an anecdotal information source to an authoritative source of information empowers overall support and local community-based endorsement of policies, vulnerability assessments and adaptation strategies required to effectively respond to climate change. Examples include Pacific regional plans and other policy instruments which embed village governance in national adaptation strategy (KIWA 2023; Barnett and Waters 2016) .

Collectively, these benefits highlight how integration of traditional knowledge hastens early warning, widens the scope of vulnerability metrics to include cultural resilience, and ensures adaptation measures resonate with, rather than overwrite, community priorities. This is of particular importance in data-poor but knowledge-rich regions such as pastoral West Africa and remote Pacific islands, where traditional knowledge provides an incredible asset.

In addition to the benefits to be realized from integrating traditional knowledge into climate change vulnerability, it is important to understand methods undertaken to effectively integrate traditional knowledge into the vulnerability assessment framework design. The major themes identified throughout the literature to best achieve this are discussed below.

5.3.1 Participatory and community-based methods

Across the literature, it was highlighted that the strongest vulnerability assessment design directly provides the space and opportunity for traditional and local expertise to be raised and incorporated early in the design phase. Workshops, focus-groups, and rural story-telling sessions should be established early and maintained to deliver both better data (by feeding in qualitative insights to fill quantitative data gaps) and stronger local ownership and cohesion, a powerful form of adaptive capacity in its own right (see for e.g Asyukri and Oktari 2025; UNEP 2017; Tee Lewis et al. 2023; Jakariya et al. 2020; Kathirvelpandian et al. 2024) .

Other useful examples of this include in the Pacific where local councils directly report shoreline observations to national planners (KIWA 2023), Il Choi (2019) where Korean fishers are sent on research cruises to validate catch trends, and Y. Li et al (2023) which concluded from a review of 189 fisheries studies that 'local and expert knowledge' workshops are essential to collect necessary information in data-poor fisheries to address data gaps and enable stock assessments.

5.3.2 Indicator Development and Scoring

Traditional and local expert knowledge should also be directly incorporated into the design of the vulnerability assessment framework indicators and the wider framework, with a particular focus of incorporating the information into exposure and sensitivity metrics, to blend the qualitative insight with available quantitative data to better reflect the intertwined nature of social-ecological realities.

Some examples of this are Heck et al , where reef fishers' catch diaries are converted into exposure scores that refine regional climate–biophysical models, Le Bris et al (2018) where pastoralists' seasonal calendars are used to inform drought early-warning indicators, de Paz and Garcia (2021) and Dhamija et al (2020) who also demonstrate the value of incorporating indigenous indicators alongside satellite metrics.

In addition to incorporating traditional and local expertise into exposure and sensitivity metrics, it should also be used to directly inform adaptive capacity based indicators, noting traditional techniques such as rotational closures (SPREP, n.d.-b), temporary closures, rain-water terracing, or pandanus-leave roofing (SPREP 2021) low-cost, culturally accepted defenses that can be readily scaled without heavy capital investment, and that renew inter-generational bonds, further improving local cohesion among communities.

5.4 Future-proofing considerations

Many studies within the literature reviewed offered insights on continuous improvement of vulnerability assessments. Three key "futureproofing" mechanisms to ensure the long-term viability and applicability of vulnerability assessments emerged.

5.4.1 Integration and adaptation

Integrating vulnerability results directly into planned management and adaptation strategies and responses is a fundamental cornerstone of future-proofing frameworks. Multiple case studies (KIWA 2023; Heck et al. 2020; Y. Li et al. 2023; Meybeck, Rose, and Gitz 2019) show how translating assessment findings into adaptive policies and management responses often bumps into institutional inertia, funding constraints, and technical gaps.

Early diagnosis of these barriers is essential to identify pragmatic solutions to help ensure assessment findings actively inform decision-making as opposed to just being a secondary / nice-to-have consideration. Types of future-proofing actions identified in the literature to help address barriers include empowered leadership, adequate long-term funding, clear communication channels, structured stakeholder engagement (UNEP 2017; Il Choi 2019; UN 2021c; WCPFC Secretariat 2023), co-development, and shared accountability (Y. Li et al. 2023; UN Habitat 2020; Brownbridge and Canagarajah 2024; Brugere and De Young 2015).

Adaptation as a concept relies on flexibility. To ensure a vulnerability assessment framework is adaptable to remain relevant, it is critical to ensure iterative review cycles, feedback opportunities, and frequent scenario planning to keep them current as risks evolve to prevent the assessment outputs from becoming obsolete (Comte 2021; OECD 2024; Bell et al. 2024). This is particularly true in relation to indicators, where periodic reviews are essential in order to retire obsolete metrics and introduce updated ones, and to ensure indicator sets stay fit for purpose (Huang et al. 2020; K. A. Thomas and Warner 2019; Apreda, D'Ambrosio, and Di Martino 2019; Hélène et al. 2022)

5.4.2 Data and Knowledge Co-production

Data scarcity is a major obstacle for vulnerability assessments. Certain studies and multiple training toolkits including, (see for e.g Fellman 2012; CRIDF, n.d.; UNFCCC 2021), advocate for the strategic use of proxy indicators – such as alternative measures like the well-known catch per unit effort (CPUE) in fisheries or local ecological knowledge – to support ongoing analysis in the face of data constraints.

Knowledge co-production further strengthens the ability to future-proof against data (R. A. Turner et al. 2016; UNEP 2017) with scientists, communities, traditional and local expertise, and policy actors jointly adding-value and insights into what types of data and information may be available that could or should be used to address gaps as and when they occur over time (Sandink and Lapp 2023; NOAA 2019; Richardson et al. 2018). Further, many studies encourage the use of open-access data platforms and continual data refresh cycles to ensure that assessment outputs are continually evolving as and when new evidence becomes available, and to help identify where new information signals a gap in the assessment framework (a new variable or measurable) that needs to be addressed.

5.4.3 Capacity Building and Knowledge Sharing

Building human and institutional capacity is indispensable to long-term futureproofing of a vulnerability assessment. Training initiatives described in Butt et al (2022), Zebisch et al (2021), Andreoni and Miola (2015) and Török, Croitoru and Man (2021) equip practitioners to conduct, interpret, and update vulnerability assessments and advance thinking over time. Further sustained support such as mentorship programs, certification pathways and bespoke long-term funding pools, help ensure the continuity of training and institutional knowledge beyond the implementation of short-term project timeframes (Tsao and Ni 2016; Subiyanto et al. 2020; Pirasteh et al. 2024; Silva et al. 2022).

Capacity building is also complemented by ensuring adequate resource availability to hold regional portals, workshops, and peer exchanges, in the knowledge that these information sharing avenues help to effectively disseminate best practices and the most up to date knowledge, to avoid wasted time, resource and energy doubling up or reinventing practices previously developed (Vandeskog, Heggen, and Engebretsen 2022; Warrick et al. 2017; Thiault et al. 2021; Olivares-Aguilar et al. 2022; Thurman et al. 2022).

6 Vulnerability Assessment learnings and insights

A key element of the literature review was to also identify the major challenges, potential solutions and lessons from climate vulnerability assessments as frameworks and methodologies have improved over time. The main themes that were identified are discussed below.

6.1 Common challenges and relevant limitations

6.1.1 Standardization and methodological inconsistencies

As already outlined in detail in Section 3.3, there is a diverse array of methodologies and vulnerability assessment frameworks globally. Throughout the studies, there is a clear lack of standardization and approaches used despite the framework guidance provided by the IPCC, along with a lack of agreement on whether standardization is requirement. This presents one of the greatest challenges, as it creates significant challenges to replicate studies, readily apply a 'best practice' framework design or methodology, or apply approaches at difference scales of application (Y. Li et al. 2023). This results in harmonization issues between studies and at different scales, often disabling the ability to readily aggregate or disaggregate findings between studies (Comte 2021).

Further, the inconsistent methodologies between studies risks obscuring the true drivers of vulnerability, depending on the approach used, or masked as a result of being unable to determine which factors are considered more critical under different settings (Il Choi 2019; UN 2021c),

These standardization issues and inconsistencies across studies undermines confidence in decision-making as found in (UNEP 2017; Meybeck, Rose, and Gitz 2019), and limits the uptake and integration of collective findings. As a result, some studies call for standardized methodologies and protocols to be developed, that have in-built flexibility that enable application in different contexts and at different scales (Comte 2021; UN 2021c; Meybeck, Rose, and Gitz 2019; Y. Li et al. 2023).

6.1.2 Data Integration and Quality Issues

Data integration and quality issues are a persistent challenge identified across the reviewed vulnerability assessments. Studies such as Al Mamun et al (2018) and Al Quadah (2021) highlight the lack of comprehensive, high-resolution data, particularly in low- and middle-income countries. Other studies identify how gaps in socio-economic and gender-disaggregated data hinder accurate vulnerability mapping (Alam, Khan, and Salam 2022; Md. S. Ali and Hossen 2022). In many cases, the sole reliance on quantitative data also creates gaps as seen in T. Ali, Mortula and Gawai (2024) and Savage et al (2020), especially where qualitative information from local communities or traditional knowledge holders is neglected.

The quality of available data is another major concern raised across studies. Amegavi et al (2021) and Savage, McIver and Schubert (2020) note that data is often outdated, inconsistent, or collected using different methodologies, making it difficult to compare results across regions or time periods. This is particularly problematic in rapidly changing environments, where static data fails to capture evolving risks and adaptive capacities (see for e.g. Ang and Blajer De La Garza 2021; De Young 2016).

Data integration is also highlighted as a major challenge, as a result of limited technical capacity, lack of coordination among agencies, a lack of capability, a lack of harmonization and standardized data management protocols, and a lack of resources to effectively implement or maintain ongoing data management activities / systems e.g., data collection, transmission, analysis and storage (Abijith, Saravanan, and Sundar 2023; Arora 2022; Attiogbé et al. 2022; Reggiani, Nijkamp, and Lanzi 2015).

For example, data limitations and uncertainties in climate projections can complicate assessing hazard-exposure, as highlighted by the FAO (Comte 2021) as well as in studies (for e.g. Meybeck, Rose, and Gitz 2019). In WCPFC's case, hazard-exposure assessment will rely on meteorological and oceanographic data that, while it is captured through other programmes, may not (yet) be sufficient to enable a robust assessment to take place – a problem also identified by the SPC (2024) . It can also make it difficult to capture the full range of variables that influence sensitivity, which can be a limiting factor (Juhola and Kruse 2015; Dudley et al. 2021). Additionally, sensitivity is dynamic and can change over time in response to shifts in economic conditions, policy environments, or ecological processes, as discussed in Fischer and Frazier (2018) and Kauffman and Hill (2021). This underscores the importance of regular monitoring and updating of sensitivity assessments, as well as the need for flexible and adaptive management strategies.

6.1.3 Temporal and Spatial Assessment Limitations

Many vulnerability assessments are static, providing a snapshot in time rather than capturing the dynamic nature of vulnerability. This approach fails to account for how vulnerability evolves in response to changing environmental, social, and economic conditions, as highlighted in Becker et al (2018) and Awolala et al (2022). As a result, assessments may quickly become outdated and less useful for long-term planning, as highlighted (Azam et al. 2021; Bainton, Skrzypek, and Lèbre 2025).

Spatial limitations are also common. Assessments often use coarse spatial scales that mask important local variations in vulnerability, as noted in Barnett (2020) and Barnes et al (2020). This can lead to generalized recommendations that are not well-suited to specific communities or ecosystems, reducing the effectiveness of adaptation interventions (Barnett and Waters 2016; Barua et al. 2020).

Capturing temporal dynamics and internal heterogeneity within vulnerable groups is essential for designing adaptive management strategies. Without this, vulnerability assessments may overlook emerging risks or fail to recognize the adaptive capacities that exist within communities, as discussed in Barzehkar et al (2021) and Basel, Goby and Johnson (2020). The need for more frequent, fine-grained vulnerability assessments is emphasized throughout literature.

6.1.4 Capacity Building and Technical Expertise Deficits

Another significant barrier identified is the limited capacity and technical expertise at local and regional levels to conduct comprehensive vulnerability assessments (Joern Birkmann et al. 2015; Biswas and Nautiyal 2021; Saverimuttu 2021; Yong Wang, Han, and Ma 2022). This is particularly true in the context of developing countries who are often the most vulnerable to climate change.

This challenge not only affects the quality of assessment design, but also the ability to interpret and build recommendations from the outputs to inform robust management and adaptation policy, with specific cases found in Bito-onon (2020) and Lomborg (2020). The root cause of this challenge is often linked to limited financial resources, short project timeframes and a lack of training and development at the local level (Robert Blasiak 2019; Bolin and Kurtz 2018), which can result in vulnerability assessments being externally driven with little local ownership, input or understanding of how to action or follow up with resulting adaptation requirements (Brown and Berry 2022; Campbell et al. 2016).

6.1.5 Stakeholder Engagement and Participatory Approach Gaps

Another major challenge identified in the literature is the lack of stakeholder engagement, particularly with local communities and marginalized groups, in the development of vulnerability assessments. Many assessments are conducted by external experts using top-down approaches that fail to incorporate local knowledge, experiences, and priorities (Hopkins, Bailey, and Potts 2016; Chas-Amil et al. 2022). A lack of engagement not only undermines the accuracy of assessments but also reduces community ownership and acceptance of the findings (Chauhan et al. 2022; Q. Chen et al. 2020).

In addition, a lack of stakeholder engagement and silo-based development of vulnerability assessments, often means important contextual factors such as historical climate patterns, ecosystem dynamics, cultural elements, and local community drivers and management approaches are missed (Y. Chen, Liu, and Zhang 2023; X. Chen 2020; Chhetri 2021; Christie et al. 2025; Cinner et al. 2018).

6.1.6 Policy Integration and Implementation Challenges

A persistent challenge in vulnerability assessment design and delivery is the difficulty of translating findings into actionable policies and implementation strategies. Many assessments produce complex technical outputs that are not easily understood or used by policymakers, creating a disconnect between scientific knowledge and policy action (Cruz-Sánchez and Monterroso-Rivas 2025; Cumberbatch et al. 2020).

The integration challenge is further complicated by institutional barriers and competing priorities within government agencies, (Cumberbatch et al. 2020; Curi and Gasalla 2021), and by requiring coordination among agencies that traditionally work in silos (Da Cunha et al. 2022; Santos et al. 2021).

Despite its importance, enhancing adaptive capacity is often constrained by limited resources, institutional weaknesses, and social inequalities, despite its key role in reducing vulnerabilities. Challenges include inadequate funding, lack of technical expertise, and barriers to participation for marginalized groups (Silva et al. 2022; Payus, Herman, and Sentian 2022; Rouleau et al. 2022a). Addressing these challenges requires a coordinated and inclusive approach, with ongoing support for capacity-building and institutional strengthening at all levels.

6.1.7 Validation and Quality Assurance Deficiencies

Finally, the last distinct type of limitation identified in many vulnerability assessments is the lack of robust validation and quality assurance mechanisms.

Most assessments are not tested against real-world outcomes or situations, making it difficult to determine their accuracy or reliability (Deguen et al. 2022; Delfino 2021). In addition, quality assurance is also hampered by the lack of standardized benchmarking procedures and peer review processes specifically designed for vulnerability assessments, leading to inconsistent results and reduced comparability across studies (Dudley et al. 2021; Duran-Izquierdo and Olivero-Verbel 2021). This absence of validation and quality control undermines confidence in assessment results (Delfino 2021; Dhamija et al. 2020) and is particularly problematic when assessments are used to allocate resources or prioritize interventions at national or international levels (Rahayu and Suryanto 2023; Edmonds, Lovell, and Lovell 2022).

6.2 Main lessons and relevant solutions

6.2.1 Comprehensive & multi-faceted approaches

To be successful, a vulnerability assessment must go beyond a single perspective, integrating ecological, social, economic, and political dimensions. This multi-faceted approach is highlighted in lessons such as those from the IPCC (2023a), global reviews (2023)and regional studies (KIWA 2023), which emphasize the need to consider the full spectrum of factors influencing vulnerability in order to generate meaningful and well-informed assessment outcomes.

A multi-faceted approach (often based on the use of composite indices or integrated models) also best aligns with the recognition that climate change impacts themselves are closely linked and integrated across different systems, warranting the need for a more holistic assessment accordingly (OECD 2025; Y. Li et al. 2023; KIWA 2023). The vulnerability of a coastal community, for example, is shaped not only by physical hazards but also by governance structures and cultural practices, as discussed by Kiwa (2023). Specific sources (SPREP, n.d.-a; Burden and Battista 2019) also highlight the need for collaboration across disciplines, drawing on diverse data sources and expertise to capture the interconnectedness of vulnerability.

Ultimately, a comprehensive and multi-dimensional approach provides a more holistic understanding of vulnerability, enabling decision-makers to design interventions that address root causes rather than symptoms. This is echoed in (SPREP, n.d.-a; Burden and Battista 2019)], which stress the importance of addressing all facets of vulnerability in planning and response in order to generate more effective and sustainable adaptation strategies.

6.2.2 Data & Knowledge Management

High-quality, reliable data is the backbone of any robust vulnerability assessment, as emphasized in (Heck et al. 2020; Y. Li et al. 2023; KIWA 2023). Many studies across the globe including the Pacific Islands, Caribbean, Afghanistan, Mediterranean region, West Africa and globally (Heck et al. 2020; Y. Li et al. 2023; Meybeck, Rose, and Gitz 2019), emphasize the need for robust data collection systems, harmonized methodologies and the integration of all available information (quantitative and qualitative) to strengthen data sets. Further, lessons from (OECD 2024; 2025) highlight the importance of transparent, standardized methods for data collection and validation, and Burden and Battista (2019) highlight the need for regular updating of datasets to reflect changing conditions noting all systems are continuously evolving.

To address data gaps, which often pose a significant challenge in regions with limited resources or technical capacity, the literature clearly identifies the need for increased participatory approaches to collecting information, such as knowledge sharing and co-production, utilizing all available information sources (both quantitative and qualitative), including traditional knowledge and local expertise (Heck et al. 2020; Y. Li et al. 2023; Meybeck, Rose, and Gitz 2019; KIWA 2023). Many global and regional studies also advocate for improved collaboration through collaborative research arrangements, open data platforms, and partnerships between governments, academia, and local communities (OECD 2025; Bell et al. 2024; Y. Li et al. 2023; UN Habitat 2020; Brugere and De Young 2015). Other tools such as remote sensing, and geospatial analysis, as described in Y.Li et al (2023), are also used to help address data gaps.

Finally, the literature underscores the need for capacity building in data management, including training in data collection, analysis, and interpretation (OECD 2024; Bell et al. 2024; Y. Li et al. 2023; UN Habitat 2020; Brugere and De Young 2015). This includes developing local expertise, investing in infrastructure, and creating institutional arrangements that support the long-term sustainability of data systems (Bell and Bahri 2018; Fellman 2012; UNEP 2017).

6.2.3 Capacity Building & Training

Capacity building and training are foundational to addressing limitations in vulnerability assessments worldwide. Many studies emphasize the need for formal education systems and contextualized training tailored to local audiences, as seen in the Pacific Islands, Afghanistan and elsewhere (Y. Li et al. 2023; UNEP 2017; KIWA 2023). These references highlight that effective vulnerability assessment requires not only technical knowledge but also a deep understanding of local contexts, cultural practices, and community priorities. This includes a consistent highlight of the need for gender equality and social inclusion in training programs, to ensure that capacity-building efforts reach all segments of society and build on existing local knowledge systems (Y. Li et al. 2023; UN Habitat 2020; Brownbridge and Canagarajah 2024).

Institutional capacity building is equally important, with solutions emphasizing the need to strengthen organizations and governance structures that support vulnerability assessment activities, such as through toolkits to support practical capacity building (CRIDF, n.d.; UNFCCC 2021; UNEP 2017). This includes developing standard operating procedures, establishing quality assurance mechanisms, and creating institutional memory systems that ensure knowledge is retained and built upon over time. By investing in both human and institutional capacity, countries can create the foundation for effective, sustainable, and locally relevant vulnerability assessments (Thurman et al. 2022; Angeon and Bates 2015; Warrick et al. 2017; Török, Croitoru, and Man 2021)

6.2.4 Stakeholder Engagement & Participation

Stakeholder engagement and participatory processes are critical for ensuring the relevance and effectiveness of vulnerability assessments. Several studies adopt participatory stakeholder processes to develop or apply operational frameworks. These studies highlight the value of involving local communities, policymakers, scientists, and other stakeholders throughout the assessment process. Participatory mapping, scenario building, and co-design help incorporate local knowledge and ensure that assessments address the needs and priorities of those most at risk (see for e.g Kathirvelpandian et al. 2024; Soucy et al. 2022; Silva et al. 2022; Giddens et al. 2022; Scott, Hall, and Gössling 2019).

Stakeholder engagement also enhances the quality and credibility of vulnerability assessments. By drawing on diverse perspectives and expertise, as encouraged by the World Bank (2024), practitioners can identify blind spots and improve the robustness of their analyses. Lessons from the OECD (2025; 2024) also highlight the value of iterative, participatory processes that allow for ongoing learning and adaptation.

By prioritizing stakeholder engagement and participatory processes, practitioners can produce vulnerability assessments that are more relevant, credible, and actionable. This approach, supported by (Burden and Battista 2019; SPREP, n.d.-a), helps ensure that adaptation strategies are responsive to the needs of those most at risk and are more likely to be successfully implemented.

6.2.5 Monitoring & Assessment

Monitoring and assessment are foundational for effective vulnerability management, as demonstrated by studies from the Pacific Islands, Caribbean, New Zealand, and global contexts (Heck et al. 2020; Y. Li et al. 2023; D. Johnson et al. 2023; Bell et al. 2024; KIWA 2023). These studies highlight the need for robust, ongoing data collection and the development of standardized indicators to track changes in vulnerability over time. Solutions emphasize the importance of integrating both quantitative and qualitative methods, as well as the use of participatory approaches to ensure that monitoring systems are relevant and responsive to local needs (Comte 2021; OECD 2024; Y. Li et al. 2023; Bell et al. 2021).

A recurring theme is the need for adaptive monitoring frameworks that can accommodate new information and changing conditions (UN Habitat 2020; Brugere and De Young 2015; Fellman 2012; CRIDF, n.d.). The literature calls for the development of flexible methodologies, the use of scenario analysis, and the incorporation of uncertainty into assessment processes. These approaches are designed to improve the accuracy and utility of monitoring data, enabling more effective decision-making and risk management (UNEP 2017; NOAA 2019; Richardson et al. 2018).

6.2.6 Scalability, flexibility and context-specificity

Scalability, flexibility, and context-specificity are essential for ensuring that vulnerability assessments remain relevant and effective across different settings. Lessons from the literature highlight the importance of adapting assessment tools and frameworks to local, regional, and sectoral contexts (Heck et al. 2020; Y. Li et al. 2023; KIWA 2023). Recognizing heterogeneity within vulnerable groups and regions helps ensure that assessments capture the unique characteristics of each context (World Bank 2024; OECD 2024).

Flexible, scalable, and modular approaches, as recommended in (OECD 2025; 2024), allow practitioners to refine assessments over time and respond to changing conditions (see for e.g. UNEP 2017; Meybeck, Rose, and Gitz 2019; CRIDF, n.d.). Lessons from Burden and Battista (2019) and SPREP (n.d.-a) emphasize the value of iterative processes that allow for ongoing learning and adaptation. Lessons from Y. Li et al (2023), provide examples of how scalability and flexibility can enhance the effectiveness of vulnerability assessments.

Context-specificity is also critical for ensuring that assessments are relevant and actionable. By tailoring methods and indicators to the specific needs and priorities of different communities, practitioners can produce more meaningful and useful results. By prioritizing scalability, flexibility, and context-specificity, practitioners can produce vulnerability assessments that are more relevant, credible, and actionable (Burden and Battista 2019; SPREP, n.d.-a).

7 Pacific marine environment considerations

To help inform the design of the WCPFC vulnerability assessment framework, we also considered it essential to also look at those vulnerability assessment frameworks and studies that are specifically focused on the Pacific marine environment. Of the 73 Pacific region-based references, we identified 58 as having a clear marine application (either marine only or marine and terrestrial considerations).

On review of the 58 references, we quickly realized that many of the design considerations, findings, challenges, solutions and learnings either significantly overlapped with, or were directly covered by those already discussed above. However, noting how unique the Pacific region is, factors unique and only raised in relation to the region were also identified. These are discussed in the below sections.

7.1 Summary of main climate change challenges for the Pacific marine environment

In addition, to the context information previously provided in Section 1.3.1, four main challenges were identified throughout the Pacific marine literature. These included:

1. **Ecological and environmental challenges** – climate-change stressors such as rising sea-surface temperatures, ocean acidification, stronger cyclones, and altered rainfall, are pushing Pacific marine ecosystems toward critical tipping points. The most at-risk habitats (coral reefs, mangroves, seagrasses) provide food, biodiversity refugia, and natural coastal defense, yet they are rapidly degrading under thermal bleaching, salinity shifts, and nutrient changes that are leading to cascading impacts across all sectors (Bell et al. 2024; 2021; Giddens et al. 2022; KIWA 2023)
2. **Financial and Resource Constraints** - while the region's adaptation needs are unequivocal, Pacific governments and local partners face chronic shortfalls in climate finance, limited technical capacity, and in many cases project cycles too short to yield durable outcomes. The literature shows that although international funds exist, complex application procedures, co-financing requirements, and weak domestic revenue bases hinder uptake, amplifying vulnerability and delaying critical investments in monitoring, resilient infrastructure and livelihood diversification (Pacific Community (SPC) 2023a; Mangubhai and Chung 2024).
3. **Policy, Governance, and Institutional Barriers** - fragmented mandates, overlapping jurisdictions, and insufficient coordination across fisheries, environment, and finance ministries stall cohesive action, as highlighted by Kiwa (2023) . Persistent gaps in enforcement, limited data sharing, and under-resourced agencies are identified as pain points in upholding the integrity of marine protected areas and integrated coastal management, and in supporting the mainstreaming of ecosystem-based adaptation and nature-based solutions into national development plans.
4. **Social and Inclusion Issues** – in addition to the preceding challenges, social and inclusion issues including: gendered labor roles, youth migration, and the marginalization of Indigenous and traditional knowledge holders from decision-making

is a significant challenge in the Pacific. Notable literature sources emphasize that equitable, culturally respectful processes that include co-design with women, elders, and persons with disabilities, are vital for sustaining ocean stewardship, strengthening adaptive capacity, and ensuring that climate solutions do not inadvertently widen existing socio-economic gaps (Bell et al. 2024; KIWA 2023; Giddens et al. 2022).

7.2 Specific VA considerations

7.2.1 Traditional knowledge

The below considerations supplement those identified in Section 5.4 above.

Gender-Sensitive Approaches

Gender-sensitive approaches recognize that traditional knowledge is often differentiated by gender, with women and men holding different but complementary expertise related to marine resources and climate adaptation. (SPREP 2021) explicitly mentions the importance of considering gendered traditional practices in vulnerability assessments, acknowledging that women often possess specialized knowledge about nearshore resources, food processing techniques, and household-level adaptation strategies. This recognition is crucial because traditional knowledge systems in Pacific marine environments often reflect complex gender divisions of labor and knowledge domains.

KIWA and (Barnett and Waters 2016) also demonstrate the value of capturing diverse perspectives within communities, ensuring that both women's and men's knowledge informs adaptation planning processes. Eastin (2018) and Llorente-Marron et al (2020) demonstrates how participatory tools can be designed to ensure gender inclusivity, capturing the full spectrum of traditional knowledge rather than privileging knowledge domains that may be more visible or accessible to external researchers. By adopting gender-sensitive methodologies, VAs can more accurately reflect the realities of Pacific communities, with the results able to inform the development of meaningful adaptation strategies that are equitable, comprehensive, and effective for all community members.

Practical Application Tools

The development of practical tools for integrating traditional knowledge is identified as an essential element for operationalizing climate adaptation planning and implementation. Across the literature, we found many examples of practical toolkits applied around the world.(see for e.g. Nairobi Convention Secretariat 2022; CRIDF, n.d.; NOAA 2019; UNEP 2017)

Kiwa (KIWA 2023) and(SPREP 2021) both highlight the importance of tools that are co-designed with communities, ensuring that traditional knowledge is not only respected but actively shapes adaptation planning processes. These references collectively demonstrate that practical application tools are most effective when they are participatory, context-specific, and designed to empower traditional knowledge holders while producing actionable information for climate adaptation planning.

7.2.2 Challenges and limitations

The challenges and limitations below supplement those identified in Section 6.1 above in the context of Pacific marine environment VAs.

Short project timeframes and limited funding

A persistent barrier to effective vulnerability assessment and adaptation in the Pacific is the limitation of financial resources and the prevalence of short project timeframes.(Dudley et al. 2021; D. Johnson et al. 2023) highlight how funding constraints often result in fragmented efforts, with projects unable to sustain long-term monitoring or capacity building. This is particularly problematic in the context of vulnerability assessments, where impacts and information evolves over time, requiring ongoing assessment. Mangubhai and Chung (2024) highlight many projects are designed as one-off interventions, with little provision for follow-up or evaluation. This lack of continuity makes it difficult to learn from past experiences or to adjust strategies in response to new information over time.

Further, limited financial support also restricts the efficacy of vulnerability assessments undertaken, as practitioners are often forced to rely on existing data and expert judgement, rather than carrying out comprehensive, context-specific analysis. This can lead to oversimplified assessments that fail to capture the full range of vulnerability faced by the Pacific marine environment and Pacific Island communities (Mangubhai and Chung 2024; Pacific Community (SPC) 2023b).

Adaptation Knowledge and Iterative Approaches

Another specific gap in Pacific marine-based VAs is the limited knowledge about how to effectively apply and iterate adaptation strategies over time. NOAA (2019) highlights that there are significant information deficits in understanding how to effectively translate vulnerability assessment results into actionable strategies, particularly when integrating scientific data with socio-economic and legal considerations.

Further, Giddens et al (2022), state the need for tailored assessments based on user needs in recognition that a one-size-fits-all approach is inadequate for the diverse contexts found across the Pacific. Iterative learning and adaptive management are recognized as essential moving forward for Pacific based vulnerability assessments, noting the majority are designed as static, one-time evaluations rather than ongoing processes that can evolve with changing conditions and as knowledge improves. Without ensuring vulnerability assessments are adaptable over time, the ability of communities and institutions to build adaptive capacity and to respond effectively to emerging challenges and opportunities is limited.

7.2.3 Lessons and solutions for the Pacific

The below lessons and solutions supplement those identified in Giddens et al (2022) above in the context of Pacific marine environment vulnerability assessments.

Framework design

Structured and standardized vulnerability assessment frameworks provide the foundation for robust and comparable assessments across Pacific marine systems. (Heck et al. 2020) highlights the importance of comprehensive frameworks that consider multiple aspects of climate change and that can clearly separate impacts between people and ecosystems for targeted recommendations, whereas (Giddens et al. 2022) applies Rapid Vulnerability Assessment (RVA) framework to evaluate climate change impacts in a way that informs management planning and intervention, but in a way that is more realistic within the Pacific context.

Bell et al (2024) recommend considering spatial variability in vulnerability and using spatial analyses and mapping to identify hotspots of vulnerability, whereas Y. Li et al (2023) emphasizes the need for balanced approaches across different spatial scales to avoid scale mismatches between assessments and management needs. These spatial and temporal considerations recognize that Pacific marine systems exhibit high variability across space and time, requiring assessment approaches that can capture this complexity while remaining practical for decision-making.

Vulnerability assessment frameworks for the Pacific marine environment should be flexible enough to be regularly updated overtime, noting that adaptive and iterative processes (including monitoring) ensure that assessments remain current, relevant and strengthen overtime as conditions and knowledge evolve (Bell et al. 2024; Giddens et al. 2022). These adaptive considerations recognize that climate change and marine systems are dynamic, requiring processes and VA frameworks that can evolve and improve over time.

Integration and implementation

The literature demonstrates that mainstreaming the use and integration of vulnerability assessment results in planning and policy decision making is vital. Kiwa (2023) in particular, emphasizes the need to utilize vulnerability assessments to develop and integrate Nature-based Solutions into national policies and plans. Michetti and Ghinoi (2020) and Pinnegar et al (2019) demonstrates the value of integrating climate change adaptation with disaster risk management strategies with examples from Mexico and Dominica respectively. Robust and well-defined policy integration approaches enables maximum value to be extracted from vulnerability assessments, and helps avoid vulnerability assessments becoming standalone technical exercises.

Institutional coordination and partnership mechanisms are also considered important to support effective collaboration across sectors, scales, and organizations involved in vulnerability assessments and adaptation. Y. Li et al (2023) highlights the importance of collaboration across traditional institutional boundaries and sectors.

Implementation planning and resource mobilization are necessary elements to develop and prioritize on developing a vulnerability framework, in the recognition that vulnerability assessment results are only valuable if they lead to concrete actions that have political support (KIWA 2023).

Part Three: Discussion & conclusions

8 Vulnerability definition

From our findings, it is clear there is currently no universally accepted definition of 'vulnerability' or its core elements. While IPCC definitions (AR4, AR5 and AR6) are widely referenced and are generally accepted as best practice, they are not always consistently applied, and older definitions (particularly those from AR4) continue to be commonly used. This variation makes it challenging for organizations like the WCPFC to select a 'best-practice' framework.

However, despite the variations in the available IPCC frameworks, we conclude that using the most up-to-date definitions provided in the IPCC's Sixth Assessment Report (AR6) should be used as the conceptual foundation from which to build the WCPFC VA framework. Although AR6 introduces a more complex framing with greater emphasis on governance, justice, and equity (which may take time to fully integrate into operational processes), it offers the most comprehensive and contemporary approach to defining 'climate risk' available at this moment.

We do foresee that there may be some initial teething difficulties with readily adopting the AR6 definition, however we are confident that the WCPFC will be able to gradually align and adapt its operational framework in accordance with the AR6 definition over time. Accordingly, we conclude that the following definition for '*climate vulnerability'* is to be used in the development of the bespoke WCPFC climate change VA framework:

Definition	How we understand it.
Climate Risk *Hazard × Exposure × Vulnerability*	Risk refers to consequences for human or ecological systems Risks can arise from potential impacts of climate change as well as human responses to climate change Adverse consequences can arise from the potential for a response to climate change failing to achieve its intended outcome; or o the intended action creating an adverse outcome elsewhere Example, the term "flood risk" should not be used if it only describes changes in the frequency and intensity of flood events; it would need to be linked explicitly to the consequences of such events for human or ecological systems
Hazard *A hazard is the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and*	A hazard is a climate driver of risk A hazard is the climate-related physical event or trend that can cause harm

loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources	It is specifically about the climate-related physical event or phenomena, not the exposure or vulnerability of systems to them It can include acute events (flood, hurricane) or long-term trends (sea level rise, ocean acidification, temperature increase)
Exposure *Exposure is the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected*	Exposure is about what is at risk, not necessarily what will be harmed, but what is located in areas where climate hazards may occur Exposure does not itself equate to harm. Exposure in combination with hazard and vulnerability determines risk
Vulnerability *Is a function of sensitivity and adaptive capacity*	We understand vulnerability is a function of adaptive capacity and sensitivity
Sensitivity *Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change*	Sensitivity is a subset of vulnerability rather than treated as a separate variable. It is linked to both biophysical and socio-economic characteristics of systems Whereas Exposure looks at whether something is in harm's way, sensitivity looks at how much harm it suffers when exposed. We consider what the system, species or group is and what makes it sensitive It depends on biological, physical, economic or social characteristics that help us identify which parts of a system, species or group are most at risk
Adaptive capacity *Adaptive capacity is the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences*	It is about the potential to adapt, not whether adaptation is currently occurring Adaptive Capacity is dynamic, context specific and inequitably distributed Higher adaptive capacity results in lower vulnerability; lower adaptive capacity results in greater susceptibility to harm Adaptive capacity is about more than ecological adaptation, but the capacity of ecosystems, people and institutions to adapt It is influenced by resources, resource management, governance and knowledge It can involve:

	• Reducing vulnerability to climate hazards, • Mitigating potential damage, • Taking advantage of beneficial opportunities (e.g., longer growing seasons in some areas), • Responding effectively to impacts after they occur

9 Assessment framework design

We are acutely aware of the risk that climate change presents to the WCPO and the people who call it home. We note the extensive efforts undertaken by many WCPFC Members and regional organizations to recognize climate change as an existential threat, and to initiate planning and strategies to effectively respond. We have therefore given serious consideration to what a climate change VA framework could mean for WCPFC in the context of its mandate and operating environment.

Given the wide range of available methodologies to draw on, it has been a particularly complex exercise to navigate in order to determine an appropriate methodological approach to inform the design of a WCPFC VA framework. However, the significant diversity of available frameworks also means WCPFC has considerable flexibility in determining the design of its operational framework to best suit its specific mandate, resource and capacity availability, and the availability and quality of information and data. It also enables the ability to design the framework with bespoke needs, such as the ability to perform regular updates (annually, biennially etc.), the need to enable harmonization with other regional frameworks as and when they come online, the need to consider traditional knowledge and cultural applications in the design etc.

Many existing methods rely on quantitative indices that require weighted indicators and that draw on extensive data sets, require complex and extensive scientific modelling capabilities, and that often take multiple years to complete along with extensive resource and investment. In our view, this approach is simply not practical or suitable for the WCPFC to consider in the context of assessing the vulnerability of its CMMs on a regular basis, particularly given its consensus-based decision-making processes, and its restricted annual resource and capacity availabilities.

Other methods explored (e.g., rapid vulnerability assessments (RVAs), provide a far more pragmatic approach, where set indicators are measured based on best available current information and with pre-set options to be used to best represent the current state of a particular system. These approaches both enable the rapid identification of where attention is required where indicators suggest vulnerability is high, while also highlighting where there are data and information gaps that need to be filled to enable more accurate indicator responses (e.g., they can signal where in-depth investigation is warranted).

Additionally, this approach to vulnerability assessments also has a high degree of flexibility, with the ability for additional indicators / considerations to be integrated into the framework as better information and knowledge becomes available over time. This is simply not the case where in-depth quantitative scientific modelling VA methods are utilized e.g. species vulnerability.

On balance and on recognizing the purpose of the WCPFC climate change VA framework (to assess the vulnerability of individual CMMs to climate change), we conclude that a pragmatic approach is best suited that specifically:

- Consolidates existing knowledge (including from traditional and local expert knowledge holders) against set criteria
- Identifies key climate risks and data gaps
- Flag issues relevant to CMM revisions
- Is responsive to management
- Enables iterative and less resource intensive updates as and when new information becomes available.

We believe this approach will directly enable WCPFC to more easily integrate climate change vulnerability assessments within its normal resourcing cycles, and enable it to remain responsive to observed biological and ecosystem changes as they evolve overtime in response to climate change.

Finally, we conclude that the common fisheries indicators (refer Section 5.2.1) together with the insights outlined below, provide an invaluable starting point that we will directly draw on to develop the WCPFC VA framework.

10General VA insights

Across the 536 sources of information reviewed, common themes quickly became apparent that provide valuable insights into how to develop a robust, well-informed, and resistant VA framework that is both durable and able to be effectively maintained over the long-term. Our key conclusions in respect of these are set out below.

10.1 Transparent and standardized methods

Transparent and standardized methods are an essential to design when developing a VA framework to enable regular and consistent updating over time. This ensures confidence in observed trends, enabling decision-makers to act, which is of particular importance in the context of WCPFC and its consensus-based decision making nature.

In addition, standardized methods also enable replication by others (including other RFMOs), directly enabling results to be integrated into other local, regional or global assessments as required. This ensures that harmonization can be more readily achieved to maximize the use of collective available data and information over time.

10.2 VAs must go beyond a single perspective

Multi-faceted VA frameworks that integrate the full spectrum of influencing factors of climate change vulnerability (including ecological, social, economic, cultural and political dimensions), are essential. Although a multi-faceted approach entails a more complex framework design and demands higher levels of information, it provides a more comprehensive and realistic assessment of vulnerability. This again improves confidence to support decision-making and planning processes. As mentioned above, we conclude that the common fisheries indicators (refer Section 5.2.1) provide a suitable starting point to draw on to create a multi-faceted VA framework for WCPFC.

10.3 Utilize all available information sources

Data and information gaps are a common constraint of VAs. This is often the case in quantitative based VAs, where qualitative data is either purposefully excluded or it is not able to be readily integrated. Based on the findings and lessons from the literature, there is unanimity in most cases that all available information (both quantitative and qualitative) should be used and that in cases where complex modelling is involved, efforts should be taken to quantify qualitative information to enable incorporation into the assessment. This approach minimizes helps to minimize information gaps, which are often found in remote and distant areas, which is particularly pertinent in the case of WCPFC.

10.4 Effective data management is essential

Effective data management systems and processes are necessary to ensure information is collected and handled in a standardized manner (receipt, analysis, storage, confidentiality etc.) to ensure VAs strengthen over time as more and improved information becomes available. We are acutely aware that WCPFC and Pacific organizations (e.g. SPC), have already well-defined data management systems and protocols in place which will support effective monitoring and regular VAs over time.

10.5 Regular stakeholder engagement (traditional and local expert knowledge)

Regular engagement with stakeholders, with a focus on traditional and local expert knowledge holders, is identified as essential across literature. Early engagement with stakeholders and local communities should be factored into the design of a VA, to help identify those elements and information gaps that can be readily filled through locally held knowledge and traditional know-how / practices. Further, regular engagement pathways and channels should be implemented that enable regular reporting and information to be collected to update VAs on a regular basis. Not only does this approach ensure robust information sharing, but it also directly improves acceptance and social cohesiveness around adaptation activities resulting from VAs.

We are well aware that WCPFC members have already well-established communication pathways in many cases that enable the regular collection of traditional, artisanal and local expert knowledge. We conclude that keeping in mind qualitative information sources to potentially draw on during the design process of the VA framework will be important, and that existing knowledge and engagement pathways provide an important resource to draw on to potentially fill quantitative information gaps.

10.6 Capacity building and training

Ensuring sufficient capacity to design, implement and maintain a VA is vital. In many examples, it is recommended that capacity requirements and training modules are designed in parallel with a VA framework to ensure the upfront investment in developing the VA framework is maximized via robust and trusted assessment outcomes i.e., to ensure the framework remains operational and to avoid it being used once before being placed on a desk to gather dust.

As mentioned above, in the case of the WCPFC VA framework, we consider a pragmatic design approach will ensure that the associated capacity requirements to regularly maintain and update the associated VA results will not overly burden the WCPFC over the long-term.

11 Pacific marine VA insights

In addition to the general VA insights, we also set out below our key conclusions in respect of several insights related more specifically to the Pacific marine environment.

11.1 Gender-sensitive approaches

Gender-sensitive approaches in the collection of traditional knowledge is considered essential across Pacific marine VA assessment literature, in the recognition that traditional and local expert knowledge is often differentiated by gender in the Pacific islands. We are again acutely aware that the WCPFC and Pacific organizations such as the SPC already provide pathways, guidance and tools to ensure this approach to traditional knowledge collection is provided for.

11.2 Funding is a very real barrier

In the case of the Pacific, a key barrier to successfully establishing and maintaining VAs over time is suitable long-term funding arrangements. VAs that require in-depth technical expertise and comprehensive analysis take more time and come with a higher cost, whereas low input, low-cost VAs may generate an oversimplified assessment that limits suitable adaptive actions to be generated.

In the case of the WCPFC VA framework, we conclude a balance must be struck between providing a pragmatic design that supports regular assessments at a relatively low cost, while providing meaningful assessment outcomes that provide the WCPFC with the required confidence to act.

11.3 Flexibility equals endurance

As information collection methods, VA assessment methods, and information technology continue to improve, it is considered essential that VA frameworks are designed in a manner that enables rapid integration of new concepts / elements and information to ensure they remain relevant over time. This is particularly true in the context of the Pacific fisheries, where significant advancements in information collection as a result of technology (e.g., electronic monitoring) are being made.

Again, this consideration supports our conclusion that a pragmatic ‘rapid assessment’ design approach is best suited to enable the required flexibility needed for the WCPFC to regularly adjust and adapt the framework over time as new and improved information becomes available.

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Annex A: Summary comparison of the four IPCC vulnerability assessment frameworks

Table 7. *Summary comparison table of the four IPCC VA frameworks*

Report	Definition	Vulnerability model	Role of exposure	View of sensitivity	View of adaptive capacity
Third Assessment Report (TAR) **(2001)**	Vulnerability was defined as: “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variation and extremes influenced by exposure, sensitivity and adaptive capacity.” This early definition framed vulnerability as a function of, Exposure, Sensitivity, Adaptive Capacity	Vulnerability as a composite function Exposure + Sensitivity – Adaptive Capacity	Component of vulnerability Defined as the nature and degree to which a system is exposed to climate variations (e.g., temperature rise, storms). Example: A coastal town directly in the path of hurricanes is highly exposed.	Component of vulnerability. Defined by the degree to which a system is affected by climate stimuli Example: Coral reefs are highly sensitive to even small temperature changes.	Component of vulnerability. Defined as the ability of a system to adjust, moderate damage, or cope. It is often assessed through technical or institutional metrics (e.g., education, income, infrastructure). It is resource- and knowledge-based. It is inversely related to vulnerability—higher adaptive capacity = lower vulnerability
Fourth Assessment Report (AR4)	Retained the TAR definition with minor editorial change (see Figure 2)	Vulnerability as a composite function	Component of vulnerability Defined as the nature and degree to which a system	Component of vulnerability.	Component of vulnerability.

(2007)	AR4 further elaborated on vulnerability by emphasizing the importance of socio-economic factors and governance structures. It recognized that vulnerability is not only a function of physical exposure but also of social and economic conditions that influence a community's ability to adapt.	Exposure + Sensitivity – Adaptive Capacity	is exposed to climate variations (e.g., temperature rise, storms). Example: A coastal town directly in the path of hurricanes is highly exposed.	Defined by the degree to which a system is affected by climate stimuli Example: Coral reefs are highly sensitive to even small temperature changes.	Defined as the ability of a system to adjust, moderate damage, or cope. It is often assessed through technical or institutional metrics (e.g., education, income, infrastructure). It is resource- and knowledge-based. It is inversely related to vulnerability—higher adaptive capacity = lower vulnerability
Fifth Assessment Report **(2014)**	Vulnerability refers to the propensity or predisposition to be adversely affected. It encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt	Shift to a risk-based framework Moved away from treating vulnerability as a function of exposure (exposure became a separate concept under risk). Vulnerability is a function of sensitivity and capacity to cope and adapt. Positioned vulnerability alongside hazard and exposure as one of three core elements of climate risk. A hazard is the climate-	Reframed as separate from vulnerability—one of three components of risk Exposure becomes part of the risk equation, distinct from vulnerability. It clarifies that exposure is not always a vulnerability, especially for people who may live in hazard-prone areas but are well-protected.	Still recognized, but folded into vulnerability as a predisposition to harm. It is a subset of vulnerability rather than treated as a separate variable. It is linked to both biophysical and socio-economic characteristics of systems Sensitivity is the degree to which a system is	Still recognized, but folded into vulnerability as a predisposition to harm. It is a subset of vulnerability rather than treated as a separate variable. Adaptive capacity is the ability of systems, institutions,

		related event or trend (e.g storm, drought, sea-level rise)	Exposure is the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. Exposure asks what is at risk—not necessarily what will be harmed, but what is located in areas where climate hazards may occur.	affected, either adversely or beneficially, by climate variability or change. Example: a community may be highly sensitive if it depends on a narrow range of species for food and income and those species are highly temperature sensitive.	humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. It is increasingly linked to institutional, economic, and governance capacity as well as social and ecological terms Still part of vulnerability, but reframed
Sixth Assessment Report (2021-2022)	Vulnerability means the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards	Retains the risk-based model but it evolves to more clearly emphasise inequality, marginalization, and development. Focused more on structural vulnerability and differential impacts (e.g., small island states, Indigenous peoples, women, the poor). Deeply contextual, justice-informed risk.	Same as AR5, but more nuanced—includes geographic, economic, and cultural exposure. It is socially and politically shaped Recognizes social and economic dimensions of exposure—e.g., not just	A component of vulnerability, as in AR5 but an expanded understanding—sensitivity includes ecological thresholds, livelihood dependencies, and social dynamics Broader and deeper—includes interactions among ecological,	A component of vulnerability, as in AR5 but an expanded understanding. It emphasizes transformation, agency, justice, equity, to power, and historical disadvantage as determinants. Transformation

		Hazards are a spectrum including acute events (e.g cyclone), chronic trends (e.g sea-level rise, ocean acidification) and compounding and cascading events. Climate Risk = Hazard × Exposure × Vulnerability	where people or systems are located by why they are there; and considers displacement, land rights and poverty.	social, and economic systems. Example: A fishing community's sensitivity depends not just on fish stocks, but also on market dependence, food security, and social networks. Climate Risk = Hazard × Exposure × Vulnerability	refers to the ability not just to adjust, but to restructure systems to reduce future risk

Annex B: Summary overview of the methodological approaches to climate change vulnerability assessment frameworks

This table presents a summary of the operational frameworks applied across the literature in this review. It illustrates the breadth of frameworks and diversity of applications used in the literature we found.

Each study with an operational framework is logged here, and categorized into one of four categories:

1) **Studies employing established theoretical or analytical frameworks (Table 8)**
2) **Studies applying or building upon existing frameworks developed by others (Table 9)**
3) **Studies utilizing mixed-methods approaches or conducting comparative analyses (Table 10)**
4) **Studies developing original composite indicator frameworks proposed by the authors (Table 11)**

Table 8. *Summary table of studies employing established theoretical or analytical frameworks*

Index Name	Origin	Description	Usage – globally endorsed/standardised/widely used in practice?	Resources – Toolkits/manuals	Applied by	Application Contexts
Drivers, Pressures, State and Trends, Impacts, Response (DPSIR)	European Environment Agency (2004) Further improved and critiqued by Kristensen (2004) Omann et al (2009). Svarstad et al (2008),	Established Integrated Environment Assessment (IEA) process oriented to the IPCC framework to focus on identifying climate change vulnerability impacts and developing adaptive responses	Widely used in practice	Yes. IEA Training Manual – Volume Two: Vulnerability and Impact Assessment (the International Institute for Environment and Development (IIED)) DPSIR-ESA Vulnerability Assessment (DEVA) Framework	Duran-Izquierdo and Olivero-Verbel (2021)	Sierra Nevada de Santa Marta Nature Reserve, Colombia

National Oceanic and Atmospheric Administration Climate Vulnerability Assessment Tool	NOAA (2019)	A structured approach developed by the NOAA to evaluate how climate change may impact marine fish and invertebrate species. This methodology assesses species' vulnerability by examining their exposure to projected environmental changes and their sensitivity based on life history characteristics.	Widely used within the U.S as a component of federal fisheries science and climate adaptation planning. Fisheries Fish Stock Climate Vulnerability Assessment Methodology	Yes	McClure et al (2023) Frawley et al (2025)	fish and invertebrate species in the USA
Fuzzy Logic Expert System Approach	Developed by Lotfi Zadeh (1965). Cheung et al (2005) developed a fuzzy logic expert system to assess the intrinsic extension vulnerability of marine species to fishing	A decision-making tool that combines fuzzy logic – to handle uncertainty and ambiguity in data and expert systems – to use expert knowledge and rules for inference It is useful in complex systems (like climate vulnerability, environmental management, or fisheries), where data are uncertain, qualitative, or imprecise.	Widely used and cited in academic research and global vulnerability cited but limited operational adoption	No.	Bueno-Pardo et al (2021) Jones and Cheung	Commercial fish and invertebrates in Portugal Vulnerability of global marine species to climate change
Livelihood Vulnerability Index	Developed by Sullivan (2009) and built on by Hahn et al (2009)	A tool used to measure how vulnerable a community is to climate change. It combines social, economic, and environmental indicators—like health, food, water, and natural disasters—into a single index. Each indicator is standardized, then grouped and averaged to	Yes, widely used in practice	Not as such, but detailed method in the referenced papers	Azam et al (2021)	Assessment of climate change and natural hazards vulnerability of char land communities in Bangladesh

		show which communities are most at risk and where support is needed				
Analytical Hierarchy Process	Saaty (1980), as applied in Maina et al (2008)	A structured decision-making method make complex decisions by breaking them down into a hierarchy of simpler sub-problems, comparing elements pairwise, and quantifying priorities.	Widely used in academic research and climate vulnerability assessments. Operationalised in environmental policy and planning but limited uptake in fisheries management.	Various tools develop to facilitate applying this method	Gathongo and Tran (2023) Oloyede et al (2022) Chauhan et al (2022) Mushwani et al (2025) Barnett (2020) He et al (2018) Singh, Singh and Tropathi (2025) Champion et al 21-06-25 11:52:00	Social vulnerability to climate change of 5 villages Mt Kasigau Kenya Adaptative Capacity assessment of Tanzanian fishing communities. Coastal vulnerability assessment of the Nigerian Coastline Flood vulnerability strategies in Afghanistan Water vulnerability and adaptation in Himalayan cities, India Ecological vulnerability assessments in China Chambal River Basin, India Coastal pelagic fishes from south Eastern Australia

Physical vulnerability to Climate Change index	Unknown, multiple variations exist.	A physical Vulnerability to Climate Change Index is a tool or framework designed to assess the susceptibility of physical systems or infrastructure to the impacts of climate change. It typically evaluates how exposed, sensitive, and adaptive a physical system (like buildings, roads, coastal defenses, or natural landscapes) is to progressive (e.g sea level rise, temperature increase) and recurrent (rainfall, heatwaves, cyclones) geophysical conditions	No	No	Closset et al (2018)	To determine the most vulnerable developing countries
Principal Component Analysis	Emerged in the early 1900s as part of the development of multivariate statistics, emerging as a quantitative method in climate change vulnerability assessments from 2005 onwards in landmark studies (Turner et al (2003), Fussel and Klein (2006))	A statistical technique for dimensionality reduction and data summarization. It transforms a large set of possibly correlated variables into a smaller set of uncorrelated variables called principal components, while preserving as much variance (information) in the data as possible.	No single, standardised approach but best practices and guidelines exist.	Yes Jolliffe "Principal Component Analysis" (1996) with Cadima (2016 edition), UNDP Vulnerability and Adaptation Assessment Guidance Handbook for Conducting Vulnerability and Adaptation Assessments (provides practical	Perez et al (2020) Marín-Monroy et al (2020) Bera et al (2022) Török, Croitoru and, Man (2021) Bito-onon (2020)	Climate vulnerability for bean growing households in Columbia Socio environmental vulnerability of coastal cities to tropical cyclones Extreme temperatures in Romania. Climate risks in the fisheries sector in provincial Philippines Coastal vulnerability index at national, regional and local scales

				steps on indicator selection, normalization and PCA use) (1996)6/21/2025 11:52:00 AM	Nguyen et al (2021) Yang et al (2019) Njoya et al (2022) Radhakrishnan et al (2022)	Social vulnerability in coastal China Smallholder farmer's adaptive response in Cameroon Whiteleg shrimp production in coastal India
Climate Vulnerability Index	Jon C. Day, Scott F. Heron (2020)	A systematic, rapid assessment tool designed to evaluate the vulnerability of World Heritage properties—both natural and cultural—to climate change.	It is a standardised conceptual and methodological framework. Increasingly recognised and applied to World Heritage properties.	Yes CVI Flyer and Overview (2019) CVI Summary Report	Losciale et al (2024)	Climate change vulnerability of World Heritage seagrass habitats
Economic Vulnerability index	Formulated by Briguglio (1995), and as outlined as a standardised methodology by Guillaumont (2009) and advanced through Lysenko and Schott's composite index (2019) and as advanced by S.	The EVI was developed to measure a country's structural vulnerability to economic and environmental shocks. It is calculated using a composite of indicators that assess factors such as Exposure to economic shocks, structural weaknesses and environmental factors such as susceptibility to natural disasters)	Standardised framework used by the UN Committee for Development policy with defined indicators, methods and processes to update.	Yes UN Committee for Development Policy Methodological Notes (2021b) UN Handbook for LDCs (2021a)	Kourantidou et al (2022) Wang, Han and Ma (2022)	Socioeconomic disruptions of harmful algal blooms in Indigenous communities International tourism

	Feindouno and M. Goujon (2015)					
Profiler approach	Harry Fischer, Ashwini Chhatre (2016)	A flexible methodological framework designed to analyse differentiated social vulnerability in the context of climate change. This approach emphasizes understanding how various household-level factors—such as assets, livelihoods, and social networks—interact to shape vulnerability to climate impacts	Moderate uptake in studies focussing on social vulnerability and differentiated adaptation to climate change. Not standardised (except for its statistical methods)	No.	Harry Fischer, Ashwini Chhatre (2016)	Analysis of differentiated social vulnerability in the context of climate change
WRASTIC model (Wastewater discharge, recreational impacts, agricultural activities, surface runoff, transportation impacts, industrial impacts, commercial land use)	USA -EPA Office of Water (early 1990s)	Used to evaluate and rank areas based on the potential risk they pose to the environment, particularly for groundwater contamination and watershed protection planning. It is often applied in land-use planning, environmental monitoring, and site selection for conservation or remediation.	Institutionalised through US EPA.	Yes, Guidelines exist. GIS-based tools have also been developed to facilitate its application.	Maheshwari and Vyas (2023)	Extension of the WRASTIC to vulnerability applied to Upper Lake city of Bhopal, India
Climate and Ocean Risk Vulnerability Index	The Stimson Centre (Rouleau et al. 2022b)	Collects data across 10 categories , grouped under ecological, financial and political risk. Produces a holistic and comprehensive	Yes, widely applied	Yes, available on the Stimson Center's CORVI project page www.stimson.org/project/corvi	Shiiba et al (2023) Rouleau et al (2022a)	Climate risk assessment of coastal resiliency in Suva

		profile for a chosen coastal city. Data is standardised on a 1-10 scale relative to 10-20 other coastal cities in a geographical region which share similar characteristics.				Climate risk assessment of coastal resiliency in Mexico City
Social Vulnerability Index (SoVI)	Cutter et al (2003)	A composite measure developed by Susan Cutter et al. (2003) to assess the social vulnerability of different geographic areas to environmental hazards and disasters. SoVI helps identify which communities are more likely to suffer harm from disasters based on their social characteristics—not just exposure to physical hazards. Many variations and adaptations are also used in literature.	Yes, widely applied	Not formally but the many examples of the method applied	De Loyola et al (2016) Tasnuva et al (2021) Aksha et al (2019)	Social vulnerability of natural hazards in Brazil. Household social vulnerability to natural hazards in Southwest coastal Bangladesh. Applied to social vulnerability assessment in Nepal, slightly modified to quantify at village and municipal level
Pressure-State-Response	OECD (1994)	Developed as a framework for understanding and assessing environmental issues.	Yes but not specifically for climate change vulnerability assessments.		Verdugo et al (2018)	Vulnerability assessment of a protected area in Cabo, Mexico.

Table 9. *Studies applying or building upon existing frameworks developed by others*

Reference	Method applied	Context
Pujino et al (2021)	Applies the AR4 climate vulnerability equation using indicators from the 2010 Indonesian Climate Change Sectoral Roadmap (2010), Muchtar Efendi (2012) and Pujiono E and Setyowati R (2015). Weighting and scoring was based on these three studies.	Vulnerability assessment of water resources to climate variability in Noelmina watershed, Timor Island, Indonesia.
De Paz and Garcia (2021),	Drew on Schroter et al (2005) to: hypothesise who is vulnerable to what, source and operationalise indicators, weight the components and produce measures of the contribution of each component to the system's vulnerability.	Environmental vulnerability assessment of Brazilian Amazon Indigenous Lands.
Farahmand et al (2023)	Based on Allison et al (2009) and Blasiak et al (2017) modifications made in assessing all three dimensions of the vulnerability index, most particularly to the exposure dimension, using an Environmental Suitability Index from Hutchison (1978) but updated through using ensemble species distribution modelling procedure described in Shickele et al (2020; 2021) (applied to small pelagic fishes and cephalopods and Lamine et al (2023) (species of high economic value)	Mediterranean countries across Europe, middle east and North Africa. Fisheries for main commercial species.
Blasiak et al (2017)	Assembled in line with Allison et al (2009) with modifications.	Global, EEZs of 147 countries to determine least develop countries global index of vulnerability based on the climate change impact on marine fisheries.
Bell et al (2024)	The vulnerability of coastal habitats to the impacts of climate change was assessed using a structured semi-quantitative vulnerability assessment framework (Johnson et al. 2024, publication pending) and a method applied previously in the Pacific Islands region (Bell et al. 2011; J. E. Johnson et al. 2016) (and in adjacent regions such as Northern Australia (Welch et al. 2014)and Arafura and Timor Seas (Johnson et al. 2021)"	Vulnerability assessment of Pacific islands Communities to food security and the effect of climate change on coastal fisheries.
Pinnegar et al (2019)	Applies Hare et al (2016) (adapted)	Vulnerability of the fisheries sector in Dominica
CRVW Tool **Klinsky and Timmons (2017)**	Adapted from the Vulnerability Sourcebook by Deutsche Gesellschaft fur International Zusammenarbeit GmbH (2014)	UK Government Department (CRIDF)-developed a Risk and Vulnerability Assessment tool to evaluate,

		at a preliminary project statement the climate risk and vulnerability of communities in Africa. UNFCCC Consultative Group of Experts to develop assessment training materials
RIchardson et al (2018)	Hunger and Climate Vulnerability Index (Krishnamurthy et al 2015) (adapted to enable future projections)	Assessment of food insecurity under a range of climate change and adaptation investment scenarios across a range of countries
Silva et al (2022)	Applied Camara et al's (2021) methodology for a socioeconomic vulnerability index which applies subjective assessments from local stakeholder with objective data	Evaluation of how susceptible Brazilian coastal communities were to the impact an of oil spill
Fisher and Frazier (2018)	Applies the Spatially Explicit Resilience and Vulnerability (SERV) model (Frazier, Thompson, and Dezzani 2014)	Social vulnerability to climate change in temperate forest areas
Ilcheva, Yordanova and Niklova (2020)	Draws on and adapts CC-WARE (South East Europe Transnational Cooperation Programme 2012)	Assessment of water resources vulnerability in different climate scenarios in Bulgaria
Asykuri and Oktari (2025)	Participatory Action Research with set questions from the Community Resilience Measurement Dashboard developed by the International Federation of Red Cross to assess vulnerability, hazard, and capacity of the selected village. (International Federation of Red Cross, n.d.)	Vulnerability assessment of a coastal village: Gampong Pande, Indonesia
Cangüz,Coşkun,Hepcan (2024)	Assessment method based on the work a range of authors (Prasad et al. 2008; Swart et al. 2012; Çobanyılmaz and Yuksel 2013; Tapia et al. 2017; Bucak et al. 2021)	Climate Change vulnerability assessment in Karsiyaka, Izmir, Turkiye.
Ramadhan et al (2022)	Smartline method to map and analyze the coastline by drawing a continuous line that represents the shore's geomorphological and physical characteristics developed by Chris Sharples et al from the University of Tasmania. (Sharples et al. 2009)	Coastal vulnerability assessment for community resilience on abrasion in Bugel Coast, Indonesia
Ghoussein et al (2018)	Gornitz (1991) Climate Vulnerability Index, using GIS.	Applied to a vulnerability assessment of the South Lebanese coast
Mukherjee and Siddique (2020)	UNEP Analytical Approach (A. Singh, Pathirana, and Shi 2006)	Vulnerability to extreme rainfall events on the Pacific coast of Mexico
Tasnuva, (2021)	Applies Adger and Vincent (2005)	Household social vulnerability in southwest coastal Bangladesh

Table 10. *Studies utilizing mixed-methods approaches or conducting comparative analyses*

Reference	Summary of methods applied	Context
Mixed **Jha et al** **(2021)**	Own assessment drawing on a combination of other methods. Bottom up, indicator-based approach applied drawing on local level indicators from Jha et al 2017; and assessment approaches based on multidimensional vulnerability from Sullivan and Meigh (2005), Livelihood Vulnerability Index from Hahn et al (2009), Livelihood Effect Index from Urothody and Larsen (1970), Climate Vulnerability Index from Pandey and Jha (2012), Capacity Assessment Index from Jha et al 2017 (2017), and Vulnerability and Capacity Assessment from Sinha and Jha 2017 (2017).	Socio ecological vulnerability assessment of Himalayan communities.
Mixed **Mekonen and Berlie** **(Mekonen and Berlie 2021)**	Livelihood vulnerability assessment drawing on indicators from Sullivan and Meigh (1982)and Sullivan and Byamba (2013); weighting indicators as in Iyengar and Sudarshan 6/21/2025 11:52:00 AM	Climate livelihood vulnerability assessment undertaken in Northeastern highlands of Ethiopia.
Comparative **Dhamija et al (2020)**	Applied Analytical Hierarchy Process, Principle Component Analysis and Equal weights to weight indicators and evaluate the degree of consistency in the vulnerability methods between the different weighting methods.	Investigation of consistency in vulnerability assessments of wheat to climate change at the district level in India
Mixed **Shibu Das Kaushal Kumar** **(2024)**	Mixed-method approach combining qualitative and quantitative methods. Qualitative methods included interviews and focus group discussions and quantitative methods included Ordered Probit Regression, multi-stage random sampling, problem confrontation index (PCI).	Livelihood vulnerability assessment among the agrarian indigenous communities of Sundarban Biosphere Reserve in India
Mixed **Giddens et al** **(2022)** **Advani, N** **(2023)**	These studies apply a Rapid Vulnerability Framework that applies expert knowledge, literature review, and climate projection models to assess the vulnerability marine species, drawing on the NOAA Fish Stock Climate Vulnerability Assessment Methodology (above), and applying the Rapid Vulnerability Assessment based on existing tools e.g Different RVA based on methods from existing tools -Foden et al (2019), Gill et al (2013), The Heinz Centre (2012) and Wiliams et al (2008).	Applied to marine species

Mixed **Panda, A** **(2017)**	A composite index with a balanced weighted average approach, where each subcomponent contributes equally to the overall index score. Indicators are selected based on a literature review and data availability, reflecting the context of drought-prone regions, developed through qualitative methods through intensive household surveys, randomly selected, to develop socio-economic and livelihood indicators The Iyengar and Sudarshan (1982) method is used for aggregating indicators, similar to the Human Development Index (HDI), to calculate vulnerability index (VI) scores for each village.	Vulnerability assessment of drought-impacted small and marginal famers in Odisha, India
Mixed **Olivares et al** **(2022)**	Review of existing methodological approaches for climate vulnerability assessment and cumulative environmental impacts using a narrative literature-based approach. Qualitative evaluation of climate vulnerability using IPCC's Reasons for Concern (RFCs) (2017)(2013). Use of the Halpern Cumulative Impact Model for assessing cumulative environmental impacts. Expert judgment for sensitivity scores and impact weightings. Spatial analysis using ArcMap for calculating cumulative impact scores.	Climate vulnerability and cumulative in Venezuelan coastal landscapes
Comparative **Singhal and Jha** **(2021)**	The methodology involves an indicator-based vulnerability assessment approach to identify vulnerable areas in agriculture. Indicators for exposure, sensitivity, and adaptive capacity are selected and normalized. Weights are assigned using the Inverse of Variance method. Two aggregation methods are used: a simple average and a weighted standardization. Vulnerability scores are categorized into five levels: Very Low, Low, Moderate, High, and Extreme as proposed by Iyengar and Sudarshan(1982). Adaptation models are identified based on category transitions using both aggregation methods.	Vulnerability assessment of the agriculture sector in India.
Mixed **Brownbridge and Cangarajah** **(2024)**	Doan et al (2023) methodology to estimate the number of people exposed to extreme weather events and vulnerable to suffering severe losses if those events materialise. ND GAIN index (University of Notre Dame 2025) indices to evaluate exposure to climate change	Analysis of the macro-fiscal impacts of major tropical cyclone disasters on Small Island Developing States (SIDS) including hurricanes Erika and Maria in Dominica (2015 and 2017), hurricane Irma in Antigua and Barbuda (2017),

	Event Study methodology to examine the tie fiscal impacts of large tropical cyclone disasters (originally developed by Ball and Brown(1968) ; Fama et al(1969).	cyclone Evan in Samoa (2012), and cyclone Pam in Vanuatu (2014)
Mixed **Pirasteh et al (2024)**	Social Vulnerability Index (Ford J.D and Smit B 2004) calculated for each country. Machine learning techniques Fuzzy Analytical Hierarchy Process (Saaty (1980) as adapted by Laarhoven and Pefrycz (1983) and Cheung et al (2005)) adapted with the opinions of 30 experts to calculate the weight of each indicator.	Vulnerability assessment of socio ecological systems exposed to multiple environment hazards (forests) in Chaharmahal and Bakhtiari Province, Iran
Mixed **Namdar, Karami and Keshavarz (2021)**	ND GAIN (University of Notre Dame 2025) index indices to evaluate exposure to climate change. Cluster analysis applied to classify MENA countries into homogenous groups (K-means)	Vulnerability assessment of MENA countries
Mixed **Cochrane et al (2020)**	Adopts Marshall et al (2009) framework, adapted through stakeholder consultations. Logic rule to aggregate scores from Cochrane et al (2020) and adaption options from Watkiss et al (2020)	Assess vulnerability and adaptability of the fisheries for small pelagic species in the Benguela countries: Angola, Namibia and South Africa
Mixed **Huynh et al (2021)**	Indicator selection as in Ludena and Yoon (2015) and Islam et al (2014) Qualitative methods (interviews and group discussions) to collect data. Own methods for analysing data.	Vulnerability assessment of fishery-based livelihoods to climate change in coastal communities in central VietNam
Mixed **Qureshi and Rachid (2022)**	Use of PCA to develop HVI maps to identify places at high risk of extreme heat and air pollution. Risk factors for social vulnerability derived from literature and risk factors for the environment identified based on extreme event analysis of the studied area.	Heat Vulnerability Index mapping in Amiens, France
Mixed **Wang, Shu and Yuan (2024)** **Zhuang et al (2024)**	PSR (Pressure-State Response) originally developed by the OECD (1994) as a framework for understanding and assessing environmental issues in the 1990s. Indicators were developed based on a literature review and applying frequency statistical methods to categorise and count the occurrences of each indicator. Indicators were refined through expert consultation. Indicator weightings calculated by entropy weight method (mathematical technique) as in Cheng et al (2020). TOPSIS as a multi-objective decision-making approach as in Sun et al (2020).	Applied to mudflat ecological vulnerability in Jiangsy, China Applied to an urban vulnerability assessment in Urban Sichuan Province, China.
Mixed **Kim and Gim (2020)**	Social Vulnerability Index developed by Cutter et al (2003) but as adapted by Holand et al 2011 to separate it into two indices, also creating the built environmental vulnerability index (SEVI and BEVI) constructed based on Borden et al (2007), Holand et al (2011), Zhou et al (2014).	Social vulnerability to floods on Java, Indonesia

	Applied Papathoma-Kohle et al (2019) method of equal weight aggregations method. Developed place-based indicators and commonly used indicators of social vulnerability as in Adger 1999, Cutter et al (2003), Kubal et al 2009 and Hummell et al 2016	
Mixed **Serafim et al (2019)**	Coastal Vulnerability Index as described by Gornitz and Kancirukvukn and Gornitz (1991), with adjustments to the adaptive capacity variables to include socio economic and locational variables; and application of analytical hierarchy process to estimate relative weights for the variables set.	Coastal vulnerability to wave impacts using a multi-criteria index in Santa Catarina, Brazil
Mixed **Kim et al (2023)**	Applied the Morrison et al (2016) framework, but used the detailed sensitivity attributes and scoring criteria of Pecl et al (2011) and Hobday et al (2011) Ecological Risk Assessment for the effects of Fishing. Own method to calculate vulnerability scores.	Applied to a vulnerability assessment of Korean fisheries to climate change
Mixed **Fernandez and Golubiewski (2019)**	Develops an Impact Index (sensitivity and exposure) indicators, and an adaptive capacity index. Indicators drawn from Fernandez, Bucaram and Renteria (2017), Ibarraran, Malone and Brenker (2010) and Eriksen and Kelly (2020), adapted to context. Indicators normalised between zero and one then combined through a geometric product function (Fernandez, Bucaram and Renteria (2017), Tol and Yohe (2007), Lung et al (2013)	Vulnerability Assessment of Auckland City, New Zealand.
Mixed **Qin et al (2022)**	Indicators extracted from Hahn et al (2009), Pandey et al (2017), Zhang et al (2019), Das et al (2020) and through qualitative Techniques i.e interactions and through participatory rural appraisal tools such as questionnaires and small-scale symposiums. Indicators normalised. Adapted Pandey et al (2018) standardisation methods to eliminate different magnitudes and own equations to calculate exposure, sensitivity and adaptive capacity at the household level.	Livelihood vulnerability assessment of pastoral households in semi-arid northern China
Mixed **Sharma, Jagtap and Rao (2022)**	Mixed methods to investigate the perception of vulnerability of coastal fisherman regarding climate change, adaptive capacity and livelihood resilience. Undertaken using a survey based on aspects of Bonan & Doney 's framework (2018). Principal axis factoring and oblimin rotation used to evaluate data.	Applied to coastal communities in Maharashtra, India
Mixed **Jeevamani et al (2021)**	Develop own composite index titled 'Sustainable Fisheries Livelihood Index' to evaluate 5 livelihood related capital asset endowments to assess existing status of asset-based livelihood strategic of the fishing community in Sindhudurg coastal and marine system area. Adapts also the Krishnan et al (2019) Cumulative Vulnerability index to explore vulnerability of the level of marine fishing spatial units. Both indices were integrated using statistical analysis (Cronbach's reliability coefficient) for evaluation of livelihood sustainability to develop targeted interventions	Applied to coastal vulnerability versus fisheries livelihood sustainability assessment in Sindhudurg, India

Mixed **Montijo-Galindo et al (2020)**	Use Qaisrani et al (2018) and Gurri et al (2019) to construct integrated vulnerability index.	Applied to climate change adaptation in rural Mexico.
Mixed **Nef et al (2022)**	Multi-method approach to collect primary and secondary data. Participatory methods to collect local knowledge contrasted with scientific findings from similar contexts. Quantitative analysis based on Ritchie et al (2003) and Bohm (2012).	Vulnerability to food security in Vanuatu
Mixed **Mekonnen et al (2019)**	Composite indicator framework with indicators selected from Piya et al (2012). Indicators normalised and PCA analysis applied given diversity of indicators used. Own method for calculating a livelihood diversity index based on Lorenz curve and Gini index to measure income inequality and distribution.	Socio-ecological vulnerability to climate change/variability in central rift valley, Ethiopia.
MIxed **Yang et al (2019)**	Own social vulnerability index based on own potential exposure index but applying PCA	Social vulnerability in coastal China
Mixed **Michetti and Ghinoi (2020)**	Applied PCA using indicators derived from PeVI (Sorg et al. 2018) , adapted to add elements that can change after a disaster such as elements of risk awareness and perception and access to information.	Case of Sint Maarten in context of Hurricane Irma in 2017
Comparative **Still et al (2015)**	Species distribution modelling (Rowland 2009) and United States Climate Change Vulnerability Index (Byers and Juarez 2023)	Comparative vulnerability assessment of methods to prioritise and manage rare plants in the U.S
Mixed **Tai, Xiao and Tang (2020)**	Applied SENCE (Ma and Wang 1984) method drawing on prior research of vulnerability characteristics of coal mining cities to develop indicators for the SENCE assessment. Applied entropy weight method to compare cities' relative vulnerability ((Lu et al. 2020; W. Xiao et al. 2020)	Quantitative vulnerability assessment of coal mining cities.
Mixed **Llorente-Marron et al (2020)**	Own social vulnerability index. Own choice of indicators with a basis from Cutter, Boruff and Shirley (2009) and Cutter and Morath (In Jörn Birkmann 2013), quantified in the event of a disaster using TOPSIS rather than PCA as was used in the Cutter index, applied Differences in Differences estimate (Angrist and Pischke 2009) to analysis impacts of the earthquake on social vulnerability of households and on the gender gap.	Social vulnerability assessment on gender and disaster and Haiti earthquake 2010
Mixed **Koutroulis et al (2019)**	Framework based on Koutroulis et al (2018), adapted, and developed from a range of different data inputs but using Fekete 's process (2009) to calculate vulnerability into a common qualitative scale.	Applied to a range of regions to assess freshwater vulnerability to climate change events.

Mixed **Kileli and Bayazit (2024)**	New methodology integrating coastal vulnerability index (Gornitz 1990 as modified by Thiler and Hammar-Klose 2000) and hot spot analysis (Getis-Ord Gi).	Applied to a spatial distribution of coastal infrastructure vulnerability in Kusadasi-Selcuk, Turkey.
Mixed **Park and Xu (2022)**	Applies Cutter et al (2003) but uses a geographically weighted analysis instead of PCA to create an alternative SoVI that accounts for the spatial heterogeneity of local conditions.	Applied to a social vulnerability assessment in Greater Houston, USA.
Mixed **Yin et al (2024)**	Constructed own SoVI using own indicator system, but determined weights using both entropy weight method and critic method. Applied improved TOPSIS method to calculate the index.	Applied to a social vulnerability analysis of earthquake disasters in mountainous areas of Sichuan Province, China
Comparative **Umamaheswari et al (2021)**	Author's own novel socio economic vulnerability framework and cumulative assessment framework compared with an existing framework – the SEVI (2019). Own scoring and indicator selection,	Applied to marine fishing village in a coastal Indian district.
Mixed **Thong et al (2022)**	Inspired by Cutter et al (2003), with conceptual vulnerability approach from Ford et al (2006) and O'Brien et al (2007) to develop indicators. Applied rapid rural appraisal for insights and PCA.	Applied to shifting cultivars in Mizoram, NE India.

Table 11. *Studies developing original composite indicator frameworks proposed by the authors*

Reference	Context
Fisheries @ Risk Index Heck et al (2020)	Identified national risks to fish, fishers and fisheries by combining data on exposure to climate change and coastal hazards and vulnerability from social, economic and governance indicators. Hazard and exposure are combined to one variable following WorldRiskIndex. Applied to Caribbean fisheries Indicators normalised on a scale of 0-1. Risk = (AC + S)*E (AR5 Model) Developed own indicators, weighting and analytical methods
Hazard and Climate Vulnerability and Capacity Assessment (HCVCA) toolkit (Nairobi Convention Secretariat 2022)	A participatory and community-based toolkit, focusing on identifying the underlying causes of vulnerability to natural hazards and climate change through social, cultural, political, economic, and environmental factors. It includes various tools such as Vision Mapping, Hazard Ranking, Community Social Mapping, Hazard and Vulnerability Mapping, Natural Resource and Livelihood Mapping, Seasonal Calendar, Timeline and Trend Analysis, Institutional Mapping, and Transect Walk. Each tool packaged individually to allow mixing and matching to create a customizable vulnerability assessment exercise. Developed for Afghanistan Developed own indicators, weighting and analytical methods
Climate Vulnerability Index (Tee Lewis et al. 2023)	Climate vulnerability assessment across U.S communities to identify and quantify vulnerabilities at the census tract level. It developed a participatory, bottom up composite indicator assessment across health, socio-economic, infrastructure, environment and climate change risks. Developed own indicators, weighting and analytical methods
Gutium and Taranu (2021)	Developed a climate change vulnerability index to assess how vulnerable different regions of Moldova are to climate change based on their exposure, sensitivity and adaptive capacity. The assessment is based on an assessment of extreme temperate and precipitation indices and examines a range of environmental and socio-economic factors such as emissions, waste, water demand and population morbidity. Developed own indicators, weighting and analytical methods
Arago et al (2022)	To conduct a climate vulnerability assessment (CVA) for demersal fisheries in Spain, focusing on regional differences between the Mediterranean and Atlantic areas. Developed own indicators, weighting and analytical methods
Soucy et al (2022)	Bottom up composite indicator approach, using stakeholder engagement and participatory process to identify and prioritise indicators. Spatial mapping and GIS overlay analysis tools used. Evaluates climate change vulnerability impacts on New England forests Developed own indicators, weighting and analytical methods
Huynh et al (2020)	Climate change vulnerability assessment for Can Tho city, Vietnam. Developed composite vulnerability indicators tailored to Can Tho city. Developed own indicators, weighting and analytical methods
Huang et al (2020)	Develops a new Global Desertification Vulnerability index using a composite indicator approach Developed own indicators, weighting and analytical methods

Scott, Hall and Gossling (2019)	Develops a new Climate Change Vulnerability Index to assess and compare the vulnerability dimension of the tourism sector in 181 countries. The method was developed through a conceptual framework, literature review and expert consultations to develop a composite indicator approach. Developed own indicators, weighting and analytical methods
CCVA TOOLKIT (UNEP 2017)	A toolkit which developed guidelines and instructions for undertaking CCVA on coastal social and ecological systems focussed on mangrove, coral reef and seagrass systems developed for near-shore Western Indian Ocean. Adopts a hybrid approach combining top down and bottom up elements with the aim to better quantify vulnerability dimensions.
Pas-Alberto et al (2019)	Climate change vulnerability assessments for Masinloc, Philippines. Developed own indicators, weighting and analytical methods
Battamo et al (2022)	Applies a TOPSIS -entropy-weight algorithm used to calculate weights and ranks of each component of the target countries, used to rank the countries based on their closeness coefficient. TOPSIS is technique for order of preference by similarity to ideal solution as used in water management in different contexts. Applied to freshwater vulnerability for 123 countries along the Belt and Road Initiative Developed own indicators, weighting and analytical methods
Macharia et al (2020)	Applies a generalised method for mapping social vulnerability to climate change, integrating biophysical and socioeconomic indicators to produce climate vulnerability index maps. Applied to river basin communities in Tanzania. Developed own indicators, weighting and analytical methods
Angeon and Bates (2015)	Developed a Net Vulnerability Resilience Index to measure how vulnerable or resilient a country is in climate change, and how well it can bounce back by determining strengths and weaknesses, illustratively applied across developing countries.
Butt et al (2022)	Novel trait-based framework for assessing marine species vulnerability developed using expert elicitation, literature review and IUCN red list guidelines. Own approach to weighting, scoring and analysis of indicators.
Warrick et al (2017)	Pacific Adaptive Capacity Analysis Framework developed specifically as an appropriate framework for the Pacific Islands context. Applied to Pileni Islands community, Solomon Islands
Dudley et al (2021)	Novel climate change vulnerability assessment to identify impacts in complex socioecological ecosystems.
Johnson et al (2016)	Semi quantitative assessment method involving a customisable 10 step process do direct assessment focus and application of results applied to Pacific Islands food security and Gulf of Carpentaria fisheries.
Montejo-Daian, Diaz-Perera and Espinoza Tenorio (2022)	Literature review and fieldwork to develop a qualitative integrative approach to study phenomena and interpret them from the perspective of the inhabitants of the area. Supported with interviews. Applied to vulnerability of artisanal fishers to climate change.

Chen et al (2023)	Multi-index long-term series functional model method integrating 22 economic, social and environmental indicators (self-developed), long-term time series data, multi-index analyses and entropy weighting. Applied to a vulnerability assessment of Belt and Road initiative countries.
Talbot et al (2022)	Author's own socioeconomic vulnerability assessment of impacts of Hurricane Irma and Maria in Puerto Rico. Data collected through household surveys. Own methods for data analysis
Turvey et al (2021)	Own method to develop a single-index measure (polymorphic production function) that relates agricultural output to temperature and precipitation. Applied to agricultural crop production within the USA.
Jakariya et al (2020)	Developed a livelihood vulnerability index for coastal fisherman based on household surveys, selected using random sampling techniques. Applies Participatory Rural Appraisal techniques through semi-structured interviews and focus group discussion methods to collect area-specific factors for exposure, adaptive capacity and sensitivity analyses from villagers. Index calculated used a balanced weight average approach, measure on a Likert scale to facilitate broad comparability with past literature. Applied to coastal fisherman communities in Bangladesh
Huai, J (2016)	Developed a six-dimensional qualitative analytical framework that considers location, time, people, focus, method and adaptation to answer where, when, who, of what, to what and how. Applied to wheat sheep zones in Australia.
Kathirvelpandian et al (2024)	Own methods to develop indicators through participatory approach (stakeholder survey of fishers in the Pachavaram region). Data was segregated by drivers from Shayam et al 2014, 2016 and Paul et al 2024 and cumulative scores for each driver were combined to arrive at a Wetland Vulnerability Index. Applied to Pachavaram mangrove ecosystem in India.
Lapola et al (2020)	Author's own vulnerability assessment method by numerically relating summarised climate-change projections for each protected area and spatially explicit data on the size and integrity of vegetation inside and in the buffer zone. Hazard was measured with the Regional Climate Change Index. Own indicators for resilience. Applied to a vulnerability assessment for Brazil's protected areas.
Malakar and Mishra (2017)	Own composite indicator framework with indicators selected based on Hahn et al 2009, literature review and from Delphi technique. Socio economic indicators taken from Cutter er al 2003 and Kelkar et al 2011, Prashar et al 2012. Indicators were standardised to percentages, except population. Density. Calculation follows Hahn et al 2009's approach, with value for a particular indicator for all 11 cities following the HDI approach from Anand and Sen 1994. Equal weighting applied to each indicator. Applied to a socioeconomic vulnerability to climate change city-level index approach in India.
Chen et al (2020)	Adaptation of the livelihood vulnerability index to develop a livelihood vulnerability framework for marine fisheries under multiple disturbances, using adapted indicators.
Kapuka and Hlásny **Kapuka A., Hlásny T. (2020)**	Own methods to derive indicators and own methods to derive overall level of vulnerability and level of social vulnerability supported by own assessment of complex vulnerability profiles Applied to district-level social vulnerability to natural hazards assessment in Namibia
Silas et al (2020)	Own method titled Adaptive Capacity Index. Quantifies adaptive capacity by integrating various indicators, reflecting the multifaceted nature of adaptation strategies in the communities studied. Applied to assessment of Tanzanian small-scale fishers.

De Bortoli et al (2019a)	Author's own integrative climate change and vulnerability index for arctic aviation and marine transportation, aiming to close a gap in methods for integrative approaches. Based on community-based research to develop a vulnerability index that incorporates both social and biophysical data with linked RCP projections. Own method to determine and calculate exposure variables
Wade et al (2017)	Own methods focussed on better incorporation of adaptative capacity measures. Applied to vulnerability assessment of trout, USA.
Ashtari, Correia (2022)	Author's own method to undertake a climate vulnerability assessment at Tchogha Zanbil World Heritage earthen site in Iran. Own approach to developing indicators, weightings and aggregation.
Awolala et al (2022)	Author's own 'Human Climate Vulnerability index. Variables selected based on literature review. Own methods for weighting and aggregation. Applied to a human vulnerability assessment to extreme climate hazards in southwest Nigeria.
Apreda, D'Ambrosio and di Martino (2019)	New hierarchical model for the calculation of synthetic vulnerability indicators in each of the 5 'levels' of the model Applied to complex urban systems, applied to East Naples considering heat wave and pluvial flooding climate hazard scenarios.
Jhan et al (2020)	Author's own socio economic indicator framework (own methods, indicators and weighting). Applied to local climate change adaptation in Tiawan.
Xiao et al (2022)	Own SoVI using improved TOPSIS method. Own selected of indicators from qualitative methods. Applied to 11 small towns in China.
Rahayu and Suryanto (2023)	Own SOVI (own indicators, weighting and scoring) applied to disaster risk vulnerability in Tawanghangu and Kejaja distributions in Indonesia
Samui and Sethi (2022)	Own bottom up approach to undertaking a SoVI. Indicators selected through literature review and external experts assigned weights. Own scoring method. Applied to a social vulnerability assessment in glacial lake outburst flood in the NE India.
Mizrahi et al (2020)	Developed a "livelihood impact potential index" to identify socioeconomic factors such as livelihood diversity, education, age and wealth and quantified individual vulnerability. Undertaken to identify individuals vulnerable to no take MPAs.
Jeevamani (2021)	Developed a cumulative vulnerability index based on community based interactions and perceptions. Applied to fishing communities in coastal India

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