SCIENTIFIC COMMITTEE
TWENTY-FIRST REGULAR SESSION

Nuku'alofa, Tonga

13 – 21 August 2025

WCPFC Climate Change Vulnerability Assessment (CCVA) Framework

WCPFC-SC21-2025/EB-WP-01
30 July 2025

Kerrie Robertson and Matthew Baird

WCPFC CMM CLIMATE CHANGE VULNERABILITY ASSESSMENT FRAMEWORK

WCPFC-SC21-2025/EB-WP-01

Prepared by: Kerrie Robertson[1] and Matthew Baird[2]

[1] Adira Consulting
[2] EnviroSea Consulting

EXECUTIVE SUMMARY

This paper provides the Scientific Committee with a comprehensive update on the development of the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, commissioned following WCPFC21. The consultancy has successfully completed the targeted literature review and developed a draft CCVA Framework based on the latest IPCC AR6 approach to climate risk assessment. The framework is designed to systematically evaluate climate change risks to Conservation and Management Measures (CMMs) through assessment of hazard, exposure, sensitivity, and adaptive capacity. Key deliverables to date include a comprehensive literature review of 500+ studies, a working definition of climate vulnerability aligned with IPCC AR6 standards, a draft Excel-based CCVA Framework designed for practical implementation within existing WCPFC processes, and a comprehensive guidance and procedural information document to support understanding and operationalization of the CCVA Framework.

1. INTRODUCTION

1.1 Purpose

Climate change poses significant and increasing risks to the effectiveness of WCPFC's Conservation and Management Measures (CMMs). In recognition of these challenges, the Commission adopted Resolution 2019-01 on Climate Change and subsequently developed the WCPFC Climate Change Workplan 2024-2027. Following WCPFC21, a consultancy was commissioned to develop a framework for assessing the vulnerability of CMMs to climate change impacts.

This paper presents the Scientific Committee with a progress update on the consultancy and introduces the draft CCVA Framework for scientific review and input.

1.2 Context

1.2.1 WCPFC CCVA Framework

The development of the CCVA Framework responds to several key Commission decisions:

- **Resolution 2019-01:** Recognized serious threats posed by climate change to highly migratory species and wider ecosystems
- **WCPFC20:** Reaffirmed the resolution and agreed to develop a dedicated workplan
- **WCPFC21:** Adopted the Climate Change Workplan 2024-2027 and Terms of Reference for the CMM Climate Change Vulnerability Assessment

1.2.2 CMM Assessment Schedule

The Commission has identified specific CMMs for assessment over the 2025-2026 period as set out below.

2025 Assessments

- CMM 2024-07 (Cetaceans)
- CMM 2019-05 (Mobulid rays)
- CMM 2024-05 (Sharks)
- CMM 2017-04 (Marine pollution)
- CMM 2024-06 (NP striped marlin)

2026 Assessments

- CMM 2023-01 (Tropical tunas)
- CMM 2018-04 (Sea turtles)
- CMM 2018-03 (Seabirds)
- CMM 2013-04 (Record of Fishing Vessels)
-

2. LITERATURE REVIEW

An extensive literature review was conducted between April and June 2025, examining over 500 studies globally, including more than 100 operational vulnerability frameworks. This review provided the theoretical and practical foundation for developing the WCPFC-specific framework. The literature review is provided as a supplementary paper (Attachment A) of the Assessment Report (see Annex A).

3. DRAFT WCPFC CCVA FRAMEWORK

3.1 Conceptual Foundation

The WCPFC CCVA Framework (see Attachment B of the Assessment Report (Annex A)) adopts the IPCC AR6 approach to climate risk assessment, 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**

It has been designed as a rapid-assessment tool to enable quick identification of areas in need of attention and what is driving climate risk, and rapid identification of information gaps.

3.2 Framework Design Principles

The framework has been designed with the following key principles:

- **Practical**: Implementable within existing WCPFC meeting cycles and resource constraints
- **Integrated**: Utilizes established WCPFC procedures and processes
- **Responsive**: Tailored to meet specific information needs of WCPFC decision-makers
- **Adaptive**: Capable of evolution as new knowledge becomes available
- **Focused**: Specifically addresses climate change risks rather than other stressors
- **User-friendly:** Easy to navigate, operate, understand and update.

3.3 Implementation Platform

The framework utilizes Microsoft Excel as the development platform, chosen for its global accessibility and familiarity, ease of modification and updating, ability to incorporate automated outputs and long-term reliability without dependency on external software or databases.

3.4 Key Design Features

- **Indicator-based assessment**: Comprehensive metrics aligned with IPCC AR6 categories, accompanied with designated indicator criteria with supporting questions and reference points to guide rapid assessment
- **Automated outputs**: Risk-based graphics and summaries generated from indicator inputs
- **Clear responsibility allocation**: Designated roles for NC, SC, and TCC in providing expertise
- **Gap identification**: Systematic highlighting of information gaps requiring attention
- **Flexible application**: Adaptable to different CMM types and assessment scales
- **Future-proofed**: Hard coding of automated functions to avoid software update issues

4. GUIDANCE AND PROCEDURAL INFORMATION

The "*WPCFC CCVA Framework – Guidance and procedural information document"* (see Attachment C of the Assessment Report (Annex A)) provides a comprehensive overview of the WCPFC CCVA Framework, it's design and methodology for establishing, operationalizing and maintaining the framework as a standard WCPFC tool to support sustainable fisheries management in the WCPO.

4.1 Structure

The Guidance document specifically outlines:

1. **Conceptual Framework**: Based on IPCC AR6 definitions and approach
2. **Key design features:** comprehensive outline of the framework functionality and indicator design
3. **Scoring methodology**: approach and calculations used to determine climate risk
4. **Assessment Process**: Step-by-step methodology for conducting CCVAs
5. **Data Requirements**: Specification of required data sources and quality standards
6. **Reporting Template**: Standardized format for presenting results

5. SCIENTIFIC CONSIDERATIONS

5.1 Climate risk indicators

The framework consists of a range of identified indicators considered relevant to WCPFC, organized by climate risk category (Hazard, Exposure, Sensitivity and Adaptability) as set out below.

Hazard Indicators

Theme	Indicator criteria
Biological and ecological	Temperature extremes
	Increased sea surface temperature (SST)
	Ocean acidification
	Salinity
	Deoxygenation
	Wind stress
	Current change
Operations and infrastructure	Storms
	Cyclones
	Precipitation extremes
	Sea level rise
	Wave height

Exposure Indicators

Theme	Indicator criteria
Biological and ecological	Habitat
	Food web
	Species population
Operations and infrastructure	Fishing fleet
	At sea operations
	At sea operators
	Port infrastructure
Socio-economic	Economies
	Livelihoods
Management	Spatial boundaries
	Scientific assumptions
	Information

Sensitivity Indicators

Theme	Indicator criteria
Biological and ecological	Thermal range
	Mobility
	Productivity
	Distribution
	Reproduction
	Prey
	Competition
Management	Health status
	Harvest strategy
	Non-compliance
	IUU
	Observer coverage

	Fishing effort
	Resource and governance
Information	Information availability
	Awareness
Socio-economic	Economic Dependence
	Food dependence
	Cultural importance

Adaptive Capacity Indicators

Theme	Indicator criteria
Biological and ecological	Thermal range
	Productivity
	Distribution
	Reproduction
	Prey
	Competition
Management	Health status
	Species diversification
	Fishing gear
	Fishing effort
	Observer coverage (human and / or EM)
	Research and technology
	Agile decision making
	Member capacity
	Resource and governance
Information	Information sharing and cooperation
	Contribution
	Traditional knowledge
Socio-economic	Diversification
	Port resilience
	Food security

Each identified indicator criteria is supported by unique questions and reference points to help guide scoring. A full overview of the indicators is available as Annex A of the Guidance document (See Attachment C of the Assessment Report (Annex A)).

5.2 Data Requirements

Because CCVAs rely on available data, their accuracy is only as strong as the information they are based on—highlighting data gaps is crucial to improving future assessments. All CCVAs must be based on:

- Verified or verifiable data
- Peer-reviewed scientific literature
- Quality-controlled observational data
- Validated model outputs
- Expert knowledge from recognized specialists
- Indigenous and local expert knowledge where appropriate, as a complementary information source to address information gaps.

Key Data Elements are outlined in the Guidance document (Attachment C of the Assessment Report(Annex A)) along with a data set tracker provided as Annex B of the document. WCPFC may only have partial (or no) data in some cases, particularly with respect to climate data. Data limitations can be easily identified in individual assessments through an "unknown" category built in as a scoring element. Key Data Elements can be updated over time.

Key Data Elements of possible interest to the SC include:

Theme	Data element
Climate data	Historical and projected oceanographic conditions
	Climate model outputs
	Extreme event projections
Ecological data	Species distribution patterns
	Life history parameters and thermal tolerances
	Stock assessment data
	Ecosystem structure and function
Fisheries data	Catch and effort statistics
	Vessel monitoring data
	Observer program data
	Fleet characteristics
Management performance	Historical CMM performance under varying conditions
	Responsiveness of management decisions to scientific advice and environmental shifts
	Implementation rates
	Compliance and fleet performance information

5.3 Scientific Uncertainties and Limitations

The framework acknowledges several key uncertainties:

- **Climate projections**: Inherent uncertainty in future climate scenarios
- **Species responses**: Limited understanding of biological responses to climate change
- **Cumulative impacts**: Interactions between climate change and other stressors
- **Management effectiveness**: Difficulty in isolating climate impacts from other factors

6. ROLE OF THE SCIENTIFIC COMMITTEE

The Scientific Committee's input is considered essential to review and assess the following categories.

6.1 Framework Validation

- Review of overall approach and methodology
- Assessment of indicator selection and metrics
- Review of the scoring methodology
- Evaluation of data requirements and sources.

6.2 Technical Input

- Identification of relevant ecological and climate data
- Assessment of data quality and limitations

- Guidance on incorporating uncertainty into assessments.

6.3 Implementation Support

- Advice on practical application of the framework, including timelines for review
- Recommendations for capacity building requirements
- Input on integration with existing scientific processes.

7. NEXT STEPS

7.1 Framework Finalization

The draft framework will be refined based on input from SC21 and TCC21 to ensure scientific rigor, technical feasibility, and practical applicability.

7.2 Pilot Implementation

Initial assessments of the 2025 CMMs will serve as pilots to test and refine the framework before full implementation.

7.3 Submission

Final outputs will be submitted to the Commission in December 2025 for approval.

8. RECOMMENDATIONS

The Scientific Committee is invited to:

1. **Review and comment** on the scientific approach and methodology of the draft framework
2. **Provide input** on the indicator system and data requirements
3. **Identify potential data sources** and quality considerations within the SC's expertise
4. **Advise on integration** with existing scientific processes and assessments
5. **Recommend capacity building** requirements for successful implementation
6. **Support pilot implementation** of the framework for 2025 CMM assessments.

9. CONCLUSION

The draft WCPFC CCVA Framework has the potential to be a step forward in integrating climate change considerations into Commission decision-making as a systematic tool for assessing climate risks to CMMs.

The Scientific Committee's expertise and input are crucial for ensuring the framework's scientific rigor and practical applicability. Through collaborative refinement and testing, this framework will support the Commission's commitment to adaptive, climate-resilient fisheries management in the Western and Central Pacific Ocean.

ANNEXES

ANNEX A: WCPFC Climate Change Vulnerability Assessment Framework_FINAL REPORT_July 25.

WCPFC CMM Climate Change Vulnerability Assessment

Assessment Report

Submitted for the completion of Milestone 2: WCPFC CMM Climate Change Vulnerability Assessment Project

Prepared by

Kerrie Robertson[1] and Matthew Baird[2]

[1] Adira Consulting

[2] EnviroSea Consulting

Table of Contents

Executive Summary

This report presents the final substantive deliverables of the WCPFC CMM Climate Change Vulnerability Assessment consultancy, commissioned following WCPFC21. The consultancy has successfully completed a comprehensive literature review of 500+ global studies on climate vulnerability assessment frameworks, developed a WCPFC-specific Climate Change Vulnerability Assessment (CCVA) Framework based on IPCC AR6 approaches, created comprehensive guidance documentation for framework implementation, and performed five pilot assessments of designated CMMs.

The Excel-based CCVA Framework provides a rapid assessment tool designed to systematically evaluate climate change risks to Conservation and Management Measures through assessment of hazard, exposure, sensitivity, and adaptive capacity. Assessments conducted on the five designated CMMs for 2025[3] demonstrate the framework's capability to distinguish climate risk levels (HIGH for cetaceans and mobulids, MEDIUM for sharks and marine pollution, and LOW for North Pacific striped marlin) and identify key management implications, while revealing both the framework's strengths and areas requiring expert input or improved data and information requirements.

The framework offers WCPFC a potential pathway for integrating climate considerations into its decision-making processes, providing an informational tool for identifying climate adaptation priorities and supporting evidence-based discussions about conservation measure effectiveness under changing environmental conditions.

Introduction and Consultancy Purpose

Climate Change and Pacific Fisheries

Climate change poses significant and increasing risks to the effectiveness of the Western and Central Pacific Fisheries Commission's (WCPFC) Conservation and Management Measures (CMMs). The Western and Central Pacific Ocean (WCPO) and its inhabitants are among the most at risk globally from climate change impacts. Climate-driven changes—such as ocean warming, shifting species distributions, and altered productivity—may pose challenges to the effectiveness of current CMMs.

Observed increases in sea temperature, ocean acidification, and frequency of marine heatwaves and violent tropical weather events are causing the degradation of coastal marine ecosystems, including those reliant on coral reef, mangrove and seagrass habitats. These impacts directly affect subsistence fishing productivity, local community fish supply, and long-term food security.

Marine fisheries, particularly tuna resources, are 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

[3] CMM 2024-07 (Cetaceans), CMM 2019-05 (Mobulids), CMM 2024-05 (Sharks), CMM 2017-04 (Marine pollution), CMM 2024-06 (NP Striped Marlin)

fisheries and also pose a serious threat to Pacific Island Countries and Territories (PICTs) that generate significant revenue from license access fees to fish for tuna within national Exclusive Economic Zones (EEZs).

WCPFC Response to Climate Change

The WCPFC and its subsidiary bodies have been actively discussing and progressing climate change related work since 2008. This work has evolved through several key milestones:

- **Resolution 2019-01:** Recognized serious threats posed by climate change to highly migratory species and wider ecosystems
  WCPFC20 (2023): Reaffirmed the resolution and agreed to develop a dedicated workplan
- **WCPFC21 (2024):** Adopted the Climate Change Workplan 2024-2027 and Terms of Reference for the CMM Climate Change Vulnerability Assessment

Following WCPFC21, a consultancy (this project) was commissioned to develop a framework for assessing the vulnerability of CMMs to climate change impacts.

The Need for Vulnerability Assessment

Climate-driven changes may impact the assumptions underpinning certain CMMs as well as alter fishing operations and fleet dynamics, impacting enforcement. Changes in productivity could require adjustments to catch limits and reference points. Altered seasonality may affect the timing and effectiveness of temporal closures and gear restrictions. Disrupted food webs could undermine current bycatch mitigation strategies, and economic and environmental instability may increase pressure on compliance and enforcement systems.

The Commission identified a need for work that aims to ensure that relevant information and data collection are adequate to support improved understanding of climate change impacts and implications for WCPFC fisheries management.

Consultancy Objectives

Primary Objectives

The consultancy was commissioned with clear objectives as outlined in the Terms of Reference adopted by the Commission:

- Review and Identify Vulnerable Provisions: Review active WCPFC CMMs and identify specific provisions that could benefit from additional discussion among Cooperating Members (CCMs) as being vulnerable to climate change
- Support Subsidiary Body Functions:
- Support Technical and Compliance Committee (TCC) discussions by identifying monitoring, control, and surveillance (MCS) data and information gaps and potential management challenges
- Support Scientific Committee (SC) discussions regarding scientific data and information gaps and research needs

- Improve Commission Understanding: Focus on improving the Commission's understanding of how climate change impacts might affect existing CMM provisions

Assessment Scope

Included in Scope:

- Review of active WCPFC CMMs defined by the Commission
- Assessment based on target or bycatch species, specific geographic areas, different gear types, review periods, and climate considerations
- Analysis using publicly available information including adopted CMMs, published climate advice, peer-reviewed scientific literature, and Indigenous and traditional knowledge
- Focus on climate change vulnerabilities specifically, not other management challenges

Excluded from Scope:

- Advising on specific management actions (limited to informing only)
- Prejudicing members' implementation of existing obligations
- Initiating renegotiation of CMMs
- Assessing compliance capabilities of subsidiary bodies

Targeted CMMs for Assessment

The Commission identified a total of nine specific CMMs for assessment over the 2025-2026 period.

Assessments to be undertaken in 2025 under this contract included[4]:

- CMM 2024-07 (Cetaceans)
- CMM 2019-05 (Mobulid rays)
- CMM 2024-05 (Sharks)
- CMM 2017-04 (Marine pollution)
- CMM 2024-06 (North Pacific striped marlin),

Deliverables

The Terms of Reference established the following deliverables

Deliverable	Evidence of completion
1. Initial compiled list of available information sources (paragraph 12a) in a bibliography and targeted literature review.	Literature Review submitted as NC21-WP-05_suppl
2. A WCPFC-relevant framework for assessing CMM provisions' vulnerability to climate change using	Excel-based framework and word-based framework guidelines Submitted to the Secretariat.

[4] The Commission also agreed to assess these CMMs in 2026: CMM 2023-01 (Tropical tunas), CMM 2018-04 (Sea turtles), CMM 2018-03 (Seabirds), CMM 2013-04 (Record of Fishing Vessels),

the best available information, per paragraph 12(a), including a definition for "vulnerability" to be used for the Assessment.	The literature review proposes a definition to be used, with a rationale. The definition is incorporated in the framework.
3. A list of the specific CMM provisions identified as being vulnerable to climate change that could benefit from additional discussion among CCMs	Discussed in this report.
4. The identification of MCS and scientific data and information gaps, research needs, and potential management challenges, including in instances where more information would improve the Assessment	Discussed in this report.
5. Suggested metrics of minimum/sufficient information required to be able to categorize CMM provisions as either being "vulnerable" or "not vulnerable" to climate change, as appropriate	The framework sets out that information we advise is required to inform a judgement on climate risk.
6. Results from the Assessment of at minimum the CMMs defined by the Commission provided as information papers to support CCMs during discussions at NC21, SC21, TCC21, and WCPFC22.	Information papers provided to NC: NC21-WP-05 SC: SC21-EB-WP-01

Literature Review and Conceptual Foundation

Literature Review Overview

An extensive literature review was conducted between April and June 2025, examining over 536 individual pieces of literature sourced globally across multiple sectors and disciplinary contexts. The review methodology followed PRISMA 2020 guidelines to ensure transparent and replicable reporting.

Scope and Coverage

- **Geographic Coverage:** Global scope with specific attention to Pacific marine environment considerations (73 Pacific region-based references, 58 with clear marine applications)
- **Sectoral Coverage:** Fisheries, agriculture, river systems, natural resource management, urban planning, and disaster risk reduction
- **Framework Analysis:** Over 100 operational vulnerability frameworks were identified and analysed, including both theoretical frameworks and applied case studies

Key Findings

- **Vulnerability Definitions:** No universally accepted definition of vulnerability exists, with over 80 unique definitions identified across literature. While IPCC definitions are widely referenced, they are not consistently applied, with older AR4 definitions (49% of studies) continuing to be more commonly used than the current AR6 framework (only 2% of studies)
- **Framework Diversity:** 132 different operational vulnerability assessment frameworks were identified, ranging from local qualitative assessments to highly quantitative global-scale analyses
- **Methodological Approaches:** Four broad categories emerged: established theoretical frameworks, adaptations of existing frameworks, mixed-methods approaches, and original composite indicator frameworks

Pacific Marine Environment Insights

The review identified specific considerations for Pacific marine vulnerability assessments, including:

- Gender-sensitive approaches for collecting traditional knowledge
- Funding constraints as a significant barrier to effective assessment implementation
- The need for flexible frameworks that can be regularly updated as conditions and knowledge evolve
- Integration challenges between scientific data and traditional/local knowledge systems.

Fisheries-Specific Indicators

The review identified the most commonly used indicators across fisheries studies. These included:

- **Hazard indicators:** Temperature extremes, sea surface temperature changes, ocean acidification, cyclones/storms
- **Sensitivity indicators:** Thermal range, mobility, productivity, spawning requirements, prey specificity
- **Adaptive capacity indicators:** Management effectiveness, gear diversity, livelihood diversification, institutional support.

This comprehensive literature review directly informed the selection of the IPCC AR6 definition for the WCPFC framework and provided the foundation for indicator selection and framework design principles.

Climate Vulnerability Definition

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 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 loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources*	A hazard is a climate driver of risk A hazard is the climate-related physical event or trend that can cause harm 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	We understand vulnerability is a function of adaptive capacity and sensitivity

Is a function of sensitivity and adaptive capacity	
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 therefore consider what the system, species or group and what makes it sensitive. This 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

See Attachment A for the literature review report.

CCVA Framework

Overview

The original Terms of Reference proposed identifying which specific CMM provisions were vulnerable or not vulnerable on an individual basis. Building on this foundation, we were able to take the assessment approach significantly further during framework development. Recognizing that vulnerability is itself a conceptual function of sensitivity and adaptive capacity - representing just one component of overall climate risk - we expanded beyond binary classifications to capture the complex interactions and nuances inherent in climate vulnerability assessment.

This enhanced approach allowed us to move beyond simple vulnerable/not-vulnerable determinations to conduct holistic examination of a CMM, enabling identification of both what a CMM included and, critically, what it did not include that was relevant to a CCVA. Our comprehensive assessment methodology enables deeper exploration across entire CMMs, clearly identifying where hazards are most relevant and determining the types and extent of vulnerability, which in turn will assist the WCPFC in identifying, relatively quickly, the interventions it wants to make. The framework was designed as a rapid-assessment tool to enable quick identification of areas requiring attention and information gaps, while providing a good sense of climate risk. This expanded approach delivers practical and accessible results for managers to inform planning and management decisions.

Framework design

Excel-Based CCVA Framework

The framework utilizes Microsoft Excel as the development platform, chosen for its global accessibility and familiarity, ease of modification and updating, ability to incorporate automated outputs and long-term reliability without dependency on external software or databases.

Key Design Features:

- Indicator-based assessment: Comprehensive metrics aligned with IPCC AR6 categories
- Automated outputs: Risk-based graphics and summaries generated from indicator inputs
- Clear responsibility allocation: ability to clearly designate roles for Northern Committee (NC), Scientific Committee (SC), and Technical and Compliance Committee (TCC)
- Gap identification: Systematic highlighting of information gaps requiring attention
- Flexible application: Adaptable to different CMM types and assessment scales.

See Attachment B for the CMM CCVA Framework master template.

Comprehensive Guidance Document

The "WCPFC CCVA Framework - Guidance and procedural information document" provides a comprehensive overview of the WCPFC CCVA Framework, its design and methodology for establishing, operationalizing and maintaining the framework as a standard WCPFC tool to support sustainable fisheries management in the WCPO.

The guidance document outlines:

- Conceptual Framework based on IPCC AR6 definitions
- Key design features and indicator design
- Scoring methodology and calculations
- Step-by-step assessment process
- Data requirements and quality standards
- Standardized reporting template.

See Attachment C for the Guidance and information document.

Identification of Data Requirements and Gaps

The framework systematically identifies critical data gaps and uncertainties to guide future research, monitoring, and data collection efforts. Key data elements include climate data, ecological data, fisheries data, management performance data, and socio-economic data.

All deliverables were designed to be practical, implementable within existing WCPFC meeting cycles and resource constraints, and responsive to the specific information needs of WCPFC decision-makers.

Testing and refinement

The Commission identified specific CMMs for the 2025 pilot assessments, which provided an excellent breadth of the types of conservation and management measures under WCPFC's responsibility. The selection included:

- Two bycatch CMMs: CMM 2024-07 (Cetaceans) and CMM 2019-05 (Mobulids)
    - Cetaceans deals with a species which falls under the primary mandate of another international organization
    - Mobulids involves species listed on the IUCN and in other Conventions as vulnerable or endangered
- A mixed target / bycatch CMM: CMM2024-05 (Sharks)
- An operational CMM: CMM 2017-04 (Marine pollution), and
- A target species CMM: CMM 2024-06 (NP striped marlin).

This diversity enabled comprehensive testing of the framework's applicability across the full spectrum of WCPFC management measures.

One of the key design principles for framework success was ensuring that anyone could use it, not just large institutions with extensive technical capacity. Throughout the development process, we asked ourselves: "Can the average person do this?" - and we considered ourselves to be that average person. This user-centric approach drove our design decisions toward simplicity, accessibility, and practical implementation, ensuring the framework would be viable for all WCPFC members regardless of their technical resources or capacity constraints.

The pilot assessments provided valuable insights into framework performance across different CMM types and revealed both the strengths and limitations of the assessment methodology when applied to diverse management contexts.

Summary CMM Pilot Assessment Findings

Key assessment findings

See Attachments D (1-5) for individual CMM CCVA assessment reports and Attachments E (1-5) for individual CMM CCVA Framework assessments.

CMM 2024-07 (Cetaceans)

Climate Risk Result: HIGH

Key Risk Drivers

- **High Hazard Rating:** Driven by significant climate stressors including ocean warming, acidification, deoxygenation, and altered current patterns that directly affect cetacean habitat and prey availability
- **High Exposure Rating:** Cetacean populations frequently encounter identified climate hazards across their broad distributional ranges in areas experiencing significant oceanographic changes, including warming waters and shifting current patterns
- **High Sensitivity Rating:** Reflects cascading effects of climate change through marine food webs, affecting cetacean distribution patterns, migration timing and ranges, and reproductive ability
- **Medium Adaptive Capacity:** Limited by biological constraints, though supported by international conservation frameworks.

Management Implications

The HIGH climate risk rating identified for cetaceans may warrant examination of the cumulative impact that fishing pressure is having on these species. When species have limited capacity to adapt to climate change, reducing other anthropogenic stressors becomes a critical conservation strategy.

This assessment aligns with global scientific literature showing that 72% of marine mammal stocks are highly vulnerable to climate change, validating the framework's effectiveness in identifying climate risks.

CMM 2019-05 (Mobulid rays)

Climate Risk Result: HIGH

Key risk drivers

- **Medium Hazard Rating:** Driven by a medium level of identified climate stressors on mobulids, taking into consideration their biological traits such as high mobility and high distribution across the WCPF Convention Area, and their reliance on prey species (zooplankton) that are likely to be impacted by climate change, particularly in tropical zones
- **High Exposure Rating:** High exposure of habitats, food-webs and mobulid populations were identified which drove the high exposure rating. A total of six indicators (35%) were scored as 'unknown' as a result of identified information gaps and limitations
- **High Sensitivity Rating:** Reflects the key biological and ecological sensitivities of mobulids including to increased sea-surface temperatures, a dependence on single prey species, low levels of reproductive fecundity. Additionally, a lack of knowledge on stock statuses and the current IUCN classifications of WCPFC mobulids as vulnerable or endangered highlighted increased sensitivity in enabling effective management and decision-making
- **Low Adaptive Capacity:** Driven by both the biological and ecological traits of mobulids (based on best available information) and the lack of available scientific information and monitoring information to clearly understand how mobulids may respond and adapt to climate changes. A total of 10 (45%) of adaptive capacity indicators were scored as "unknown" highlighting significant information gaps.

Management implications

The HIGH climate risk rating of mobulids, warrants immediate attention to fill identified information gaps. It is encouraging to see that projects to understand fisheries characteristics, biological traits and to establish stock assessments for key WCPFC mobulid species are included in the 2021-2030 Shark Research plan.

The current prohibition of fishing approach for mobulids is considered effective to ensure that fishing pressure is minimized until further information on stock status and life-biology is known. However, more cumulative impact research is also required noting mobulids face multiple hazards, including exposure to marine pollution, vessel strike, loss of spawning habitats etc., that need to be understood in order to effectively improve understanding of overall climate risk and species-specific vulnerability.

CMM 2024-05 (Sharks)

Climate Risk Result: MEDIUM

Key risk drivers

- **High Hazard Rating:** reflects the significant levels of climate hazards faced by WCPO shark species, including temperature extremes, increased sea surface temperatures, ocean acidification, deoxygenation and current changes. These collective hazards are all identified stressors that could affect shark distribution, growth, development, feeding behaviours and reproductive success
- **High Exposure Rating:** high levels of exposure to identified climate hazards include sharks habitats, Pacific shark populations and relevant fishing fleets. However, a total of

nine (47%) of indicators were unable to be scored as a result of identified information gaps / limitations
- **Medium Sensitivity Rating:** driven by a range of "low" to "High' indicator scores. While sharks are sensitive to environmental changes, in particular their reliance on seasonal cues and low age-at-maturity, the high mobility, broad distribution and opportunistic feeding behaviours provides resilience against identified climate hazards
- **High Adaptive Capacity rating:** this rating suggests Pacific shark species managed by the WCPFC are in a relatively good position to effectively respond and adapt to climate change stressors. This rating is mainly driven by natural traits such as high mobility, broad distribution and opportunistic feeding behaviour, coupled with a WCPFCs relatively flexible management framework, research plans (2021-2030 Shark Research Plan), and capacity and support for responsive decision-making and implementation

Management implications

Although a Medium climate risk assessment score is promising, a key limitation in the assessment is the share breadth of shark species managed by the WCPFC and the CMM (72 species). This is also reflected in the management approach to sharks by the WCPFC, with clearly identified key shark species and non-key shark species. Despite this, there is a good and improving amount of information associated with key shark species, including stock status, biological function, effects from fishing, and vulnerability to climate change, enabling greater ability to identify how climate stressors may affect Pacific sharks.

Key considerations for WCPFC include:

- Strengthening information of both key and non-key shark species, including stock status
- CCVA of individual shark species (both key and non-key species noting the diverse nature of species covered by the CMM)
- addressing identified CCM CCVA information gaps
- incorporating environmental indicators as standard practice into shark stock assessments
- developing climate-informed reference points for key shark species
- greater investment in research and monitoring activities (noting the 2021-2030 Shark Research Plan represents a significant investment).

CMM 2017-04 (Marine pollution)

Climate Risk Result: Medium

Key Risk Drivers

- **Operational vs. Biological Hazards:** The assessment revealed a fundamental distinction between biological/ecological hazards (rated LOW) and operational hazards (rated MEDIUM to HIGH) . Climate change increases pollution risk primarily through extreme weather events rather than direct environmental changes
- **High Exposure Rating:** Based on the frequent occurrence of operational hazards in the WCPO, including 25-30 tropical cyclones annually in the Western Pacific and regular storm events affecting major fishing ports

- **Framework Limitations:** No sensitivity indicators within the framework were found relevant to this operational CMM, highlighting that the framework was primarily designed for species-focused assessments

Management Implications

The assessment demonstrates that climate change acts as a risk multiplier for marine pollution rather than a direct driver. Climate impacts create conditions that make proper waste management more difficult or impossible to maintain. Key considerations include:

- Development of climate-specific waste management protocols for extreme weather conditions
- Strengthening port waste reception facility resilience to climate impacts
- Enhanced vessel waste storage systems to withstand operational hazards
- Improved crew training on waste management during emergency conditions
- This assessment highlighted climate as a risk multiplier rather than a direct driver. It leads to the need to consider operationally practical solutions that can minimise risks of waste management and storage and potentially related issues affecting crew well-being.

CMM 2024-06 (NP Striped Marlin)

Climate Risk Result: LOW

Key Risk Drivers

- **Medium Hazard Rating:** Moderate levels of climate-related threats including temperature extremes, ocean acidification, and current changes, balanced by the species' pelagic nature reducing infrastructure-related impacts
- **High Exposure Rating:** Broad distributional range across areas experiencing significant oceanographic changes, though with substantial data gaps (36% unknown scores)
- **Medium Sensitivity Rating:** Moderate susceptibility balanced by biological characteristics including broad thermal tolerance, high mobility, and opportunistic feeding behaviour
- **High Adaptive Capacity:** Strong biological resilience (mobility, distribution, feeding flexibility) combined with WCPFC's flexible management framework and scientific monitoring programs

Management Implications

The LOW climate risk rating suggests current management approaches are likely to remain effective under projected climate scenarios, though continued vigilance is required. Key considerations include:

- Enhanced monitoring of stock distribution and abundance patterns to track climate-related changes

- Strengthened data collection on environmental-biological relationships to reduce uncertainty
- Improved integration of climate considerations into stock assessments
- Maintenance of flexible management measures that can adapt to changing conditions
- Continued rebuilding efforts to maximize resilience to climate impacts
- This positive assessment reflects both the inherent resilience of this highly mobile pelagic species and the adaptive management framework in place.

Data Dependencies and Limitations

The framework's effectiveness relies heavily on access to relevant climate data and information, which presented limitations across all assessments.

Regional Climate Projection Uncertainties

All five assessments faced challenges with limited spatial and temporal resolution of climate projections specific to the WCPO region. Global climate models often lack the regional specificity needed to accurately assess localized climate risks.

Extreme Event Frequency and Intensity Data

Critical gaps existed in projections for extreme weather events, which proved particularly important for operational assessments:

- Limited long-term projections for cyclone frequency and intensity changes
- Uncertainty about storm track modifications affecting different fishing areas
- Insufficient data on compound extreme events (e.g., simultaneous storms and marine heatwaves)

Ocean Chemistry Trend Information

Assessments revealed substantial gaps in regional ocean chemistry projections:

- Limited high-resolution ocean acidification information for specific WCPO areas and/or species
- Uncertainty about deoxygenation patterns and timing
- Gaps in understanding of chemical change interactions with biological systems.

These climate data limitations fundamentally constrain the framework's precision, regardless of the quality of biological or operational information available.

This information will be more critical if the WCPFC wants to undertake these assessments on a longer time horizon. The consultants used available data and scientific literature, where available, to draw inferences; however this is a limitation if the study does not relate to the direct circumstances of the assessment.

Additional Critical Data Gaps

Fleet Operational Response During Extreme Weather

The marine pollution assessment particularly highlighted the absence of data on:

- How fishing operations adapt waste management procedures during extreme weather
- Vessel operational decision-making under climate stress conditions
- Fleet behavioural responses to increasingly frequent extreme events
- Economic and safety trade-offs affecting environmental compliance during emergencies.

Infrastructure and Asset Resilience

Across all assessments, limited information was available on:

- Port waste reception facility climate resilience and adaptation capacity
- Fishing infrastructure vulnerability to sea-level rise and storm damage
- Communication and monitoring system reliability during extreme events
- Supply chain resilience affecting fishing operations and compliance systems.

Common Data Gaps Across Assessments

Spatial Resolution and Distribution Data

- **Cetaceans**: WCPFC does not typically hold comprehensive biological and ecological data on cetacean populations, requiring reliance on published literature for most assessment components. However, global and regional scientific studies provided substantial evidence on cetacean climate vulnerability that proved highly informative for the assessment. Expert review by marine mammal specialists would be valuable to verify the appropriateness of applying global findings to WCPO populations and to address regional climate projection uncertainties
- **Mobulids:** WCPFC specific information on mobulid distribution was limited, however available information did provide good insights into specific species distributions based on observer reporting. In order to provide more certainty on spatial distribution of individual species and migratory movements, key monitoring gaps need to be addressed particularly for longline fleet coverage. Input and review from mobulid ray specialists would be valuable to identify additional information sources and research approaches to help strengthen this information for future assessments
- **Sharks:** there was relatively good spatial and distributional data available for key shark species, although there are clear information gaps associated with non-key shark species. However, general shark distributional information was able to be used to improve confidence in information used in the assessment. Input from global and Pacific shark experts could refine understanding of shark distributions throughout the WCPF Convention Area, to help better understand how these may change in response to different climate projections

- **Marine Pollution**: No WCPFC-specific data available about vessel operations and waste management performance during extreme weather events, though maritime safety literature and regional climate vulnerability studies provided logical frameworks for assessment. Input from maritime safety experts and vessel operators would strengthen future assessments, particularly regarding fleet operational responses and infrastructure resilience
- **North Pacific Striped Marlin**: While WCPFC holds regular stock assessments and fisheries data, uncertainty remained about how climate impacts vary spatially across the species' range, though scientific literature on billfish climate responses filled many knowledge gaps. Expert input from billfish researchers could refine understanding of regional variations, particularly given climate projection uncertainties

Member-Specific Institutional Capacity

All five assessments noted that while WCPFC maintains information on management frameworks and compliance, detailed member-specific institutional capacity and governance arrangements were not accessible to external assessors. Many adaptive capacity indicators required country-level information including:

- Economic diversification capabilities
- Livelihood diversification potential
- Institutional support structures
- Resource availability for implementation
- Infrastructure and asset resilience capacity at national levels

Expert verification by Members themselves would likely significantly improve adaptive capacity ratings by incorporating detailed institutional knowledge not available to external assessors.

Climate-Biological Relationships

- WCPFC's focus on fisheries management means limited direct climate monitoring data, though peer-reviewed literature provided extensive evidence on climate impacts for target species
- Regional oceanographic data and climate projections from scientific sources supplemented WCPFC's fisheries-focused datasets, though significant uncertainties remain in regional climate projections
- International scientific reports proved valuable for understanding species responses to environmental variability, but gaps persist in extreme event frequency and ocean chemistry trend information

Expert review by regional oceanographers and climate scientists could validate the application of broader climate projections to specific WCPO contexts and help address assessment uncertainties.

Assessment-Specific Data Sources and Gaps

Cetaceans (HIGH Risk)

WCPFC Data Limitations

- Limited comprehensive biological data on cetacean populations within WCPFC holdings
- Inadequate longline observer coverage affecting interaction data quality
- Limited spatial data on cetacean-fishery interactions

Scientific Literature Contributions and Climate Data Constraints

The assessment was significantly strengthened by extensive scientific literature, including global vulnerability assessments showing 72% of marine mammal stocks are highly vulnerable to climate change. Key literature provided evidence on:

- Climate impacts on cetacean distribution, migration timing, and reproductive success
- Physiological responses to ocean warming and acidification
- Ecosystem-level impacts on prey species and food webs

However, the assessment was constrained by regional climate projection uncertainties and limited ocean chemistry trend information specific to cetacean habitat areas. Expert review by cetacean specialists familiar with WCPO populations would be valuable to verify whether global patterns apply regionally and to address climate data limitations.

Mobulids (HIGH risk)

WCPFC Data Limitations

There were clear data and information gaps on WCPFC mobulids with little understanding on stock status, biology and ecology of individual species.

Specific indicator information gaps were found across all four climate risk categories:

- **Hazard:** 10% of indicators classified as “Unknown”
- **Exposure:** 40% of indicators classified as “Unknown”
- **Sensitivity:** 18% of indicators classified as “Unknown”
- **Adaptive capacity:** 45% of indicators classified as “Unknown”.

Identified information limitations not only applied to biological and ecological themed indicators but also across themes related to management, socio-economics, and the effects of fishing operations on mobulid populations.

Scientific Literature Contributions and Climate Data Constraints

Although there is some good recent scientific reporting on general mobulid traits, populations, and vulnerabilities to overfishing and other hazards, there is limited robust information on the effects of climate change on these species, with general observations of Chondrichthyes used to draw insights into how mobulids may be affected. Nevertheless, this information provided useful insights and information to draw on to effectively perform the CCVA.

Sharks (MEDIUM risk)

WCPFC Data Limitations

WCPFC holds a lot of information and reporting on Pacific sharks, mostly focussed on research planning, stock assessment information and sustainability risk assessments from fishing. However, there is limited to no information held by the WCPFC on the effects of climate change and associated shark vulnerabilities (for both key and non-key shark species).

Specific indicator information gaps were found across three climate risk categories:

- **Exposure:** 53% of indicators classified as "Unknown"
- **Sensitivity:** 21% of indicators classified as "Unknown"
- **Adaptive capacity:** 30% of indicators classified as "Unknown".

Identified information limitations not only applied to biological and ecological themed indicators but also across themes related to management, socio-economics, and the effects of fishing operations on sharks.

Scientific Literature Contributions and Climate Data Constraints

A wealth of scientific literature on sharks is available, including species specific climate vulnerability assessments that were drawn on to inform the assessments. However, regional climate scenario uncertainties, and ecological consequences (e.g., increased competition as species distribution changes) was limited. However, despite key shark species of commercial importance there is limited information available on other non-key sharks and rays in the Pacific. Expert review and input from Pacific shark scientists and researchers could help fill these identified gaps, to strengthen the overall assessment.

Marine Pollution (MEDIUM risk)

WCPFC Data Limitations

- No operational data on vessel waste management performance during extreme weather
- Limited information on equipment failure modes during climate hazards
- Absence of behavioural data on crew responses under operational stress
- No data on fleet operational responses during extreme weather events
- Limited information on infrastructure and asset resilience of port facilities

Literature and Logical Inference with Climate Data Constraints: Given the operational nature of marine pollution prevention, the assessment relied heavily on:

- Maritime safety literature on extreme weather impacts on vessel operations
- Regional climate vulnerability studies for Pacific Island ports and infrastructure
- Logical inferences about climate hazard impacts on waste storage and handling systems

However, the assessment was significantly constrained by limited extreme event frequency and intensity projections, making it difficult to assess future operational risks. This assessment would particularly benefit from expert input from vessel operators, maritime safety specialists, and port authorities who could validate assumptions about operational impacts and provide insights into infrastructure resilience.

North Pacific Striped Marlin (LOW Risk)

WCPFC Data Strengths and Gaps

WCPFC's relatively robust knowledge base for this species included regular stock assessments, biological research, and fisheries monitoring data. However, gaps remained in:

- **Exposure**: 36% of indicators scored as "Unknown"
- **Adaptive Capacity**: 43% of indicators scored as "Unknown"
- **Limited regional climate projection specificity for the species' habitat range**

Scientific Literature Supplementation with Climate Data Limitations

Extensive peer-reviewed literature on billfish biology and climate responses provided crucial evidence:

- Studies on striped marlin environmental preferences and habitat use
- Research on billfish responses to climate variability and environmental change
- International scientific reports on species distribution modelling and climate projections

However, regional climate projection uncertainties and limited ocean chemistry trend information specific to billfish habitat contributed to the high proportion of "Unknown" scores. Expert review by billfish researchers and regional stock assessment scientists could help resolve uncertainties, though climate data limitations remain a fundamental constraint.

Framework Performance as an Informational Tool

The pilot assessments demonstrated that the WCPFC CCVA Framework enables **rapid completion** of vulnerability assessments, with each assessment completed within weeks rather than months or years. However, these rapid assessments revealed the critical importance of **group review and expert verification** to ensure technical accuracy and to capture important research nuances that might be missed by individual assessors.

The framework functions effectively as a **broad-brush informational tool** for problem identification and triage, helping to quickly identify which CMMs may face higher climate risks and where critical data gaps exist. However, given its rapid assessment nature, it should be used as an **informational rather than instructional tool** - providing valuable insights to guide further investigation and expert consultation rather than definitive management directives.

The pilot assessments demonstrate that the framework excels as a **rapid triage tool** for:

1. Problem Identification

- Quickly distinguishing between high-risk (cetaceans) and low-risk (striped marlin) CMMs
- Identifying possible drivers of climate risk
- Identifying where climate risk may be a significant concern requiring further attention
- Highlighting CMMs where current approaches may need adaptation
- Revealing where climate data limitations most critically constrain assessment quality

2. Data Gap Identification

- Systematically revealing where critical information is missing
- Identifying areas where targeted research or expert consultation is needed
- Highlighting indicators where "Unknown" scores suggest assessment uncertainty
- Pinpointing specific climate data needs (regional projections, extreme events, ocean chemistry)

3. Climate Data Dependency Mapping

- Demonstrating which assessments are most constrained by regional climate data uncertainties
- Identifying where extreme event frequency and intensity data gaps most affect risk evaluation
- Highlighting the critical need for improved ocean chemistry trend information

4. Prioritization for Detailed Analysis

- Providing evidence-based justification for allocating resources to high-risk CMMs
- Identifying which assessments would benefit most from expert input
- Guiding where more detailed, species-specific vulnerability studies may be warranted
- Highlighting where investment in regional climate data would most improve assessment quality

Recommendations for Framework Application

1. Rapid Assessment + Expert Review Process Future applications could follow a two-stage process, which could also be achieved through full review by subsidiary bodies and Members mobilising experts:

- Initial rapid assessment using the framework to identify key risks and data gaps
- Follow-up expert review sessions to validate findings and capture technical nuances
- Explicit acknowledgment of climate data limitations and their impact on assessment confidence

2. Climate Data Investment Priorities The assessments highlight critical needs for:

- Enhanced regional climate projections with higher spatial and temporal resolution
- Improved extreme event frequency and intensity projections for the WCPO
- Better ocean chemistry trend monitoring and projection capabilities
- Regional infrastructure and asset resilience assessments

3. Collaborative Validation with Climate Expertise Group review processes should include relevant experts (species specialists, operational experts, regional scientists) and regional climate scientists to address projection uncertainties and validate climate assumptions.

4. Transparent Uncertainty Communication The framework should clearly communicate where climate data limitations constrain assessment confidence, helping users understand which risk ratings are well-supported versus those affected by fundamental data gaps.

The pilot assessments confirm that the WCPFC CCVA Framework successfully serves its intended purpose as a rapid, informational vulnerability screening tool, while highlighting both the critical importance of regional climate data and the value of expert verification to address technical uncertainties within existing climate data constraints.

Conclusions

The WCPFC CCVA Framework offers a potential pathway for integrating climate change considerations into fisheries management decision-making within the Commission. By providing a systematic approach to evaluating climate vulnerability across diverse Conservation and Management Measures, the framework could enable WCPFC to identify and consider climate adaptation needs within its existing governance structures and resource constraints.

The pilot assessments suggest the framework's potential value in helping to distinguish between measures that may face higher climate risks (such as cetacean protection) and those where current approaches appear more robust from a climate perspective (such as North Pacific striped marlin management), while systematically identifying data gaps and research priorities. This capability could support more informed discussions about resource allocation and management priorities in the context of climate change.

The framework may also provide a foundation for adaptive management approaches by offering a standardized methodology that could evolve with improving climate science and expanding institutional capacity. As regional climate projections improve and expert input becomes available, such a framework could become a useful tool for informing discussions about whether WCPFC's conservation and management measures remain appropriate under changing environmental conditions.

Should the Commission choose to adopt and refine this approach, the CCVA Framework could contribute to WCPFC's ongoing efforts to ensure effective fisheries management while maintaining the collaborative, evidence-based approach that characterizes the Commission's work in managing the world's largest and most productive tuna fishery.

Attachments

Attachment A: Literature Review report

Attachment B: CMM CCVA Framework (Master template)

Attachment C: CMM CCVA Framework – Guidance and information

Attachment D: CMM Pilot Assessment Reports (D1-5)

Attachment E: CMM CCVA Framework results (E1-E5)

EnviroSea

ADIRA

WCPFC CMM Climate Change Vulnerability Assessment

Literature Review

21 June 2025

Contents

About this document

The Team

This document was prepared by Matthew Baird (*EnviroSea Consulting)* and Kerrie Robertson (*Adira Consulting Ltd*).

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.

For more information about *EnviroSea Consulting* visit: www.enviroseaconsulting.com

Adira Consulting Limited

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.

For more information about *Adira Consulting Limited* contact: Kerrie@adiraconsulting.com.au

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.

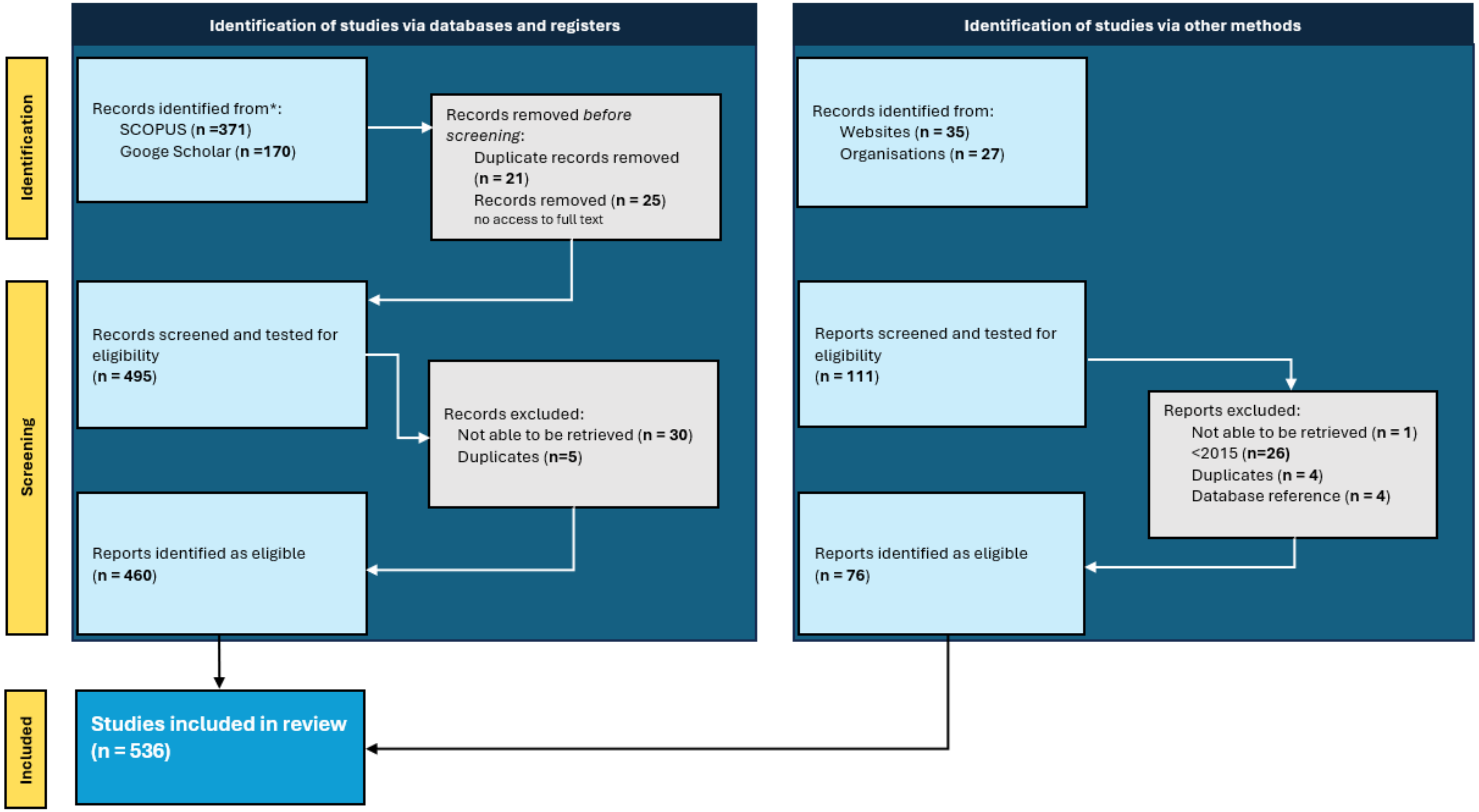


Figure 1. *PRISMA 2020 flow diagram illustrating the study selection process for climate change vulnerability literature*

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.

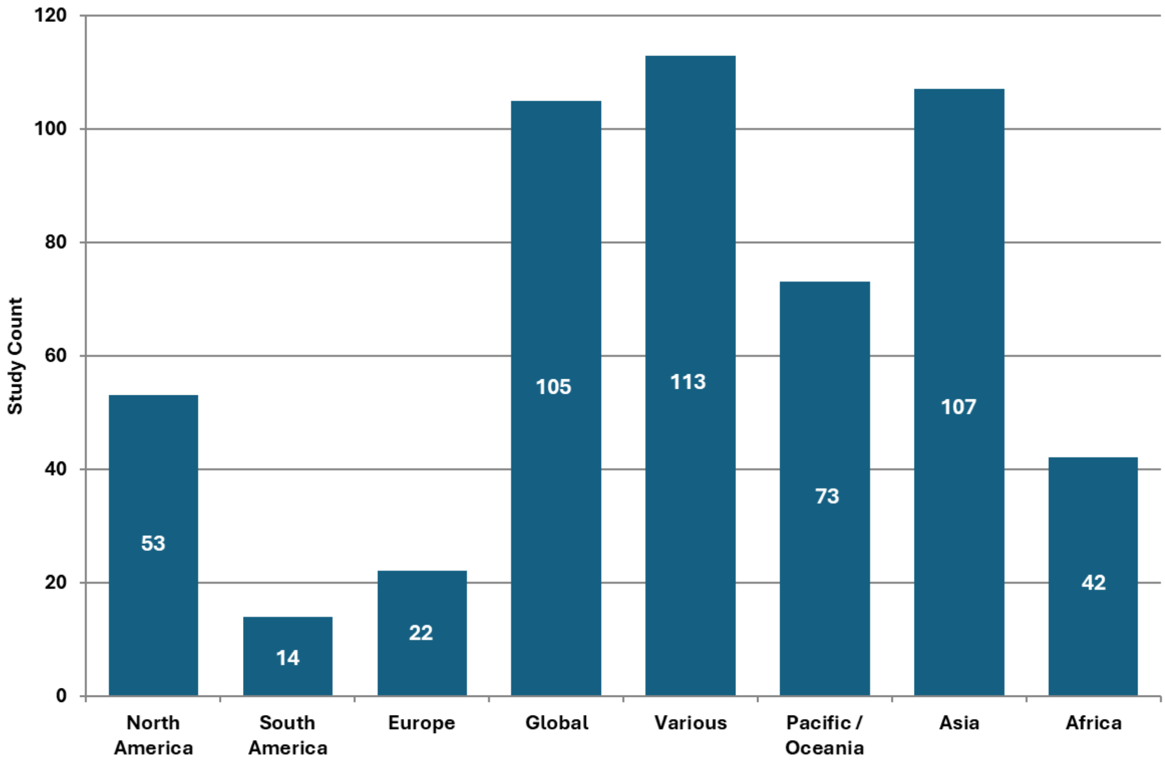


Figure 2. *Number of literature sources by region (Various = more than one regional application but not global; Total n=529 (7 studies cross-referenced without determining the study focus)*

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.

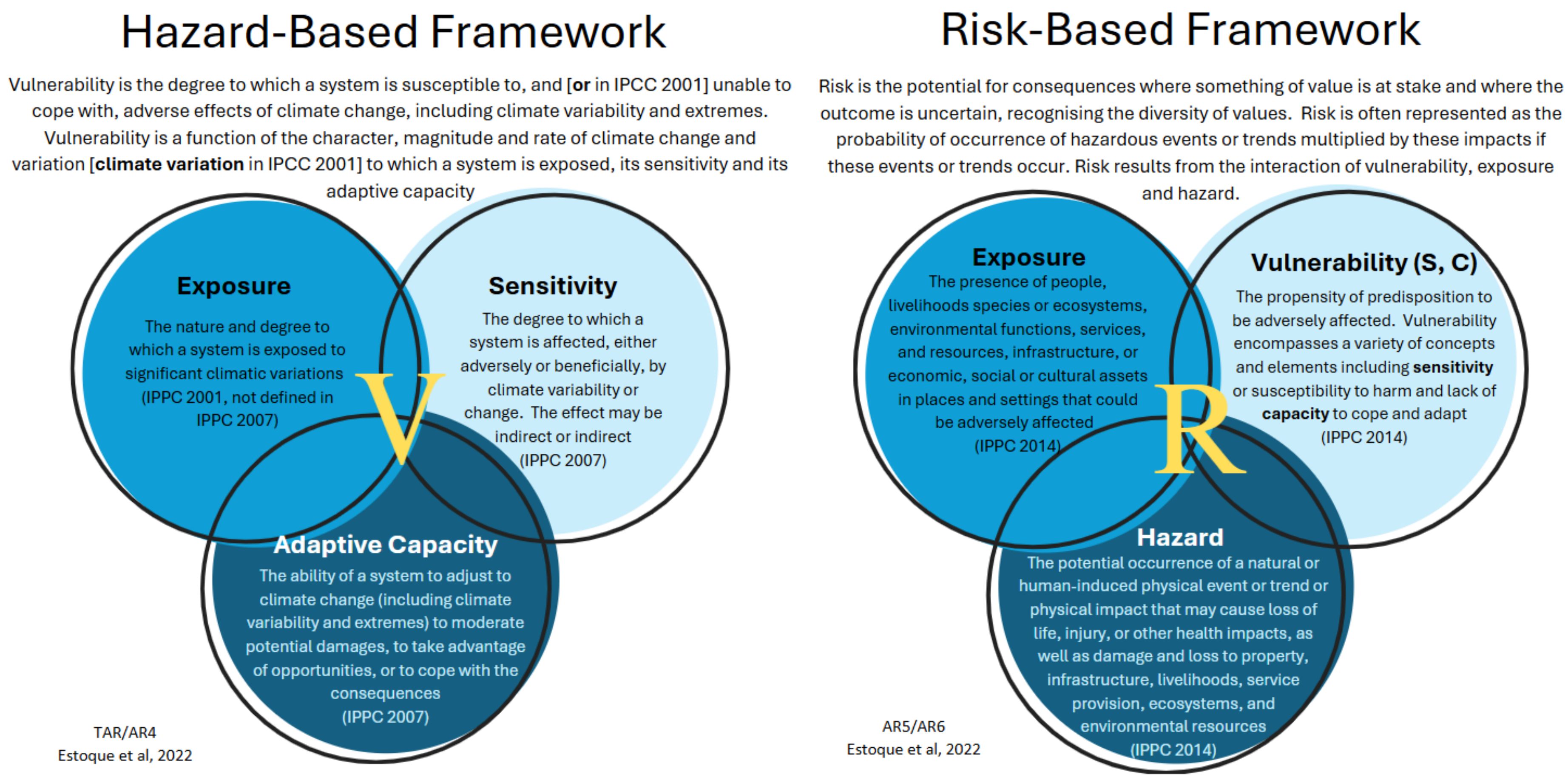


Figure 3. *VENN diagrams by Estoque et al (2022) of the hazard-based approach and risk-centered approach*

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%)

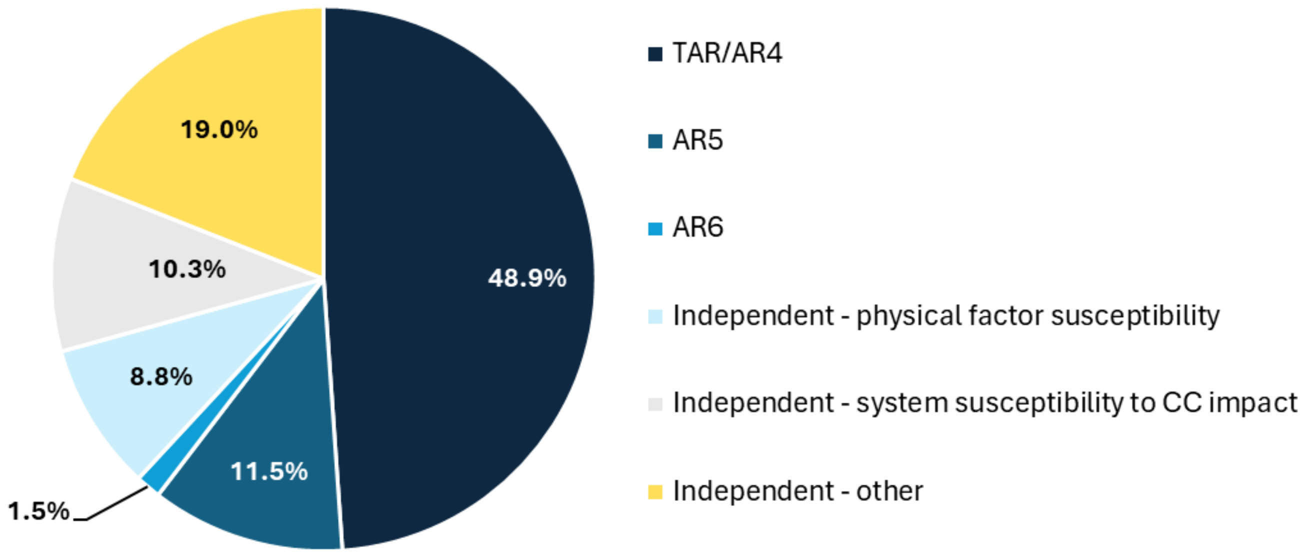


Figure 4. *Breakdown of reviewed information sources by identified vulnerability assessment category*

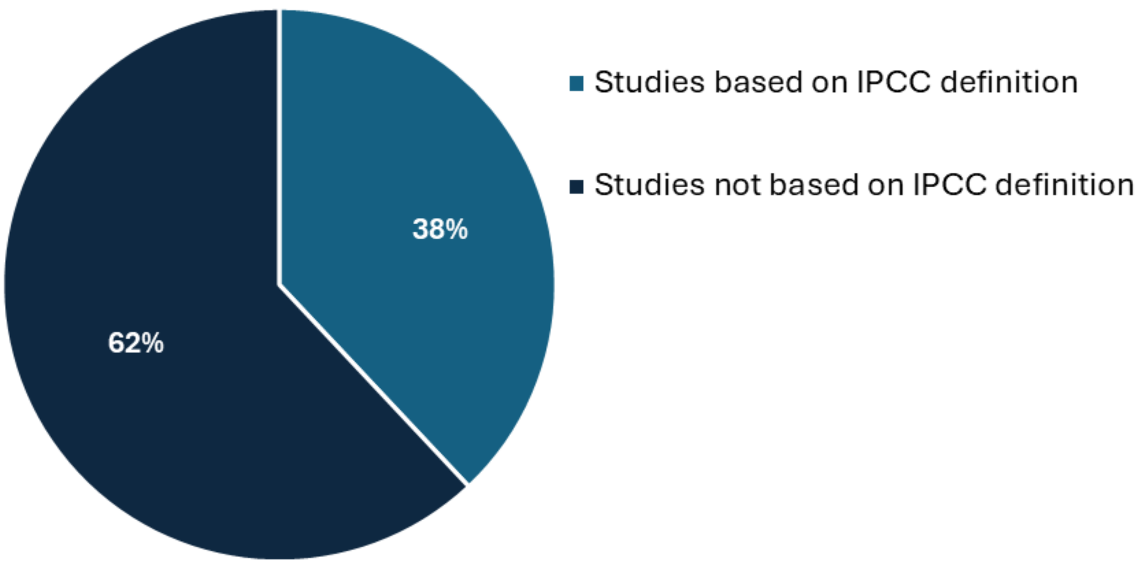


Figure 5. *Percentage of reviewed studies using and not using an IPCC vulnerability assessment definition*

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 degree 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.

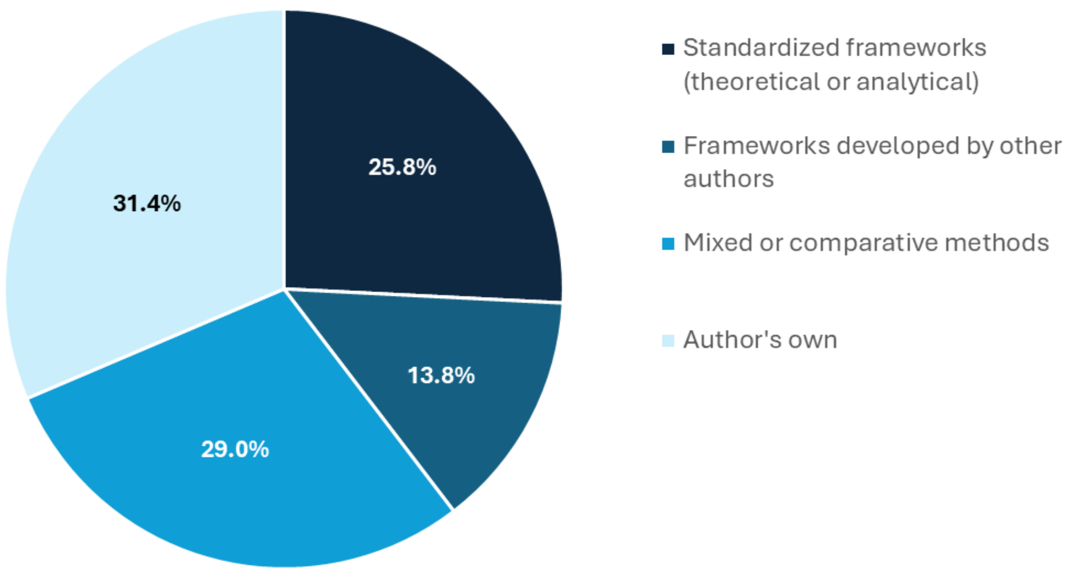


Figure 6. *Breakdown of VA frameworks by broad method categories found across the reviewed case studies (n =132)*

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.

References

Abijith, Devanantham, Subbarayan Saravanan, and Parthasarathy Kulithalai Shiyam Sundar. 2023. “Coastal Vulnerability Assessment for the Coast of Tamil Nadu, India—a Geospatial Approach.” *Environmental Science and Pollution Research* 30 (30): 75610–28. https://doi.org/10.1007/s11356-023-27686-8.

Acconcia, Antonio, Maria Carannante, Michelangelo Misuraca, and Germana Scepi. 2020. “Measuring Vulnerability to Poverty with Latent Transition Analysis.” *Social Indicators Research* 151 (1): 1–31. https://doi.org/10.1007/s11205-020-02362-3.

Adger, W. Neil, and Katharine Vincent. 2005. “Uncertainty in Adaptive Capacity.” *Comptes Rendus. Géoscience* 337 (4): 399–410. https://doi.org/10.1016/j.crte.2004.11.004.

Adraoui, Imane, and Brahim Jaafar. 2023. “Sustainable Management of Water Resources and Assessment of the Vulnerability of Moroccan Oases to Climate Change.” *Environmental Science and Pollution Research* 31 (12): 17981–93. https://doi.org/10.1007/s11356-023-25498-4.

Advani, Nikhil K. 2023. “Assessing Species Vulnerability to Climate Change, and Implementing Practical Solutions.” *Biological Conservation* 286 (October):110284. https://doi.org/10.1016/j.biocon.2023.110284.

Aksha, Sanam K., Luke Juran, Lynn M. Resler, and Yang Zhang. 2019. “An Analysis of Social Vulnerability to Natural Hazards in Nepal Using a Modified Social Vulnerability Index.” *International Journal of Disaster Risk Science* 10 (1): 103–16. https://doi.org/10.1007/s13753-018-0192-7.

Al Mamun, Abdullah, Noorshella Nawi, Mohd Ibrahim, and Rajennd Muniady. 2018. “Effect of Economic Vulnerability on Competitive Advantages, Enterprise Performance and Sustainability.” *Social Sciences* 7 (4): 54. https://doi.org/10.3390/socsci7040054.

Al Qudah, Ayat, Munir J. Rusan, Mohammed I. Al-Qinna, and Fayez A. Abdulla. 2021. “Climate Change Vulnerability Assessment for Selected Agricultural Responses at Yarmouk River Basin Area, Jordan.” *Mitigation and Adaptation Strategies for Global Change* 26 (1): 3. https://doi.org/10.1007/s11027-021-09944-7.

Alam, Edris, Md Sabur Khan, and Roquia Salam. 2022. “Vulnerability Assessment Based on Household Views from the Dammar Char in Southeastern Bangladesh.” *Natural Hazards* 113 (1): 329–44. https://doi.org/10.1007/s11069-022-05302-1.

Ali, Md. Shahjahan, and Md. Bellal Hossen. 2022. “Climate Change Vulnerability Assessment: A Case Study of South West Coastal Community of Bangladesh.” *Asian Journal of Water, Environment and Pollution* 19 (2): 25–32. https://doi.org/10.3233/AJW220020.

Ali, Tarig, Md Maruf Mortula, and Rahul Gawai. 2024. “Coastal Vulnerability Analysis of the UAE Coast Due to Sea Level Rise.” In *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions (4th Edition)*, edited by Mohamed Ksibi, Arturo Sousa, Olfa Hentati, Haroun Chenchouni, José Lopes Velho, Abdelazim Negm, Jesús Rodrigo-Comino, Riheb Hadji, Sudip Chakraborty, and Achraf

Ghorbal, 749–52. Advances in Science, Technology & Innovation. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-51904-8_164.

Allison, Edward H., Allison L. Perry, Marie-Caroline Badjeck, W. Neil Adger, Katrina Brown, Declan Conway, Ashley S. Halls, et al. 2009. "Vulnerability of National Economies to the Impacts of Climate Change on Fisheries." *Fish and Fisheries* 10 (2): 173–96. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

Amegavi, George Babington, Zechariah Langnel, Jerome Jeffison Yaw Ofori, and Daisy Rose Ofori. 2021. "The Impact of Adaptation on Climate Vulnerability: Is Readiness Relevant?" *Sustainable Cities and Society* 75 (December):103325. https://doi.org/10.1016/j.scs.2021.103325.

Andreoni, Valeria, and Apollonia Miola. 2015. "Climate Change and Supply-Chain Vulnerability: Methodologies for Resilience and Impacts Quantification." Edited by Professor Shankar Sankaran. *International Journal of Emergency Services* 4 (1): 6–26. https://doi.org/10.1108/IJES-09-2014-0012.

Ang, Milena, and Yuna Blajer De La Garza. 2021. "Vulnerability, Due Process, and Reform in Modern Mexico." *Constitutional Political Economy* 32 (3): 346–75. https://doi.org/10.1007/s10602-020-09305-7.

Angeon, Valérie, and Samuel Bates. 2015. "Reviewing Composite Vulnerability and Resilience Indexes: A Sustainable Approach and Application." *World Development* 72 (August):140–62. https://doi.org/10.1016/j.worlddev.2015.02.011.

Angrist, Joshua David, and Jörn-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton: Princeton University Press.

Anthony, Kenneth R.N. 2016. "Coral Reefs Under Climate Change and Ocean Acidification: Challenges and Opportunities for Management and Policy." *Annual Review of Environment and Resources* 41 (1): 59–81. https://doi.org/10.1146/annurev-environ-110615-085610.

Apreda, Carmela, Valeria D'Ambrosio, and Ferdinando Di Martino. 2019. "A Climate Vulnerability and Impact Assessment Model for Complex Urban Systems." *Environmental Science & Policy* 93 (March):11–26. https://doi.org/10.1016/j.envsci.2018.12.016.

Aragão, Guilherme Martins, Lucía López-López, Antonio Punzón, Elena Guijarro, Antonio Esteban, Encarnación García, José Manuel González-Irusta, Julia Polo, Miguel Vivas, and Manuel Hidalgo. 2022. "The Importance of Regional Differences in Vulnerability to Climate Change for Demersal Fisheries." Edited by Valerio Bartolino. *ICES Journal of Marine Science* 79 (2): 506–18. https://doi.org/10.1093/icesjms/fsab134.

Arora, Shubhda. 2022. "Intersectional Vulnerability in Post-disaster Contexts: Lived Experiences of Dalit Women after the Nepal Earthquake, 2015." *Disasters* 46 (2): 329–47. https://doi.org/10.1111/disa.12471.

Asyukri, Tibyan, and Rina Suryani Oktari. 2025. "Equitable Coastal Development: Assessing Hazards, Vulnerability, and Capacity through Local Knowledge." *IOP Conference Series: Earth and Environmental Science* 1479 (1): 012029. https://doi.org/10.1088/1755-1315/1479/1/012029.

Attiogbé, Afi Amen Christèle, Komla Elikplim Abotsi, Kossi Adjossou, Essi Nadège Parkoo, Kossi Adjonou, and Kouami Kokou. 2022. “Climate Vulnerability of Coffee-Cocoa Agrosystems in the Sub-Humid Mountain Ecosystems in South-West Togo (West Africa).” *Environmental Systems Research* 11 (1): 31. https://doi.org/10.1186/s40068-022-00274-4.

Awolala, David Olufemi, Igbekele Amos Ajibefun, Kehinde Ogunjobi, and Ruiqing Miao. 2022. “Integrated Assessment of Human Vulnerability to Extreme Climate Hazards: Emerging Outcomes for Adaptation Finance Allocation in Southwest Nigeria.” *Climate and Development* 14 (2): 166–83. https://doi.org/10.1080/17565529.2021.1898925.

Azam, Gausul, Mohammad Emadul Huda, Mohammad Amir Hossain Bhuiyan, Mohammad Mohinuzzaman, Md. Bodrud-Doza, and S. M. Didar-Ul Islam. 2021. “Climate Change and Natural Hazards Vulnerability of Char Land (Bar Land) Communities of Bangladesh: Application of the Livelihood Vulnerability Index (LVI).” *Global Social Welfare* 8 (1): 93–105. https://doi.org/10.1007/s40609-019-00148-1.

Bainton, Nicholas, Emilia E. Skrzypek, and Éléonore Lèbre. 2025. “Compound Exposure: Climate Change, Vulnerability and the Energy-Extractives Nexus in the Pacific.” *World Development* 190 (June):106958. https://doi.org/10.1016/j.worlddev.2025.106958.

Ball, Ray, and Philip Brown. 1968. “An Empirical Evaluation of Accounting Income Numbers.” *Journal of Accounting Research* 6 (2): 159. https://doi.org/10.2307/2490232.

BAPPENAS. 2010. “Indonesia Climate Change Sectoral Roadmap (ICCSR): Synthesis Report. Badan Perencanaan Pembangunan Nasional.”

Barange, M, T Bahri, M.C.M Beveridge, K.L Cochrane, S Funge-Smith, and F Poulain. 2018. “Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options.” 627. FAO Fisheries and Aquaculture Technical Paper. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Barnes, Michele L., Peng Wang, Joshua E. Cinner, Nicholas A. J. Graham, Angela M. Guerrero, Lorien Jasny, Jacqueline Lau, Sarah R. Sutcliffe, and Jessica Zamborain-Mason. 2020. “Social Determinants of Adaptive and Transformative Responses to Climate Change.” *Nature Climate Change* 10 (9): 823–28. https://doi.org/10.1038/s41558-020-0871-4.

Barnett, Jon. 2020. “Global Environmental Change II: Political Economies of Vulnerability to Climate Change.” *Progress in Human Geography* 44 (6): 1172–84. https://doi.org/10.1177/0309132519898254.

Barnett, Jon, and Elissa Waters. 2016. “Rethinking the Vulnerability of Small Island States: Climate Change and Development in the Pacific Islands.” In *The Palgrave Handbook of International Development*, edited by Jean Grugel and Daniel Hammett, 731–48. London: Palgrave Macmillan UK. https://doi.org/10.1057/978-1-137-42724-3_40.

Barua, Prabal, Syed Hafizur Rahman, Suman Barua, and Ismail M.M. Rahman. 2020. “CLIMATE CHANGE VULNERABILITY AND RESPONSES OF FISHERFOLK COMMUNITIES IN THE SOUTH-EASTERN COAST OF BANGLADESH.” *Water Conservation and Management* 4 (1): 20–31. https://doi.org/10.26480/wcm.01.2020.20.31.

Barzehkar, Mojtaba, Kevin E. Parnell, Tarmo Soomere, Deirdre Dragovich, and Johanna Engström. 2021. "Decision Support Tools, Systems and Indices for Sustainable Coastal Planning and Management: A Review." *Ocean & Coastal Management* 212 (October):105813. https://doi.org/10.1016/j.ocecoaman.2021.105813.

Basel, Britt, Gillian Goby, and Johanna Johnson. 2020. "Community-Based Adaptation to Climate Change in Villages of Western Province, Solomon Islands." *Marine Pollution Bulletin* 156 (July):111266. https://doi.org/10.1016/j.marpolbul.2020.111266.

Battamo, Ashenafi Yohannes, Olli Varis, John P. Giesy, Belay Tafa Oba, Moses Akintayo Aborisade, Peizhe Sun, Yongkui Yang, and Lin Zhao. 2022. "A Framework for Assessing Freshwater Vulnerability along China's Belt and Road Initiative: An Exposure, Sensitivity and Adaptive Capacity Approach." *Environmental Science & Policy* 132 (June):247–61. https://doi.org/10.1016/j.envsci.2022.03.001.

Beccari, Benjamin. 2016. "A Comparative Analysis of Disaster Risk, Vulnerability and Resilience Composite Indicators." *PLoS Currents*. https://doi.org/10.1371/currents.dis.453df025e34b682e9737f95070f9b970.

Becker, Austin, Adolf K.Y. Ng, Darryn McEvoy, and Jane Mullett. 2018. "Implications of Climate Change for Shipping: Ports and Supply Chains." *WIREs Climate Change* 9 (2): e508. https://doi.org/10.1002/wcc.508.

Bedeke, Sisay Belay. 2023. "Climate Change Vulnerability and Adaptation of Crop Producers in Sub-Saharan Africa: A Review on Concepts, Approaches and Methods." *Environment, Development and Sustainability* 25 (2): 1017–51. https://doi.org/10.1007/s10668-022-02118-8.

Bell, Johann D. 2016. "Climate Change and Pacific Island Food Systems: The Future of Food, Farming and Fishing in the Pacific Islands Under a Changing Climate." SPC.

Bell, Johann D., and T Bahri. 2018. "A New Climate Change Vulnerability Assessment for Fisheries and Aquaculture." *SPC Fisheries Newsletter*, 2018.

Bell, Johann D., A.S Ganachaud, P.C Gehrke, A.J Hobday, O Hoegh-Guldberh, and M Waycott. 2011. "10.1007/S10584-015-1583-z." SPC.

Bell, Johann D., Inna Senina, Timothy Adams, Olivier Aumont, Beatriz Calmettes, Sangaalofa Clark, Morgane Dessert, et al. 2021. "Pathways to Sustaining Tuna-Dependent Pacific Island Economies during Climate Change." *Nature Sustainability* 4 (10): 900–910. https://doi.org/10.1038/s41893-021-00745-z.

Bell, Johann D., D.J. Welch, B Youngs, D Tracey, K Sambrooke, E Fulton, J.L Blanchard, B.R Moore, D Fierro-Arcos, and B Molinari. 2024. "Assessment of the Vulnerability of Pacific Island Communities and Food Security to the Effects of Climate Change on Coastal Fisheries." Suppmenentary Technical Report for GCF Study 1. Noumea.

Ben Lamine, Emna, Alexandre Schickele, Paolo Guidetti, Denis Allemand, Nathalie Hilmi, and Virginie Raybaud. 2023. "Redistribution of Fisheries Catch Potential in Mediterranean and North European Waters Under Climate Change Scenarios." SSRN. https://doi.org/10.2139/ssrn.4327481.

Benioff, Ron, Sandra Guill, and Jeffrey Lee, eds. 1996. *Vulnerability and Adaptation Assessments: An International Handbook*. Vol. 7. Environmental Science and Technology Library. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-009-0303-6.

Bera, Aparna, Gowhar Meraj, Shruti Kanga, Majid Farooq, Suraj Kumar Singh, Netrananda Sahu, and Pankaj Kumar. 2022. "Vulnerability and Risk Assessment to Climate Change in Sagar Island, India." *Water* 14 (5): 823. https://doi.org/10.3390/w14050823.

Beroya-Eitner, Mary Antonette. 2016. "Ecological Vulnerability Indicators." *Ecological Indicators* 60 (January):329–34. https://doi.org/10.1016/j.ecolind.2015.07.001.

Berrouet, Lina María, Jenny Machado, and Clara Villegas-Palacio. 2018. "Vulnerability of Socio—Ecological Systems: A Conceptual Framework." *Ecological Indicators* 84 (January):632–47. https://doi.org/10.1016/j.ecolind.2017.07.051.

Bertilsson, Jonas. 2023. "Managing Vulnerability in the Green Climate Fund." *Climate and Development* 15 (4): 304–11. https://doi.org/10.1080/17565529.2022.2081118.

Birkmann, Joern, Susan L. Cutter, Dale S. Rothman, Torsten Welle, Matthias Garschagen, Bas Van Ruijven, Brian O'Neill, et al. 2015. "Scenarios for Vulnerability: Opportunities and Constraints in the Context of Climate Change and Disaster Risk." *Climatic Change* 133 (1): 53–68. https://doi.org/10.1007/s10584-013-0913-2.

Birkmann, Jörn, ed. 2013. *Cutter, S. L., & Morath, D. P. (2013). The Evolution of the Social Vulnerability Index. In Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*. 2. ed. Tokyo: United Nations Univ. Press.

Biswas, Sneha, and Sunil Nautiyal. 2021. "An Assessment of Socio-Economic Vulnerability at the Household Level: A Study on Villages of the Indian Sundarbans." *Environment, Development and Sustainability* 23 (7): 11120–37. https://doi.org/10.1007/s10668-020-01085-2.

Bito-onon, Jescel B. 2020. "Climate Risk Vulnerability Assessment: Basis for Decision Making Support for the Agriculture Sector in the Province of Iloilo." *International Journal of Innovation, Creativity and Change* 13 (3).

Blasiak, R., R. Wynberg, K. Grorud-Colvert, S. Thambisetty, N.M. Bandarra, A.V.M. Canário, J. da Silva, et al. 2020. "The Ocean Genome and Future Prospects for Conservation and Equity." *Nature Sustainability* 3 (8): 588–96. https://doi.org/10.1038/s41893-020-0522-9.

Blasiak, Robert. 2019. "Climate Change Vulnerability and Ocean Governance." In *Predicting Future Oceans*, 357–64. Elsevier. https://doi.org/10.1016/B978-0-12-817945-1.00039-3.

Blasiak, Robert, Jessica Spijkers, Kanae Tokunaga, Jeremy Pittman, Nobuyuki Yagi, and Henrik Österblom. 2017. "Climate Change and Marine Fisheries: Least Developed Countries Top Global Index of Vulnerability." Edited by Brian R. MacKenzie. *PLOS ONE* 12 (6): e0179632. https://doi.org/10.1371/journal.pone.0179632.

Bohm, A. 2012. "Theoretisches Codieren: Textanalyse in Der Grounded Theory," in Qualitative Forschung: Ein Handbuch." *Rowohlt Paperback Publishing* 9th edition.

Bolin, Bob, and Liza C. Kurtz. 2018. “Race, Class, Ethnicity, and Disaster Vulnerability.” In *Handbook of Disaster Research*, edited by Havidán Rodríguez, William Donner, and Joseph E. Trainor, 181–203. Handbooks of Sociology and Social Research. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-63254-4_10.

Bonan, Gordon B., and Scott C. Doney. 2018. “Climate, Ecosystems, and Planetary Futures: The Challenge to Predict Life in Earth System Models.” *Science* 359 (6375): eaam8328. https://doi.org/10.1126/science.aam8328.

Borden, Kevin A., Mathew C. Schmidtlein, Christopher T. Emrich, Walter W. Piegorsch, and Susan L. Cutter. 2007. “Vulnerability of U.S. Cities to Environmental Hazards.” *Journal of Homeland Security and Emergency Management* 4 (2). https://doi.org/10.2202/1547-7355.1279.

Briguglio, Lino. 1995. “Small Island Developing States and Their Economic Vulnerabilities.” *World Development* 23 (9): 1615–32. https://doi.org/10.1016/0305-750X(95)00065-K.

Brown, Iain, and Pam Berry. 2022. “National Climate Change Risk Assessments to Inform Adaptation Policy Priorities and Environmental Sustainability Outcomes: A Knowledge Systems Perspective.” *Climatic Change* 175 (3–4): 13. https://doi.org/10.1007/s10584-022-03464-2.

Brownbridge, Martin, and Sudharshan Canagarajah. 2024. *Climate Change Vulnerability, Adaptation and Public Debt Sustainability in Small Island Developing States*. Washington, DC: World Bank. https://doi.org/10.1596/1813-9450-10787.

Brugere, C, and C De Young. 2015. “Assessing Climate Change Vulnerability in Fisheries and Aquaculture: Available Methodologies and Their Relevance for the Sector.” 597. FAO Fisheries and Aquaculture Technical Paper. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Bucak, T, B Bulus, GD Bilgin, G Atkin, Caglayan Demirbas, and U Zeydanli. 2021. “Sektörel Risk/Etkilenebilirlik Analizleri ve Bölgesel İklim Eylem Planları.” *UNDP*.

Bueno-Pardo, Juan, Daniela Nobre, João N. Monteiro, Pedro M. Sousa, Eudriano F. S. Costa, Vânia Baptista, Andreia Ovelheiro, et al. 2021. “Climate Change Vulnerability Assessment of the Main Marine Commercial Fish and Invertebrates of Portugal.” *Scientific Reports* 11 (1): 2958. https://doi.org/10.1038/s41598-021-82595-5.

Burden, M, and W Battista. 2019. “Pathways for Climate-Ready Fisheries - Environmental Defense Fund, Oceans.” Environmental Defense Fund. https://www.edf.org/sites/default/files/documents/pathwaysClimateReadyFisheries-Dec2019.pdf.

Butt, Nathalie, Benjamin S. Halpern, Casey C. O’Hara, A. Louise Allcock, Beth Polidoro, Samantha Sherman, Maria Byrne, et al. 2022. “A Trait-based Framework for Assessing the Vulnerability of Marine Species to Human Impacts.” *Ecosphere* 13 (2): e3919. https://doi.org/10.1002/ecs2.3919.

Byers, Steven N., and Chelsey A. Juarez. 2023. *Introduction to Forensic Anthropology*. 6th ed. New York: Routledge. https://doi.org/10.4324/9781003283935.

Cahyadi Ramadhan, Dina Ruslanjari, Diana Puspitasari, Gading Dita Indasari, and Naufal Sandro. 2022. “Coastal Vulnerability Assessment for Community Resilience on Abrasion: Case of Bugel Coast, Kulon Progo Regency, Indonesia.” *ASEAN Journal on Science and Technology for Development* 39 (1). https://doi.org/10.29037/ajstd.715.

Câmara, Samuel Façanha, Francisco Roberto Pinto, Felipe Roberto Da Silva, Marcelo De Oliveira Soares, and Thiago Matheus De Paula. 2021. “Socioeconomic Vulnerability of Communities on the Brazilian Coast to the Largest Oil Spill (2019–2020) in Tropical Oceans.” *Ocean & Coastal Management* 202 (March):105506. https://doi.org/10.1016/j.ocecoaman.2020.105506.

Campagnolo, Lorenza, and Marinella Davide. 2019. “Can the Paris Deal Boost SDGs Achievement? An Assessment of Climate Mitigation Co-Benefits or Side-Effects on Poverty and Inequality.” *World Development* 122 (October):96–109. https://doi.org/10.1016/j.worlddev.2019.05.015.

Campbell, Bruce M., Sonja J. Vermeulen, Pramod K. Aggarwal, Caitlin Corner-Dolloff, Evan Girvetz, Ana Maria Loboguerrero, Julian Ramirez-Villegas, et al. 2016. “Reducing Risks to Food Security from Climate Change.” *Global Food Security* 11 (December):34–43. https://doi.org/10.1016/j.gfs.2016.06.002.

Cangüzel, Aybüke, and Çiğdem Coşkun Hepcan. 2024. “Climate Change Vulnerability Assessment of Karşıyaka, İzmir.” *Natural Hazards* 120 (15): 14869–88. https://doi.org/10.1007/s11069-024-06798-5.

Champion, Curtis, James R. Lawson, Joanna Pardoe, Derrick O. Cruz, Ashley M. Fowler, Fabrice Jaine, Hayden T. Schilling, and Melinda A. Coleman. 2023. “Multi-Criteria Analysis for Rapid Vulnerability Assessment of Marine Species to Climate Change.” *Climatic Change* 176 (8): 99. https://doi.org/10.1007/s10584-023-03577-2.

Chas-Amil, Maria-Luisa, Emilio Nogueira-Moure, Jeffrey P. Prestemon, and Julia Touza. 2022. “Spatial Patterns of Social Vulnerability in Relation to Wildfire Risk and Wildland-Urban Interface Presence.” *Landscape and Urban Planning* 228 (December):104577. https://doi.org/10.1016/j.landurbplan.2022.104577.

Chauhan, Disha, Muthuprasad Thiyaharajan, Anvita Pandey, Nidhi Singh, Vishal Singh, Sumit Sen, and Rajiv Pandey. 2022. “Climate Change Water Vulnerability and Adaptation Mechanism in a Himalayan City, Nainital, India.” *Environmental Science and Pollution Research* 29 (57): 85904–21. https://doi.org/10.1007/s11356-021-15713-5.

Chen, Qi, Hongyan Su, Xuan Yu, and Qiuguang Hu. 2020. “Livelihood Vulnerability of Marine Fishermen to Multi-Stresses under the Vessel Buyback and Fishermen Transfer Programs in China: The Case of Zhoushan City, Zhejiang Province.” *International Journal of Environmental Research and Public Health* 17 (3): 765. https://doi.org/10.3390/ijerph17030765.

Chen, Xinjun. 2020. “Global Environmental Change and Fisheries.” In *Brief Introduction to Fisheries*, edited by Xinjun Chen and Yingqi Zhou, 225–49. Singapore: Springer Singapore. https://doi.org/10.1007/978-981-15-3336-5_6.

Chen, Yuxin, Bing Liu, and Fan Zhang. 2023. "Vulnerability Assessment in Economy-Society Environment of the Belt and Road Initiative Countries." *Environment, Development and Sustainability* 26 (8): 21529–52. https://doi.org/10.1007/s10668-023-03542-0.

Cheng, Wenju, Haiyang Xi, Celestin Sindikubwabo, Jianhua Si, Chenguang Zhao, Tengfei Yu, Ailin Li, and Tuanrong Wu. 2020. "Ecosystem Health Assessment of Desert Nature Reserve with Entropy Weight and Fuzzy Mathematics Methods: A Case Study of Badain Jaran Desert." *Ecological Indicators* 119 (December):106843. https://doi.org/10.1016/j.ecolind.2020.106843.

Cheung, William W.L., Tony J. Pitcher, and Daniel Pauly. 2005. "A Fuzzy Logic Expert System to Estimate Intrinsic Extinction Vulnerabilities of Marine Fishes to Fishing." *Biological Conservation* 124 (1): 97–111. https://doi.org/10.1016/j.biocon.2005.01.017.

Chhetri, Neha. 2021. "Vulnerabilities of Coastal and Inland Fisheries to Climate Change: Assessing Adaptation Policy to Improve Resiliency of Social Ecological System of Bangladesh." In *Natural Resource Governance in Asia*, 255–70. Elsevier. https://doi.org/10.1016/B978-0-323-85729-1.00018-9.

Chin, Andrew, Peter M. Kyne, Terence I. Walker, and Rory B. McAULEY. 2010. "An Integrated Risk Assessment for Climate Change: Analysing the Vulnerability of Sharks and Rays on Australia's Great Barrier Reef." *Global Change Biology* 16 (7): 1936–53. https://doi.org/10.1111/j.1365-2486.2009.02128.x.

Christie, Maria Elisa, Daniel Sumner, Lidya A. Chala, and Wondi Mersie. 2025. "Gendered Livelihood Impacts and Responses to an Invasive, Transboundary Weed in a Rural Ethiopian Community." *Gender, Place & Culture* 32 (1): 11–33. https://doi.org/10.1080/0966369X.2023.2294257.

Cinner, Joshua E., W. Neil Adger, Edward H. Allison, Michele L. Barnes, Katrina Brown, Philippa J. Cohen, Stefan Gelcich, et al. 2018. "Building Adaptive Capacity to Climate Change in Tropical Coastal Communities." *Nature Climate Change* 8 (2): 117–23. https://doi.org/10.1038/s41558-017-0065-x.

Cinner, Joshua E., Cindy Huchery, Emily S. Darling, Austin T. Humphries, Nicholas A. J. Graham, Christina C. Hicks, Nadine Marshall, and Tim R. McClanahan. 2013. "Evaluating Social and Ecological Vulnerability of Coral Reef Fisheries to Climate Change." Edited by Sam Dupont. *PLoS ONE* 8 (9): e74321. https://doi.org/10.1371/journal.pone.0074321.

Closset, M, S Feindouno, P Guillaumont, and C Simonet. 2018. "A Physical Vulnerability to Climate Change Index: Which Are the Most Vulnerable Developing Countries?" FERDI Working Paper P213.

Çobanyılmaz, P, and U Yuksel. 2013. "Determination of Vulnerability of Cities to Climate Change: The Case of Ankara." *Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi* 17 (3): 39–50.

Cochrane, Kl, K Ortega-Cisneros, Ja Iitembu, Ci Dos Santos, and Whh Sauer. 2020. “Application of a General Methodology to Understand Vulnerability and Adaptability of the Fisheries for Small Pelagic Species in the Benguela Countries: Angola, Namibia and South Africa.” *African Journal of Marine Science* 42 (4): 473–93. https://doi.org/10.2989/1814232X.2020.1844798.

Comte, Adrien. 2021. “Recent Advances in Climate Change Vulnerability/Risk Assessments in the Fisheries and Aquaculture Sector.” 1225. FAO Fisheries and Aquaculture Circular. Rome, Italy.

Contreras, Diana, Alondra Chamorro, and Sean Wilkinson. 2020. “Review Article: The Spatial Dimension in the Assessment of Urban Socio-Economic Vulnerability Related to Geohazards.” *Natural Hazards and Earth System Sciences* 20 (6): 1663–87. https://doi.org/10.5194/nhess-20-1663-2020.

CRIDF. n.d. “Climate Risk and Vulnerability Assessment Tool: Communities and Water Infrastructure Projects.” Climate Resilient Infrastructure Development Facility. Accessed June 17, 2025.

Cruz-Sánchez, Yadihra, and Alejandro Ismael Monterroso-Rivas. 2025. “Climate Change-Driven Vulnerability of Mexico Regions toward Food Insecurity.” *Food Security* 17 (3): 721–38. https://doi.org/10.1007/s12571-025-01536-6.

Cumberbatch, Janice, Crystal Drakes, Tara Mackey, Mohammad Nagdee, Jehroum Wood, Anna Karima Degia, and Catrina Hinds. 2020. “Social Vulnerability Index: Barbados – A Case Study.” *Coastal Management* 48 (5): 505–26. https://doi.org/10.1080/08920753.2020.1796193.

Curi, Rodrigo Luis Comini, and Maria A. Gasalla. 2021. “Social Vulnerability and Human Development of Brazilian Coastal Populations.” *Frontiers in Ecology and Evolution* 9 (July):664272. https://doi.org/10.3389/fevo.2021.664272.

Cutter, Susan L., Bryan J. Boruff, and W. Lynn Shirley. 2003. “Social Vulnerability to Environmental Hazards*.” *Social Science Quarterly* 84 (2): 242–61. https://doi.org/10.1111/1540-6237.8402002.

Cutter, Susan L., C.T Emrich, J.J Webb, and D.P Morath. 2009. “Social Vulnerability to Climate Variability Hazards: A Review of the Literature.” Final Report to Oxfam America, Hazards and Vulnerability Research Institute. University of South Carolina. https://sompiseth.weebly.com/uploads/4/8/4/8/4848831/literature_review_on_climate_change_vulnerability.pdf?utm_source=chatgpt.com.

Da Cunha, Charlotte, Inga Nikulkina, Jean-Paul Vanderlinden, Vyacheslav Shadrin, Natalia Doloisio, and Dina Salakhova. 2022. “Adaptive Capacity for Climate Change: Local Initiatives and Federal Planning. The Case of Tiksi, Sakha Republic, Russia.” *Polar Science* 31 (March):100761. https://doi.org/10.1016/j.polar.2021.100761.

Da Paz, Luciana Rocha Leal, and Katia Cristina Garcia. 2021. “Vulnerability to Climate Change and Indigenous People in the Amazon Region.” In *Handbook of Climate Change Management*, edited by Johannes M. Luetz and Desalegn Ayal, 5189–5206. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-57281-5_278.

Das, Shibu, and Kaushal Kumar Sharma. 2024. "Livelihood Vulnerability Assessment among the Agrarian Indigenous Communities of Sundarban Biosphere Reserve in India for Building Resilience and Adaptation." *Environmental Science and Pollution Research* 31 (56): 65137–68. https://doi.org/10.1007/s11356-024-35560-4.

Das, Shouvik, Amit Ghosh, Sugata Hazra, Tuhin Ghosh, Ricardo Safra De Campos, and Sourav Samanta. 2020. "Linking IPCC AR4 & AR5 Frameworks for Assessing Vulnerability and Risk to Climate Change in the Indian Bengal Delta." *Progress in Disaster Science* 7 (October):100110. https://doi.org/10.1016/j.pdisas.2020.100110.

Dasgupta, Dipak, Gerhard Krinner, Aditi Mukherji, Peter W. Thorne, Christopher Trisos, José Romero, Paulina Aldunce, et al. 2023a. "IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." First. Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647.

———. 2023b. "IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change ." First. Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647.

Day, J.C., and S.F Heron. 2019. "Climate Vulnerability Index (CVI): Summary Report 2019." James Cook University. https://www.jcu.edu.au/__data/assets/pdf_file/0005/2059070/CVI-Summary-2019.pdf.

Day, Jon C., Scott F. Heron, and Adam Markham. 2020. "Assessing the Climate Vulnerability of the World's Natural and Cultural Heritage." *Parks Stewardship Forum* 36 (1). https://doi.org/10.5070/P536146384.

De Loyola Hummell, Beatriz Maria, Susan L. Cutter, and Christopher T. Emrich. 2016. "Social Vulnerability to Natural Hazards in Brazil." *International Journal of Disaster Risk Science* 7 (2): 111–22. https://doi.org/10.1007/s13753-016-0090-9.

De Young, C. 2016. "Climate Change Implications for Fisheries and Aquaculture: Summary of the Findings of the Intergovernmental Panel on Climate Change Fifth Assessment Report." C1122. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Debortoli, Nathan S., Dylan G. Clark, James D. Ford, Jesse S. Sayles, and Emilia P. Diaconescu. 2019a. "An Integrative Climate Change Vulnerability Index for Arctic Aviation and Marine Transportation." *Nature Communications* 10 (1): 2596. https://doi.org/10.1038/s41467-019-10347-1.

———. 2019b. "An Integrative Climate Change Vulnerability Index for Arctic Aviation and Marine Transportation." *Nature Communications* 10 (1): 2596. https://doi.org/10.1038/s41467-019-10347-1.

Deguen, Séverine, Mary Amuzu, Valentin Simoncic, and Wahida Kihal-Talantikite. 2022. "Exposome and Social Vulnerability: An Overview of the Literature Review." *International Journal of Environmental Research and Public Health* 19 (6): 3534. https://doi.org/10.3390/ijerph19063534.

Delfino, Ariel. 2021. “Comparative Analysis of Social Vulnerability and Adaptive Capacity to Impacts of Climate Change among Fisherfolk in Garchitorena, Camarines Sur, Philippines.” *The International Journal of Climate Change: Impacts and Responses* 13 (2): 127–46. https://doi.org/10.18848/1835-7156/CGP/v13i02/127-146.

Deutsche Gesellschaft für Internationale Zusammenarbeit. 2014. “The Vulnerability Sourcebook: Concept and Guidelines for standardised Vulnerability Assessments.” https://adelphi.de/en/system/files/mediathek/bilder/Vulnerability_Sourcebook_Poster_GIZ_2014.pdf?utm_source=chatgpt.com.

Dhamija, Vanshika, Roopam Shukla, Christoph Gornott, and Pk Joshi. 2020. “Consistency in Vulnerability Assessments of Wheat to Climate Change—A District-Level Analysis in India.” *Sustainability* 12 (19): 8256. https://doi.org/10.3390/su12198256.

Doan, Miki Miki Khahn, Ruth Hill, Stephane Hallegatte, Rodas Corral, Paul Andres, Ben Brunckhorst, Minh Nguyen, Samuel Freije-Rodriguez, and Esther Naikal. 2023. “Counting People Exposed to, Vulnerable to, or at High Risk from Climate Shocks: A Methodology.” 10619. Policy Research Working Paper Series. The World Bank.

Dudley, Peter N., Tanya L. Rogers, Mark M. Morales, Amanda D. Stoltz, Casey J. Sheridan, Anne K. Beulke, Carrie Pomeroy, and Mark H. Carr. 2021. “A More Comprehensive Climate Vulnerability Assessment Framework for Fisheries Social-Ecological Systems.” *Frontiers in Marine Science* 8 (June):678099. https://doi.org/10.3389/fmars.2021.678099.

Duran-Izquierdo, Margareth, and Jesus Olivero-Verbel. 2021. “Vulnerability Assessment of Sierra Nevada de Santa Marta, Colombia: World’s Most Irreplaceable Nature Reserve.” *Global Ecology and Conservation* 28 (August):e01592. https://doi.org/10.1016/j.gecco.2021.e01592.

Eastin, Joshua. 2018. “Climate Change and Gender Equality in Developing States.” *World Development* 107 (July):289–305. https://doi.org/10.1016/j.worlddev.2018.02.021.

Edmonds, Heidi K., C. A. Knox Lovell, and Julie E. Lovell. 2022. “The Inequities of National Adaptation to Climate Change.” *Resources* 12 (1): 1. https://doi.org/10.3390/resources12010001.

Effendi, M. 2012. “Assessment of Community Vulnerability to Climate Variability in the Garang Watershed, Central Java, Using GIS.”

Eriksen, Christine, Gregory L. Simon, Florian Roth, Shefali Juneja Lakhina, Ben Wisner, Carolina Adler, Frank Thomalla, et al. 2020. “Rethinking the Interplay between Affluence and Vulnerability to Aid Climate Change Adaptive Capacity.” *Climatic Change* 162 (1): 25–39. https://doi.org/10.1007/s10584-020-02819-x.

Estoque, Ronald C., Asif Ishtiaque, Jagadish Parajuli, Darshana Athukorala, Yasin Wahid Rabby, and Makoto Ooba. 2023. “Has the IPCC’s Revised Vulnerability Concept Been Well Adopted?” *Ambio* 52 (2): 376–89. https://doi.org/10.1007/s13280-022-01806-z.

European Environment Agency. 2004. “Integrated Environmental Assessment (IEA) the Interdisciplinary Process of Identification, Analysis and Appraisal of All Relevant Natural and Human Processes and Their Interactions Which Determine Both the Current and Future State of

Environmental Quality, and Resources, on Appropriate Spatial and Temporal Scales, Thus Facilitating the Framing and Implementation of Policies and Strategies."

Fama, E, L Fisher, M.C Jensen, and Roll R. 1969. "The Adjustment of Stock Prices to New Information." *International Economic Review* 10 (1): 1–21.

Farahmand, Shekoofeh, Nathalie Hilmi, Mine Cinar, Alain Safa, Vicky W.Y. Lam, Salpie Djoundourian, Wassim Shahin, et al. 2023. "Climate Change Impacts on Mediterranean Fisheries: A Sensitivity and Vulnerability Analysis for Main Commercial Species." *Ecological Economics* 211 (September):107889. https://doi.org/10.1016/j.ecolecon.2023.107889.

Feindouno, S, and M Goujon. 2015. "The Retrospective Economic Vulnerability Index, 2015 Update." FERDI Working Paper 147. Fondation pour les Études et Recherches sur le Développement International.

Fekete, A. 2009. "Validation of a Social Vulnerability Index in Context to River-Floods in Germany." *Natural Hazards and Earth System Sciences* 9 (2): 393–403. https://doi.org/10.5194/nhess-9-393-2009.

Fellman, T. 2012. "The Assessment of Climate Change-Related Vulnerability in the Agricultural Sector: Reviewing Conceptual Frameworks." Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Fernandez, Mario Andres, Santiago Bucaram, and Willington Renteria. 2017. "(Non-) Robustness of Vulnerability Assessments to Climate Change: An Application to New Zealand." *Journal of Environmental Management* 203 (December):400–412. https://doi.org/10.1016/j.jenvman.2017.07.054.

Fernandez, Mario Andres, and Nancy Golubiewski. 2019. "An Assessment of Vulnerability to Climate Change in Auckland Technical Report 2019/011." Technical Report 2019/011. New Zealand: Auckland City Council.

FFA Secretariat, and SPC-OFP Secretariat. 2024. "Additional Oceanic Environmental Data." In *20th Regular Session*.

Fischer, Alexandra Paige, and Tim G. Frazier. 2018. "Social Vulnerability to Climate Change in Temperate Forest Areas: New Measures of Exposure, Sensitivity, and Adaptive Capacity." *Annals of the American Association of Geographers* 108 (3): 658–78. https://doi.org/10.1080/24694452.2017.1387046.

Fischer, Harry W, and Ashwini Chhatre. 2016. "Assets, Livelihoods, and the 'Profile Approach' for Analysis of Differentiated Social Vulnerability in the Context of Climate Change." *Environment and Planning A: Economy and Space* 48 (4): 789–807. https://doi.org/10.1177/0308518X15623278.

Foden, Wendy B., Bruce E. Young, H. Resit Akçakaya, Raquel A. Garcia, Ary A. Hoffmann, Bruce A. Stein, Chris D. Thomas, et al. 2019. "Climate Change Vulnerability Assessment of Species." *WIREs Climate Change* 10 (1): e551. https://doi.org/10.1002/wcc.551.

Ford, James D., Barry Smit, and Johanna Wandel. 2006. "Vulnerability to Climate Change in the Arctic: A Case Study from Arctic Bay, Canada." *Global Environmental Change* 16 (2): 145–60. https://doi.org/10.1016/j.gloenvcha.2005.11.007.

Ford J.D, and Smit B. 2004. “A Framework for Assessing the Vulnerability of Communities in the Canadian Arctic to Risks Associated with Climate Change.” *Arctic* 57 (4): 389–400.

Frawley, Timothy, Mikaela Provost, Lyall Bellquist, Noah Ben-Aderet, Hannah Blondin, Stephanie Brodie, Mercedes Pozo Buil, et al. 2025. “A Collaborative Climate Vulnerability Assessment of California Marine Fishery Species.” Edited by Noureddine Benkeblia. *PLOS Climate* 4 (2): e0000574. https://doi.org/10.1371/journal.pclm.0000574.

Frazier, Tim G., Courtney M. Thompson, and Raymond J. Dezzani. 2014. “A Framework for the Development of the SERV Model: A Spatially Explicit Resilience-Vulnerability Model.” *Applied Geography* 51 (July):158–72. https://doi.org/10.1016/j.apgeog.2014.04.004.

Froese, Rainer, Eva Papaioannou, and Marco Scotti. 2022. “Climate Change or Mismanagement?” *Environmental Biology of Fishes* 105 (10): 1363–80. https://doi.org/10.1007/s10641-021-01209-1.

Füssel, Hans-Martin, and Richard J. T. Klein. 2006. “Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking.” *Climatic Change* 75 (3): 301–29. https://doi.org/10.1007/s10584-006-0329-3.

Ghoussein, Youssra, Mario Mhawej, Ali Jaffal, Ali Fadel, Roy El Hourany, and Ghaleb Faour. 2018. “Vulnerability Assessment of the South-Lebanese Coast: A GIS-Based Approach.” *Ocean & Coastal Management* 158 (May):56–63. https://doi.org/10.1016/j.ocecoaman.2018.03.028.

Giddens, Jonatha, Donald R. Kobayashi, Gabriella N. M. Mukai, Jacob Asher, Charles Birkeland, Mark Fitchett, Mark A. Hixon, et al. 2022a. “Assessing the Vulnerability of Marine Life to Climate Change in the Pacific Islands Region.” Edited by David Hyrenbach. *PLOS ONE* 17 (7): e0270930. https://doi.org/10.1371/journal.pone.0270930.

Gill, D., G Magin, and E Bertram. 2013. “Trees and Climate Change: A Guide to the Factors That Influence Species Vulnerability and a Summary of Adaptation Options.” *Flora and Fauna International*.

Gornitz, V. 1991. “Vulnerability of the U.S. to Future Sea Level Rise. Proceedings of the Symposium on Coastal and Ocean Management.”

Guillaumont, P. 2009. “An Economic Vulnerability Index: Its Design and Use for International Development Policy.” WIDER working paper 2008/99. Helsinki: UNU-WIDER.

———. 2015. “Measuring Vulnerability to Climate Change for Allocating Funds for Adaptation.” Working Paper P136. FERDI.

Gumel, Danladi Yusuf. 2022. “Assessing Climate Change Vulnerability: A Conceptual and Theoretical Review,” February. https://doi.org/10.5281/ZENODO.6206933.

Gurri, Francisco D., Wilma Ruiz-García, Dolores O. Molina-Rosales, and Mirna I. Vallejo-Nieto. 2019. “Measuring Individual Vulnerability to Floods in the Lower and Middle Grijalva River Basin, Tabasco, Mexico.” *Natural Hazards* 96 (1): 149–71. https://doi.org/10.1007/s11069-018-3533-3.

Gutium, T, and L Taran. 2021. “Climate Change Vulnerability Index: Case Study for the Republic of Moldova.” *Cogito - Multidisciplinary Research Journal* 13 (4): 145–64.

Hahn, Micah B., Anne M. Riederer, and Stanley O. Foster. 2009. “The Livelihood Vulnerability Index: A Pragmatic Approach to Assessing Risks from Climate Variability and Change—A Case Study in Mozambique.” *Global Environmental Change* 19 (1): 74–88. https://doi.org/10.1016/j.gloenvcha.2008.11.002.

Halpern, Benjamin S., Carissa J. Klein, Christopher J. Brown, Maria Beger, Hedley S. Grantham, Sangeeta Mangubhai, Mary Ruckelshaus, et al. 2013. “Achieving the Triple Bottom Line in the Face of Inherent Trade-Offs among Social Equity, Economic Return, and Conservation.” *Proceedings of the National Academy of Sciences* 110 (15): 6229–34. https://doi.org/10.1073/pnas.1217689110.

Hare, Jonathan A., Wendy E. Morrison, Mark W. Nelson, Megan M. Stachura, Eric J. Teeters, Roger B. Griffis, Michael A. Alexander, et al. 2016. “A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf.” Edited by Jan Geert Hiddink. *PLOS ONE* 11 (2): e0146756. https://doi.org/10.1371/journal.pone.0146756.

He, Li, Jing Shen, and Yang Zhang. 2018. “Ecological Vulnerability Assessment for Ecological Conservation and Environmental Management.” *Journal of Environmental Management* 206 (January):1115–25. https://doi.org/10.1016/j.jenvman.2017.11.059.

Heck, N, V Agostini, B Reguero, K Pfliegner, P Mucke, L Kirch, and M.W Beck. 2020. “Fisheries at Risk - Vulnerability of Fisheries to Climate Change.” Berlin: The Nature Conservancy.

Hélène, Buchholzer, Frésard Marjolaine, Le Grand Christelle, and Pascal Le Floc’h. 2022. “Vulnerability and Spatial Competition: The Case of Fisheries and Offshore Wind Projects.” *Ecological Economics* 197 (July):107454. https://doi.org/10.1016/j.ecolecon.2022.107454.

Herrick, Charles. 2021. “Self and Place Constructs in Climate Change Vulnerability Assessments: Gaps and Recommendations.” *Sustainability* 13 (5): 2990. https://doi.org/10.3390/su13052990.

Hobday, A.J., A.D.M. Smith, I.C. Stobutzki, C. Bulman, R. Daley, J.M. Dambacher, R.A. Deng, et al. 2011. “Ecological Risk Assessment for the Effects of Fishing.” *Fisheries Research* 108 (2–3): 372–84. https://doi.org/10.1016/j.fishres.2011.01.013.

Holand, Ivar S., Päivi Lujala, and Jan Ketil Rød. 2011. “Social Vulnerability Assessment for Norway: A Quantitative Approach.” *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography* 65 (1): 1–17. https://doi.org/10.1080/00291951.2010.550167.

Hopkins, Charlotte Rachael, David Mark Bailey, and Tavis Potts. 2016. “Perceptions of Practitioners: Managing Marine Protected Areas for Climate Change Resilience.” *Ocean & Coastal Management* 128 (August):18–28. https://doi.org/10.1016/j.ocecoaman.2016.04.014.

Huai, Jianjun. 2016. “Integration and Typologies of Vulnerability to Climate Change: A Case Study from Australian Wheat Sheep Zones.” *Scientific Reports* 6 (1): 33744. https://doi.org/10.1038/srep33744.

Huang, Jianping, Guolong Zhang, Yanting Zhang, Xiaodan Guan, Yun Wei, and Ruixia Guo. 2020. “Global Desertification Vulnerability to Climate Change and Human Activities.” *Land Degradation & Development* 31 (11): 1380–91. https://doi.org/10.1002/ldr.3556.

Hutchinson, G E. 1978. “An Introduction to Population Ecology.” *Yale University Press*.

Huynh, Huong Lan Thi, Anh Tien Do, and Trang Minh Dao. 2020. “Climate Change Vulnerability Assessment for Can Tho City by a Set of Indicators.” *International Journal of Climate Change Strategies and Management* 12 (1): 147–58. https://doi.org/10.1108/IJCCSM-01-2018-0003.

Huynh, Phuong T. A., Ngoan D. Le, Sen T. H. Le, and Hong X. Nguyen. 2021. “Vulnerability of Fishery-Based Livelihoods to Climate Change in Coastal Communities in Central Vietnam.” *Coastal Management* 49 (3): 275–92. https://doi.org/10.1080/08920753.2021.1899927.

Ibarrarán, María E., Elizabeth L. Malone, and Antoinette L. Brenkert. 2010. “Climate Change Vulnerability and Resilience: Current Status and Trends for Mexico.” *Environment, Development and Sustainability* 12 (3): 365–88. https://doi.org/10.1007/s10668-009-9201-8.

Il Choi, Hyun. 2019. “Assessment of Aggregation Frameworks for Composite Indicators in Measuring Flood Vulnerability to Climate Change.” *Scientific Reports* 9 (1): 19371. https://doi.org/10.1038/s41598-019-55994-y.

Ilcheva, Irena, Anna Yordanova, and Krasimira Nikolova. 2020. “INDENTIFICATION AND MITIGATION VULNERABILITY OF WATER SUPPLY AND ENVIRONMENT UNDER CLIMATE CHANGE.” In , 193–200. https://doi.org/10.5593/sgem2020/3.1/s12.026.

International Federation of Red Cross. n.d. “Community Resilience Measurement Dashboard.” Accessed June 19, 2025. https://rmd.ifrc.org/.

IPCC. 2001. “Climate Change 2001: Synthesis Report. Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.” TAR. Geneva, Switzerland: IPCC.

———. 2007. “Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.” AR4. Geneva, Switzerland.

———. 2014. “Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.” AR5. Geneva, Switzerland: IPCC.

———. 2023a. *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press. https://doi.org/10.1017/9781009325844.

———. 2023b. “Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.” AR6. Geneva, Switzerland.

Iyengar, N S, and P Sudarshan. 1982. “A Method of Classifying Regions from Multivariate Data.” *Economic and Political Weekly* 17 (51): 2048–52.

Jakariya, Md, Abir Rahman, Sheikh Mohammad Sayem, Saman Saad, Md Sajadul Alam, Sazzadur Rahman Sarker, Mirza Shawkat Ali, and Dilruba Akter. 2020. “Development of Livelihood Vulnerability Index for the Coastal Fishermen Communities of Bangladesh Using Spatial Information Technique.” *Groundwater for Sustainable Development* 11 (October):100475. https://doi.org/10.1016/j.gsd.2020.100475.

Jeevamani, J. Joyson Joe, P. Priya, J. Amali Infantina, K. R. Abhilash, Durga Prasad Behera, V. Deepak Samuel, R. Soundararajan, R. Purvaja, and R. Ramesh. 2021. “An Integrated Approach to Assess Coastal Vulnerability versus Fisheries Livelihood Sustainability: Strategies for Climate Change Adaptation in Sindhudurg, West Coast of India.” *Environment, Development and Sustainability* 23 (3): 4011–42. https://doi.org/10.1007/s10668-020-00754-6.

Jha, Shashidhar Kumar, Sameera Mishra, Bhaskar Sinha, Juha M. Alatalo, and Rajiv Pandey. 2017. “Rural Development Program in Tribal Region: A Protocol for Adaptation and Addressing Climate Change Vulnerability.” *Journal of Rural Studies* 51 (April):151–57. https://doi.org/10.1016/j.jrurstud.2017.02.013.

Jha, Shashidhar Kumar, A. K. Negi, Juha M. Alatalo, and R. S. Negi. 2021. “Socio-Ecological Vulnerability and Resilience of Mountain Communities Residing in Capital-Constrained Environments.” *Mitigation and Adaptation Strategies for Global Change* 26 (8): 38. https://doi.org/10.1007/s11027-021-09974-1.

Jhan, Hao-Tang, Rhoda Ballinger, Azmath Jaleel, and Kuo-Huan Ting. 2020. “Development and Application of a Socioeconomic Vulnerability Indicator Framework (SVIF) for Local Climate Change Adaptation in Taiwan.” *Sustainability* 12 (4): 1585. https://doi.org/10.3390/su12041585.

Johnson, Danielle, Paula Blackett, Andrew E. F. Allison, and Ashley M. Broadbent. 2023. “Measuring Social Vulnerability to Climate Change at the Coast: Embracing Complexity and Context for More Accurate and Equitable Analysis.” *Water* 15 (19): 3408. https://doi.org/10.3390/w15193408.

Johnson, Johanna E., David J. Welch, Jeffrey A. Maynard, Johann D. Bell, Gretta Pecl, Julie Robins, and Thor Saunders. 2016. “Assessing and Reducing Vulnerability to Climate Change: Moving from Theory to Practical Decision-Support.” *Marine Policy* 74 (December):220–29. https://doi.org/10.1016/j.marpol.2016.09.024.

Jolliffe, Ian T., and Jorge Cadima. 2016. “Principal Component Analysis: A Review and Recent Developments.” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 374 (2065): 20150202. https://doi.org/10.1098/rsta.2015.0202.

Juhola, Sirkku, and Sylvia Kruse. 2015. “A Framework for Analysing Regional Adaptive Capacity Assessments: Challenges for Methodology and Policy Making.” *Mitigation and Adaptation Strategies for Global Change* 20 (1): 99–120. https://doi.org/10.1007/s11027-013-9481-z.

Kapuka, Alpo, and Tomáš Hlásny. 2020. “Social Vulnerability to Natural Hazards in Namibia: A District-Based Analysis.” *Sustainability* 12 (12): 4910. https://doi.org/10.3390/su12124910.

Kathirvelpandian, Ayyathurai, Ahamed Rasheeq, Ganesan Kantharajan, Tarachand Kumawat, Thipramalai Thangappan Ajith Kumar, and Uttam Kumar Sarkar. 2024. “Evaluating the Climate Change–Induced Vulnerability of the Pichavaram Mangrove Ecosystem through a Stakeholder-Centric Multiscale Approach.” *Journal of Water and Climate Change* 15 (8): 4177–95. https://doi.org/10.2166/wcc.2024.373.

Kauffman, Nate, and Kristina Hill. 2021. “Climate Change, Adaptation Planning and Institutional Integration: A Literature Review and Framework.” *Sustainability* 13 (19): 10708. https://doi.org/10.3390/su131910708.

Kelman, Ilan, Jessica Mercer, and Jc Gaillard, eds. 2017. *The Routledge Handbook of Disaster Risk Reduction Including Climate Change Adaptation*. 1st ed. Abingdon, Oxon ; New York, NY : Routledge, 2017.: Routledge. https://doi.org/10.4324/9781315684260.

Kim, Juri, and Tae-Hyoung Tommy Gim. 2020. “Assessment of Social Vulnerability to Floods on Java, Indonesia.” *Natural Hazards* 102 (1): 101–14. https://doi.org/10.1007/s11069-020-03912-1.

Kim, Moo-Jin, Jae-Beum Hong, In-Seong Han, Joon-Soo Lee, and Do-Hoon Kim. 2023. “Vulnerability Assessment of Korean Fisheries to Climate Change.” *Marine Policy* 155 (September):105735. https://doi.org/10.1016/j.marpol.2023.105735.

KIWA. 2023. “Capacity Needs Assessment for Implementing Nature-Based Solutions for Climate Change Adaptation.” Provided to SPREP. KIWA. https://library.sprep.org/sites/default/files/2023-09/Lit-Policy-Review_Mainstreaming_Kiwa-Cap-Needs-Assessment.pdf.

Klinsky, Sonja, Timmons Roberts, Saleemul Huq, Chukwumerije Okereke, Peter Newell, Peter Dauvergne, Karen O’Brien, et al. 2017. “Why Equity Is Fundamental in Climate Change Policy Research.” *Global Environmental Change* 44 (May):170–73. https://doi.org/10.1016/j.gloenvcha.2016.08.002.

Kourantidou, Melina, Di Jin, and Ervin Joe Schumacker. 2022. “Socioeconomic Disruptions of Harmful Algal Blooms in Indigenous Communities: The Case of Quinault Indian Nation.” *Harmful Algae* 118 (October):102316. https://doi.org/10.1016/j.hal.2022.102316.

Koutroulis, A.G., L.V. Papadimitriou, M.G. Grillakis, I.K. Tsanis, R. Warren, and R.A. Betts. 2019. “Global Water Availability under High-End Climate Change: A Vulnerability Based Assessment.” *Global and Planetary Change* 175 (April):52–63. https://doi.org/10.1016/j.gloplacha.2019.01.013.

Koutroulis, A.G., L.V. Papadimitriou, M.G. Grillakis, I.K. Tsanis, K. Wyser, and R.A. Betts. 2018. “Freshwater Vulnerability under High End Climate Change. A Pan-European Assessment.” *Science of The Total Environment* 613–614 (February):271–86. https://doi.org/10.1016/j.scitotenv.2017.09.074.

Krishnan, Pandian, Pachampalayam Shanmugam Ananthan, Ramachandran Purvaja, Jeyapaul Joyson Joe Jeevamani, John Amali Infantina, Cherukumalli Srinivasa Rao, Arur Anand, et al. 2019. “Framework for Mapping the Drivers of Coastal Vulnerability and Spatial Decision Making for Climate-Change Adaptation: A Case Study from Maharashtra, India.” *Ambio* 48 (2): 192–212. https://doi.org/10.1007/s13280-018-1061-8.

Kristensen, Peter. 2004. “The DPSIR Framework.” In *Workshop*. Nairobi, Kenya. https://www.studocu.com/co/document/universidad-autonoma-de-occidente/medio-ambiente-y-desarrollo/kristensen-2004-the-dpsir-framework-overview/15944910.

Kuleli, Tuncay, and Seyma Bayazit. 2024. “An Integrated Approach to the Spatial Distribution of the Coastal Infrastructure Vulnerability by Using Coastal Vulnerability Index and Hot Spot Analysis: A Case Study of Kusadasi-Selcuk.” *Natural Hazards* 120 (15): 14117–51. https://doi.org/10.1007/s11069-024-06749-0.

Kyoto Protocol. 1997. *Kyoto Protocol to the United Nations Framework Convention on Climate Change*. Vol. 2303 UNTS 162. https://unfccc.int/kyoto_protoco.

Lapola, David M., José Maria C. Da Silva, Diego R. Braga, Larissa Carpigiani, Fernanda Ogawa, Roger R. Torres, Luis C. F. Barbosa, Jean P. H. B. Ometto, and Carlos A. Joly. 2020. “A Climate-change Vulnerability and Adaptation Assessment for Brazil’s Protected Areas.” *Conservation Biology* 34 (2): 427–37. https://doi.org/10.1111/cobi.13405.

Le Bris, Arnault, Katherine E. Mills, Richard A. Wahle, Yong Chen, Michael A. Alexander, Andrew J. Allyn, Justin G. Schuetz, James D. Scott, and Andrew J. Pershing. 2018. “Climate Vulnerability and Resilience in the Most Valuable North American Fishery.” *Proceedings of the National Academy of Sciences* 115 (8): 1831–36. https://doi.org/10.1073/pnas.1711122115.

Li, Chengkun, Xiyi Yang, and Dong Yang. 2025. “Port Vulnerability to Natural Disasters: An Integrated View from Hinterland to Seaside.” *Transportation Research Part D: Transport and Environment* 139 (February):104563. https://doi.org/10.1016/j.trd.2024.104563.

Li, Yunzhou, Ming Sun, Kristin M. Kleisner, Katherine E. Mills, and Yong Chen. 2023. “A Global Synthesis of Climate Vulnerability Assessments on Marine Fisheries: Methods, Scales, and Knowledge Co-production.” *Global Change Biology* 29 (13): 3545–61. https://doi.org/10.1111/gcb.16733.

Licuanan, Wilfredo Y., Maricar S. Samson, Samuel S. Mamauag, Laura T. David, Roselle Borja-del Rosario, Miledel Christine C. Quibilan, Fernando P. Siringan, et al. 2015. “I-C-SEA Change: A Participatory Tool for Rapid Assessment of Vulnerability of Tropical Coastal Communities to Climate Change Impacts.” *Ambio* 44 (8): 718–36. https://doi.org/10.1007/s13280-015-0652-x.

Llorente-Marrón, Mar, Montserrat Díaz-Fernández, Paz Méndez-Rodríguez, and Rosario González Arias. 2020. “Social Vulnerability, Gender and Disasters. The Case of Haiti in 2010.” *Sustainability* 12 (9): 3574. https://doi.org/10.3390/su12093574.

Lomborg, Bjorn. 2020. “Welfare in the 21st Century: Increasing Development, Reducing Inequality, the Impact of Climate Change, and the Cost of Climate Policies.” *Technological Forecasting and Social Change* 156 (July):119981. https://doi.org/10.1016/j.techfore.2020.119981.

Losciale, Riccardo, Jon C. Day, Michael A. Rasheed, and Scott F. Heron. 2024. “The Vulnerability of World Heritage Seagrass Habitats to Climate Change.” *Global Change Biology* 30 (1): e17113. https://doi.org/10.1111/gcb.17113.

Lu, Shasha, Xu Tang, Xingliang Guan, Fan Qin, Xu Liu, and Dahong Zhang. 2020. “The Assessment of Forest Ecological Security and Its Determining Indicators: A Case Study of the Yangtze River Economic Belt in China.” *Journal of Environmental Management* 258 (March):110048. https://doi.org/10.1016/j.jenvman.2019.110048.

Ludeña, Carlos E., and Sang Won Yoon. 2015. “Local Vulnerability Indicators and Adaptation to Climate Change: A Survey.” Inter-American Development Bank. https://doi.org/10.18235/0009259.

Lung, Tobias, Carlo Lavalle, Roland Hiederer, Alessandro Dosio, and Laurens M. Bouwer. 2013. “A Multi-Hazard Regional Level Impact Assessment for Europe Combining Indicators of Climatic and Non-Climatic Change.” *Global Environmental Change* 23 (2): 522–36. https://doi.org/10.1016/j.gloenvcha.2012.11.009.

Lysenko, Dmitry, and Stephan Schott. 2019. “Food Security and Wildlife Management in Nunavut.” *Ecological Economics* 156 (February):360–74. https://doi.org/10.1016/j.ecolecon.2018.10.008.

Ma, S.J, and R.R Wang. 1984. “Social–Economic–Natural Compound Ecosystem.” *Acta Ecol. Sinica* 4 (1): 1–9.

Macharia, Denis, Erneus Kaijage, Leif Kindberg, Grace Koech, Lilian Ndungu, Anastasia Wahome, and Robinson Mugo. 2020. “Mapping Climate Vulnerability of River Basin Communities in Tanzania to Inform Resilience Interventions.” *Sustainability* 12 (10): 4102. https://doi.org/10.3390/su12104102.

Maheshwari, Smita, and Supriya Vyas. 2023. “Vulnerability Assessment of Urban Waterbodies Based on WRASTIC Model.” *Environment, Development and Sustainability* 26 (6): 15803–21. https://doi.org/10.1007/s10668-023-03274-1.

Maina, Joseph, Valentijn Venus, Timothy R. McClanahan, and Mebrahtu Ateweberhan. 2008. “Modelling Susceptibility of Coral Reefs to Environmental Stress Using Remote Sensing Data and GIS Models.” *Ecological Modelling* 212 (3–4): 180–99. https://doi.org/10.1016/j.ecolmodel.2007.10.033.

Malakar, Krishna, and Trupti Mishra. 2017. “Assessing Socio-Economic Vulnerability to Climate Change: A City-Level Index-Based Approach.” *Climate and Development* 9 (4): 348–63. https://doi.org/10.1080/17565529.2016.1154449.

Mangubhai, S, and M Chung. 2024. “Assessing Human Rights Risks to Inform Nature-Based Solutions in the Pacific Islands.” SPREP.

Marín-Monroy, Elvia Aida, Víctor Hernández-Trejo, Eleonora Romero-Vadillo, and Antonina Ivanova-Boncheva. 2020. “Vulnerability and Risk Factors Due to Tropical Cyclones in Coastal Cities of Baja California Sur, Mexico.” *Climate* 8 (12): 144. https://doi.org/10.3390/cli8120144.

Marshall, Nadine A., Renae C. Tobin, Paul A. Marshall, Margaret Gooch, and Alistair J. Hobday. 2013. “Social Vulnerability of Marine Resource Users to Extreme Weather Events.” *Ecosystems* 16 (5): 797–809. https://doi.org/10.1007/s10021-013-9651-6.

Mathews, Shifali, Genee Smith, and Jaime Madrigano. 2025. “Hurricanes and Health Equity: A Review of Structural Determinants of Vulnerability for Climate and Health Research.” *Current Environmental Health Reports* 12 (1): 10. https://doi.org/10.1007/s40572-025-00475-w.

McClure, Michelle M., Melissa A. Haltuch, Ellen Willis-Norton, David D. Huff, Elliott L. Hazen, Lisa G. Crozier, Michael G. Jacox, et al. 2023. "Vulnerability to Climate Change of Managed Stocks in the California Current Large Marine Ecosystem." *Frontiers in Marine Science* 10 (February):1103767. https://doi.org/10.3389/fmars.2023.1103767.

Mekonen, Abebe Arega, and Arega Bazezew Berlie. 2021. "Rural Households' Livelihood Vulnerability to Climate Variability and Extremes: A Livelihood Zone-Based Approach in the Northeastern Highlands of Ethiopia." *Ecological Processes* 10 (1): 55. https://doi.org/10.1186/s13717-021-00313-5.

Mekonnen, Zenebe, Teshale Woldeamanuel, and Habtemariam Kassa. 2019. "Socio-Ecological Vulnerability to Climate Change/Variability in Central Rift Valley, Ethiopia." *Advances in Climate Change Research* 10 (1): 9–20. https://doi.org/10.1016/j.accre.2019.03.002.

Meybeck, A, A Rose, and V Gitz. 2019. *Climate Change Vulnerability Assessment of Forests and Forest-Dependent People*. FAO. https://doi.org/10.4060/CA7064EN.

Michetti, Melania, and Stefano Ghinoi. 2020. "Climate-Driven Vulnerability and Risk Perception: Implications for Climate Change Adaptation in Rural Mexico." *Journal of Environmental Studies and Sciences* 10 (3): 290–302. https://doi.org/10.1007/s13412-020-00607-8.

Mizrahi, Me'ira, Stephanie Duce, Zin Lin Khine, Tracy MacKeracher, Khin May Chit Maung, Ei Thal Phyu, Robert L. Pressey, Colin Simpfendorfer, and Amy Diedrich. 2020. "Mitigating Negative Livelihood Impacts of No-Take MPAs on Small-Scale Fishers." *Biological Conservation* 245 (May):108554. https://doi.org/10.1016/j.biocon.2020.108554.

Monirul Islam, Md., Susannah Sallu, Klaus Hubacek, and Jouni Paavola. 2014. "Limits and Barriers to Adaptation to Climate Variability and Change in Bangladeshi Coastal Fishing Communities." *Marine Policy* 43 (January):208–16. https://doi.org/10.1016/j.marpol.2013.06.007.

Montejo-Damián, Karol C, Miguel Á Díaz-Perera, and Alejandro Espinoza-Tenorio. 2022. "The Social Construction of Risk: A Local Perspective of the Vulnerability of Artisanal Fisheries to Climate Change." *Coastal Studies & Society* 1 (1): 55–77. https://doi.org/10.1177/26349817221080864.

Montijo-Galindo, Abril, Arturo Ruiz-Luna, Miguel Betancourt Lozano, and Rafael Hernández-Guzmán. 2020. "A Multicriteria Assessment of Vulnerability to Extreme Rainfall Events on the Pacific Coast of Mexico." *Coastal Management* 48 (6): 623–42. https://doi.org/10.1080/08920753.2020.1803572.

Morrison, Wendy E., Mark W. Nelson, Roger B. Griffis, and Jonathan A. Hare. 2016. "Methodology for Assessing the Vulnerability of Marine and Anadromous Fish Stocks in a Changing Climate." *Fisheries* 41 (7): 407–9. https://doi.org/10.1080/03632415.2016.1182507.

Mukherjee, Nabanita, and Giyasuddin Siddique. 2020. "Assessment of Climatic Variability Risks with Application of Livelihood Vulnerability Indices." *Environment, Development and Sustainability* 22 (6): 5077–5103. https://doi.org/10.1007/s10668-019-00415-3.

Mushwani, Hayatullah, Abidullah Arabzai, Lutfullah Safi, Hayat Ullah, Amirullah Afghan, and Afshana Parven. 2025. "Evaluation of Flood Hazard Vulnerabilities and Innovative Management Strategies in Afghanistan's Central Region." *Natural Hazards* 121 (4): 4639–55. https://doi.org/10.1007/s11069-024-06974-7.

Nairobi Convention Secretariat. 2022. "A Toolkit for Climate Change Vulnerability Assessment (CCVA) of near-Shore Marine Social-Ecological Systems in the Western Indian Ocean." UNEP. https://www.nairobiconvention.org/clearinghouse/sites/default/files/UNEP_EAF_CP11_3_Annex_XII_Climate_Change_Vulnerability_Assessment_%28CCVA%29_toolkit.pdf.

Nakhaei Ashtari, Masoud, and Mariana Correia. 2022. "Assessment of Vulnerability and Site Adaptive Capacity to the Risk of Climate Change: The Case of Tchogha Zanbil World Heritage Earthen Site in Iran." *Journal of Cultural Heritage Management and Sustainable Development* 12 (2): 107–25. https://doi.org/10.1108/JCHMSD-06-2021-0108.

Namdar, Razieh, Ezatollah Karami, and Marzieh Keshavarz. 2021. "Climate Change and Vulnerability: The Case of MENA Countries." *ISPRS International Journal of Geo-Information* 10 (11): 794. https://doi.org/10.3390/ijgi10110794.

Nef, Danny Philipp, Krishna Kumar Kotra, Michael Stauffacher, Johan Six, and Pius Kruetli. 2022. "Vulnerability to Food Insecurity in a Telecoupled World: Insights From Vanuatu." *Frontiers in Sustainable Food Systems* 6 (March):818586. https://doi.org/10.3389/fsufs.2022.818586.

Neil Adger, W., Nigel W. Arnell, and Emma L. Tompkins. 2005. "Successful Adaptation to Climate Change across Scales." *Global Environmental Change* 15 (2): 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005.

Nguyen, Cao Huan, Kinh Bac Dang, Van Liem Ngo, Van Bao Dang, Quang Hai Truong, Dang Hoi Nguyen, Tuan Linh Giang, et al. 2021. "New Approach to Assess Multi-Scale Coastal Landscape Vulnerability to Erosion in Tropical Storms in Vietnam." *Sustainability* 13 (2): 1004. https://doi.org/10.3390/su13021004.

Nicotra, Adrienne B., Erik A. Beever, Amanda L. Robertson, Gretchen E. Hofmann, and John O'Leary. 2015. "Assessing the Components of Adaptive Capacity to Improve Conservation and Management Efforts under Global Change: Assessing Components of Adaptive Capacity." *Conservation Biology* 29 (5): 1268–78. https://doi.org/10.1111/cobi.12522.

Njoya, Hamza Moluh, Custodio Efraim Matavel, Haji Athumani Msangi, Hervé Alain Napi Wouapi, Katharina Löhr, and Stefan Sieber. 2022. "Climate Change Vulnerability and Smallholder Farmers' Adaptive Responses in the Semi-Arid Far North Region of Cameroon." *Discover Sustainability* 3 (1): 41. https://doi.org/10.1007/s43621-022-00106-6.

NOAA. 2019. "Climate Vulnerability Assessment Tool." National Oceanic and Atmospheric Administration.

O'Brien, Karen, Siri Eriksen, Lynn P. Nygaard, and Ane Schjolden. 2007. "Why Different Interpretations of Vulnerability Matter in Climate Change Discourses." *Climate Policy* 7 (1): 73–88. https://doi.org/10.1080/14693062.2007.9685639.

OECD. 2024. “Climate Change Adaptation: Policies for a Resilient Future.” OECD Net Zero+ Policy Papers. 3rd ed. OECD Net Zero+ Policy Papers. https://doi.org/10.1787/8f29a387-en.

———. 2025. *OECD Review of Fisheries 2025*. OECD Review of Fisheries: Policies and Summary Statistics. OECD Publishing. https://doi.org/10.1787/560cd8fc-en.

Ojea, Elena, Sarah E. Lester, and Diego Salgueiro-Otero. 2020. “Adaptation of Fishing Communities to Climate-Driven Shifts in Target Species.” *One Earth* 2 (6): 544–56. https://doi.org/10.1016/j.oneear.2020.05.012.

Ojea, Elena, Isaac Pearlman, Steven D. Gaines, and Sarah E. Lester. 2017. “Fisheries Regulatory Regimes and Resilience to Climate Change.” *Ambio* 46 (4): 399–412. https://doi.org/10.1007/s13280-016-0850-1.

Okey, Thomas A., Selina Agbayani, and Hussein M. Alidina. 2015. “Mapping Ecological Vulnerability to Recent Climate Change in Canada’s Pacific Marine Ecosystems.” *Ocean & Coastal Management* 106 (March):35–48. https://doi.org/10.1016/j.ocecoaman.2015.01.009.

Olivares-Aguilar, Isabel C., Gabriel Sánchez-Dávila, Natalie Elizabeth Wildermann, Dana Clark, Lisa Floerl, Estrella Villamizar, Silvia D. Matteucci, Norma Patricia Muñoz Sevilla, and Gustavo J. Nagy. 2022. “Methodological Approaches to Assess Climate Vulnerability and Cumulative Impacts on Coastal Landscapes.” *Frontiers in Climate* 4 (October):1018182. https://doi.org/10.3389/fclim.2022.1018182.

Oloyede, Mary O., Nsikak U. Benson, and Akan B. Williams. 2021. “Climate Change and Coastal Vulnerability Assessment Methods: A Review.” *IOP Conference Series: Earth and Environmental Science* 665 (1): 012069. https://doi.org/10.1088/1755-1315/665/1/012069.

Oloyede, Mary O., Akan B. Williams, Godwin O. Ode, and Nsikak U. Benson. 2022. “Coastal Vulnerability Assessment: A Case Study of the Nigerian Coastline.” *Sustainability* 14 (4): 2097. https://doi.org/10.3390/su14042097.

Omann, Ines, Andrea Stocker, and Jill Jäger. 2009. “Climate Change as a Threat to Biodiversity: An Application of the DPSIR Approach.” *Ecological Economics* 69 (1): 24–31. https://doi.org/10.1016/j.ecolecon.2009.01.003.

O’Neill, Brian C., Michael Oppenheimer, Rachel Warren, Stephane Hallegatte, Robert E. Kopp, Hans O. Pörtner, Robert Scholes, et al. 2017. “IPCC Reasons for Concern Regarding Climate Change Risks.” *Nature Climate Change* 7 (1): 28–37. https://doi.org/10.1038/nclimate3179.

Organisation de coopération et de développement économiques, ed. 1994. *Environmental Indicators: OECD Core Set*. Paris: OCDE.

Otto, Ilona M., Diana Reckien, Christopher P. O. Reyer, Rachel Marcus, Virginie Le Masson, Lindsey Jones, Andrew Norton, and Olivia Serdeczny. 2017. “Social Vulnerability to Climate Change: A Review of Concepts and Evidence.” *Regional Environmental Change* 17 (6): 1651–62. https://doi.org/10.1007/s10113-017-1105-9.

Pacific Community (SPC). 2023a. “Accelerating Climate Action, Resilience, and Access to Climate Finance: SPC’s Climate Change Flagship.” Noumea.

———. 2023b. “The Pacific Community’s Climate Change Flagship Programme: Design Overview 2023–2031.” Noumea.

Page, Matthew J, Joanne E McKenzie, Patrick M Bossuyt, Isabelle Boutron, Tammy C Hoffmann, Cynthia D Mulrow, Larissa Shamseer, et al. 2021. “The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews.” *BMJ*, March, n71. https://doi.org/10.1136/bmj.n71.

Panda, Architesh. 2017. “Vulnerability to Climate Variability and Drought among Small and Marginal Farmers: A Case Study in Odisha, India.” *Climate and Development* 9 (7): 605–17. https://doi.org/10.1080/17565529.2016.1184606.

Pandey, Rajiv, Juha M. Alatalo, Kavita Thapliyal, Sharmila Chauhan, Kelli M. Archie, Ajay K. Gupta, Shashidhar Kumar Jha, and Manoj Kumar. 2018. “Climate Change Vulnerability in Urban Slum Communities: Investigating Household Adaptation and Decision-Making Capacity in the Indian Himalaya.” *Ecological Indicators* 90 (July):379–91. https://doi.org/10.1016/j.ecolind.2018.03.031.

Pandey, Rajiv, Shashidhar Kumar Jha, Juha M. Alatalo, Kelli M. Archie, and Ajay K. Gupta. 2017. “Sustainable Livelihood Framework-Based Indicators for Assessing Climate Change Vulnerability and Adaptation for Himalayan Communities.” *Ecological Indicators* 79 (August):338–46. https://doi.org/10.1016/j.ecolind.2017.03.047.

Pandey, Rajiv, and ShashidharKumar Jha. 2012. “Climate Vulnerability Index - Measure of Climate Change Vulnerability to Communities: A Case of Rural Lower Himalaya, India.” *Mitigation and Adaptation Strategies for Global Change* 17 (5): 487–506. https://doi.org/10.1007/s11027-011-9338-2.

Papathoma-Köhle, M., G. Cristofari, M. Wenk, and S. Fuchs. 2019. “The Importance of Indicator Weights for Vulnerability Indices and Implications for Decision Making in Disaster Management.” *International Journal of Disaster Risk Reduction* 36 (May):101103. https://doi.org/10.1016/j.ijdrr.2019.101103.

Paris Agreement. 2015. *Treaties and Other International Acts Series (USA)*. Vol. TIAS No 16-1104. https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

Park, Gainbi, and Zengwang Xu. 2022. “The Constituent Components and Local Indicator Variables of Social Vulnerability Index.” *Natural Hazards* 110 (1): 95–120. https://doi.org/10.1007/s11069-021-04938-9.

Payus, C. M., F. Herman, and J. Sentian. 2022. “Combined Climate Impacts and Vulnerability Index on Coastal Ecosystems in Prediction of Future Scenarios: Extended Sustainable Indicator Tool for Adaptive Strategy.” *SN Applied Sciences* 4 (8): 222. https://doi.org/10.1007/s42452-022-05112-x.

Paz-Alberto, A. M., E. E. Camaso, G. P. L. Abella, C. H. E. A. De Guzman, C. R. Genaro, and K. M. Mapanao. 2019. “VULNERABILITY ASSESSMENT TO CLIMATE-INDUCED HAZARDS OF THE MUNICIPALITY OF MASINLOC, ZAMBALES, PHILIPPINES.” *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLII-4/W19 (December):327–29. https://doi.org/10.5194/isprs-archives-XLII-4-W19-327-2019.

Pecl, G, T Ward, Z Doubleday, S Clarke, J Day, C Dixon, and R Stoklosa. 2011. “Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia.”

Perez, Lisset, David A. Rios, Diana C. Giraldo, Jennifer Twyman, Genowefa Blundo-Canto, Steven D. Prager, and Julian Ramirez-Villegas. 2020. “Determinants of Vulnerability of Bean Growing Households to Climate Variability in Colombia.” *Climate and Development* 12 (8): 730–42. https://doi.org/10.1080/17565529.2019.1685931.

Pike, Felicity, Narriman S. Jiddawi, and Maricela De La Torre-Castro. 2022. “Adaptive Capacity within Tropical Marine Protected Areas – Differences between Men- and Women-Headed Households.” *Global Environmental Change* 76 (September):102584. https://doi.org/10.1016/j.gloenvcha.2022.102584.

Pinnegar, John K, Georg H Engelhard, Norman J Norris, Derrick Theophille, and Riviere Delanco Sebastien. 2019. “Assessing Vulnerability and Adaptive Capacity of the Fisheries Sector in Dominica: Long-Term Climate Change and Catastrophic Hurricanes.” Edited by Manuel Hidalgo. *ICES Journal of Marine Science*, June, fsz052. https://doi.org/10.1093/icesjms/fsz052.

Pirasteh, Saied, Yiming Fang, Davood Mafi-Gholami, Ammar Abulibdeh, Akram Nouri-Kamari, and Nasim Khonsari. 2024. “Enhancing Vulnerability Assessment through Spatially Explicit Modeling of Mountain Social-Ecological Systems Exposed to Multiple Environmental Hazards.” *Science of The Total Environment* 930 (June):172744. https://doi.org/10.1016/j.scitotenv.2024.172744.

Piya, Luni, Keshav Lall Maharjan, and Niraj Prakash Joshi. 2012. “Vulnerability of Rural Households to Climate Change and Extremes: Analysis of Chepang Households in the Mid-Hills of Nepal.” https://doi.org/10.22004/AG.ECON.126191.

Prasad, Neeraj, Federica Ranghieri, Fatima Shah, Zoe Trohanis, Earl Kessler, and Ravi Sinha. 2008. *Climate Resilient Cities: A Primer on Reducing Vulnerabilities to Disasters*. The World Bank. https://doi.org/10.1596/978-0-8213-7766-6.

Pujiono, E, B D Prasetyo, R Setyowati, and R Kurniadi. 2021. “Vulnerability Assessment of Water Resources to Climate Variability in Noelmina Watershed, Timor Island, Indonesia.” *IOP Conference Series: Earth and Environmental Science* 874 (1): 012007. https://doi.org/10.1088/1755-1315/874/1/012007.

Pujiono, E, and R Setyowati. 2015. “Assessment of Community Vulnerability to Climate Variability in the Garang Watershed, Central Java, Using GIS.” *Jurnal Penelitian Sosial Dan Ekonomi Kehutanan* 12 (3): 177–95.

Qaisrani, Ayesha, Muhammad Awais Umar, Ghamz E Ali Siyal, and Kashif Majeed Salik. 2018. “What Defines Livelihood Vulnerability in Rural Semi-Arid Areas? Evidence from Pakistan.” *Earth Systems and Environment* 2 (3): 455–75. https://doi.org/10.1007/s41748-018-0059-5.

Qin, Zhang, Xue Haili, Lan Xiao, Dai Luwei, Wang Bojie, Cui Fengqi, and Tang Haiping. 2022. “Livelihood Vulnerability of Pastoral Households in the Semiarid Grasslands of Northern China: Measurement and Determinants.” *Ecological Indicators* 140 (July):109020. https://doi.org/10.1016/j.ecolind.2022.109020.

Qureshi, Aiman Mazhar, and Ahmed Rachid. 2022. “Heat Vulnerability Index Mapping: A Case Study of a Medium-Sized City (Amiens).” *Climate* 10 (8): 113. https://doi.org/10.3390/cli10080113.

Rabiei-Dastjerdi, Hamidreza, Finbarr Brereton, and Eoin O’Neill. 2025. “Towards Designing a Comprehensive Composite Index for Social Vulnerability to Natural Hazards in the Big Data Era: Potential Challenges and Partial Solutions.” *Natural Hazards* 121 (4): 3885–3913. https://doi.org/10.1007/s11069-024-06874-w.

Radhakrishnan, Kalidoss, C. Lloyd Chrispin, R. Sendhil, M. Krishnan, Sandip Shil, J. Amali Infantina, A. Karthy, Ankhita Chutia, and Swadesh Prakash. 2022. “Vulnerability of Whiteleg Shrimp Production to Climate Change in Coastal India: An Indicator Approach.” *Aquaculture Research* 53 (16): 5486–99. https://doi.org/10.1111/are.16030.

Rahayu, Lusia Advenia Dwi and Suryanto. 2023. “Analysis of Economic and Social Vulnerability to Disaster Risk in Tawangmangu and Kejajar Districts.” Edited by Komariah and K. Hiramatsu. *E3S Web of Conferences* 467:02003. https://doi.org/10.1051/e3sconf/202346702003.

Reggiani, Aura, Peter Nijkamp, and Diego Lanzi. 2015. “Transport Resilience and Vulnerability: The Role of Connectivity.” *Transportation Research Part A: Policy and Practice* 81 (November):4–15. https://doi.org/10.1016/j.tra.2014.12.012.

Reid, JB, S Lombardo, U Ovienmahda, C Jaffe, and DR Wood. 2022. “The Environment-Vulnerability-Decision-Technology Framework: A Process for Developing Multi-Disciplinary Decision Support Systems for Sustainable Development Applications.” In *73rd International Astronautical Congress (IAC)*. Paris, France.

Retnowati, Endang, Safran Yusri, Idris, Mikael Prastowo Sesotyo Widodo, and Fakhrurrozi. 2019. “Vulnerability Analysis to Climate Change in Lembeh Island, North Sulawesi.” *IOP Conference Series: Earth and Environmental Science* 363 (1): 012011. https://doi.org/10.1088/1755-1315/363/1/012011.

Richardson, Katy J., Kirsty H. Lewis, P. Krishna Krishnamurthy, Chris Kent, Andrew J. Wiltshire, and Helen M. Hanlon. 2018. “Food Security Outcomes under a Changing Climate: Impacts of Mitigation and Adaptation on Vulnerability to Food Insecurity.” *Climatic Change* 147 (1–2): 327–41. https://doi.org/10.1007/s10584-018-2137-y.

Ritchie, J, J Lewis, C.M Nicholls, and R Ormston. 2003. “Qualitative Research Practice: A Guide for Social Science Students and Researchers.” *SAGE Publications*.

Rosengren, Linda M., Christopher M. Raymond, Mila Sell, and Hilkka Vihinen. 2020. “Identifying Leverage Points for Strengthening Adaptive Capacity to Climate Change.” *Ecosystems and People* 16 (1): 427–44. https://doi.org/10.1080/26395916.2020.1857439.

Rouleau, Tracy, Jack Stuart, Maia Call, Sally Yozell, Nagisa Yoshioka, Miko Maekawa, and Natalie Fiertz. 2022a. “The Climate and Ocean Risk Vulnerability Index: Measuring Coastal City Resilience to Inform Action.” *Frontiers in Sustainable Cities* 4 (September):884212. https://doi.org/10.3389/frsc.2022.884212.

———. 2022b. “The Climate and Ocean Risk Vulnerability Index: Measuring Coastal City Resilience to Inform Action.” *Frontiers in Sustainable Cities* 4 (September):884212. https://doi.org/10.3389/frsc.2022.884212.

Rowland, Tim, ed. 2009. *Developing Primary Mathematics Teaching: Reflecting on Practice with the Knowledge Quartet*. Los Angeles: SAGE.

Saaty, T.L. 1980. “The Analytic Hierarchy Process.” *McGraw Hill*.

Samui, Sayantan, and Narayan Sethi. 2022. “Social Vulnerability Assessment of Glacial Lake Outburst Flood in a Northeastern State in India.” *International Journal of Disaster Risk Reduction* 74 (May):102907. https://doi.org/10.1016/j.ijdrr.2022.102907.

Sandink, D., and D. Lapp. 2023. “The PIEVC Protocol for Assessing Public Infrastructure Vulnerability to Climate Change Impacts: National and International Application.” In *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, edited by Scott Walbridge, Mazdak Nik-Bakht, Kelvin Tsun Wai Ng, Manas Shome, M. Shahria Alam, Ashraf El Damatty, and Gordon Lovegrove, 249:371–83. Lecture Notes in Civil Engineering. Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-19-1061-6_39.

Santos, Marcos Ronielly Da Silva, Maria Isabel Vitorino, Luci Cajueiro Carneiro Pereira, Marcia Aparecida Da Silva Pimentel, and Ana Flávia Quintão. 2021. “Socioenvironmental Vulnerability to Climate Change: Conditions of Coastal Municipalities in Pará State.” *Ambiente & Sociedade* 24:e01671. https://doi.org/10.1590/1809-4422asoc20200167r1vu2021l3ao.

Savage, Amy, Lachlan McIver, and Lisa Schubert. 2020. “Review: The Nexus of Climate Change, Food and Nutrition Security and Diet-Related Non-Communicable Diseases in Pacific Island Countries and Territories.” *Climate and Development* 12 (2): 120–33. https://doi.org/10.1080/17565529.2019.1605284.

Savage, Amy, Lisa Schubert, Corey Huber, Hilary Bambrick, Nina Hall, and Bill Bellotti. 2020. “Adaptation to the Climate Crisis: Opportunities for Food and Nutrition Security and Health in a Pacific Small Island State.” *Weather, Climate, and Society* 12 (4): 745–58. https://doi.org/10.1175/WCAS-D-19-0090.1.

Saverimuttu, Vivienne. 2021. “REDUCING COMMUNITY VULNERABILITY IN PACIFIC ISLANDS FORUM COUNTRIES: LESSONS FROM A PANDEMIC.” In , 3–14. Rome, Italy. https://doi.org/10.2495/DMAN210011.

Schickele, Alexandre, Patrice Francour, and Virginie Raybaud. 2021. “European Cephalopods Distribution under Climate-Change Scenarios.” *Scientific Reports* 11 (1): 3930. https://doi.org/10.1038/s41598-021-83457-w.

Schickele, Alexandre, Boris Leroy, Gregory Beaugrand, Eric Goberville, Tarek Hattab, Patrice Francour, and Virginie Raybaud. 2020. “Modelling European Small Pelagic Fish Distribution: Methodological Insights.” *Ecological Modelling* 416 (January):108902. https://doi.org/10.1016/j.ecolmodel.2019.108902.

Schröter, Dagmar, Colin Polsky, and Anthony G. Patt. 2005. “Assessing Vulnerabilities to the Effects of Global Change: An Eight Step Approach.” *Mitigation and Adaptation Strategies for Global Change* 10 (4): 573–95. https://doi.org/10.1007/s11027-005-6135-9.

Scott, Daniel, C. Michael Hall, and Stefan Gössling. 2019. “Global Tourism Vulnerability to Climate Change.” *Annals of Tourism Research* 77 (July):49–61. https://doi.org/10.1016/j.annals.2019.05.007.

Serafim, Mirela Barros, Eduardo Siegle, Alessandra Cristina Corsi, and Jarbas Bonetti. 2019. “Coastal Vulnerability to Wave Impacts Using a Multi-Criteria Index: Santa Catarina (Brazil).” *Journal of Environmental Management* 230 (January):21–32. https://doi.org/10.1016/j.jenvman.2018.09.052.

Sharma, Ravi, Shrishti Jagtap, and Prakash Rao. 2022. “Impressions of Coastal Communities on Climate Change and Livelihood: A Case Study of Coastal Maharashtra, India.” *Nature Environment and Pollution Technology* 21 (2): 553–61. https://doi.org/10.46488/NEPT.2022.v21i02.013.

Sharples, Chris, Richard Mount, Tore Pedersen, Michael Lacey, Jenny Newton, Dominic Jasierniak, and Luke Wallace. 2009. “Smartline Coastal Data Segmentation.” University of Tasmania. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=d879161b8a789a3af64ac7f47af477f397a732b9.

Shiiba, Nagisa, Priyatma Singh, Dhrishna Charan, Kushaal Raj, Jack Stuart, Arpana Pratap, and Miko Maekawa. 2023. “Climate Change and Coastal Resiliency of Suva, Fiji: A Holistic Approach for Measuring Climate Risk Using the Climate and Ocean Risk Vulnerability Index (CORVI).” *Mitigation and Adaptation Strategies for Global Change* 28 (2): 9. https://doi.org/10.1007/s11027-022-10043-4.

Silas, Mathew O., Said S. Mgeleka, Patrick Polte, Mattias Sköld, Regina Lindborg, Maricela De La Torre-Castro, and Martin Gullström. 2020. “Adaptive Capacity and Coping Strategies of Small-Scale Coastal Fisheries to Declining Fish Catches: Insights from Tanzanian Communities.” *Environmental Science & Policy* 108 (June):67–76. https://doi.org/10.1016/j.envsci.2020.03.012.

Silva, Felipe Roberto Da, Alexandre Schiavetti, Ana Cláudia Mendes Malhado, Beatrice Ferreira, Caio Victor De Paula Sousa, Fábio Pessoa Vieira, Francisco Roberto Pinto, et al. 2022. “Oil Spill and Socioeconomic Vulnerability in Marine Protected Areas.” *Frontiers in Marine Science* 9 (May):859697. https://doi.org/10.3389/fmars.2022.859697.

Singh, Ashbindu, Sumith Pathirana, and Hua Shi. 2006. *Assessing Coastal Vulnerability: Developing a Global Index for Measuring Risk*. Nairobi: United Nations Environment Programme.

Singh, Leelambar, Ankita Singh, and Ravindra Nath Tripathi. 2025. “Assessment of Eco-Environmental Vulnerability, Sustainability, and Alignment with Sustainable Development Goals in the Chambal River Basin, India.” *Theoretical and Applied Climatology* 156 (3): 184. https://doi.org/10.1007/s00704-025-05417-y.

Singhal, Akshay, and Sanjeev Kumar Jha. 2021. “Can the Approach of Vulnerability Assessment Facilitate Identification of Suitable Adaptation Models for Risk Reduction?” *International Journal of Disaster Risk Reduction* 63 (September):102469. https://doi.org/10.1016/j.ijdrr.2021.102469.

Sinha, Bhaskar. 2017. *Vulnerability and Capacity Assessment to Climate Change of Malwa Region, Madhya Pradesh*. Bhopal, M.P., Dehra Dun, India: Indian Institute of Forest Management ; Bishen Singh Mahendra Pal Singh.

Sorg, Linda, Neiler Medina, Daniel Feldmeyer, Arlex Sanchez, Zoran Vojinovic, Jörn Birkmann, and Alessandra Marchese. 2018. "Capturing the Multifaceted Phenomena of Socioeconomic Vulnerability." *Natural Hazards* 92 (1): 257–82. https://doi.org/10.1007/s11069-018-3207-1.

Soucy, Alyssa, Parinaz Rahimzadeh-Bajgiran, Sandra De Urioste-Stone, Aaron Weiskittel, Matthew J Duveneck, and Bridie McGreavy. 2022. "A Comprehensive and Spatially Explicit Regional Vulnerability Assessment of the Forest Industry to Climate Change." *Journal of Forestry* 120 (2): 170–85. https://doi.org/10.1093/jofore/fvab057.

South East Europe Transnational Cooperation Programme. 2012. "CC-WARE: Mitigating Vulnerability of Water Resources under Climate Change." https://keep.eu/projects/9853/Mitigating-Vulnerability-of--EN/.

SPREP. 2021. "Effects of Climate Change on Extreme Events." c8783a78-eb6c-46e2-96fc-6c276dc02230. https://samoa-data.sprep.org/dataset/effects-climate-change-extreme-events.

———. n.d.-a. "Resources on Fisheries and the Effects of Climate Change in the Pacific." Pacific Climate Change Portal. https://www.pacificclimatechange.net/document/resources-fisheries-and-effects-climate-change-pacific.

———. n.d.-b. "Virtual Taining Course - Human Rights in Nature-Based Solutions for Climate Change Adaptation (Module 2)." KIWA Initative Training module. Accessed June 18, 2025. https://library.sprep.org/content/virtual-training-course-human-rights-nature-based-solutions-climate-change-adaptation.

Still, Shannon M., Anne L. Frances, Amanda C. Treher, and Leah Oliver. 2015. "Using Two Climate Change Vulnerability Assessment Methods to Prioritize and Manage Rare Plants: A Case Study." *Natural Areas Journal* 35 (1): 106–21. https://doi.org/10.3375/043.035.0115.

Subiyanto, Adi, Rizaldi Boer, Edvin Aldrian, Perdinan, and Rilus Kinseng. 2020. "Climate Resilience: Supply System: Concepts, Theory and Methods of Measuring." *EnvironmentAsia* 13:113. https://doi.org/10.14456/EA.2020.1.

Sullivan, C., and J. Meigh. 2005. "Targeting Attention on Local Vulnerabilities Using an Integrated Index Approach: The Example of the Climate Vulnerability Index." *Water Science and Technology* 51 (5): 69–78. https://doi.org/10.2166/wst.2005.0111.

"Sullivan, C. A., & Byamba, E." 2013. In *Climate Adaptation Workshop*. Geneva, Switzerland.

Sun, Xiubo, Changlai Guo, and Jian Cui. 2020. "Research on Evaluation Method of Water Resources Carrying Capacity Based on Improved TOPSIS Model." *La Houille Blanche* 106 (5): 68–74. https://doi.org/10.1051/lhb/2020040.

Svarstad, Hanne, Lars Kjerulf Petersen, Dale Rothman, Henk Siepel, and Frank Wätzold. 2008. "Discursive Biases of the Environmental Research Framework DPSIR." *Land Use Policy* 25 (1): 116–25. https://doi.org/10.1016/j.landusepol.2007.03.005.

Swart, R, W Geertsema, B van Hove, and et al. 2012. “Urban Vulnerability Indicators. A Joint Report of ETC-CCA and ETC-SIA Copenhagen: ETC-CCA and ETC-SIA Technical Report 1.” https://core.ac.uk/download/pdf/29222603.pdf.

Tai, Xiaoli, Wu Xiao, and Yuxuan Tang. 2020. “A Quantitative Assessment of Vulnerability Using Social-Economic-Natural Compound Ecosystem Framework in Coal Mining Cities.” *Journal of Cleaner Production* 258 (June):120969. https://doi.org/10.1016/j.jclepro.2020.120969.

Talbot, Jessica, Cristina Poleacovschi, and Sara Hamideh. 2022. “Socioeconomic Vulnerabilities and Housing Reconstruction in Puerto Rico After Hurricanes Irma and Maria.” *Natural Hazards* 110 (3): 2113–40. https://doi.org/10.1007/s11069-021-05027-7.

Tapia, Carlos, Beñat Abajo, Efren Feliu, Maddalen Mendizabal, José Antonio Martinez, J. German Fernández, Txomin Laburu, and Adelaida Lejarazu. 2017. “Profiling Urban Vulnerabilities to Climate Change: An Indicator-Based Vulnerability Assessment for European Cities.” *Ecological Indicators* 78 (July):142–55. https://doi.org/10.1016/j.ecolind.2017.02.040.

Tasnuva, Anjum, Md. Riad Hossain, Roquia Salam, Abu Reza Md. Towfiqul Islam, Muhammad Mainuddin Patwary, and Sobhy M. Ibrahim. 2021. “Employing Social Vulnerability Index to Assess Household Social Vulnerability of Natural Hazards: An Evidence from Southwest Coastal Bangladesh.” *Environment, Development and Sustainability* 23 (7): 10223–45. https://doi.org/10.1007/s10668-020-01054-9.

Tee Lewis, P. Grace, Weihsueh A. Chiu, Ellu Nasser, Jeremy Proville, Aurora Barone, Cloelle Danforth, Bumsik Kim, Jolanda Prozzi, and Elena Craft. 2023. “Characterizing Vulnerabilities to Climate Change across the United States.” *Environment International* 172 (February):107772. https://doi.org/10.1016/j.envint.2023.107772.

The Heinz Center. 2012. “The State of the Nation’s Ecosystems: Environmental Information: A Road Map to the Future.” Washington D.C: H. John Heinz III Center for Science, Economics and the Environment.

Thiault, Lauric, Stacy D. Jupiter, Johanna E. Johnson, Joshua E. Cinner, Rebecca M. Jarvis, Scott F. Heron, Joseph M. Maina, Nadine A. Marshall, Paul A. Marshall, and Joachim Claudet. 2021. “Harnessing the Potential of Vulnerability Assessments for Managing Social-Ecological Systems.” *Ecology and Society* 26 (2): art1. https://doi.org/10.5751/ES-12167-260201.

Thomas, Adelle, April Baptiste, Rosanne Martyr-Koller, Patrick Pringle, and Kevon Rhiney. 2020. “Climate Change and Small Island Developing States.” *Annual Review of Environment and Resources* 45 (1): 1–27. https://doi.org/10.1146/annurev-environ-012320-083355.

Thomas, Kimberley Anh, and Benjamin P. Warner. 2019. “Weaponizing Vulnerability to Climate Change.” *Global Environmental Change* 57 (July):101928. https://doi.org/10.1016/j.gloenvcha.2019.101928.

Thong, Pentile, Uttam Thangjam, Uttam Kumar Sahoo, and Rocky Pebam. 2022. “Socio-Economic Vulnerability Assessment of Shifting Cultivators (Jhumias) amidst the Changing Climate in Mizoram, Northeast India.” *Applied Geography* 147 (October):102790. https://doi.org/10.1016/j.apgeog.2022.102790.

Thurman, Lindsey L., John E. Gross, Claudia Mengelt, Erik A. Beever, Laura M. Thompson, Gregor W. Schuurman, Christopher L. Hoving, and Julian D. Olden. 2022. "Applying Assessments of Adaptive Capacity to Inform Natural-resource Management in a Changing Climate." *Conservation Biology* 36 (2): e13838. https://doi.org/10.1111/cobi.13838.

Tol, Richard S.J., and Gary W. Yohe. 2007. "The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test." *Global Environmental Change* 17 (2): 218–27. https://doi.org/10.1016/j.gloenvcha.2006.08.001.

Török, Ibolya, Adina-Eliza Croitoru, and Titus-Cristian Man. 2021. "Assessing the Impact of Extreme Temperature Conditions on Social Vulnerability." *Sustainability* 13 (15): 8510. https://doi.org/10.3390/su13158510.

Tsao, Chien-yu, and Chin-cheng Ni. 2016. "Vulnerability, Resilience, and the Adaptive Cycle in a Crisis-Prone Tourism Community." *Tourism Geographies* 18 (1): 80–105. https://doi.org/10.1080/14616688.2015.1116600.

Turner, B. L., Roger E. Kasperson, Pamela A. Matson, James J. McCarthy, Robert W. Corell, Lindsey Christensen, Noelle Eckley, et al. 2003. "A Framework for Vulnerability Analysis in Sustainability Science." *Proceedings of the National Academy of Sciences* 100 (14): 8074–79. https://doi.org/10.1073/pnas.1231335100.

Turner, R.A., J. Addison, A. Arias, B.J. Bergseth, N.A. Marshall, T.H. Morrison, and R.C. Tobin. 2016. "Trust, Confidence, and Equity Affect the Legitimacy of Natural Resource Governance." *Ecology and Society* 21 (3). https://doi.org/10.5751/ES-08542-210318.

Turvey, Calum G., Jiajun Du, Yurou He, and Ariel Ortiz-Bobea. 2021. "A Vulnerability Index for Priority Targeting of Agricultural Crops under a Changing Climate." *Climatic Change* 166 (3–4): 34. https://doi.org/10.1007/s10584-021-03135-8.

Umamaheswari, Thavasiyandi, Gopalrajan Sugumar, Pandian Krishnan, Pachampalayam Shanmugam Ananthan, Arur Anand, Jeyapaul Joyson Joe Jeevamani, Ranganalli Somashekharappa Mahendra, John Amali Infantina, and Cherukumalli Srinivasa Rao. 2021. "Vulnerability Assessment of Coastal Fishing Communities for Building Resilience and Adaptation: Evidences from Tamil Nadu, India." *Environmental Science & Policy* 123 (September):114–30. https://doi.org/10.1016/j.envsci.2021.05.009.

UN. 2015. "Transforming Our World: The 2030 Agenda for Sustainable Development." NewYork: United Nations. https://sdgs.un.org/2030agenda.

———. 2021a. *Handbook on the Least Developed Country Category: Inclusion, Graduation and Special Support Measures*. New York. https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/LDC-Handbook-2021.pdf.

———. 2021b. "Methodological Notes on the Identification Criteria for the Least Developed Countries." New York. https://www.un.org/development/desa/dpad/document_cdp/books/.

———. 2021c. "Multidimensional Vulnerability Index: Methodology and Results." United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (OHRLLS).

UN Habitat. 2020. “Climate Change Vulnerability and Risk: A Guide for Community Assessments, Action Planning and Implementation.” United Nations Human Settlements Programme.

UNEP. 2017. “Hazard and Climate Vulnerability and Capacity Assessment Toolkit.” UNEP.

UNFCCC. 2021. “CGE Training Materials for Vulnerability and Adaptation Assessment – Chapter 2: Vulnerability and Adaptation.” Bonn, Germany.

University of Notre Dame. 2025. “Notre-Dame Global Adaptation Initiative (ND-GAIN) Country Inded Technical Report.”

Urothody, Aa, and Ho Larsen. 1970. “Measuring Climate Change Vulnerability: A Comparison of Two Indexes.” *Banko Janakari* 20 (1): 9–16. https://doi.org/10.3126/banko.v20i1.3503.

Valencia, Jhon B., Jeison Mesa, Juan G. León, Santiago Madriñán, and Andrés J. Cortés. 2020. “Climate Vulnerability Assessment of the Espeletia Complex on Páramo Sky Islands in the Northern Andes.” *Frontiers in Ecology and Evolution* 8 (September):565708. https://doi.org/10.3389/fevo.2020.565708.

Valera, Kirverlin, and Ayyoob Sharifi. 2025. “Index-Based Mapping and Assessment of Flood Vulnerability for Climate Adaptation at the Neighborhood Level: A Case Study of Santo Domingo, the Dominican Republic.” *International Journal of Disaster Risk Reduction* 120 (April):105362. https://doi.org/10.1016/j.ijdrr.2025.105362.

Van Laarhoven, P.J.M, and W Pedrycz. 1983. “A Fuzzy Extension of Saaty’s Priority Theory.” *Fuzzy Sets and Systems* 11 (1–3): 229–41.

Vandeskog, Hilde Ousland, Kristin Margrethe Heggen, and Eivind Engebretsen. 2022. “Gendered Vulnerabilities and the Blind Spots of the 2030 Agenda’s ‘Leave No One behind’ Pledge.” *Critical Policy Studies* 16 (4): 424–40. https://doi.org/10.1080/19460171.2021.2014342.

Vasilica, Florentina-Aurelia, Mariana I. Panaitescu, Fanel_Viorel Panaitescu, Alexandru_Andrei Scupi, and Valeriu-Nicolae Panaitescu. 2023. “Assessing the Vulnerability of Marine Ecosystems in the Context of Climate Change.” In *Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies XI*, edited by Marian Vladescu, Ionica Cristea, and Razvan D. Tamas, 44. Constanta, Romania: SPIE. https://doi.org/10.1117/12.2643109.

Verdugo, Mario Daniel, Oscar Arizpe, and Arturo Gonzalez-Baheza. 2018. “VULNERABILITY ASSESSMENT FOR RESOURCE MANAGEMENT OF A NATURAL PROTECTED AREA.” In , 117–23. Siena, Italy. https://doi.org/10.2495/SDP180111.

Vo, Thi Anh Nguyet, and Tien Khai Tran. 2022. “Climate Change and Rural Vulnerability in Vietnam: An Analysis of Livelihood Vulnerability Index.” *Human and Ecological Risk Assessment: An International Journal* 28 (3–4): 326–53. https://doi.org/10.1080/10807039.2022.2052262.

Wade, Alisa A., Brian K. Hand, Ryan P. Kovach, Gordon Luikart, Diane C. Whited, and Clint C. Muhlfeld. 2017. “Accounting for Adaptive Capacity and Uncertainty in Assessments of Species’ Climate-change Vulnerability.” *Conservation Biology* 31 (1): 136–49. https://doi.org/10.1111/cobi.12764.

Wang, Yong, Linna Han, and Xuejiao Ma. 2022. “International Tourism and Economic Vulnerability.” *Annals of Tourism Research* 94 (May):103388. https://doi.org/10.1016/j.annals.2022.103388.

Wang, Yongjie, Jinjin Shu, and Yu Yuan. 2024. “Navigating Urban Risks for Sustainability: A Comprehensive Evaluation of Urban Vulnerability Based on a Pressure–Sensitivity–Resilience Framework.” *Sustainable Cities and Society* 117 (December):105961. https://doi.org/10.1016/j.scs.2024.105961.

Warrick, Olivia, William Aalbersberg, Patrina Dumaru, Rebecca McNaught, and Kate Teperman. 2017. “The ‘Pacific Adaptive Capacity Analysis Framework’: Guiding the Assessment of Adaptive Capacity in Pacific Island Communities.” *Regional Environmental Change* 17 (4): 1039–51. https://doi.org/10.1007/s10113-016-1036-x.

Watkiss, P, R Wilby, and Charles Rodgers. 2020. “Principles of Climate Risk Management for Climate Proofing Projects.” 69. ADB Sustainable Development Working Paper Series. Asian Development Bank.

WCPFC. 2000. *Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean*.

———. 2019. *Resolution on Climate Change as It Relates to the Western and Central Pacific Fisheries Commission*. *Resolution 2019-02*.

———. 2023. “Outcomes of the 20th Regular Session of the Western and Central Pacific Fisheries Commission.” In . Rarotonga, Cook Islands. https://meetings.wcpfc.int/node/21645.

WCPFC Secretariat. 2023. “Incorporating Climate Change Considerations into Conservation and Management of WCPO Fisheries and Ecosystems. WCPFC20-2023-12.” In *20th Regular Session*. WCPFC2020-2023-12.

Welch, D.J., T Saunders, J Robins, A Harry, JE Johnson, J Maynard, R Saunders, G Pecl, B Sawynok, and A Tobin. 2014. “Implications of Climate Change Impacts on Fisheries Resources of Northern Australia: Part 1—Vulnerability Assessment and Adaptation Options.” 2010/565. FRDC.

Wheatley, Christopher J., Colin M. Beale, Richard B. Bradbury, James W. Pearce-Higgins, Rob Critchlow, and Chris D. Thomas. 2017. “Climate Change Vulnerability for Species—Assessing the Assessments.” *Global Change Biology* 23 (9): 3704–15. https://doi.org/10.1111/gcb.13759.

Williams, Stephen E, Luke P Shoo, Joanne L Isaac, Ary A Hoffmann, and Gary Langham. 2008. “Towards an Integrated Framework for Assessing the Vulnerability of Species to Climate Change.” Edited by Craig Moritz. *PLoS Biology* 6 (12): e325. https://doi.org/10.1371/journal.pbio.0060325.

WMO. 2025. “State of the Global Climate 2024.” WMO-No 1368. https://library.wmo.int/idurl/4/69455.

World Bank. 2024. “People in a Changing Climate: From Vulnerability to Action.” World Bank. https://www.worldbank.org/en/topic/climatechange/publication/people-in-a-changing-climate-from-vulnerability-to-action.

Xiao, Wu, Xuejiao Lv, Yanling Zhao, Haoxuan Sun, and Jiaqi Li. 2020. “Ecological Resilience Assessment of an Arid Coal Mining Area Using Index of Entropy and Linear Weighted Analysis: A Case Study of Shendong Coalfield, China.” *Ecological Indicators* 109 (February):105843. https://doi.org/10.1016/j.ecolind.2019.105843.

Xiao, Yi, Xiao Tang, Yuan Li, Huan Huang, and Bo-Wen An. 2022. “Social Vulnerability Assessment of Landslide Disaster Based on Improved TOPSIS Method: Case Study of Eleven Small Towns in China.” *Ecological Indicators* 143 (October):109316. https://doi.org/10.1016/j.ecolind.2022.109316.

Yang, Xuchao, Lin Lin, Yizhe Zhang, Tingting Ye, Qian Chen, Cheng Jin, and Guanqiong Ye. 2019. “Spatially Explicit Assessment of Social Vulnerability in Coastal China.” *Sustainability* 11 (18): 5075. https://doi.org/10.3390/su11185075.

Yang, Xue, Shili Guo, Xin Deng, Wei Wang, and Dingde Xu. 2021. “Study on Livelihood Vulnerability and Adaptation Strategies of Farmers in Areas Threatened by Different Disaster Types under Climate Change.” *Agriculture* 11 (11): 1088. https://doi.org/10.3390/agriculture11111088.

Yin, Hao, Yong Xiang, Yangjuan Lei, and Jiaojiao Xu. 2024. “Analysis of Social Vulnerability to Earthquake Disasters in Mountainous Areas: A Case Study of Sixteen Cities along the Fault Zone in Sichuan Province, China.” *Sustainability* 16 (15): 6479. https://doi.org/10.3390/su16156479.

Zadeh, L.A. 1965. “Fuzzy Sets.” *Information and Control* 8 (3): 338–53. https://doi.org/10.1016/S0019-9958(65)90241-X.

Zebisch, Marc, Stefan Schneiderbauer, Kerstin Fritzsche, Philip Bubeck, Stefan Kienberger, Walter Kahlenborn, Susanne Schwan, and Till Below. 2021. “The Vulnerability Sourcebook and Climate Impact Chains – a Standardised Framework for a Climate Vulnerability and Risk Assessment.” *International Journal of Climate Change Strategies and Management* 13 (1): 35–59. https://doi.org/10.1108/IJCCSM-07-2019-0042.

Zhang, Qin, Xueyan Zhao, and Haiping Tang. 2019. “Vulnerability of Communities to Climate Change: Application of the Livelihood Vulnerability Index to an Environmentally Sensitive Region of China.” *Climate and Development* 11 (6): 525–42. https://doi.org/10.1080/17565529.2018.1442808.

Zhou, Yang, Ning Li, Wenxiang Wu, and Jidong Wu. 2014. “Assessment of Provincial Social Vulnerability to Natural Disasters in China.” *Natural Hazards* 71 (3): 2165–86. https://doi.org/10.1007/s11069-013-1003-5.

Zhuang, Lulu, Lirong Huang, Chengyi Zhao, Guanghui Zheng, Wei Tang, Dian Zhou, and Jianting Zhu. 2024. “Identification and Assessment of the Mudflat Ecological Vulnerability Dominated by Coastline Evolution in Jiangsu.” *Ecological Indicators* 168 (November):112761. https://doi.org/10.1016/j.ecolind.2024.112761.

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

EnviroSea

Ph (France): +33 6 47 20 05 65

Email: enquiries@enviroseaconsulting.com

ADIRA

Ph (Australia): +61 407 016 692

Email: kerrie@adiraconsulting.com.au

WCPFC Climate Change Vulnerability Assessment (CCVA) Framework

Guidance and procedural information

Prepared by: Kerrie Robertson[1] and Matthew Baird[2]

[1] Adira Consulting
[2] EnviroSea Consulting

About this document

Version

Element	Detail
Version number	V1.0
Approved	DD/MM/YY
Responsible	[Approval party]
Next review	DD/MM/YY

Purpose

This document provides a comprehensive overview of the Climate Change Vulnerability Assessment (CCVA) Framework developed for the Western and Central Pacific Fisheries Commission (WCPFC) to assess the level of climate risk associated with Conservation Management Measures (CMMs). In addition to outlining guidance for how to understand, interpret and operate the CCVA Framework, a comprehensive methodology (procedure) is provided to support the establishment, operation and refinement of CMM CCVAs to ensure the CCVA Framework is effectively implemented and maintained, as a standard WCPFC tool to ensure effective and sustainable fisheries management in the Western and Central Pacific Ocean (WCPO).

Structure

This document is presented in three parts:

Contents

Table of Figures

Table of tables

Glossary

Acronym	Definition
AIS	Automatic Identification System
CCVA	Climate change vulnerability assessment
CMM	Conservation Management Measure
EBSA	Ecologically and Biologically Significant Areas
GIS	Geographic Information System
IMMA	Important Marine Mammal Areas
IPCC	International Panel on Climate Change
IPCC AR6	IPCC Annual Report 6
LEK	Local ecological knowledge
MCS	Monitoring, Control and Surveillance
NC	WCPFC Northern Committee
PICT	Pacific Island Country or Territory
RCP	Representative concentration pathways
SAR	Search and rescue
SC	WCPFC Scientific Committee
SEAPODYM	Spatial Ecosystem and Population Dynamics Model
SIDS	Small Island Developing States
SST	Sea Surface Temperature
TCC	WCPFC Technical and Compliance Committee
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring System
WCPO	Western and Central Pacific Ocean
WCPFC	Western and Central Pacific Fisheries Commission

Part one: Introduction

1 Context

1.1 Origin of the WCPFC CCVA Framework

The WCPFC Climate Change Vulnerability Assessment (CCVA) Framework has been developed in response to the recognition that climate change poses significant risks to the effectiveness of existing Conservation and Management Measures (CMMs). In line with Resolution 19-01, which calls for enhanced understanding of climate change impacts on highly migratory fish stocks, fisheries, and associated ecosystems, the framework supports efforts to integrate climate considerations into Commission decision-making.

CCVAs are increasingly valuable tools for informing management planning—not only by identifying biological and ecological risks, but also by identifying institutional and governance vulnerabilities, and an institution's capacity to cope with or adapt to these changes.

CCVA are intended to assist the Commission to anticipate, monitor, prevent and mitigate potential threats, especially when scientific information is uncertain or inadequate. These assessments can highlight where existing management structures, decision-making processes, or technical planning processes could improve to respond to shifting species distributions or increased resource uncertainty.

This CCVA Framework is intended to be a diagnostic tool, and one of the factors the Commission considers, when the Commission adopts new or amended CMMs.

1.2 Benefits of having a CCVA Framework

Climate change is impacting the WCPO, which has direct implications for the WCPFC. Climate-driven changes—such as ocean warming, shifting species distributions, and altered productivity—may pose challenges to the effectiveness of current CMMs. For example:

- Shifting species distributions may impact the assumptions underpinning certain CMMs as well as alter fishing operations and fleet dynamics, impacting enforcement
- Changes in productivity could require adjustments to catch limits and reference points
- Altered seasonality may affect the timing and effectiveness of temporal closures and gear restrictions
- Disrupted food webs could undermine current bycatch mitigation strategies, and
- Economic and environmental instability may increase pressure on compliance and enforcement systems.

The Commission aspires to take a proactive approach by undertaking standardized CCVAs. For the WCPFC, CCVAs support adaptive management by informing strategic adjustments to CMMs and strengthening the governance structures needed to ensure long-term sustainability in a changing climate.

2 Purpose

CCVAs focus specifically on identifying risks arising from climate-related drivers—such as changing ocean temperatures, acidification, and sea-level rise—because these stressors are largely external to the control of fisheries management and may require distinct, long-term adaptation strategies. Separating climate risks from other pressures, such as fishing mortality, enables the Commission to develop targeted, forward-looking policies that complement existing management measures rather than conflate different sources of risk.

The primary purpose of this CCVA is to:

- **Inform Decision-Making:** Provide evidence and analysis to the WCPFC bodies and the Commission to inform the development, review, and adaptation of climate-resilient CMMs
- **Identify and Prioritize Risks:** Systematically identify and prioritize climate change risks to the effectiveness of existing or proposed management measures, and their capacity to ensure the long-term conservation of target stocks, non-target species, associated and dependent species, and the broader marine ecosystem, as well as the human communities that are reliant on them
- **Identify Data Needs:** Highlight critical data gaps and uncertainties to guide future research, monitoring, and data collection efforts
- **Document Risks:** Maintain scientific evidence of climate change risks to WCPFC-managed species and fisheries, and
- **Risk Prioritization:** Identify which CMMs are most vulnerable to climate change risks

3 Role within WCPFC

The CCVA Framework functions as one of several tools within the Commission's broader fisheries management toolbox. For example, it complements:

- **Stock Assessments** – Evaluate the current status of fish stocks
- **Ecosystem Indicators** – Monitor the health and dynamics of marine ecosystems
- **Compliance Monitoring** – Assess the effectiveness of management measures and ensure compliance, and
- **Technical Implementation** – Considering practical and enforceable management approaches.

Together, these tools support adaptive, science-based decision-making in response to environmental and management challenges.

3.1 Contributions across WCPFC Bodies

The CCVA Framework is intended to draw on expertise and input from various WCPFC bodies to ensure it is robust, relevant, and implementable, including:

- **Scientific Committee (SC):** Provides input on the biological and ecological dimensions of the CCVA, and identifies data needs, technical limitations, and potential methodological approaches

- **Technical and Compliance Committee (TCC):** Offer insights into fleet dynamics and fishing activities relevant to CCVA considerations; advises on the operational feasibility of implementing CCVA-informed measures under changing conditions; and evaluates practical implications of climate-related risks, including potential impacts on MCS.
- **Northern Committee (NC):** Contributes to CCVAs conducted within its specific geographic and species remit
- **Commission:** Makes strategic decisions regarding the evolution of the management framework; determines which CMMs require a CCVA; and reviews CCVA findings and decide on any follow-up actions or policy responses.

Part Two: Framework design

4 Principles

This framework draws on the IPCC AR6[3] approach to understanding climate risk, emphasizing the roles of hazards, exposure, sensitivity, and adaptive capacity as key components. In line with IPCC AR6, it also reflects a shift toward holistic assessments, moving beyond purely biophysical vulnerability to consider the broader social and governance context within which WCPFC operates. The WCPFC CCVA Framework is a systematic evaluation tool that examines how climate change may affect the performance and effectiveness of new or existing CMMs.

The CCVA Framework is underpinned by the following principles:

- **Practical**: Designed to be implemented during normal meeting cycles and within existing resource constraints. It can be used by the Commission efficiently and independently, without requiring ongoing reliance on external support or funding.
- **Integrated into Existing Processes**: CCVAs should be conducted using established WCPFC procedures and meetings, and, where appropriate, in line with normal CMM review processes. This ensures the framework is feasible, adequately resourced, and capable of informing evidenced-based, responsive updates to CMMs.
- **Responsive to Management Needs**: The framework is tailored to meet the specific information needs of WCPFC managers and decision-makers, offering clear, actionable insights to support climate-resilient fisheries management.
- **Adaptive and Iterative**: Built to evolve, the framework can be updated as new scientific knowledge, socio-economic data, and insights into climate change impacts become available. This aligns with adaptive management principles, which are essential for managing uncertainty in fisheries.
- **Focused**: While recognizing that other stressors may compound climate risk, the CCVA is specifically focused on identifying and addressing risks directly attributable to climate change, rather than unrelated pressures such as overfishing.
- **User-friendly:** Designed so that it is easy to navigate, operate and understand without necessarily having an in-depth scientific or technical background.

5 Key definitions

To ensure consistency and clarity across all CCVAs, the following concepts, aligned with IPCC AR6 terminology, are used:

- **Climate Risk:** The potential for adverse consequences of climate change, resulting from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems.
- **Hazard:** 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 loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In the context of climate change, this refers to climate stressors (e.g., ocean warming, acidification, sea-level rise, changes in ocean currents, extreme weather events).

[3] Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. AR6. Geneva, Switzerland.

- **Exposure:** The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by climate hazards.
- **Vulnerability:** The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. This includes the propensity of *management measures or strategies* to be adversely affected by climate change impacts.
- **Sensitivity:** The degree to which a system or species is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in productivity in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damage caused by an increase in the frequency of storm events).
- **Adaptive Capacity:** The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. This includes the ability to implement effective *and flexible* management measures, adjust fishing practices, or develop new technologies *to respond to climate-driven changes*.

6 Conceptual approach

6.1 IPCC IR6

In line with the IPCC AR6 approach, the WCPFC CCVA Framework assesses the level of Climate Risk associated with CMMs. Climate Risk is defined as a function of Hazard, Exposure and Vulnerability, where Vulnerability is determined as a function of Sensitivity and Adaptive Capacity (see **Figure 1** below).

Simply:

Climate Risk = combined output of Hazard, Exposure and Vulnerability

Where:

Vulnerability = combined output of Sensitivity and Adaptive Capacity.

6.2 Rapid assessment

In line with the literature review findings, a pragmatic rapid assessment approach was chosen as the most appropriate for developing the CCVA Framework. The rapid assessment approach:

- enables rapid identification of where attention is required where climate risk is determined 'high' and what elements drive it
- offers a high degree of flexibility with the ability to add or remove indicators
- enables efficient determination of where information gaps exist, and
- can be readily updated or modified on a regular basis without requiring extensive technical expertise and investment.

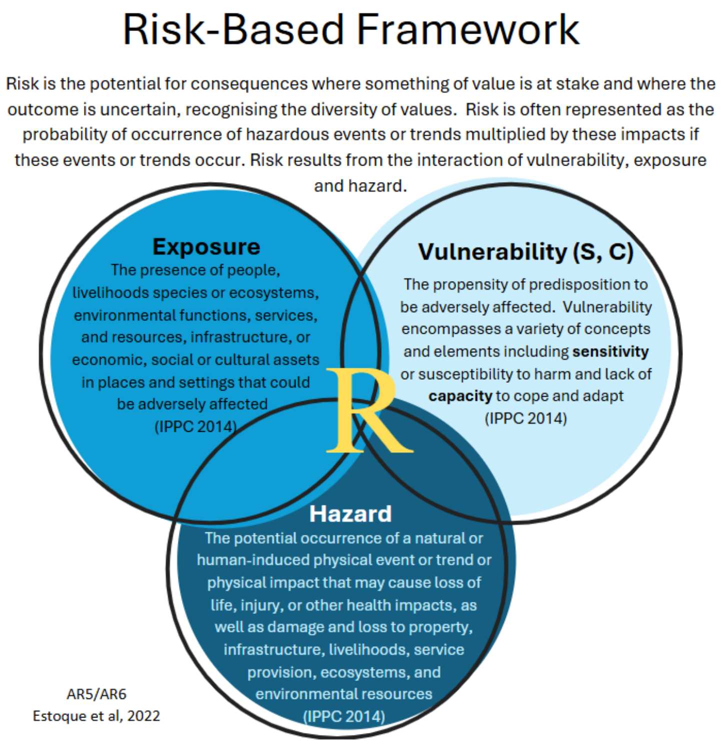


Figure 1. *VENN diagram by Estoque et al (2022) of the climate risk-based approach defined in the IPCC AR6.*

7 Key design features

7.1 Software platform

Microsoft Excel was chosen as the design platform of the CCVA Framework in recognition that it is a globally accessible and well-known software platform, that can be easily modified and updated over time, and that readily enables automated outputs and long-term reliability without it being dependent on other external software or operating systems.

7.2 Structure

The CCVA is made up of a total of eight tabs. The first tab is a ‘guidance and information’ tab to aid users in understanding the structure and functionality of the workbook in the case that they do not have access to this document. The remaining tabs are numbered and are split into two category types (working tabs and results tabs), which are described in

Table 1 below.

7.3 Tab design

Each working tab follows the same design to ensure consistency in scoring and understanding while navigating through the scoring process. An exception to this is the ‘1. Start’ tab which provides the starting point from which to identify the CMM that is to be scored. In all cases, a user-friendly design approach was taken to ensure that any delegate or Member can readily access the framework and operate it.

Colour coding was used on the four main working tabs (2.-5.) to ensure users could easily navigate between tabs.

Table 1. *Summary overview of the seven working and results tabs that make up the WCPFC CCVA framework*

Type	Tab	Description
Working tab	1. Start	The start tab is the starting point from which the relevant CMM is selected. Once selected, embedded functionality in working tabs 2. - 5. automatically updates
	2. Hazard	The hazard tab provides a series of indicators to identify and determine the level of application of individual climate change hazards relevant to the CMM
	3. Exposure	The exposure tab provides a set of indicators to determine the level of exposure a particular CMM faces when facing an identified climate change hazard
	4. Sensitivity	A set of indicators to determine the level of harm faced by a particular CMM when it is exposed to a climate change hazard
	5. Adaptive capacity	A set of indicators to measure the adaptive capacity of a CMM to lower its sensitivity in the face of exposure to a climate change hazard
Result tab	6. Climate risk	An automated results tab that shows the climate risk associated with the CMM via a combination of Hazard, Exposure and Vulnerability (Sensitivity x Adaptive Capacity)
	7. Indicator summary	A summary overview of the different scores for individual indicators under each of the components of climate risk

7.4 Working tabs

Four working tabs are provided to score Hazard, Exposure and Vulnerability (as a function of Sensitivity and Adaptive Capacity). Within each working tab, a set of indicators are provided to generate a score for that component of Climate Risk. To ensure consistency in scoring, each indicator is framed as a question, with indicator reference point information provided to guide the scorer in selecting an appropriate score for the indicator. An example of the design is provided below in **Figure 2**. In addition, several further sections are provided to record the supporting rationale used to justify the determination of the score, to record commentary, and to identify any planned activities / developments / requirements to aid scoring in future.

7.5 Result tabs

The two result tabs (6. and 7.) are fully automated output sheets that are protected to ensure the longevity of the implemented code required to generate the climate risk scores. Tab 6 provides an overview of all the generated scores including for individual components (Tabs 2.-5.), as well as an overall Climate Risk score. Graphics are also automated to help users identify visually how each score has been influenced by individual indicator scores. Tab 7 provides a comprehensive automated list of each indicator by scoring category to aid in the easy identification of indicators requiring immediate or further attention (see **Figure 3**).

7.6 Auto-indicator selection

Several design features are included in each of the working tabs (2.-5.), including drop-down options to ensure consistent scoring and an ability to turn on or off auto-indicator selection based on the type of CMM being scored. The auto-indicator selection only applies to MCS based CMMs at this time in which all biological and ecological indicators are automatically set to N/A. This automation will be further updated should it prove to be useful when running assessments.

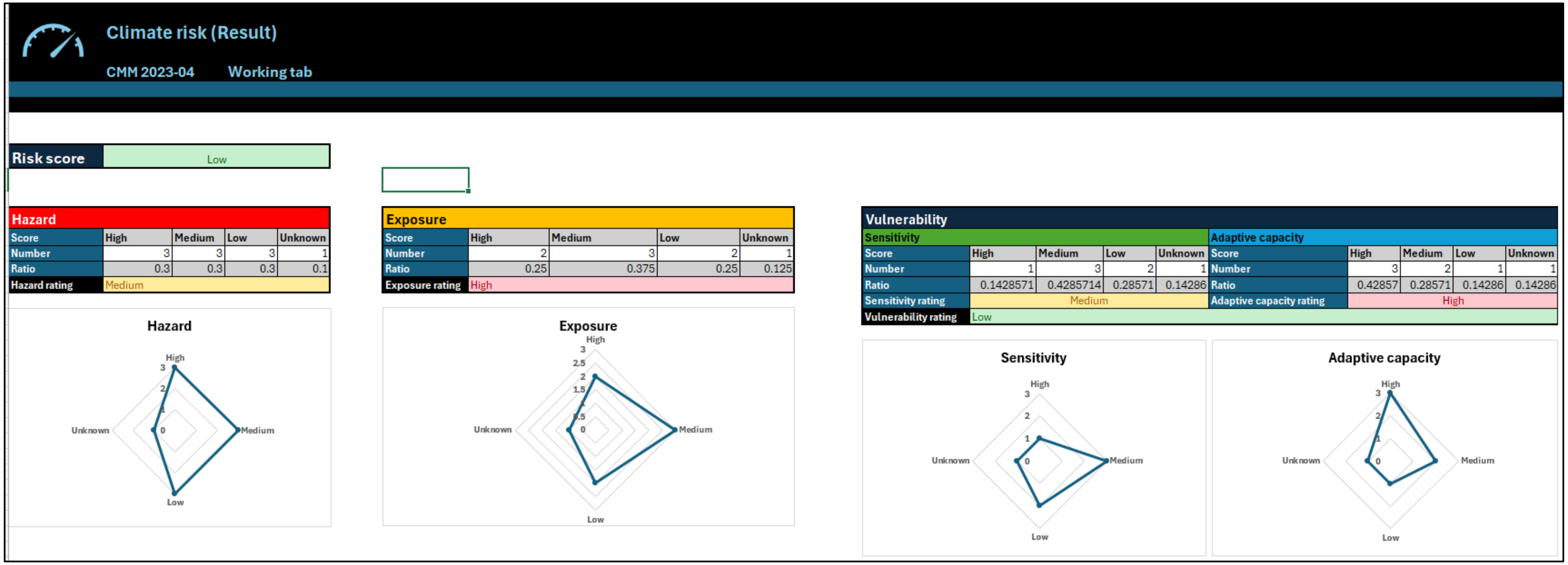
Sensitivity

CMM 2023-04 **Working tab**

☐ Auto indicator selection (On/Off)

Theme	Ind. Ref #	Committee	Criteria	Question	Indicator reference information: Low sensitivity	Medium sensitivity	High Sensitivity	Score
Biological and ecological	S1		Thermal range	What is the temperature tolerance of the focus species? (when unknown the breadth of distribution can be used as a proxy for temperature range)	Temperature tolerance is broad, with the ability to function normally under a broad range of temperatures	Temperature tolerance is considered mid-range, with the focus species able to function normally under medium temperature changes for short durations (e.g., heatwaves)	Temperature tolerance is considered very narrow, with small temperature changes causing significant difficulties for normal functionality	
	S2		Mobility	What is the ability of the focus species to move to a new location if the current location changes and is no longer favourable for growth and / or survival?	The focus species has high mobility, able to travel significant distances to new locations	Mobility of the focus species is considered moderate, with the species able to change locations but not to the level observed under 'low sensitivity'	Mobility of the focus species is low, with limited ability to actively move to change to more favorable conditions	
	S3		Productivity	What is the productivity of the species?	The focus species has high productivity, with an ability of the population to rapidly recover after a negative impact	Moderate productivity, with the population able to recover after a negative impact over a longer period of time	Low productivity, with negative events to the population causing sustained impact over long periods of time	
	S4		Distribution	What is the distributional range of the species?	The focus species has a high distributional range, covering large areas of the ocean and able to adjust to a range of habitats found in coastal and open-ocean environments	Moderate distributional range with the species found across a wide range of areas in the ocean but limited in their ability to adjust and occupy different habits (e.g., restricted to specific coastal environments)	Low distributional range with the species confined to specific / localised areas and habitat requirements	
	S5			What is the level of influence of environmental cues on the distribition of the species?	Environmental cues such as seasonality have minor influences on the distribution of the focus species	Environmental cues have some influence on the distribution of the species	Environmental cues have very high levels of influence on the distribution of the species	
	S6		Reproduction	How dependent is reproductive success on specific or complex environmental conditions / triggers?	The focus species is a broadcast spawner, with environmental conditions having a limited influence on spawning events	The focus species spawns (broadcast / aggregate) when conditions are favourable and with environmental conditions playing a role in these events to a moderate degree	The focus species is an aggregate spawner, with the formation and gathering of aggregations heavily dependent on seasonality and environmental conditions	
	S7			How sensitive is the spawning cycle and duration to changes in seasonal cues and temperature changes?	The focus species is a year-round spawner or spawns over relatively long periods of time when conditions are favourable	The focus species spawns at several different times throughout the year when environmental conditions are favourable	The focus species spawns once annually and for short durations, heavily reliant on seasonal cues and temperature changes	
	S8			What is the age at maturity of the species?	The focus species matures rapidly (<1 year) during its lifecycle	The focus species matures relatively quickly (1-2 years)	The focus species matures over longer time periods (+5 years)	
	S9		Prey	What is the prey specificity of the focus species?	The focus species predates on a relatively wide range of prey species, able to readily adjust and target different prey	The focus species predates on several species of prey, but is more reliant on these particular target prey species	The focus species is relatively restricted to specific prey species that it targets	

Figure 2. *Snapshot of indicator scoring system for 'Sensitivity'*



Climate risk (Result)

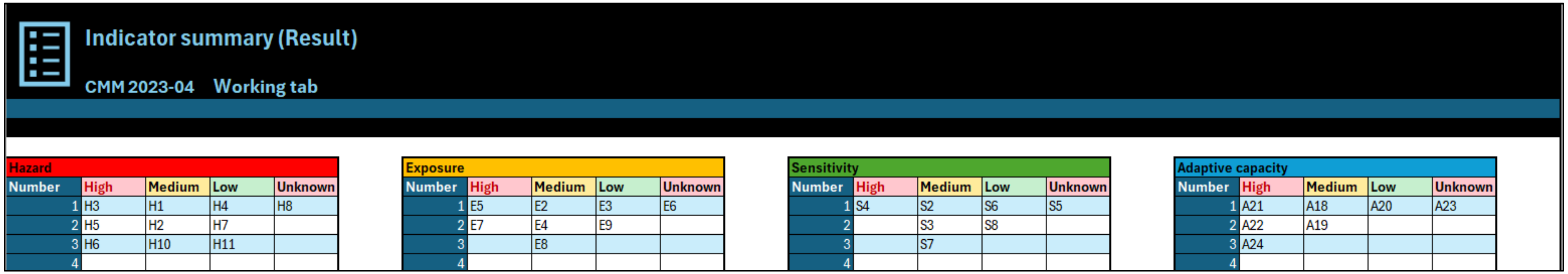
CMM 2023-04 Working tab

Risk score	Low

Hazard				
Score	High	Medium	Low	Unknown
Number	3	3	3	1
Ratio	0.3	0.3	0.3	0.1
Hazard rating	Medium			

Exposure				
Score	High	Medium	Low	Unknown
Number	2	3	2	1
Ratio	0.25	0.375	0.25	0.125
Exposure rating	High			

Vulnerability									
Sensitivity					Adaptive capacity				
Score	High	Medium	Low	Unknown	Score	High	Medium	Low	Unknown
Number	1	3	2	1	Number	3	2	1	1
Ratio	0.1428571	0.4285714	0.28571	0.14286	Ratio	0.42857	0.28571	0.14286	0.14286
Sensitivity rating	Medium				Adaptive capacity rating	High			
Vulnerability rating	Low								



Indicator summary (Result)

CMM 2023-04 Working tab

Hazard				
Number	High	Medium	Low	Unknown
1	H3	H1	H4	H8
2	H5	H2	H7	
3	H6	H10	H11	
4				

Exposure				
Number	High	Medium	Low	Unknown
1	E5	E2	E3	E6
2	E7	E4	E9	
3		E8		
4				

Sensitivity				
Number	High	Medium	Low	Unknown
1	S4	S2	S6	S5
2		S3	S8	
3		S7		
4				

Adaptive capacity				
Number	High	Medium	Low	Unknown
1	A21	A18	A20	A23
2	A22	A19		
3	A24			
4				

Figure 3. *Snapshots of Result tabs 6. and 7.*

7.7 Indicators

The specific indicators for each climate risk component were designed based on best judgement and taking into consideration the most commonly identified fisheries specific indicators identified during the literature review. A total of 82 indicators make up the scoring framework. These are split by climate risk component as set out in **Table 2** below.

Table 2. *Number of indicators by climate risk component*

Climate risk component	Number of indicators
Hazard	12
Exposure	17
Sensitivity	29
Adaptive capacity	24

The indicators per climate risk component are also grouped by theme for easy reference. These include:

- Biological and ecological
- Operations and infrastructure
- Management
- Information
- Socio-economic.

The themes are not consistently applied for each climate risk component noting that in some cases they are not applicable e.g., a climate change hazard does not exist for the theme 'Information'.

A full list of the CCVA Framework indicators per climate risk component is attached as Annex A.

7.7.1 Indicator scoring

Five scoring options are built in as drop-down selection options for each indicator in working tabs (2.-5.). These are set out in table **Table 3**.

Table 3. *Scoring options*

Score	Description
High	The user determines either a high, medium or low score using the indicator reference information to guide determination
Medium	
Low	
Unknown	In the case there is no information, or a high uncertainty associated with available information, 'Unknown' can be selected. The 'Unknown' score enables the quick identification of information gaps. It does not influence the overall scoring.
N/A	In the case the indicator does not apply to the CMM, N/A is able to be selected

The scoring methodology used to generate scores based on the individual indicator responses is discussed in detail in the Section 8 below.

7.8 Responsible WCPFC bodies

To help increase efficiency in scoring, each working tab (2. -5.) also has a ‘Committee’ column which enables users to select which indicators individual WCPFC bodies are responsible for reviewing or providing the necessary information to generate an indicator score. Available options are provided as a drop-down list, with one, two, or all WCPFC bodies able to be selected as required.

7.9 Future-proofing

The entire workbook has been designed in a manner that allows for the ready addition, deletion or modification of indicators as required over time, without impacting in-built automated functionality. In addition, all automated functionalities have been manually coded into the workbook to avoid the use of macros, to ensure longevity and functionality as software updates occur over time.

7.10 Indicator timeframe

A timeframe of 5-years has been set as the default timeframe for assessing the indicators in working tabs 2. – 5. This timeframe was selected as the most reasonable starting point for CMM review noting that the accuracy of best available scientific information diminishes over longer timeframes, the rate at which systems change and considering the process / operational timeframes at which the Commission operates. The timeframe of the framework can be manually updated to longer time-periods as required by adjusting the relevant questions accompanying individual indicators throughout the framework.

8 Scoring method

8.1 Ratio-based approach

The scoring methodology of Hazard, Exposure, Sensitivity and Adaptive Capacity was purposefully designed to avoid weighting individual indicators. This approach was identified as the most suitable for the CCVA Framework, to avoid consistent review and updates to the weighting arrangement in the event indicators are added or removed or become less or more significant over time.

A counting methodology has been used that automatically sums up the number of times a specific score has been selected for an indicator and then generates a ratio from the total number of indicators that have been scored. This approach also ensures that indicators that are not applicable and are scored accordingly are not used in the development of the overall score for each climate risk component.

Additionally, this approach assists each component resulting in a ‘truer’ score, because of the ratio-based approach which also helps to remedy differences that could otherwise be caused by having different numbers of indicators per component. These automated counting and ratio functions are ‘hidden’ as a default within the framework but can be made visible by ‘unhiding’ the columns found at the end of each scoring table.

8.2 Component results

To generate an overall rating for each climate risk component, including Hazard, Exposure, Sensitivity and Adaptive Capacity, a series of thresholds were identified that would generate either a High, Medium or Low final rating (see **Table 4** below).

Table 4. *Thresholds used to determine overall component score*

Scenario	High	Moderate	Low	Result
1	>0.5			High
2	>=0.3		<0.3	High
3	>=0.3		>=0.3	Medium
4	<=0.29		<0.3	Medium
5	<0.3		<0.5	Medium
6	<0.3		>=0.5	Low

The thresholds and associated results can be updated by accessing the applicable code for each result cell in Tab 6 and adjusting the thresholds within the code accordingly.

8.2.1.1 Unknown score

As noted earlier in Section 7.1.1, an indicator score of 'unknown' identifies specific information gaps but does not affect the overall scoring of each component, noting in some instances there may be very little information available, but that does not necessarily equate to the focus topic being vulnerable.

8.3 Vulnerability

Noting that Vulnerability is a function of Sensitivity and Adaptive Capacity, a Vulnerability final rating was developed by combining the Sensitivity final rating with the Adaptive Capacity final rating. This was done using a matrix of combinations that reflects that when Sensitivity is high and Adaptive capacity is low, Vulnerability is High and vice versa (see Table 5. Below).

Table 5. *Vulnerability matrix (Sensitivity and Adaptive capacity)*

		Sensitivity		
		High	Medium	Low
Adaptive capacity	High	Medium	Low	Low
	Medium	High	Medium	Low
	Low	High	High	Medium

8.4 Climate risk

The final climate risk score is determined based on the combination of the Hazard, Exposure and Vulnerability final ratings (see

Table 6 above below).

Table 6. *Climate risk result based on combinations of final ratings for Hazard, Exposure and Vulnerability*

Hazard	Exposure	Vulnerability	Climate risk result
High	High	High	High
High	High	Medium	High
High	High	Low	Medium
High	Medium	High	High
High	Medium	Medium	High
High	Medium	Low	Low
High	Low	High	Medium
High	Low	Medium	Medium
High	Low	Low	Low
Medium	High	High	High
Medium	High	Medium	High
Medium	High	Low	Low
Medium	Medium	High	High
Medium	Medium	Medium	Medium
Medium	Medium	Low	Low
Medium	Low	High	Medium
Medium	Low	Medium	Medium
Medium	Low	Low	Low
Low	High	High	High
Low	High	Medium	Medium
Low	High	Low	Low
Low	Medium	High	High
Low	Medium	Medium	Medium
Low	Medium	Low	Low
Low	Low	High	Medium
Low	Low	Medium	Low
Low	Low	Low	Low

Part Three: Assessment methodology

9 Objective

The key objective for each CCVA is to determine:

- Whether a CMM has a low, medium or high risk to climate change impacts
- How vulnerable the CMM is and what drives that vulnerability (sensitivity vs. adaptive capacity)
- Whether and why current management approaches may become less effective
- Information gaps that need to be filled
- When critical adaptation requirements may be needed
- Whether the WCPFC can cope with the identified level of risk, meaning
    - Institutional capacity: Does WCPFC have the legal authority, technical expertise, and financial resources to implement necessary adaptations?
    - Operational flexibility: Can existing processes be modified quickly enough to respond to climate-driven changes?
    - Management effectiveness: Will current tools and measures remain effective, or do they need fundamental redesign?

10 Scope

The scope for each CCVA must be explicitly defined, including:

- The specific CMM
- The accompanying spatial focus of the CMM:
    - Single Site/Area: e.g., a specific area or a designated fishing area
    - Network of Sites: e.g., a series of areas across the WCPFC Area
    - Range of Sites: e.g., the entire WCPFC Convention Area or specific sub-regions
- Timeframe
    - As a default, the CCVA Framework has a timeframe of five years, however this can be readily updated as required to longer timeframes as required.

11 Scoring

Using the best available information, the CCVA Framework should be worked through systematically from Tabs 1. – 5., scoring individual indicators to generate the climate risk result. Responsible WCPFC bodies should be identified for each indicator to ensure the required level of technical input and expertise required to effectively score each indicator is involved.

For each indicator scored, relevant reference information and supporting rationale for why the score was chosen must be recorded as justification, and to enable effective tracking of how information is changing over time in relation to individual indicators.

Where discussions or different views are expressed in relation to the scoring of an individual indicator, these should be captured in the comments section provided for each indicator. Likewise, if the information does not exist at a particular point in time, this should be clearly recorded to justify a score of “unknown” for the indicator.

Lastly, if future activities or planned actions are known that relate to the indicator are known, these should also be recorded to ensure effective tracking of progress towards strengthening the indicator score over time.

12 Data requirements

12.1 Data Credibility

Because CCVAs rely on available data, their accuracy is only as strong as the information they are based on. Highlighting data gaps is crucial to improving future assessments. All CCVAs must be based on:

- Verified or verifiable data
- Peer-reviewed scientific literature
- Quality-controlled observational data
- Validated model outputs
- Expert knowledge from recognized specialists, and
- Indigenous and local knowledge where appropriate.

Indigenous and local ecological knowledge (LEK) should be viewed as a primary information source together with other knowledge categories, particularly where there is low confidence or limited / no availability of other information types. In these cases, indigenous and LEK will play a fundamental role in ensuring effective overall scoring.

12.2 Core Data Categories

12.2.1 Climate Data

Data that provides the environmental context for assessing how changing ocean conditions may affect fisheries management effectiveness. This could include historical observations of ocean temperature, chemistry, currents, and extreme events, future projections from IPCC-validated climate models and scenarios and key variables such as sea surface temperature, ocean acidification, current patterns, and productivity levels.

12.2.2 Ecological Data

This data provides the biological context for understanding how species and ecosystems may respond to climate-driven environmental changes. This could include species information on distribution patterns (e.g., SEAPODYM outputs), life history parameters, and thermal tolerances and ecosystem structure, including food web dynamics, habitat mapping, and bycatch records.

12.2.3 Fisheries Data

Biological and operational data that provides the information to monitor, manage and assess fishery resources. It could include catch and effort data, biological data on species size, sex, age and reproductive status, and independent observer (human or electronic monitoring) data

12.2.4 Management Performance Data

Management performance data refers to the information used to evaluate the effectiveness, accountability, and outcomes of fisheries management systems. It includes records and analyses of how CMMs have performed over time, outcomes from monitoring, enforcement, and compliance processes, assessments of whether management objectives (such as stock sustainability, bycatch reduction, or ecosystem protection) have been achieved, performance metrics as well as evaluations of the resources, staffing, infrastructure, and governance systems in place to support implementation and enforcement of management measures.

12.2.5 Socio-economic data

Socio-economic data refers to available information on the importance of specific species or fisheries to fisheries dependent local communities (e.g., employment, income, cultural significant fisheries), market data trends (e.g., the relative importance of the species or fisheries to overall annual economic stability), and governance and institutional capacity information of individual PICTs and WCPFC members.

A tool to effectively track the availability of data sets is attached as Annex B. This should be used to effectively trace available sources of information while undertaking a CCVA.

12.3 Data Sources and Tools

The following data sources and tools should be utilized when acquiring best available information to inform a CCVA:

- WCPFC Data Holdings: Utilize existing WCPFC data catalogue, including those from the SC and compliance monitoring schemes
- Academic Literature and Scientific Reports: Incorporate findings from peer-reviewed publications and relevant scientific assessments
- Databases including the Pacific Data Hub, World Bank, International Monetary Fund, identifying and including relevant socio-economic assessments
- Traditional and LEK: Integrate local and traditional expert knowledge where available and appropriate, as a valuable source of information for understanding ecosystem dynamics and historical changes, and
- Defined Tools and Software: Specify the analytical tools, models, and software platforms to be used for data processing, analysis, and visualization to ensure consistency and reproducibility across CCVAs such as the Compliance Case File System, AIS, GIS, VMS.

13 Roles and responsibilities

Each year at its annual meeting, the Commission will decide which CMMs will undergo climate change vulnerability review in the following year. The selected review will be led by a CCM, or a group of CCMs, which will coordinate the assessment and compile relevant data and analysis.

The review process will follow established pathways for technical input and oversight. Specifically, it will be submitted to the SC for scientific review, the TCC for consideration of implementation and compliance implications, and to the NC where the measure falls within its area of responsibility.

Based on the outcomes of these subsidiary body discussions, the findings and any recommendations will be submitted to the Commission for consideration and decision-making. All CCVAs will utilise the approach outlined in the CCVA Framework and report the findings using the CCVA Report format (Annex C).

A detailed process breakdown is provided in **Table 7** below.

Table 7. *CCVA procedure.*

Step	Responsible
Step 1: Establish a CCVA review process • Confirm a CCM(s) to undertake the CCVA • Select a CMM(s) to be assessed • Determine why the assessment is required • Determine what will be assessed and at what scale (scope) • Determine what time horizon is to be used (5 years is default)	Commission

Step 2: Use the CCVA Framework to assess the CMM(s).
Determine:
• Whether a CMM is at a low, medium or high risk to climate change impacts
• The components driving the climate risk and individual indicators that require further attention
• Whether and why certain management approaches may become less effective
• Where adaptation is required to reduce vulnerability
• Whether the WCPFC can cope with identified risks in the absence of action, or through strengthening adaptive management, taking into consideration:
  ○ Institutional capacity: Does WCPFC have the legal authority, technical expertise, and financial resources to implement necessary adaptations?
  ○ Operational flexibility: Can existing processes be modified quickly enough to respond to climate-driven changes?
  ○ Management effectiveness: Will current tools and measures remain effective, or do they need fundamental redesign?
• How results can be used to inform management proposals and decision-making.
	CCM reviewer

Step 3: Consultation and validation of findings with expert input	NC
Step 4: Consultation and validation of findings with expert input	SC
Step 5: Consultation and validation of findings with expert input	TCC
Step 6: Present findings to the Commission using the report template (Annex C)	CCM reviewer
Step 7: Consider CCVA and determine appropriate actions or decisions in accordance with recommendations	WCPFC Commission
Step 8: On approval Commission, the CCVA is uploaded on the WCPFC website and used to inform the development of proposals with required management actions	WCPFC Secretariat CCMs

14 Review and continuous improvement

14.1 Regular Review Cycle

The CCVA Framework and this document should be reviewed on both a regular basis (annually) and comprehensively reviewed on a longer-term basis (5-years).

Annual reviews should focus on updating individual indicators, refining methods in response to new climate and biological information, validating results against observations, and incorporating feedback from CCMs to ensure the framework remains responsive and relevant.

Every five years, a comprehensive review should be conducted to evaluate the overall effectiveness of the framework as a decision-support tool, to compare alternative assessment approaches (including against new IPCC definitions / approaches), assess institutional capacity, and set strategic priorities for the next five-year cycle.

14.2 Adaptive Framework Development

The framework is designed to support continuous improvement. This includes ongoing development of assessment methods, integration of emerging data sources, efforts to reduce uncertainty, and streamlining of processes to improve efficiency. Over time, the framework may also expand to incorporate newly identified approaches to measuring socioeconomic and other ecosystem dimensions, to allow for region-specific application, be adapted as broader multilateral thinking develops, and to align more closely with other ocean sectors to support cross-sectoral climate adaptation planning.

Annexes

Annex A: Indicator list by climate risk component

Hazard indicators

Theme	Indicator reference	Criteria	Description	Question
Biological and ecological	**H1**	Temperature extremes	Temperature extremes (e.g., marine heatwaves) have the potential to significantly affect species distribution and survival if they have narrow thermal tolerances and limited mobility, adaptability to new habitats / areas	How applicable is the hazard to the focus topic of the CMM?
	H2	Increased sea surface temperature (SST)	Stock displacement, increased mortality, reduced productivity, reduced prey availability a species is dependent on	
	H3	Ocean acidification	Can cause harm to exposed systems in acidifying zones by impairing calcification, disrupting food webs and weakening species resilience	
	H4	Salinity	Salinity fluctuations can severely impact fish biology, affecting both health and homeostasis. Deviations from optimal salinity can cause mortality, reduced growth and impaired immune function	
	H5	Deoxygenation	Tropical pelagic species live near or above oxygen minimum zones. Changes in hypoxic or suboxic zones can affect species physiology, habitat availability and ecosystem function	
	H6	Wind stress	Changes in wind strength or direction can disrupt ecological or physical systems e.g., upwelling, larval dispersal and can contribute to other hazard e.g., intensification of tropical cyclones	

	H7	Current change	Changes in strength, direction, timing or vertical structure can disrupt larval dispersal, nutrient delivery, primary producitivty; alter species migration routes; affect heat distribution, oxygen levels and acidification patters, destabalize or shift climate systems	How applicable is the hazard to the focus topic of the CMM?
Operations & infrastructure	**H8**	Storms	Wind damage, storm surge, port infrastructure damage, loss of life or injury, damage to vessel infrastructure, loss of fishing days	
	H9	Cyclones	Wind damage, storm surge, port infrastructure damage	
	H10	Precipitation extremes	Flooding, port infrastructure damage, reduction in port access and service	
	H11	Sea level rise	Flooding, port infrastructure damage, reduction in port access and service	
	H12	Wave height	Changes in wave heigh, frequency or intensity can result in disruption to marine operations, infrastructure damage, wave-driven over wash and saline instruction and stress to intertidal ecosystems	

Exposure indicators

Theme	Indicator reference	Criteria	Question
Biological and ecological	**E1**	Habitat	How frequently does the habitat of the focus species experience the identified hazards?
	E2	Food web	How frequently is the food web of the focus species exposed to the identified hazards? (considering predator and prey relationships)
	E3	Species population	How frequently does the focus species population experience the identified hazards?
Operations and infrastructure	**E4**	Fishing fleet	How exposed are the relevant fleets to the identified hazards?
	E5	At sea operations	How frequently do operations face inadequate weather information for decision-making?

	E6		What percentage of operations cannot financially survive a major weather event?
	E7		How often must operations relocate fishing grounds due to climate-driven species shifts?
	E8	At sea operators	How often are crew and observers exposed to dangerous working conditions or hazardous deck conditions due to weather and identified hazard events
	E9		What is the crew's proximity to SAR services during extreme weather events?
	E10		How often do crew experience dangerous heat stress conditions while working at-sea?
	E11		How frequently do crew face reduced navigating conditions that increase the risk of collision or incidents
	E12	Port infrastructure	How frequently are port facilities affected by the identified hazards (e.g., storm surge/flooding)?
Socio-economic	E13	Economies	What percentage of SIDS/Territory income is affected by the identified hazards?
	E14	Livelihoods	What is the level of exposure to community livelihoods of WCPFC members from the identified hazards?
Management	E15	Spatial boundaries	Do the identified hazards affect any fixed geographic boundaries used to manage the fisheries or set by the CMM?
	E16	Scientific assumptions	Are the identified hazards factored into the temporal and spatial assumptions used to define management settings?
	E17	Information	How often does the WCPFC receive updated scientific information on these hazards?

Sensitivity indicators

Theme	Indicator reference	Criteria	Question
Biological and ecological	S1	Thermal range	What is the temperature tolerance of the focus species? (when unknown the breadth of distribution can be used as a proxy for temperature range)

	S2	Mobility	What is the ability of the focus species to move to a new location if the current location changes and is no longer favourable for growth and / or survival?
	S3	Productivity	What is the productivity of the species?
	S4	Distribution	What is the distributional range of the species?
	S5		What is the level of influence of environmental cues on the distribution of the species?
	S6	Reproduction	How dependent is reproductive success on specific or complex environmental conditions / triggers?
	S7		How sensitive is the spawning cycle and duration to changes in seasonal cues and temperature changes?
	S8		What is the age at maturity of the species?
	S9	Prey	What is the prey specificity of the focus species?
	S10	Competition	What is the level of competition that the focus species has with other species for the same habitat requirements / prey and diet requirements?
Management	S11	Health status	What is the current health status of the focus species population?
	S12		What is the projected health status of the focus species population in 5 years' time based on current environmental conditions?
	S13		What is the variability of the focus species' abundance / CPUE indexes?
	S14	Harvest strategy	Is there a harvest strategy or equivalent best practice management measure implemented for the species?
	S15		How does the harvest strategy account for increased uncertainty due to climate change?
	S16		How quickly can the harvest strategy adjust to new information about stock status or environmental conditions?
	S17	Non-compliance	What is the level of non-compliance across the fishery / fisheries that the focus species is associated?

	S18	IUU	What is the level of serious IUU fishing activity across the fishery / fisheries that the focus species is associated?
	S19	Observer coverage	What is the level of observer coverage (human and / or EM) across the fishery/ies that the focus species is associated with?
	S20	Fishing effort	What is the level of collective fishing effort associated with the focus species?
	S21	Resource and governance	What is the level of resource available to comprehensively assess the health status and distribution of the focus species regularly?
	S22		What is the current capacity of WCPFC members to respond and implement required changes?
	S23		What is the level of confidence to make informed decisions associated with current available information on the focus species?
Information	S24	Information availability	What is the level of availability of climate change information associated with the focus species?
	S25	Awareness	What is the level of climate change knowledge and environmental awareness among WCPFC members reliant on the focus species?
Socio-economic	S26	Economic Dependence	What is the relative economic importance of the focus species to WCPFC membership?
	S27		What is the livelihood reliance of WCPFC members on the focus species?
	S28	Food dependence	What is the relative dependency of PICTs on the focus species for food security?
	S29	Cultural importance	What is the level of cultural / social significance of the focus species to the WCPFC membership?

Adaptive capacity indicators

Theme	Indicator reference	Criteria	Question
Biological and ecological	A1	Thermal range	What is the ability of the focus species to adapt to increased temperatures?
	A2	Productivity	What is the likelihood of the focus species to maintain or improve its productivity in response to increased temperatures and different environmental conditions?

	A3	Distribution	What is the ability for the focus species to change its distributional patterns?
	A4	Reproduction	What is the likelihood of the focus species being able to adapt to successfully spawn under differing environmental conditions and changes in seasonal / temperature cues?
	A5	Prey	What is the likelihood of the focus species being able to change its prey and diet if required in response to environmental changes?
	A6	Competition	What is the ability of the focus species to adapt to reduce its level of competition with other species for habitat requirements / prey and diet requirements?
Management	**A7**	Health status	Under the current management settings, what is the likelihood of the focus species being able to maintain its current health status or rebuild its health status in response to environmental change (SST, ocean acidification, dissolved oxygen, salinity)
	A8	Species diversification	What is the level of flexibility to change the focus species (if it is a target species) to another target to reduce the impact of fishing?
	A9	Fishing gear	What is the level of flexibility to modify gear requirements or implement gear restrictions for fishing gear identified as creating a higher risk to the focus species compared to others?
	A10	Fishing effort	What is the likelihood of fishing effort associated with the focus species of being significantly affected because of not being able to operate at sea due to increased storm events etc.?
	A11	Observer coverage (human and / or EM)	What is the likelihood of monitoring levels being consistently sufficient for the fisheries associated with the focus species over the next 5 years?
	A12	Research and technology	What is the level of investment (current and planned) in research and technology of direct relevance to the focus species to improve understanding?
	A13	Agile decision making	How easily is the management framework / management settings for the focus topic able to be readily adapted?
	A14	Member capacity	What is the likelihood of WCPFC members having the required capacity to readily respond to required changes over the next 5 years?

	A15		What is the capability of the fleet to change its distribution (fishing grounds)?
	A16	Resource and governance	Is the level of resource currently required (and likely to be required in future) to effectively assess the status of the focus species likely to be sustainable?
	A17		Is there likely to be appropriate resource and capacity for the WCPFC secretariat, SPC, FFA and other notable organizations that contribute support and information to effectively manage the focus species likely to be sustainable?
Information	**A18**	Information sharing and cooperation	What is the level of certainty / likelihood of improved cooperation and information sharing between members and internationally, to improve efficiencies and understanding associated with the focus species over the next five years?
	A19	Contribution	What is the level of contribution (currently and in future) with social, environmental and fishery organizations on the climate change issues facing the focus species?
	A20	Traditional knowledge	What is the level of engagement (currently and in future) by members with their nationals? (including traditional knowledge holders and local communities) on the climate change issues facing the focus species and to fill information gaps where possible?
Socio-economic	**A21**	Diversification	What is the relative ability for WCPFC members to diversify their economic interests in response to required changes to reduce risk to the focus species?
	A22		What is the relative ability for WCPFC members to diversify livelihood reliance away from the focus species if required?
	A23	Port resilience	What is the relative ability of the ports of WCPFC members being able to maintain function over the next five years as climate changes become more observed e.g. sea-level rise
	A24	Food security	What is the relative ability for WCPFC members to ensure food security should the focus species require changes to current food supply associated with the fisheries?

Annex B: Data Set Tracker

Category	Does WCPFC have this data?	Source
Climate Data		
Historical and projected oceanographic data (e.g., sea surface temperature, ocean heat content, pH, oxygen levels, current patterns).	☐ Yes ☐ Partial ☐ No	
Climate model outputs (e.g., IPCC Representative Concentration Pathways - RCPs).	☐ Yes ☐ Partial ☐ No	
Extreme event frequency and intensity projections.	☐ Yes ☐ Partial ☐ No	
Ecological Data		
Species distribution data (historical and current).	☐ Yes ☐ Partial ☐ No	
Life history parameters (e.g., growth rates, reproductive cycles, thermal tolerances).	☐ Yes ☐ Partial ☐ No	
Stock assessment data (biomass, fishing mortality, recruitment).	☐ Yes ☐ Partial ☐ No	
Ecosystem structure and function data (e.g., food web dynamics, habitat mapping, EBSA locations, IMMA locations).	☐ Yes ☐ Partial ☐ No	
Bycatch and associated species data.	☐ Yes ☐ Partial ☐ No	
Fisheries Data		
Catch and effort data (by species, gear, area, time)	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Vessel monitoring system (VMS) data.	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Observer data (including bycatch and VME encounters).	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Fleet characteristics and fishing capacity.	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives

Management Effectiveness Data		
Historical CMM performance and compliance rates under varying environmental conditions.	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Responsiveness of management decisions to scientific advice and environmental shifts.	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Implementation rates of management measures	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Fleet information (number/age of vessels, fleet movements)	☐ Yes ☐ Partial ☐ No	WCPFC Data Archives
Socio-economic Data		
Fisheries-dependent community data (e.g., employment, income, cultural significance of fisheries).	☐ Yes ☐ Partial ☐ No	
Market data (e.g., prices, trade flows).	☐ Yes ☐ Partial ☐ No	
Governance and institutional capacity data	☐ Yes ☐ Partial ☐ No	

Annex C: CCVA Report Format

Executive Summary

- Key findings and management implications
- Vulnerability [rankings]
- Uncertainties and limitations
- Priority actions

Introduction

- Assessment objectives and scope
- CMMs (incl species and regions covered)
- Climate scenarios considered

Methods

- Data sources and quality assessment
- Indicator selection and metrics
- Analysis approaches and tools
- Validation procedures

Results

- Climate risk [Hazard, Exposure and Vulnerability outcomes]
- Spatial and temporal patterns
- Sensitivity analysis results

Discussion

- Interpretation of results
- Comparison with other studies
- Management implications
- Data Gaps, Uncertainties, and Limitations

Conclusions

- Summary of key findings
- Priority actions for management
- Future assessment needs
- Research recommendations
- Management Implications and Recommendations (Specific actions/triggers for CMMs, Harvest Strategies, etc.)

Appendices

- Supporting data, model outputs, and information of the assessment
- References

CCVA Report For 2024-07 (Cetaceans)

Executive Summary

The Climate Change Vulnerability Assessment (CCVA) for CMM 2024-07 (Cetaceans) reveals a **HIGH** overall climate risk rating, driven by high hazard, exposure, and sensitivity ratings combined with medium adaptive capacity.

This finding aligns with global scientific literature showing that 72% of marine mammal stocks are highly vulnerable to climate change. The assessment indicates that cetaceans face significant climate-related threats including ocean warming, acidification, and altered prey distribution that may compromise the effectiveness of current protection measures.

Priority actions within WCPFC's scope could include: enhanced monitoring of cetacean populations, review of fishing pressure as an adaptable stressor to reduce cumulative impacts, strengthened spatial management informed by better interaction data, and incorporation of expert input to refine future assessments

Introduction

Conservation and Management Measure (CMM) 2024-07 relates to the protection of cetaceans from purse seine and longline fishing operations across the entire Western and Central Pacific Fisheries Commission (WCPFC) Convention Area. The principal aim of this measure is to minimize impacts on the sustainability of cetaceans from fishing activities. Key provisions of CMM 2024-07 include the prohibition of intentionally setting a net on cetaceans and requirements for safe release procedures in cases of accidental encirclement.

Climate change poses multifaceted threats to cetacean populations through direct impacts such as ocean warming, acidification, and sea-level rise, as well as indirect effects including altered prey distribution, changed migration patterns, and increased disease susceptibility. These climate-driven changes may affect the assumptions underlying current management measures and potentially compromise their effectiveness in protecting cetacean sustainability.

This assessment aims to evaluate the climate change vulnerability of CMM 2024-07 using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, providing evidence-based insights to support adaptive management and enhance the climate resilience of cetacean protection measures in the Western and Central Pacific Ocean.

Method

The climate change vulnerability assessment for CMM 2024-07 was conducted using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, an Excel based assessment tool. The assessment followed the approach and methodology outlined in the CCVA Framework guidance and information document.

Each of the four climate risk components (Hazard, Exposure, Sensitivity, and Adaptive Capacity) was evaluated using specific indicators grouped by theme. Indicators were scored using a five-point scale (High, Medium, Low, Unknown, N/A) based on available evidence.

For each indicator, supporting rationale was documented to justify scoring decisions and to identify information gaps. Where data were insufficient or uncertain, indicators were scored as "Unknown" to highlight areas requiring further research or assessment.

The assessment employed the standard five-year time horizon provided in the framework to evaluate potential climate change impacts and management responses within a policy-relevant timeframe.

Data Sources and Approach

Given that WCPFC does not typically hold comprehensive biological and ecological data on cetacean populations, the majority of data for this assessment was obtained through desktop review of peer-reviewed scientific articles. Data sources included:

- Published literature on cetacean biology, ecology, and climate change impacts
- Global and regional climate vulnerability assessments for marine mammals
- Scientific reports on cetacean-fishery interactions and bycatch patterns
- Climate change projections and oceanographic data relevant to the WCPFC Convention Area
- WCPFC technical reports and meeting documents related to cetacean interactions

Scope and Limitations

The assessment scope encompasses the entire WCPFC Convention Area and all cetacean species potentially affected by purse seine and longline fishing operations covered under CMM 2024-07. The five-year assessment timeframe focuses on near-term climate change impacts and management responses, recognizing that longer-term climate projections carry greater uncertainty and are generally not available.

Key limitations include reliance on published literature rather than region-specific data, limited spatial resolution of available information on cetacean-fishery interactions, and uncertainty regarding member-specific institutional capacity and governance arrangements that could influence adaptive capacity ratings.

Results

Climate Risk Assessment

The CCVA yielded a **HIGH** overall climate risk rating for CMM 2024-07 (Cetaceans), determined by the combination of:

- **Hazard: High**(42% High indicators, 33% Medium, 25% Low)
- **Exposure: High**(83% High indicators, 17% Medium, 0% Low; 2 Unknown)
- **Sensitivity: High**(30% High indicators, 43% Medium, 26% Low; 1 Unknown)

- **Adaptive Capacity: Medium** (50% High indicators, 83% Medium, 42% Low, 9 Unknown)
- **Vulnerability: High**(combination of Medium sensitivity and High adaptive capacity)

Component Analysis

Hazard (High Rating) – The high hazard rating reflects significant climate-related threats that are highly applicable to cetacean populations in the WCPFC Convention Area. Key hazards scoring as "High" include temperature extremes, increased sea surface temperature, ocean acidification, deoxygenation, and current changes. These represent major environmental stressors that directly affect cetacean habitat quality, prey distribution, and physiological stress levels. Ocean warming forces cetaceans to make longer, deeper, and more frequent dives to find food, resulting in increased energetic costs that can reduce reproductive success. Additionally, hazards related to extreme weather events such as storms and cyclones scored highly, as these can disrupt migration patterns and increase mortality risk for air-breathing marine mammals.

Exposure (High Rating) – The high exposure rating indicates that cetacean populations across the WCPFC Convention Area frequently encounter identified climate hazards. This reflects the wide-ranging nature of many cetacean species that traverse areas experiencing significant oceanographic changes, including warming waters, altered current patterns, and changing prey distributions. Cetaceans' reliance on specific oceanographic features for feeding and breeding makes them particularly exposed to climate-driven environmental changes. The assessment found substantial exposure across multiple themes, including biological and ecological systems (habitat and food web changes), operations and infrastructure (affecting research and monitoring capabilities), and management systems (spatial boundaries and scientific assumptions underlying current protection measures).

Sensitivity (High Rating) – The high sensitivity rating reflects cetaceans' significant susceptibility to climate-related changes. While some cetacean species demonstrate adaptability, many exhibit characteristics that increase their sensitivity to environmental changes, including long generation times, specific habitat requirements, and specialized feeding behaviors. Key sensitivity factors include dependence on environmental cues for reproduction and migration timing, specific thermal ranges and prey dependencies, and relatively low productivity with extended maternal care periods. The assessment identified particular sensitivity in reproduction (with climate change affecting breeding timing and success), prey availability (as climate change alters marine food webs), and habitat suitability (with changing oceanographic conditions affecting critical feeding and breeding areas).

Adaptive Capacity (Medium Rating) – The medium adaptive capacity rating reflects a mixed picture of biological and management-related factors affecting cetaceans' ability to respond to climate change. While some cetacean species show high mobility and broad distributions that provide natural adaptive capacity, others have more limited ranges or specialized habitat requirements. The rating acknowledges that WCPFC has institutional frameworks for monitoring and management, but also recognizes significant limitations in cetacean-specific data collection, research capacity, and targeted management measures. Factors contributing to medium rather than high adaptive capacity include limited observer coverage for cetacean interactions, insufficient spatial data on cetacean-fishery overlap patterns, and uncertainty about member-specific institutional capacity for cetacean conservation measures. The assessment highlighted that many adaptive capacity indicators required information about individual member countries' capabilities and resources that was not readily accessible to external assessors.

Discussion

Interpretation of Climate Risk Assessment Results

The Climate Change Vulnerability Assessment (CCVA) for CMM 2024-07 (Cetaceans) yielded a **HIGH** overall climate risk rating, driven by **high** ratings for hazard, exposure, and sensitivity, combined with **medium** adaptive capacity. This finding is strongly supported by the growing body of scientific literature documenting the vulnerability of whales and dolphins to climate change impacts across global marine ecosystems.

Concordance with Scientific Literature

The high climate risk assessment for cetaceans aligns closely with recent global vulnerability assessments. For example, a comprehensive study of U.S.-managed marine mammals found that 72% of cetacean and pinniped stocks are highly or very highly vulnerable to climate change, with 44% receiving "very high" vulnerability scores (Lettrich et al., 2023). Similarly, trait-based vulnerability assessments have identified fin whales, sperm whales, bottlenose dolphins, and Bryde's whales as among the most vulnerable species to climate change, many of which occur within the WCPFC Convention Area. Scientific literature formed the basis of most assessment scores, and reference are noted in the assessment framework sheet.

The high hazard rating identified in this assessment reflects well-documented climate stressors affecting cetaceans globally. Rising sea surface temperatures and reducing sea ice extent have been observed to cause poleward shifts in cetacean distributions, alterations in migration timing, and increased extinction risk for some species. Ocean warming is causing unprecedented changes that affect cetacean foraging behaviour, with some species requiring longer, deeper, and more frequent dives to find food, resulting in increased stress that can reduce reproductive success.

The high exposure rating is consistent with evidence that cetacean species with limited habitat usage face greater challenges in coping with temperature changes, particularly as they approach their thermal threshold (at higher temperatures), while even adaptable species face ecosystem-wide repercussions from habitat shifts

The high sensitivity rating reflects the cascading effects of climate change through marine food webs. Climate change affects cetacean distribution patterns, migration timing and ranges, and reproductive ability, with some populations potentially unable to adapt quickly enough to survive. Changes in group behaviour have been documented in response to climate variability, with smaller groups observed during periods of lower prey availability.

Assessment Limitations and Data Gaps

While the overall high climate risk rating is supported by available evidence, several important limitations in the assessment should be acknowledged that may have influenced the precision of component ratings.

Hazard Applicability and Extent

There is uncertainty about the specific applicability and spatial extent of various climate hazards to cetacean populations within the WCPFC Convention Area. The assessment framework required evaluating the relevance of hazards such as ocean acidification, deoxygenation, and changing current patterns to cetaceans, but available data was not specific to the WCPO. This uncertainty may have led to conservative scoring approaches that could either underestimate or overestimate actual hazard levels for specific cetacean populations or species within different areas of the Convention Area.

The temporal dimension of hazard exposure also presented challenges, as the five-year assessment timeframe may not capture the full scope of long-term climate trends that are most relevant to long-lived cetacean species. Climate change impacts on cetaceans are expected to be diverse and mediated in various ways, with some direct impacts occurring through distributional shifts, while indirect impacts include increased disease susceptibility and altered prey availability.

Member-Specific Adaptive Capacity Information

The moderate rating for adaptive capacity (Medium) may not fully reflect the actual institutional and management capacity available within the WCPFC. Many adaptive capacity indicators were specific to individual Member countries' capabilities, resources, and governance structures—information that was not accessible to the external assessor but would be readily available to WCPFC Members themselves. For example, indicators relating to:

- Diversification of economic interests in response to required changes to reduce risk to the focus species
- Diversification of livelihood reliance away from the focus species if required
- Relative ability for WCPFC members to ensure food security should the focus species require changes to current food supply associated with the fisheries

Members conducting their own assessments would likely have access to detailed information about their institutional capacity, potentially resulting in more nuanced and possibly higher adaptive capacity ratings. This suggests that the current Medium rating may represent a conservative baseline that could be improved through Member-led assessments incorporating country-specific institutional knowledge.

Spatial Data Gaps in Interaction Patterns

There was no spatial data available to the assessor about cetacean-fishery interactions across the Convention Area, which limited the assessment. Furthermore, given longline observer coverage is inadequate, available data may not capture the full extent of interactions.

This creates uncertainty about:

- Seasonal and spatial patterns of cetacean-fishery overlap
- Areas of highest interaction risk requiring priority attention
- Effectiveness of current spatial management measures
- Opportunities for adaptive spatial management approaches

The absence of comprehensive spatial interaction data directly impacts adaptive capacity scoring, particularly for indicators related to spatial management flexibility, targeted mitigation measures, and area-based conservation strategies. While WCPFC maintains bycatch databases for key species groups, the spatial resolution and taxonomic detail may not be sufficient to support fine-scale adaptive management for cetaceans.

Strengthening Future Assessments

The current assessment could be significantly strengthened through the incorporation of expert input from cetacean specialists, marine mammal biologists, and regional ecosystem experts.

WCPFC's Role in a Broader Conservation Context

It is important to recognize that WCPFC is not the primary organization responsible for global cetacean conservation, but rather one component of a broader international governance framework. Organizations such as the International Whaling Commission (IWC) and the Secretariat of the Pacific Regional Environment Programme (SPREP) have explicit mandates for cetacean conservation and protection. However, WCPFC has a critical responsibility for managing the impact of tuna fisheries on cetacean sustainability, which becomes increasingly important under climate change scenarios.

While cetacean conservation requires coordinated action across multiple international bodies, WCPFC's unique position as manager of the world's largest tuna fishery gives it significant influence over a major anthropogenic stressor affecting cetacean populations in the Pacific.

Management Implications - Fishing Pressure as an Adaptable Stressor

Although the CCVA framework focuses specifically on climate-related stressors, it is crucial to acknowledge that fishing pressure represents a significant non-climate stressor that interacts with climate vulnerability. Unlike climate change impacts, which are largely external to fisheries management control, fishing pressure is a stressor that can be directly adjusted through management intervention. This creates important opportunities for adaptive management responses.

Given the HIGH climate vulnerability identified for cetaceans and their reduced adaptive capacity to respond to climate stressors, there may be compelling reasons to examine more comprehensively the cumulative impact that fishing pressure is having on these species. When species have limited capacity to adapt to climate change, reducing other anthropogenic stressors becomes a critical conservation strategy. The economic and cultural importance of cetaceans to Pacific Island communities, combined with their ecological significance as apex predators and ecosystem engineers, further supports the case for examining potential adjustments to fishing management.

Attachment D1

Specific areas to improve cross-stressor management might include:

- Enhanced spatial and temporal fishing restrictions in critical cetacean habitats
- Strengthened bycatch mitigation measures, particularly for highly vulnerable species
- Adaptive management triggers based on cetacean population status and climate indicators

References

WCPFC Documents:

WCPFC. Final Compliance Monitoring Reports (CMRs) 2021, 2022, 2023, 2024.

WCPFC. (2024). Regional Observer Programme Annual Report. WCPFC-TCC20-2024-RPO02.

WCPFC. (2024). Scientific Committee Summary Report. WCPFC-SC20-2024, para 36.

Academic Journal Articles:

Albouy, C., Delattre, V., Donati, G., Frölicher, T.L., Algar, A.C., Erisman, B., et al. (2020). Global vulnerability of marine mammals to global warming. *Scientific Reports*, 10, 548.

S. Elizabeth Alter, Mark P. Simmonds, John R. Brandon (2010) Forecasting the consequences of climate-driven shifts in human behavior on cetaceans, Marine Policy, Volume 34, Issue 5, 2010, Pages 943-954, ISSN 0308-597X, https://doi.org/10.1016/j.marpol.2010.01.026.

Barlow, D.R., Torres, L.G., Hodge, K.B., Steel, D., Baker, C.S., Chandler, T.E., Bott, N., Constantine, R., Double, M.C., Gill, P., Glasgow, D., Hamner, R.M., Lilley, C., Ogle, M., Olson, P.A., Peters, C., Stockin, K.A., Tessaglia-Hymes, C.T., & Klinck, H. (2021). Temporal and spatial lags between wind, coastal upwelling, and blue whale occurrence. *Scientific Reports*, 11, 6915.

Bloodgood, J.C.G., Kleinman, S., Turnley, J.G., Lovewell, G., Sawyer, S. & Townsend, F.I. (2023). Physiological Effects of Low Salinity Exposure on Bottlenose Dolphins (Tursiops truncatus). *Animals*, 1(1), 5.

Croll, D.A., Marinovic, B., Benson, S., Chavez, F.P., Black, N., Ternullo, R., & Tershy, B.R. (2005). From wind to whales: Trophic links in a coastal upwelling system. *Marine Ecology Progress Series*, 289, 117-130.

Garland EC, Goldizen AW, Lilley MS, Rekdahl ML, Garrigue C, Constantine R, Hauser ND, Poole MM, Robbins J, Noad MJ. (2015) Population structure of humpback whales in the western and central South Pacific Ocean as determined by vocal exchange among populations. Conserv Biol. Aug;29(4):1198-1207. doi: 10.1111/cobi.12492. Epub 2015 Apr 7. PMID: 25851618.

Guinn, M.A., Elliott, J.Y., Wittmaack, C.S., Sinclair, C., Abdulla, H.A. & Orbach, D.N. (2024). Stress and Reproductive Hormones of Free-Ranging Dolphins Across a Natural Salinity Gradient. *ACS Omega*, 9(45), 45068-45079.

Izquierdo-Serrano M, Revuelta O, Míguez-Lozano R, Gozalbes P, Ruiz-García D, Raga JA and Tomás J (2022) Assessment of the interactions between cetaceans and fisheries at the south of the Cetacean Migration Corridor and neighboring waters (Western Mediterranean). *Front. Mar. Sci.* 9:981638. doi: 10.3389/fmars.2022.981638

Kebke A, Samarra F, Derous D. (2022) Climate change and cetacean health: impacts and future directions. Philos Trans R Soc Lond B Biol Sci. 2022 Jul 4;377(1854):20210249. doi: 10.1098/rstb.2021.0249. PMID: 35574848; PMCID: PMC9108940.

Lettrich, M. D., Asaro, M. J., Borggaard, D. L., Dick, D. M., Griffis, R. B., Litz, J. A., ... & Whitehead, H. R. (2023). Vulnerability to climate change of United States marine mammal stocks in the western North Atlantic, Gulf of Mexico, and Caribbean. *PLOS ONE*, 18(9), e0290643. https://doi.org/10.1371/journal.pone.0290643

MacLeod, C.D., Santos, M.B., López, A., & Pierce, G.J. (2006). Relative prey size consumption in toothed whales: implications for prey selection and level of specialisation. *Marine Ecology Progress Series*, 326, 295-307.

Magera, A.M., Mills Flemming, J.N., Kaschner, K., Christensen, L.B., & Lotze, H.K. (2013). Recovery trends in marine mammal populations. *PLoS ONE*, 8(10), e75909.

Ortiz, R.M. (2001). Osmoregulation in marine mammals. *Journal of Experimental Biology*, 204(11), 1831-1844.

Palmer EI, Betty EL, Murphy S, Perrott MR, Smith ANH, Stockin KA. Reproductive biology of female common dolphins (*Delphinus delphis*) in New Zealand waters. Mar Biol. 2022;169(12):158. doi: 10.1007/s00227-022-04139-3. Epub 2022 Nov 28. PMID: 36466079; PMCID: PMC9705467.

Russell Richards, Jan-Olaf Meynecke, Oz Sahin (2021), Addressing dynamic uncertainty in the whale-watching industry under climate change and system shocks, Science of The Total Environment, Volume 756, 43889, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.143889.

Rykaczewski, R.R., & Checkley, D.M. (2008). Influence of ocean winds on the pelagic ecosystem in upwelling regions. *Proceedings of the National Academy of Sciences*, 105(6), 1965-1970.

Simmonds, M.P. (2019). Climate change and cetaceans - an update. *Journal of Marine Animals and Their Ecology*, 12(1), 11-28.

Simmonds, M.P., & Isaac, S.J. (2007). Potential Effects of Climate Change on Marine Mammals. Report for DEFRA Research Contract CR0302.

Sousa, A., et al. (2023). Integrated climate, ecological and socioeconomic scenarios for the whale watching sector. *Science of the Total Environment*, 857(Pt 3), 159589.

Trites, A.W., Christensen, V., & Pauly, D. (1997). Competition between fisheries and marine mammals for prey and primary production in the Pacific Ocean. *Journal of Northwest Atlantic Fishery Science*, 22, 173-187.

van Weelden, C., Towers, J.R., & Bosker, T. (2021). Impacts of climate change on cetacean distribution, habitat and migration. *Climate Change Ecology*, 2, 100009.

Venegas, R.M., Acevedo, J., & Treml, E.A. (2024). Three decades of ocean warming impacts on marine ecosystems: A review and perspective. *Deep Sea Research Part II: Topical Studies in Oceanography*.

Von Hammerstein H, Setter RO, van Aswegen M, Currie JJ and Stack SH (2022) High-Resolution Projections of Global Sea Surface Temperatures Reveal Critical Warming in Humpback Whale Breeding Grounds. *Front. Mar. Sci.* 9:837772. doi: 10.3389/fmars.2022.837772

Reports and Technical Documents:

IPCC. (2021). Sixth Assessment Report (AR6). Intergovernmental Panel on Climate Change.

IOC Sub-Commission for the Western Pacific (WESTPAC). (2022). Ocean Deoxygenation. https://ioc-westpac.org/ocean-deoxygenation/

Williams, T.M., et al.(2024) Travel at low energetic cost by swimming and wave-riding bottlenose dolphins. "Whales and Dolphins" ocean.si.edu.

WWF. (2022). Protecting Blue Corridors Report.

Attachment D1

Online Resources and Websites:

Bégin Marchand, C. (2020). Do tides have an influence on whales? *Baleines en direct*. https://baleinesendirect.org/en/do-tides-have-an-influence-on-whales/

Biology Insights. (2025). Whale migration: Patterns, currents, and communication. https://biologyinsights.com/whale-migration-patterns-currents-and-communication/

GEMM Lab. (2021). Wave riders or deep divers: What do cetaceans do in stormy weather? *Geospatial Ecology of Marine Megafauna Laboratory*. https://blogs.oregonstate.edu/gemmlab/2021/05/03/wave-riders-or-deep-divers-what-do-cetaceans-do-in-stormy-weather/

International Union for Conservation of Nature (IUCN). IUCN Red List of Threatened Species. https://www.iucnredlist.org/

NOAA Fisheries. (n.d.). Whales and climate change: Big risks to the ocean's biggest species. https://www.fisheries.noaa.gov/national/climate/whales-and-climate-change-big-risks-oceans-biggest-species

NOAA Fisheries. (n.d.). Spinner Dolphin Conservation Management. https://www.fisheries.noaa.gov/species/spinner-dolphin/conservation-management

Ocean Processes: Whales and Climate. (2020). https://whalesandclimate.org/ocean-processes/

World Cetacean Alliance. (2024). Celebrating Cetaceans in Indigenous Cultures. https://worldcetaceanalliance.org/2024/08/09/celebrating-cetaceans-in-indigenous-cultures/

Attachment D2

CCVA Report for CMM 2019-05 (Mobulid Rays)

Executive Summary

The Climate Change Vulnerability Assessment (CCVA) for CMM 2019-05 (mobulid rays) results in a **HIGH** overall climate risk rating, driven by medium hazard, high exposure and high vulnerability rating. Identified information gaps ("unknown" indicator scores) ranged between 1 and 10, with adaptive capacity carrying the highest number (10), highlighting the general lack of information on mobulid rays in respect of climate change capacity and the need for further investigation to strengthen the assessment findings.

The known biological characteristics of mobulid rays in the WCPF Convention Area, together with the lack of in-depth knowledge about key life traits, results in them having a high sensitivity to identified climate hazards and low adaptive capacity to effectively respond. Together, these create an overall high vulnerability score that drives the climate risk result.

Given the vulnerable or endangered IUCN status of WCPFC mobulid species, the existing management framework appears adequate in terms of prohibiting targeting, fishing in the presence of, transhipping or landing mobulid rays, and best handling requirements, as a means of protection. However, there is limited scientific understanding of key biological traits, environmental dependencies and ecology of mobulid rays, required to properly assess the health status of individual species, in addition to understanding how mobulid rays may react, be impacted or adapt to climate change.

In light of this, the WCPFC has taken meaningful steps towards addressing these issues with planned activities for assessing fishery characteristics, stock status and the biology of key WCPFC mobulid species (see 2021-2030 Shark Research Plan). This information should help to enable some information gaps in the CCVA to be addressed once it becomes available.

Priority actions within WCPFC's scope could include: enhanced observer monitoring requirements (longline fleets in particular), continued effort to advance planned mobulid ray research projects (refer 2021-2030 Shark Research Plan), advancing collaboration efforts to improve global understanding and available information, addressing identified CCVA information gaps, and considering further adaptive management requirements (e.g., integration of environmental indicators into planned mobuild ray stock assessments).

Introduction

Conservation and Management Measure (CMM) 2019-05 relates to the conservation and management of mobulid rays including all species of the family Mobulidae, including manta rays and mobula rays in the WCPFC Convention Area. The principal objective of this measure is to ensure the long-term conservation of mobulid rays in the recognition that:

1. manta and mobula rays are listed in Appendix I and Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals, and

2. manta and mobula rays are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

The CMM specifically sets out prohibition requirements of targeted fishing, intentional setting with mobulid rays in the area, onboard retention, transhipping or landing any part or whole carcasses of mobulid rays caught in the Convention Area. In addition, specific reporting and handling requirements are set out for landing mobulid rays in the case it is required, and best handling practices for the safe release of mobulid rays when fishing.

Due to a lack of available information, there are currently no mobula stock assessments available, and therefore there is high uncertainty of the current health status of all mobula ray species in the WCPF Convention Area.

Climate change poses various threats to Mobula rays through direct impacts such as ocean warming, changes in ocean chemistry (e.g., ocean acidification), and altered current patterns, as well as indirect effects including shifts / declines in prey distribution, seasonal cues, and altered ecosystem productivity.

This assessment aims to evaluate the climate change vulnerability of CMM 2019-05 using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, providing evidence-based insights to support adaptive management and enhance the climate resilience of WCPFC's mobulid rays conservation measure – CMM 2019-05.

Method

The climate change vulnerability assessment for CMM 2019-05 was conducted using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, an Excel based assessment tool. The assessment followed the approach and methodology outlined in the CCVA Framework guidance and information document.

Each of the four climate risk components (Hazard, Exposure, Sensitivity, and Adaptive Capacity) was evaluated using specific indicators grouped by theme. Indicators were scored using a five-point scale (High, Medium, Low, Unknown, N/A) based on available evidence.

For each indicator, supporting rationale was documented to justify scoring decisions and to identify information gaps. Where data were insufficient or uncertain, indicators were scored as "Unknown" to highlight areas requiring further research or assessment.

The assessment employed the standard five-year time horizon provided in the framework to evaluate potential climate change impacts and management responses within a policy-relevant timeframe.

Data Sources and Approach

The assessment drew upon multiple data sources to evaluate climate vulnerability across the four risk components:

- Peer-reviewed scientific literature on Mobulid ray biology, ecology, and potential hazards, including climate change and pollution

- WCPFC scientific committee documents
- International scientific reports and articles on Mobulid rays both in the Pacific and globally
- WCPFC technical reports and meeting documents related to Mobulid rays.

Scope and Limitations

The assessment scope encompasses the high seas and EEZs of the WCPF Convention Area as described in CMM 2019-05. The five-year assessment timeframe focuses on near-term climate change impacts and management responses.

Key limitations include a lack of robust information on mobulid rays both within the Pacific and globally, limited available scientific information on climate change and mobulid rays, spatial resolution of some climate projections, and high uncertainty with identified information and conclusions for WCPFC mobulid rays due to identified information gaps.

Results

Climate Risk Assessment

The CCVA yielded a **HIGH** overall climate risk rating for CMM 2019-05 (Sharks), determined by the combination of:

- **Hazard: Medium** (11% High indicators, 45% Medium, 44% Low)
- **Exposure: High** (44% High indicators, 33% Medium, 22% Low)
- **Sensitivity: High** (50% High indicators, 39% Medium, 11% Low)
- **Adaptive Capacity: Low** (25% High indicators, 25% Medium, 50% Low)
- **Vulnerability: High** (combination of High sensitivity and Low adaptive capacity)

Component Analysis

Hazard (Medium Rating) – The medium hazard rating reflects a moderate level of identified climate-related threats relevant to mobulid rays. Only increased sea surface temperature scored as "High", with temperature extremes scored as “Low”, and remaining biological and ecological indicators scored as “Medium” (with the exception of ocean acidification which was scored as “Unknown”). The high levels of ‘Medium’ scores reflected the high mobility and distribution of mobulid rays, while acknowledging that they are reliant on zooplankton as a prey species. Other identified hazards including extreme weather events scored low.

Exposure (High Rating) - The high exposure rating was mainly driven by “High” scores for habitat exposure, food web exposure, fishing fleet exposure and lack of information. Habit and food web exposure were classified ‘High’ in the recognition that despite their wide distribution, mobulid ray habitats (pelagic, coastal and shelf) and their primary food source (zooplankton) will be exposed to the identified climate hazards. Importantly, a total of six indicators (35%) were scored as “unknown” as a result of identified information gaps related to operations.

Sensitivity (High Rating) – The high sensitivity rating resulted a range of “High” indicator scores across the majority of themes. Biological and ecological indicators that were scored “High”, included thermal range, productivity, reproduction and prey, reflecting the level of sensitivity to increased temperatures, a dependence on a single prey species (with some exceptions), and low levels of fecundity. Management based indicators that scored “High” included health status, resource and governance, and information availability, noting limited information impedes required understanding to inform decision-making.

Adaptive Capacity (Low Rating) – The low adaptive capacity rating is driven by “Low” indicator scores across both biological and management indicator themes. “Low” biological and ecological indicators included thermal range and prey, whereas management indicators included fishing gear, observer coverage, agile decision making, and resource and governance. Again, many of these “Low” adaptive capacity scores reflect the level of information available for WCPFC mobulid rays. Importantly, a significant number (n=10: 45%) of indicators were scored “Unknown”, including biological and ecological themed indicators, due to a lack of available information. These indicators identify information gaps through which insights into targeted adaptive capacity activities can be identified.

Discussion

Interpretation of Climate Risk Assessment Results

The **HIGH** overall climate risk rating for mobulid rays is representative of known biological and ecological traits, coupled with low available information and certainty. The resulting high vulnerability rating directly drives the resulting climate risk.

These assessment findings align well with recent scientific literature, however there are a clear number of identified information gaps (“Unknown” indicator scores) that require attention to increase overall confidence in the climate risk score.

Concordance with Scientific Literature

The high climate risk assessment is consistent across available scientific literature on mobulid rays both within the Pacific and globally. Scientific studies and available reports detail the need for improved information to help bridge the understanding of the current health status and vulnerability (to fishing and climate change) of mobulid rays, noting their listings as vulnerable or endangered by the IUCN and relevant Conventions. However, there is a decent amount of general knowledge on mobulid ray distribution, feeding habitats and potential vulnerability to climate change impacts notably in the form of food web and distribution disruptions – this information was drawn on to inform the CCVA.

Assessment Limitations and data gaps

The assessment enables the identification of indicator information gaps while also reflecting indicator scores based on best available information, generating a climate risk rating that reflects understanding across available literature. In addition, the assessment directly identifies the WCPFC's management, research and capacity requirements, helping to improve overall understanding and management of mobulid rays in the WCPF Convention Area. The following assessment limitations and data gaps were found:

Limited information – As previously outlined, there are identified information limitations across available information on key biological and ecological traits required to effectively understand both the status of mobulid ray populations and their potential vulnerability to fishing and climate change.

Species-specific Understanding – Although the CCVA drew on available information for WCPFC mobulid rays, general information on mobulid rays was also used to help fill in specific indicator scores. Understanding species-specific differences will help deliver a more robust CCVA.

Ecosystem-Level Interactions - The assessment focused primarily on direct impacts to mobulid rays, however climate change will likely directly affect food distribution of direct importance to mobulid rays, which may result in changes to broader ecosystem functionality, distributional patterns and behaviours. These cumulative impacts somewhat go beyond the capability of the CCVA Framework to provide insights on in respect of mobulid rays.

Compounding effects – In addition to understanding the effect of climate change on mobula rays, there are also numerous other identified hazards, including fishing activities, vessel strikes, pollution (e.g., heavy metals and micro plastics) and loss of habitat to list a few, for which limited information is known. These creates a key limitation in understanding the level of observed changes or patterns being driven solely by climate related impacts.

Long-term Projections – The five-year assessment timeframe, while appropriate for management planning, may not capture longer-term climate change impacts that could become more pronounced over decades. The general longevity of mobulid ray species means that some climate effects may manifest over longer time scales than the current assessment provides for.

Member-Specific Capacity Variations – The adaptive capacity assessment relied on general WCPFC-level information, but individual member capacity for monitoring, research, and management response varies, with clear evidence of members requiring capacity support to improve compliance found in annual compliance reporting. Some members may have greater or lesser capacity to implement adaptive management measures, potentially affecting overall system resilience.

Management Implications

Maintaining Management Effectiveness – The High climate risk rating suggests that the current CMM requirements are appropriate and will remain effective at minimizing the risk from fishing operations on modula rays, helping WCPFC species to maintain healthy stock status required to provide improved adaptive capacity. However, it is well documented that continued monitoring and strengthening of information is required to better understand the modula ray species (all aspects) found within the WCPF Convention Area.

Addressing Data Gaps – The significant scientific information gaps and relatively large number of "Unknown" scores, particularly for adaptive capacity (45%), highlights the importance of targeted research and monitoring to reduce uncertainty. Priority areas include:

- Enhanced monitoring of environmental-biological traits and relationships
- Improved observer coverage requirements to understand longline fishing interactions

- Improved understanding of mobulid ray stock health
- Improved understanding of ecosystem considerations for mobulid rays, including seasonal cues, competition and food-web dynamics
- Assessment of member-specific adaptive capacity

Strengthening Adaptive Management – While the current management framework reflects low adaptive capacity, much of this is driven by the need for improved information. As information availability improves over time, opportunities to further enhance climate resilience of mobulid rays should be considered, including:

- Integration of environmental indicators into mobuild ray stock assessments
- Development of climate-informed reference points
- Enhanced early warning systems for detecting climate-related changes
- Improved coordination with other RFMOs managing mobulid rays

Proactive Conservation Approaches – The high vulnerability rating suggests proactive management is required. The CMM currently provides strict prohibition, landing and best practice handling requirements, based on currently available information. As further information becomes available on the status, biology and ecology of mobulid rays, further proactive management considerations should be explored including:

- Protection of critical habitats and migration corridors
- Minimization of other stressors that could or are known to compound climate impacts
- Greater investment in research and monitoring activities to strengthen available information

Future Assessment Considerations

Regular reassessment using the CCVA Framework will be important to track changes in vulnerability status as better information becomes available. Future assessments should prioritize:

- Incorporation of new WCPFC mobulid ray specific biology, fishery characteristics and stock assessment information
- Integration of ecosystem-level impact assessments
- Enhanced spatial analysis of vulnerability patterns, related to SST, reproduction, prey distribution and distribution
- Updated evaluation of adaptive capacity as management and research continues to evolve

Conclusions

The Climate Change Vulnerability Assessment for CMM 2019-05 (Mobuild rays) reveals a **HIGH** overall climate risk, driven by high exposure and sensitivity ratings, coupled with a low adaptive capacity rating. This outlook reflects the current state of knowledge of WCPFC mobulid rays, which is a current Achilles heel in understanding their biological and ecological traits, and in enabling effective adaptive management. The high climate risk rating reflects current global concern for mobulid rays in general, and in the knowledge that climate change is likely to impact these species into the future.

Attachment D2

References

WCPFC Documents

- CMM2019-05 – Conservation and Management Measure on Mobulid Rays caught in association with fisheries in the WCPFC Convention Area
- Data review and potential assessment approaches for Mobulids in the WCPO (SC16-SA-IP-12
- Progress against the 2021-2030 Shark Research Plan – 2025 (SC21-SA-IP-19)
- Progress in addressing key research to inform Mobulid ray conservation in the Pacific Ocean (SC20-EB-IP-18)
- Review of non-key shark species (2016) (SC12-EB-WP-08)
- WCPFC Final Compliance Monitoring Report 2024, 2023, 2021

Scientific Literature

- Argeswara, J. K. P., et al. (2025). Estimating the abundance and population trends of reef manta rays (Mobula alfredi) in Nusa Penida, Bali, Indonesia. Environmental Biology of Fishes, 108(791-805)
- Beale, C. S., et al. (2019). Population dynamics of oceanic manta rays (Mobula birostris) in the Raja Ampat Archipelago, West Papua, Indonesia, and the impacts of the El Niño–Southern Oscillation on their movement ecology. Diversity and Distributions, 25 (1472-1487)
- Cerutti-Pereyra, F. et al. (2024). Vulnerability of Eastern Tropical Pacific chondrichthyan fish to climate change. Global Change Biology, 30(7)
- Couturier, L. I. E., et al. (2012). Biology, ecology and conservation of the Mobulidae. Journal of Fish Biology, 80(1075-1119)
- Croll, D.A., et al. (2015). Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. Aquatic Conservation: Marine and Freshwater Ecosystems, Vol 26 (562-575)
- Cronin, M. R., et al. (2023). Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. ICES Journal of Marine Science, 80 (620-634)
- Francis, M. & Jones, E. G. (2017). Movement, depth distribution and survival of spinetail devilrays (*Mobula japonica*) tagged and released from purse-seine catches in New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems, 27 (219-236)
- Lezama-Ochoa, N. et al. (2019). Spatial and temporal distribution of mobulid ray species in the eastern Pacific Ocean ascertained from observer data from the tropical tuna purse-seine fishery. Environmental Biology of Fishes, 102 (1 – 17)
- Lezama-Ochoa, N. et al. (2019). Environmental characteristics associated with the presence of the Spinetail devil ray (Mobula mobular) in the eastern tropical Pacific. PLoS One.

- Osgood, G. J., et al. (2021). Effects of climate-change-driven gradual and acute temperature changes on shark and ray species. Journal of Animal Ecology, 90(2547-2559)
- Ozaki, R., et al. (2024). Evidence of environmental niche separation between threatened mobulid rays in Aotearoa New Zealand: Insights from species distribution modelling. Journal of Biogeography, 51(2117-2135)
- Palacios, M. D. et al. (2023). Manta and devil ray aggregations: conservation challenges and developments in the field. Frontiers in Marine Science, 10: https://doi.org/10.3389/fmars.2023.1148234
- Stewart, J. D., et al. (2018). Research Priorities to Support Effective Manta and Devil Ray Conservation. Frontiers in Marine Science, 5: https://doi.org/10.3389/fmars.2018.00314
- Ward-Paige, C. A., et al. (2013). Global Population Trends and Human Use Patterns of Manta and Mobula Rays. PLoS One.

Technical Reports

- Hearn, A., et al. (Unknown). Vulnerability of top predators to climate change and adaptations for coastal and pelagic ecosystems: sharks, a case study. University of California. Retrieved from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=291336d16bb8abd4ea5262b0f35d2003c55ee8c8ICCAT. (2024). Mobulid Rays in the ICCAT Convention Area: A Review of Current Knowledge (SCRS.2024.098).
- IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report.
- Japan Meteorological Agency. (2024). RSMC Tokyo-Typhoon Center. Retrieved from https://www.jma.go.jp/

Other information sources

- ADRA International (2020). URL: https://adra.org/worst-cyclone-to-ever-hit-fiji-cuts-power-water-and-communication
- Bakun, A. (2017). Climate change and ocean deoxygenation within intensified surface-driven upwelling circulations. Accessed: https://royalsocietypublishing.org/doi/10.1098/rsta.2016.0327
- Geography Realm. (2024). Storms in the Western Pacific Ocean. Retrieved from https://www.geographyrealm.com/storms-western-pacific-ocean/
- IATTC (2018). Mobulid rays in the eastern Pacific. Accessed: https://www.bmis-bycatch.org/system/files/zotero_attachments/library_1/UZJ5GJT2%20-%20Hall%20-%20Mobulid%20rays%20in%20the%20eastern%20Pacific.pdf
- ICIS (2022). https://www.icis.com/explore/resources/news/2020/09/03/10548390/typhoon-maysak-forces-port-closures-as-it-makes-landfall-in-busan-south-korea/
- Manta Trust (2018). Conserving Mobulid Rays: A global strategy and action plan. Accessed: https://www.iucnssg.org/uploads/5/4/1/2/54120303/2018_-_conserving_mobulid_rays_-_a_global_strategy___action_plan.pdf

- Pacific Island Climate Adaptation Science Center. URL: https://pi-casc.soest.hawaii.edu/research/research-projects/inundation-risk-for-majuro/
- Pacific RISA (2021). URL: https://www.pacificrisa.org/places/republic-of-the-marshall-islands/
- PMC (Climate change and coastal resiliency of Suva, Fiji). URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC9838293/
- Port Technology International (2022). URL: https://www.porttechnology.org/news/busan-halt-ops-as-super-typhoon-impacts-asian-supply-chains/
- ScienceDirect (2024). "The effects of tropical cyclone on the container shipping network". URL: https://www.sciencedirect.com/science/article/abs/pii/S1361920924004061
- Spennemann, Dirk H.R. Typhoons in the Marshall Islands. URL: https://marshall.csu.edu.au/Marshalls/html/typhoon/typhoon.html
- WorldFish (2024). "New Study Uncovers How Climate Change Is Deepening Labour Risks in Industrial Fisheries". URL: https://www.worldfishcenter.org/blog/new-study-uncovers-how-climate-change-deepening-labour-risks-industrial-fisheries

CCVA Report for CMM 2024-05 (Sharks)

Executive Summary

There are 72 species of shark found in WCPFC fisheries that are covered by the WCPF Convention and to which this CMM pertains to. However, in accordance with the prioritized list of shark species as per 2021-2030 Shark Research Plan, the assessment was undertaken based on information located for the key shark species set out in the research plan, as well as general information found in literature on Pacific based sharks.

The Climate Change Vulnerability Assessment (CCVA) for CMM 2024-05 (Sharks) reveals a **MEDIUM** overall climate risk rating, driven by high hazard, medium exposure and a low vulnerability rating. Identified information gaps ("unknown" indicator scores) ranged between 6 and 9 across Exposure (9), Sensitivity (6) and Adaptive Capacity (8), highlighting the need for further investigation to strengthen the assessment findings.

The inherent biological characteristics of Pacific shark species in general, including high mobility, opportunistic feeding behaviours and large distributional ranges, equips them with a good level of adaptive capacity to balance their known sensitivities, reducing their overall vulnerability to low.

The existing management framework for sharks appears to be adequate in terms of maintaining healthy shark populations necessary to reduce climate risk, with best available stock health information for key Pacific shark species interacting with longline and purse seine fisheries concluding the majority of species are not overfished and not subject to overfishing (although there are exceptions). Further, the 2021-2030 Shark Research Plan demonstrates active progression towards filling known information gaps to provide greater certainty on the health status of key shark species.

Although the overall climate risk rating is low, there are significant information gaps that need attention to strengthen confidence in the overall assessment rating. Nevertheless, evidence of effective management is evident under the existing CMM arrangements with several key shark species having improved their health status from pre-2000's fishing, following implementation of strict measures such as the ban on shark finning. As better information becomes available both in terms of stock health of key shark species, non-key shark species, and climate changes in the Pacific, refined adjustments will be able to made to the assessment to further ensure confidence that CMM 2024-05 remains fit-for purpose moving forward.

Priority actions within WCPFC's scope could include: enhanced monitoring of stock distribution and abundance patterns, strengthened data collection on Pacific sharks (key and non-key species), addressing identified CCVA information gaps, undertaking key shark species CCVAs, improved integration of climate considerations into key shark species stock assessments, and maintenance of flexible management measures that can adapt to changing conditions.

Introduction

Conservation and Management Measure (CMM) 2024-05 relates to the conservation and management of Sharks including all species of sharks, skates, rays and chimaeras (Class Chondrichthyes) in the WCPFC Convention Area. The principal objective of this measure is to ensure the long-term conservation and sustainable use of WCPO sharks through science-based management approaches, including prohibitions (e.g., shark finning and retention of key species), bycatch and handling requirements, and reporting, research and capacity building requirements.

The current health status of key shark populations including North and South Pacific Bluefin Sharks, Silky shark, Southern hemisphere porbeagle shark, North Pacific Shortfin Mako Shark and Whale sharks are considered either not overfished or subject to overfishing, or are no longer subject to overfishing or are likely not at risk from WCPFC fisheries. However, others including the Oceanic white-tip and the Bigeye thresher shark are considered overfished and subject to overfishing, or have an unknown health status respectively.

Climate change poses various threats to Pacific sharks through direct impacts such as ocean warming, changes in ocean chemistry (e.g., ocean acidification), and altered current patterns, as well as indirect effects including shifts in prey distribution, seasonal cues, and altered ecosystem productivity. These climate-driven changes may affect the biological assumptions underlying current stock assessments and management measures.

This assessment aims to evaluate the climate change vulnerability of CMM 2024-05 using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, providing evidence-based insights to support adaptive management and enhance the climate resilience of WCPFC's Shark conservation measure – CMM 2024-05.

Method

The climate change vulnerability assessment for CMM 2024-05 (Sharks) was conducted using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, an Excel based assessment tool. The assessment followed the approach and methodology outlined in the CCVA Framework guidance and information document.

Each of the four climate risk components (Hazard, Exposure, Sensitivity, and Adaptive Capacity) was evaluated using specific indicators grouped by theme. Indicators were scored using a five-point scale (High, Medium, Low, Unknown, N/A) based on available evidence.

For each indicator, supporting rationale was documented to justify scoring decisions and to identify information gaps. Where data were insufficient or uncertain, indicators were scored as "Unknown" to highlight areas requiring further research or assessment.

The assessment employed the standard five-year time horizon provided in the framework to evaluate potential climate change impacts and management responses within a policy-relevant timeframe.

Data Sources and Approach

The assessment drew upon multiple data sources to evaluate climate vulnerability across the four risk components:

- Peer-reviewed scientific literature on shark biology, ecology, and climate change impacts
- WCPFC stock assessment reports and scientific committee documents
- Regional climate change projections and oceanographic data for the Pacific
- International scientific reports on shark responses to environmental variability
- WCPFC technical reports and meeting documents related to shark management

Scope and Limitations

The assessment scope encompasses the high seas and EEZs of the WCPF Convention Area as described in CMM 2024-05. The five-year assessment timeframe focuses on near-term climate change impacts and management responses.

Key limitations include reliance on primarily Pacific-focused data and information sources (noting some key shark species are global in their distribution), limited spatial resolution of some climate projections, reliance on general shark information (noting there is limited information available on many species in the Pacific), and uncertainty regarding region-specific biological responses that may vary depending on the shark species across the WCPF Convention Area.

Results

Climate Risk Assessment

The CCVA yielded a **MEDIUM** overall climate risk rating for CMM 2024-05 (Sharks), determined by the combination of:

- **Hazard: High** (60% High indicators, 0% Medium, 40% Low)
- **Exposure: High** (38% High indicators, 37% Medium, 25% Low)
- **Sensitivity: Medium** (14% High indicators, 43% Medium, 43% Low)
- **Adaptive Capacity: High** (56% High indicators, 38% Medium, 6% Low)
- **Vulnerability: Low** (combination of Medium sensitivity and High adaptive capacity)

Component Analysis

Hazard (High Rating) – The high hazard rating reflects significant levels of climate-related threats relevant to Pacific sharks. Key hazards scoring as "High" include temperature extremes, increased sea surface temperature, ocean acidification, deoxygenation, wind stress and current changes. These represent significant environmental stressors that could affect shark distribution, growth and development, feeding behaviours and reproductive success. Hazards including extreme weather events generally scored low, as a result of the predominately used pelagic shark information used to inform the assessment.

Exposure (High Rating) – The high exposure rating is driven by three high indicator scores associated with: 1) shark habitats (coastal, pelagic and bathyal), 2) Pacific shark populations, and 3) relevant fishing fleets. However, there was a total of nine indicators that were unable to be scored due to identified information gaps. As a result, only 8 indicators out of 17 (47%) were able to be scored to inform the exposure rating.

Sensitivity (Medium Rating) – The medium sensitivity rating resulted from a mixed bag of indicator scores, that included all five indicator score categories (five-point scale, refer Method section). While Pacific sharks show some sensitivity to environmental changes, their biological characteristics—including broad thermal tolerance, high mobility, and opportunistic feeding behaviour—provide resilience against the identified climate stressors. Indicators that scored high included the age at maturity of Pacific shark species (>5 years in general) and the reliance on seasonal cues for distribution (e.g., spawning aggregations) for some species.

Adaptive Capacity (High Rating) – The high adaptive capacity rating is driven by high indicator scores across both biological and management indicator themes. These scores suggest Pacific sharks and WCPFC are in a relatively good position to effectively respond and adapt to climate stressors as they increase over the medium term (over the next five years). The high mobility (including within the water column) of Pacific sharks, broad distribution, and opportunistic feeding behaviour provide Pacific sharks with natural adaptive capacity. Additionally, WCPFC's flexible management framework, 2021-2030 Shark Research Plan, and capacity for responsive decision-making contribute to institutional adaptive capacity. However, it must be noted that there were eight indicators (out of 24 (33%)) that were scored as "Unknown", again highlighting information gaps that require attention to strengthen overall confidence in the assessment.

Discussion

Interpretation of Climate Risk Assessment Results

The **MEDIUM** overall climate risk rating for Pacific sharks is driven by the low vulnerability rating resulting from a high adaptive capacity. The high adaptive capacity both biologically and through management, provides a good level of confidence that although Pacific sharks will be exposed to climate stressors, in general they will likely be able to respond well.

These assessment findings align well with recent scientific literature, however there are a clear number of identified information gaps that require attention in order to increase overall confidence in the climate risk score. Further, the biological and ecological themed indicators are based on key WCPFC shark species and general global shark information (generally pelagic species), which may require further attention to increase overall accuracy.

Concurrence with Scientific Literature

The medium climate risk assessment is consistent (within limitations) to recent global shark scientific assessment literature. Recent scientific studies detail that although tropical, pelagic species will be subject to high levels of threat, they naturally have high biological and ecological tolerances and adaptability, enabling them to effectively reduce overall risk-rating to mid to mid-to-high ratings in the short-term with these possibly reducing over longer timeframes under different scenarios.

Studies have also shown that Pacific shark species like the North Pacific Blue Shark can readily adjust their distribution patterns in response to environmental changes, particularly temperature and prey availability shifts which naturally fluctuate. These attributes directly result in generally high adaptive capacity ratings, as reflected in scientific literature. However, it must be noted that the majority of climate assessment studies available focus on individual species, providing greater certainty through increased accuracy for these species.

Assessment limitations and gaps

The assessment benefits from a good level of information on stock status of key shark species in the WCPFC, and a relatively rich amount of global studies related to climate change and sharks. In addition, the assessment directly identifies the WCPFC's management, research, capacity building and cooperative efforts to improve overall understanding and management of Pacific shark species, in recognition of the role they play in healthy marine ecosystem functionality. Key limitation and information gaps included:

Spatial Resolution of Climate Impacts – While the assessment utilized the best available information, there remains uncertainty about how climate impacts may vary spatially across the Pacific and how different shark species may be affected. Different areas within the WCPFC Convention Area may experience varying degrees of climate change impacts, potentially creating spatial heterogeneity in vulnerability that the current assessment may not fully capture.

Species-specific Understanding – Although the assessment drew on key WCPFC shark species information along with recent global shark assessment studies, the information used to score individual indicators was generalized based on best interpretation by the assessor of available information. As a result, the climate risk score provides a ‘generalized’ overview of how Pacific shark species collectively will fare in the face of climate change. However, key differences in species-specific health status and biological traits will drive climate risk potentially higher or lower for individual shark species.

Ecosystem-Level Interactions – The assessment focused primarily on direct impacts on key WCPFC shark species, however climate change will likely directly affect food distribution (including primary productivity some shark species rely on), which may result in broader ecosystem changes and increased levels of competition as sharks migrate poleward or encroach on other shark species habitats to hunt. These cumulative impacts are beyond the capability of the CCVA Framework to provide insights on, and bespoke research on this is considered necessary over the long-term (10 years) to more accurately understand how WCPFC marine ecosystem changes may influence shark vulnerability.

Long-term Projections – The five-year assessment timeframe, while appropriate for management planning, may not capture longer-term climate change impacts that could become more pronounced over decades. The general longevity of Pacific shark species (including the very long-live sleeper shark) means that some climate effects may manifest over longer time scales than the current assessment provides for.

Member-Specific Capacity Variations – The adaptive capacity assessment relied on general WCPFC-level information, but individual member capacity for monitoring, research, and management response varies, with clear evidence of members requiring capacity support to improve compliance found in annual compliance reporting. Some members may have greater or lesser capacity to implement adaptive management measures, potentially affecting overall system resilience.

Management Implications

Maintaining Management Effectiveness

The Medium climate risk rating suggests that current management approaches are likely to remain effective under different projected climate scenarios for key WCPFC shark species. However, it is well documented that continued monitoring and strengthening of information is required to fully understand the population trends of Pacific sharks across WCPFC fisheries, and to identify suitable adaptive measures that can be taken to further strengthen the CMM to ensure long-term conservation and sustainable use of Pacific sharks.

Addressing Data Gaps

The significant number of "Unknown" scores, particularly for exposure (53%) and adaptive capacity (29%), highlights the importance of targeted research and monitoring to reduce uncertainty. Priority areas include:

- Enhanced monitoring of environmental-biological relationships
- Improved understanding of key WCPFC shark species stock health
- Improved understanding of ecosystem considerations for sharks, including prey distribution, behaviours and competition
- Better characterization of spatial variability in climate impacts on Pacific shark species
- Assessment of member-specific adaptive capacity
- Enhanced socio-economic understanding in relation to Pacific sharks

Strengthening Adaptive Management

While the current management framework shows high adaptive capacity, there are opportunities to further enhance climate resilience:

- Integration of environmental indicators into stock assessments
- Development of climate-informed reference points
- Enhanced early warning systems for detecting climate-related changes
- Improved coordination with other RFMOs managing shark species

Proactive Conservation

The low vulnerability rating provides an opportunity to take proactive conservation measures that could help maintain this favourable status:

- Maintaining or continuing efforts to rebuild key WCPFC shark species towards healthy stock status to maximize population resilience to climate impacts
- Updated efforts to better understand the health status of non-key shark species, including skates and rays
- Protection of critical habitats and migration corridors

- Minimization of other stressors that could or are known to compound climate impacts
- Greater investment in research and monitoring activities to strengthen available information

Future Assessment Needs

Regular reassessment using the CCVA Framework will be important to track changes in vulnerability status and ensure management measures remain appropriate. Future assessments should prioritize:

- Incorporation of new climate research and projections
- Integration of ecosystem-level impact assessments
- Enhanced spatial analysis of vulnerability patterns
- Updated evaluation of adaptive capacity as management evolves
- Species-specific shark CCVAs to better understand specific management requirements and information gaps of key WCPFC shark species as identified in the 2021-2030 Shark Research Plan

Conclusions

The Climate Change Vulnerability Assessment for CMM 2024-05 (Sharks) reveals a **MEDIUM** overall climate risk, driven by high hazard and exposure ratings, offset by a low vulnerability rating. This outlook reflects the reality that Pacific sharks are under direct threat from climate change, but they have a high adaptive capacity through natural biological traits and current management and research plans to reduce the overall level of climate change risk. However, the Medium rating showcases that more work is required to both fill indicator information gaps and increase wider understanding of Pacific shark species in general (both key and non-key species) to better understand with greater certainty the level of climate risk faced. Further, individual CCVAs of individual Pacific shark species should be explored to better understand climate risk implications for both key and non-key shark species (particularly those that are currently overfished or subject to overfishing).

References

WCPFC Documents

- A Proposal for a Research Plan to Determine the Status of the Key Shark Species (2010). EB-WP-01
- A Status Snapshot of Key Shark Species in the Western and Central Pacific and Potential Management Options. WCPFC-SC7-2011/EB-WP-04
- CMM 2024-05 – Conservation and Management Measure for Sharks
- 2021-2025 Shark Research Plan.WCPFC-SC16-2020.
- Pacific-wide Silky Shark (*Carcharhinus falciformis*) Stock Status Assessment (22 July 2018) and Addendum (8 August 2018). SC14-SA-WP-08
- Pacific- wide sustainability risk assessment of bigeye thresher shark (*Alopias superciliosus*): Final Report (2016).
- Pacific-wide sustainability risk assessment of bigeye thresher shark (*Alopias superciliosus*). WCPFC-SC13-2017/SA-WP-11
- Progress against the 2021-2030 Shark Research Plan (2025). SC21-SA-IP-19.
- Southern Hemisphere porbeagle shark (*Lamna nasus*) stock status assessment (2017). SC13-SA-WP-12_rev1
- Stock Assessment and Future Projections of Blue Shark in the North Pacific Ocean through 2015 (2017). SC13-SA-WP-10.
- Stock Assessment of Southwest Pacific Blue Shark (2021). SC17-SA-WP-03
- Pacific Islands – Regional Plan of Action for Sharks (2009)
- Process for designating WCPFC key shark species for data provision and assessment (2012). SC-08
- Progress against the 2021-2030 Shark Research Plan (2024). WCPFC-SC20-2024.
- Review of non-key shark species (2016). SC12-EB-WP-08
- WCPFC: Current Stock Status and Advice Key Documents:
    - Oceanic Whitetip Shark
    - Silky Shark
    - South Pacific Blue Shark
    - North Pacific Blue Shark
    - North Pacific Shortfin Mako Shark
    - Pacific Bigeye Thresher Shark
    - Southern Hemisphere Porbeagle Shark
    - Whale Shark
    - South Pacific Shortfin Mako Shark
- WCPFC Final Compliance Monitoring Report 2024, 2023, 2021 WCPFC Shark Research Plan (2010). SC6-EB-WP-01.

- Whale Shark Mitigation (2015). SC11-EB-WP-03
- WCPFC Shark Research Plan (2014).WCPFC-SC10-2014/EB-IP06

Scientific Literature

- Cerutti-Pereyra, F., et al. (2024). Vulnerability of Eastern Tropical Pacific chondrichthyan fish to climate change. Global Change Biology, 30 (7).
- Chin, A., et al. (2010). An integrated risk assessment for climate change: analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. Global Change Biology, 16(7): 1936-1953.Mas, F., et al. (2023). New insights into the reproductive biology of the blue shark (*Prionace glauca*) in the South Atlantic Ocean. Fisheries Research, 262(106643).
- D'Antonia, B., et al. (2025). Salinity drives the distribution of a top-order predator, the tiger shark (*Galeocerdo cuvier)*, in an inverse estuary. Scientific Reports, 15 (9612).
- Diaz-Delgado, E., et al. (2021). Environmental preferences of sharks bycaught by the tuna purse-seine fishery in the Eastern Pacific Ocean. Fisheries Research, 243 (106076).
- Giddens, F., et al. (2022). Assessing the vulnerability of marine life to climate change in the Pacific Islands region. PLoS ONE, 17(7).
- Jean-Noel, D. et al. (2022). Global-Scale Environmental Niche and Habitat of Blue Shark (Prionace glauca) by Size and Sex: A Pivotal Step to Improving Stock Management. Frontiers in Marine Science, 9 (828412).
- Joung, S. & Hsu, H. (2005). Reproduction and Embryonic Development of the Shortfin Mako, *Isurus oxyrinchus* Rafinesque, 1810, in the Northwestern Pacific. Zoological Studies, 44(487-496)
- Kindong, R. et al. (2022). Size distribution patterns of silky shark *Carcharhinus falcliformis* shaped by environmental factors in the Pacific Ocean. Science of the Total Environment, 850 (157927).
- Liu, K-M., et al. (2021). Vulnerability Assessment of Pelagic Sharks in the Western North Pacific by Using an Integrated Ecological Risk Assessment. Animals, 11(2161).
- Matsumoto, R. et al. (2019). Sexual maturation in a male whale shark (*Rhincodon typus*) based on observations made over 20 years of captivity. Fishery Bulletin, 117 (78-86).
- Mejuto, J. & Garcia-Cortes, B.(2005). Reproductive and distribution parameters of the blue shark, Prionace glauca, on the basis of on-board observations at sea in Atlantic Indian and Pacific Oceans. Collective Volume of Scientific Papers ICCAT, 58.
- Musyl, M., et al. (2011). Postrelease survival, vertical and horizontal movements, and thermal habitats of five species of pelagic sharks in the central Pacific Ocean. Fishery Bulletin, 109(4): 341-368.
- Oshitani, S., et al. (2003). Age and growth of the silky shark Carcharhinus falciformis from the Pacific Ocean. Fisheries Science, 69 (456-464).
- Pistevos, J. C. A., et al. (2015). Ocean acidification and global warming impair shark hunting behaviour and growth. Nature – Scientific Reports, 5 (16293).
- Rosa, R., et al. (2014). Early-life exposure to climate change impairs tropical shark survival. Proc Biol Sci, 281 (1793).

- Rummer, J. L., et al. (2022). Climate Change and Sharks. CHAP, 767-793.
- Santos, C., P. , et al. (2024). Global risk assessment of sharks to climate change. Science of the Total Environment, 954 (176361).
- Zhang, Y. et al. (2024). Seasonal distribution patterns and conservation gaps of blue sharks in the Indo-Western Pacific Ocean. Diversity and Distributions, 30.
- Zhu, J. et al. (2023). Reproductive Biology and Distribution of the Blue Shark (*Prionace glauca*) in the Western Indian Ocean. Biology, 12(8)(1128).

Technical Reports:

- Hearn, A., et al. (Unknown). Vulnerability of top predators to climate change and adaptations for coastal and pelagic ecosystems: sharks, a case study. University of California. Retrieved from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=291336d16bb8abd4ea5262b0f35d2003c55ee8c8
- International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (2022). Stock Assessment and Future Projections of Blue Sharks in the North Pacific Ocean through 2020. Annex 12, ISC/22/ANNEX/12.
- IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report.
- Japan Meteorological Agency. (2024). RSMC Tokyo-Typhoon Center. Retrieved from https://www.jma.go.jp/
- Mukai., et al. (2022). Pacific Islands Vulnerability Assessment Shark Species Narrative. PIFSC Data Report DR-22-0019.

Other

- ADRA International (2020). URL: https://adra.org/worst-cyclone-to-ever-hit-fiji-cuts-power-water-and-communication
- Environment Hawai'i. Invertebrates, Sharks May Suffer Most From Climate Changes in the Pacific. [Cited Tuesday, July 29th 2025]. https://www.environment-hawaii.org/?p=11532
- FAO (2025). Prionace glauca Linnaeus,1758. In: *Fisheries and Aquaculture*. [Cited Tuesday, July 29th 2025]. https://www.fao.org/fishery/en/aqspecies/alpha3code/bsh
- Geography Realm. (2024). Storms in the Western Pacific Ocean. Retrieved from https://www.geographyrealm.com/storms-western-pacific-ocean/
- ICIS (2022). https://www.icis.com/explore/resources/news/2020/09/03/10548390/typhoon-maysak-forces-port-closures-as-it-makes-landfall-in-busan-south-korea/
- NOAA (2025). Sharks, Rays, and Climate Change: Impacts on Habitat, Prey Distribution, and Health. [Cited Tuesday, July 29th 2025]. https://www.fisheries.noaa.gov/feature-story/sharks-rays-and-climate-change-impacts-habitat-prey-distribution-and-healthPacific Island Climate Adaptation Science Center. URL: https://pi-casc.soest.hawaii.edu/research/research-projects/inundation-risk-for-majuro/
- Pacific RISA (2021). URL: https://www.pacificrisa.org/places/republic-of-the-marshall-islands/

- PMC (Climate change and coastal resiliency of Suva, Fiji). URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC9838293/
- Port Technology International (2022). URL: https://www.porttechnology.org/news/busan-halt-ops-as-super-typhoon-impacts-asian-supply-chains/
- ScienceDirect (2024). "The effects of tropical cyclone on the container shipping network". URL: https://www.sciencedirect.com/science/article/abs/pii/S1361920924004061
- Spennemann, Dirk H.R. Typhoons in the Marshall Islands. URL: https://marshall.csu.edu.au/Marshalls/html/typhoon/typhoon.html
- WorldFish (2024). "New Study Uncovers How Climate Change Is Deepening Labour Risks in Industrial Fisheries". URL: https://www.worldfishcenter.org/blog/new-study-uncovers-how-climate-change-deepening-labour-risks-industrial-fisheries

CCVA Report For CMM 2017-04 (Marine Pollution)

Executive Summary

The Climate Change Vulnerability Assessment (CCVA) for CMM 2017-04 (Marine pollution arising from fishing vessels) reveals **MEDIUM** overall climate risk rating, driven primarily by a high exposure score and a high adaptive capacity score, which stems from a number of 'unknowns.'

This finding demonstrates that while marine pollution from fishing vessels is primarily driven by operational practices rather than climate factors, extreme weather events significantly increase pollution risk by compromising vessel safety systems and waste management procedures. The assessment indicates that fishing vessels face climate-related operational threats including storms, cyclones, and wind stress that may compromise the effectiveness of current pollution prevention measures.

Few actions to mitigate these risks are within WCPFC's mandate. Actions to mitigate risk from other organisations might include: development of climate-specific waste management protocols for extreme weather conditions, strengthening port waste reception facility resilience, enhanced vessel waste storage systems to withstand operational hazards, and improved crew training on waste management during emergency conditions. However, from the WCPFC perspective, it could be useful to ground truth whether this assessment represents reality for fishers and whether there are any actions within WCPFC's remit it can take.

Introduction

Conservation and Management Measure (CMM) 2017-04 relates to marine pollution arising from fishing vessels, including oil or fuel products, oily residues, garbage (including dumped fishing gear), food waste, domestic waste, incinerator ashes, cooking oil, and sewage discharged into the ocean across the entire Western and Central Pacific Fisheries Commission (WCPFC) Convention Area. The principal aim of this measure is to prevent and reduce pollution from fishing vessel operations that could impact marine ecosystems and sustainability.

Climate change poses multifaceted operational threats to effective pollution prevention through direct impacts such as extreme weather events that compromise vessel operations, as well as indirect effects including damaged port waste reception facilities, equipment failures, and emergency situations that prioritize crew safety over environmental protocols. These climate-driven changes may affect the operational assumptions underlying current pollution prevention measures and potentially compromise their effectiveness in maintaining marine environmental protection.

Method

The climate change vulnerability assessment for CMM 2024-05 (Sharks) was conducted using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, an Excel based assessment tool. The assessment followed the approach and methodology outlined in the CCVA Framework guidance and information document.

Each of the four climate risk components (Hazard, Exposure, Sensitivity, and Adaptive Capacity) was evaluated using specific indicators grouped by theme. Indicators were scored using a five-point scale (High, Medium, Low, Unknown, N/A) based on available evidence.

For each indicator, supporting rationale was documented to justify scoring decisions and to identify information gaps. Where data were insufficient or uncertain, indicators were scored as "Unknown" to highlight areas requiring further research or assessment.

The assessment employed the standard five-year time horizon provided in the framework to evaluate potential climate change impacts and management responses within a policy-relevant timeframe.

Data Sources and Approach

Given the operational nature of marine pollution prevention, the majority of data for this assessment was obtained through logical inferences about the impact of climate hazards on vessel management, particularly waste storage and handling systems, supplemented by literature review. Data sources included:

- Published literature on maritime safety and extreme weather impacts on vessel operations
- Regional climate vulnerability assessments for Pacific Islands ports and infrastructure
- Studies on vessel safety and operational challenges during severe weather

Scope and Limitations

The assessment scope encompasses the entire WCPFC Convention Area and all fishing vessel operations potentially covered under CMM 2017-04. The five-year assessment timeframe focuses on near-term climate change impacts on operational systems and waste management capabilities.

Key limitations include the framework's primary design for biological rather than operational assessments, limited availability of vessel-specific waste management data during extreme weather events, and uncertainty regarding the spatial distribution of port waste reception facilities and their climate resilience across the region.

Results

Climate Risk Assessment

The CCVA yielded a **Medium** overall climate risk rating for CMM 201-07 (Marine Pollution), determined by the combination of:

- **Hazard: Medium** (25% High indicators, 17% Medium, 59% Low)
- **Exposure: High** (50% High indicators, 33% Medium, 17% Low; 6 Unknown)
- Sensitivity: Low (100% N/A)
- **Adaptive Capacity: High** (67% Medium, 33% Low, 5 Unknown)
- **Vulnerability: Medium** (combination of Low sensitivity and High adaptive capacity

Component Analysis

Hazard Assessment: LOW

The hazard assessment reveals a fundamental distinction between biological/ecological hazards and operational hazards in their relevance to marine pollution from fishing vessels.

Biological/Ecological Hazards (All Rated LOW)

Temperature extremes (H1) demonstrated no established causal relationship between temperature extremes and increased pollution discharges. Pollution prevention measures (proper waste storage, discharge protocols, equipment maintenance) operate independently of temperature extremes.

Increased sea surface temperature (H2) showed limited direct causal relationship but potentially some indirect operational impacts such as warmer waters extending fishing seasons leading to longer voyages and more waste accumulation or equipment stress on cooling systems or storage systems.

Ocean acidification (H3) represents a chemical process with no operational connection - it doesn't affect vessel mechanical systems or waste management procedures, garbage handling, or crew behaviour.

Salinity (H4) and deoxygenation (H5) are biological stressors with no direct operational connection to fishing vessels. The pollution sources occur regardless of salinity or seawater oxygen levels.

Current change (H7) shows limited causal relationship as pollution sources are operational decisions not current-driven events. More nuanced than other biological hazards as current change can affect where pollution might go or affect fuel consumption or operational costs.

Operational Hazards (Rated MEDIUM to HIGH):

Wind stress (H6) received a HIGH rating due to direct operational impacts affecting vessel stability, making waste/gear handling difficult. Crew focus shifts to safety over environmental protocols during dangerous wind conditions. These hazards may cause pollution through high winds causing unsecured materials to blow overboard, damage waste storage systems, or increase the risk of gear loss. Garbage and food waste may be easily blown overboard, and hazards may affect deck cleaning procedures.

Storms (H8) received a HIGH rating as they create dangerous conditions and can affect deck operations. These events could lead to gear loss, waste containment failure, emergency discharges, or a higher risk of fuel or oil spill.

Cyclones (H9) received a HIGH rating as they can lead to extreme vessel instability, operational shutdown, equipment damage to waste storage, and emergency response where crew focus will be on safety not waste disposal.

Precipitation extremes (H10) received a MEDIUM rating as they present less immediate safety threat which potentially means less disruption to waste management, but still risk affecting waste management systems, washing accumulated pollutants (oil, debris) off decks, storage system overflow. Flooding can also disrupt port waste management services or limit access for waste disposal.

Wave height (H12) received a MEDIUM rating as it can potentially affect normal waste management procedures, with higher risk of gear or other garbage being lost or swept overboard. High waves make waste handling dangerous and difficult.

Sea level rise (H11) received a LOW rating as there is no direct vessel impact (vessels adapt to different water levels) but could in time lead to flooded or damaged port waste reception facilities. As a gradual infrastructure issue, this rating may be updated to medium over time.

Exposure Assessment: HIGH

The exposure assessment is based on literature review and logical inferences about the impact of identified hazards on vessel management, particularly waste storage and handling systems. The high exposure rating reflects the frequent occurrence of operational hazards in the WCPO, as documented in regional disaster frequency studies, and the widespread nature of fishing operations across areas prone to extreme weather events.

Key exposure factors include the high frequency of tropical cyclones (25-30 annually in the Western Pacific), regular storm events affecting major fishing ports, and the extensive maritime area where fishing vessels operate often far from emergency assistance.

Vulnerability Assessment: Medium (a combination of low sensitivity and low adaptive capacity)

Sensitivity Analysis: No Sensitivity Indicators Relevant to the CMM

A critical finding of this assessment is that no sensitivity indicators within the framework were found to be relevant to CMM 2017-04. This does not necessarily represent a limitation of the framework, but does reflect that operational measures are likely to have less relevance to any given CCVA. The CCVA was primarily designed for species-focused assessments.

The absence of relevant sensitivity indicators highlights the fundamental difference between climate impacts on biological systems versus operational systems. While biological sensitivity relates to species' physiological and ecological responses to environmental change, operational sensitivity involves equipment functionality, procedural effectiveness, and human behavioural responses under stress conditions.

Adaptive Capacity Analysis: Framework Limitations

The adaptive capacity assessment attempts to examine the ability of the fishing industry and regulatory systems to adjust waste management practices in response to climate-driven operational challenges. However, the framework's biological focus limited the applicability of many indicators to operational pollution prevention measures. Some adaptive capacity indicators were ‘unknown’ because they relate to the experience and observation of seafarers. Ground-truthing this would possibly alter the overall assessment outcome.

The assessment revealed that marine pollution is interconnected with climate change and can impact climate resilience, but the relationship operates primarily through operational disruption rather than biological pathways.

Discussion

Interpretation of Climate Risk Assessment Results

The Climate Change Vulnerability Assessment (CCVA) for CMM 2017-04 (Marine Pollution) yielded a **MEDIUM** overall climate risk rating, driven by contrasting low hazard ratings for biological factors and high exposure to operational hazards. This finding reflects the unique nature of pollution prevention as primarily an operational rather than ecological challenge.

Operational vs. Biological Risk

The assessment clearly demonstrates that marine pollution from fishing vessels is primarily driven by operational factors rather than biological/ecological climate impacts:

- Operational practices and procedures
- Equipment functionality
- Crew training and compliance
- Port waste reception facility availability
- Economic and human safety incentives/disincentives

Climate change increases pollution risk primarily through extreme weather events that compromise these operational systems rather than through direct environmental changes affecting marine life. The hazard assessment revealed that temperature extremes (marine heatwaves) do not directly influence vessel pollution behaviours, while operational hazards create conditions where normal waste management procedures break down.

This assessment has broader implications beyond marine pollution, potentially extending into other operational aspects such as labour practices and vessel safety protocols. The framework's biological focus means it cannot adequately capture:

- Human behavioural responses under operational stress

- Mental health and physical health impacts that result from working in increasingly difficult weather conditions or spending longer at sea due to weather impacting catch.
- Equipment resilience and failure modes
- Procedural effectiveness during emergency conditions
- Infrastructure vulnerability to climate impacts
- Economic and logistical factors affecting compliance

Labor and Operational Practices: The same climate hazards that compromise waste management also affect crew safety, working conditions, and operational decision-making during extreme weather events.

Infrastructure Resilience: Port waste reception facilities and vessel waste management systems require climate-resilient design to maintain functionality during increasingly frequent extreme weather events.

Emergency Response Coordination: Climate hazards that create pollution emergencies can simultaneously disable communication systems needed for emergency response, creating compounded risks.

Regional Disaster Preparedness: The frequent occurrence of operational hazards (storms, cyclones) documented in regional studies indicates a need for enhanced preparedness specifically addressing waste management during emergencies.

Management Implications - Climate Change as a Risk Multiplier

Although the CCVA framework focuses specifically on climate-related stressors, the assessment reveals that climate change acts as a risk multiplier for marine pollution rather than a direct driver. Unlike direct pollution sources, which are operational decisions, climate impacts create conditions that make proper waste management more difficult or impossible to maintain.

The assessment suggests several areas for enhanced management attention:

Immediate Operational Responses:

- Development of extreme weather waste management protocols
- Enhanced vessel waste storage system resilience
- Improved crew training for emergency waste handling procedures
- Strengthened port waste reception facility climate protection

Medium-term Strategic Adaptations:

- Integration of climate projections into pollution prevention planning
- Development of regional emergency waste management coordination
- Enhanced monitoring of pollution incidents during extreme weather events
- Review of compliance frameworks to account for climate emergency situations

Long-term Framework Development

The assessment highlights the need for operational-specific vulnerability assessment tools that can better capture the unique risks faced by management measures focused on human activities rather than biological conservation.

Strengthening Future Assessments

Future assessments could be significantly strengthened through:

- Development of operational-specific indicators for climate vulnerability assessment
- Integration of maritime safety expertise and emergency response specialists
- Enhanced data collection on vessel waste management performance during extreme weather
- Regional coordination to share best practices for climate-resilient pollution prevention

The assessment demonstrates that while current frameworks may be limited for operational measures, the underlying climate risks are real and require targeted management responses that account for the operational nature of pollution prevention challenges.

References

ADRA International. (2020). Worst cyclone to ever hit Fiji cuts power, water and communication. Retrieved from https://adra.org/worst-cyclone-to-ever-hit-fiji-cuts-power-water-and-communication

Asian Development Bank. (2020). Regional Study. Pacific Community (SPC).

Geography Realm. (2024). Storms in the Western Pacific Ocean. Retrieved from https://www.geographyrealm.com/storms-western-pacific-ocean/

ICIS. (2022). Typhoon Maysak forces port closures as it makes landfall in Busan, South Korea. Retrieved from https://www.icis.com/explore/resources/news/2020/09/03/10548390/typhoon-maysak-forces-port-closures-as-it-makes-landfall-in-busan-south-korea/

International Monetary Fund. (2025). Impact Dynamics of Natural Disasters and the Case of Pacific Island Countries.

IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Japan Meteorological Agency. (2024). RSMC Tokyo-Typhoon Center. Retrieved from https://www.jma.go.jp/

Pacific Island Climate Adaptation Science Center. Inundation risk for Majuro. Retrieved from https://pi-casc.soest.hawaii.edu/research/research-projects/inundation-risk-for-majuro/

Pacific RISA. (2021). Republic of the Marshall Islands. Retrieved from https://www.pacificrisa.org/places/republic-of-the-marshall-islands/

Pacific Risk Information System (PacRIS). Retrieved from https://www.spc.int/pacrisk

PMC. Climate change and coastal resiliency of Suva, Fiji. Retrieved from https://pmc.ncbi.nlm.nih.gov/articles/PMC9838293/

Port Technology International. (2022). Busan halt ops as super typhoon impacts Asian supply chains. Retrieved from https://www.porttechnology.org/news/busan-halt-ops-as-super-typhoon-impacts-asian-supply-chains/

ScienceDirect. (2024). The effects of tropical cyclone on the container shipping network. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S1361920924004061

SPC. (2022). Advancing climate change monitoring in the Pacific Islands Countries and Territories.

Spennemann, D. H. R. Typhoons in the Marshall Islands. Retrieved from https://marshall.csu.edu.au/Marshalls/html/typhoon/typhoon.html

Assessment conducted using WCPFC Climate Change Vulnerability Assessment Framework
Assessment period: July 2025

CCVA Report for CMM 2024-06 (North Pacific Striped Marlin)

Executive Summary

The Climate Change Vulnerability Assessment (CCVA) for CMM 2024-06 (North Pacific Striped Marlin) reveals a **LOW** overall climate risk rating, driven by medium hazard and sensitivity ratings, high exposure rating, but notably high adaptive capacity that reduces overall vulnerability to low.

This finding suggests that while North Pacific striped marlin face significant climate-related exposures and moderate sensitivity to environmental changes, the species' inherent biological characteristics and existing management framework provide substantial adaptive capacity to respond to climate challenges. The assessment indicates that current management approaches are likely to remain effective under projected climate scenarios, though targeted enhancements could further strengthen resilience.

Priority actions within WCPFC's scope could include: enhanced monitoring of stock distribution and abundance patterns, strengthened data collection on environmental-biological relationships, improved integration of climate considerations into stock assessments, and maintenance of flexible management measures that can adapt to changing conditions.

Introduction

Conservation and Management Measure (CMM) 2024-06 relates to the conservation and management of North Pacific striped marlin (*Kajikia audax*) in the North Pacific Ocean portion of the WCPFC Convention Area. The principal aim of this measure is to ensure the long-term sustainability of the North Pacific striped marlin stock through science-based management approaches, including catch limits, monitoring requirements, and data collection standards. The stock is currently overfished and subject to overfishing.

Climate change poses various threats to billfish species through direct impacts such as ocean warming, changes in ocean chemistry, and altered current patterns, as well as indirect effects including shifts in prey distribution, changes in spawning and migration patterns, and altered ecosystem productivity. These climate-driven changes may affect the biological assumptions underlying current stock assessments and management measures.

This assessment aims to evaluate the climate change vulnerability of CMM 2024-06 using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, providing evidence-based insights to support adaptive management and enhance the climate resilience of North Pacific striped marlin conservation measures.

Method

The climate change vulnerability assessment for CMM 2024-06 was conducted using the WCPFC Climate Change Vulnerability Assessment (CCVA) Framework, an Excel based assessment tool. The assessment followed the approach and methodology outlined in the CCVA Framework guidance and information document.

Each of the four climate risk components (Hazard, Exposure, Sensitivity, and Adaptive Capacity) was evaluated using specific indicators grouped by theme. Indicators were scored using a five-point scale (High, Medium, Low, Unknown, N/A) based on available evidence.

For each indicator, supporting rationale was documented to justify scoring decisions and to identify information gaps. Where data were insufficient or uncertain, indicators were scored as "Unknown" to highlight areas requiring further research or assessment.

The assessment employed the standard five-year time horizon provided in the framework to evaluate potential climate change impacts and management responses within a policy-relevant timeframe.

Data Sources and Approach

The assessment drew upon multiple data sources to evaluate climate vulnerability across the four risk components:

- Peer-reviewed scientific literature on striped marlin biology, ecology, and climate change impacts
- WCPFC stock assessment reports and scientific committee documents
- Regional climate change projections and oceanographic data for the North Pacific
- International scientific reports on billfish responses to environmental variability
- WCPFC technical reports and meeting documents related to North Pacific striped marlin management

Scope and Limitations

The assessment scope encompasses the North Pacific Ocean portion of the WCPFC Convention Area where North Pacific striped marlin occur and are managed under CMM 2024-06. The five-year assessment timeframe focuses on near-term climate change impacts and management responses.

Key limitations include reliance on primarily North Pacific-focused data sources, limited spatial resolution of some climate projections, and uncertainty regarding region-specific biological responses that may vary across the species' range within the WCPFC area.

Results

Climate Risk Assessment

The CCVA yielded a **LOW** overall climate risk rating for CMM 2024-06 (North Pacific Striped Marlin), determined by the combination of:

- **Hazard: Medium** (45% High indicators, 9% Medium, 45% Low)
- **Exposure: High** (56% High indicators, 33% Medium, 11% Low;, 8 Unknown)
- **Sensitivity: Medium** (21% High indicators, 42% Medium, 38 Low, 3 Unknown)
- **Adaptive Capacity: High** (62% High indicators, 23% Medium, 15% Low, 10 Unknown)
- **Vulnerability: Low** (combination of Medium sensitivity and High adaptive capacity)

Component Analysis

Hazard (Medium Rating) – The medium hazard rating reflects moderate levels of climate-related threats relevant to North Pacific striped marlin. Key hazards scoring as "High" include temperature extremes, increased sea surface temperature, ocean acidification, deoxygenation, and current changes. These represent significant environmental stressors that could affect striped marlin habitat and prey availability. However, hazards related to extreme weather events and infrastructure impacts generally scored lower, reflecting the pelagic nature of the species and its habitat.

Exposure (High Rating) – The high exposure rating indicates that North Pacific striped marlin populations and their ecosystems frequently encounter identified climate hazards. This reflects the species' broad distributional range across areas experiencing significant oceanographic changes, including warming waters and shifting current patterns. The high proportion of "Unknown" scores (36%) highlights substantial data gaps regarding specific exposure patterns across the species' range.

Sensitivity (Medium Rating) – The medium sensitivity rating suggests moderate susceptibility to climate-related changes. While striped marlin show some sensitivity to environmental changes, their biological characteristics—including broad thermal tolerance, high mobility, and opportunistic feeding behaviour—provide resilience to climate stressors. Areas of higher sensitivity include potential impacts on reproduction and prey availability.

Adaptive Capacity (High Rating) – The high adaptive capacity rating reflects both biological and management-related factors that enable effective responses to climate change. Striped marlin's high mobility, broad distribution, and opportunistic feeding behaviour provide natural adaptive capacity. Additionally, WCPFC's flexible management framework, scientific monitoring programs, and capacity for responsive decision-making contribute to institutional adaptive capacity. However, the high proportion of "Unknown" scores (43%) indicates uncertainty about some adaptive capacity elements.

Discussion

Interpretation of Climate Risk Assessment Results

The **LOW** overall climate risk rating for North Pacific striped marlin represents a relatively positive outlook compared to other species assessments, reflecting both the inherent resilience of this highly mobile pelagic species and the adaptive management framework in place. This finding aligns with scientific understanding of billfish as generally resilient to environmental variability due to their life history characteristics.

Concordance with Scientific Literature

The low climate risk assessment is consistent with existing literature on billfish responses to climate variability. Striped marlin are known to be highly mobile, wide-ranging predators capable of tracking favourable environmental conditions and prey availability. Their broad thermal tolerance and opportunistic feeding behaviour provide natural buffering against climate-related changes.

Studies have shown that billfish species like striped marlin can adjust their distribution patterns in response to environmental changes, particularly temperature and prey availability shifts. The species' capacity for long-distance movements and flexible habitat use supports the high adaptive capacity rating identified in this assessment.

Assessment Strengths and Limitations

Strengths

The assessment benefits from a relatively robust knowledge base for North Pacific striped marlin compared to some other species, including regular stock assessments, biological research, and monitoring through fisheries data collection. The WCPFC's established management framework provides a solid foundation for evaluating institutional adaptive capacity.

Key Limitations and Data Gaps

Spatial Resolution of Climate Impacts – While the assessment utilized the best available information, there remains uncertainty about how climate impacts may vary spatially across the North Pacific striped marlin's range. Different areas within the WCPFC Convention Area may experience varying degrees of climate change impacts, potentially creating spatial heterogeneity in vulnerability that the current assessment may not fully capture.

Ecosystem-Level Interactions – The assessment focused primarily on direct impacts on striped marlin, but climate change effects on prey species and broader ecosystem dynamics could have significant indirect impacts. Changes in food web structure and prey availability represent important pathways for climate impacts that require further investigation.

Long-term Projections – The five-year assessment timeframe, while appropriate for management planning, may not capture longer-term climate change impacts that could become more pronounced over decades. Striped marlin's longevity means that some climate effects may manifest over longer time scales than the current assessment window.

Member-Specific Capacity Variations – The adaptive capacity assessment relied on general WCPFC-level information, but individual member capacity for monitoring, research, and management response may vary significantly. Some members may have greater or lesser capacity to implement adaptive management measures, potentially affecting overall system resilience.

Management Implications

Maintaining Management Effectiveness – The low climate risk rating suggests that current management approaches are likely to remain effective under projected climate scenarios. However, this should not lead to complacency, as continued monitoring and adaptive management will be essential to maintain this positive status.

Addressing Data Gaps – The significant number of "Unknown" scores, particularly for exposure (36%) and adaptive capacity (43%), highlights the importance of targeted research and monitoring to reduce uncertainty. Priority areas include:

- Enhanced monitoring of environmental-biological relationships
- Improved understanding of climate impacts on prey species and food webs
- Better characterization of spatial variability in climate impacts
- Assessment of member-specific adaptive capacity

Strengthening Adaptive Management – While the current management framework shows high adaptive capacity, there are opportunities to further enhance climate resilience:

- Integration of environmental indicators into stock assessment and management procedures
- Development of climate-informed reference points and harvest control rules
- Enhanced early warning systems for detecting climate-related changes
- Improved coordination with other RFMOs managing billfish species

Proactive Conservation Approaches – The relatively low vulnerability provides an opportunity to take proactive conservation measures that could help maintain this favourable status:

- Maintenance of rebuilding efforts towards healthy stock status to maximize resilience to climate impacts
- Protection of critical habitats and migration corridors
- Minimization of other stressors that could compound climate impacts
- Investment in research and monitoring infrastructure

Future Assessment Needs

Regular reassessment using the CCVA framework will be important to track changes in vulnerability status and ensure management measures remain appropriate. Future assessments should prioritize:

- Incorporation of new climate research and projections
- Integration of ecosystem-level impact assessments
- Enhanced spatial analysis of vulnerability patterns
- Updated evaluation of adaptive capacity as management evolves

Conclusions

The Climate Change Vulnerability Assessment for North Pacific striped marlin reveals a **LOW** overall climate risk, driven primarily by the species' high adaptive capacity and moderate sensitivity to climate stressors. This positive outlook reflects both the biological resilience of this highly mobile pelagic species and the effectiveness of current management arrangements.

References

WCPFC Documents

- CMM 2024-06 - Conservation and Management Measure for the North Pacific Striped Marlin
- SC19-SA-WP-11 ISC23 Annex 14 - Stock Assessment Report for Striped Marlin (Kajikia audax) in the Western and Central North Pacific Ocean through 2020
- WCPFC Final Compliance Monitoring Report 2024, 2023, 2022, 2021, 2020
- WCPFC. https://www.wcpfc.int/doc/10/north-pacific-striped-marlin

Scientific Literature

- Breitburg, D., et al. (2018). Declining oxygen in the global ocean and coastal waters. *Science*, 359(6371).
- Cattano, C., et al. (2018). Correlated effects of ocean acidification and warming on behavioral and metabolic traits of a large pelagic fish. *Ecology*, 99(4), 806-815.
- Chang, H.-Y., Sun, C.-L., Yeh, S.-Z., Chang, Y.-J., Su, N.-J., & DiNardo, G. (2018). Reproductive biology of female striped marlin *Kajikia audax* in the western Pacific Ocean. *Journal of Fish Biology*, 92(1), 105-130.
- Esbaugh, A.J. (2017). Physiological implications of ocean acidification for marine fish: emerging patterns and new insights. *Annual Review of Marine Science*, 10, 1-26.
- Evans, D.H., Piermarini, P.M., & Choe, K.P. (2009). Fish osmoregulation for general marine fish physiology. *Physiological Reviews*, 89(3), 971-1007.
- Humphreys, R. & Brodziak, J. (2019). Reproductive maturity of striped marlin, (*Kajikia audax*), in the central North Pacific off Hawaii. ISC/19/BILLWG-2/2.
- Kültz, D. (2015). Physiological mechanisms used by fish to cope with salinity stress. *Journal of Experimental Biology*, 218(12), 1907-1914.
- Lam, C.H., Kiefer, D.A., & Domeier, M.L. (2015). Habitat characterization for striped marlin in the Pacific Ocean. *Fisheries Research*, 166, 80-91.
- Lam, C.H., Tam, C., & Lutcavage, M.E. (2022). Connectivity of striped marlin from the Central North Pacific Ocean. *Frontiers in Marine Science*, 9, 879463. https://doi.org/10.3389/fmars.2022.879463
- Lam, C.H., Tam, C., Nielsen, A., & Lutcavage, M.E. (2022). Striped marlin in their Pacific Ocean milieu: Vertical movements and habitats vary with time and place. *Frontiers in Marine Science*, 9, 879503. https://doi.org/10.3389/fmars.2022.879503
- Rykaczewski, R.R. & Checkley, D.M. (2008). Influence of ocean winds on the pelagic ecosystem in upwelling regions. *Proceedings of the National Academy of Sciences*, 105(6), 1965-1970.
- Shimose, T., Yokawa, K., & Saito, H. (2010). Habitat and food partitioning of billfishes (Xiphioidei). *Aquatic Biology*, 10, 203-214.
- Sippel, T., et al. (2007). Studies on striped marlin movements and habitat utilization in the Southwest Pacific Ocean. *Marine and Freshwater Research*, 58(11), 1095-1108.

- Stramma, L., et al. (2012). Expansion of oxygen minimum zones may reduce available habitat for tropical pelagic fishes. *Nature Climate Change*, 2(1), 33-37.
- Su, N.-J., Sun, C.-L., Punt, A.E., Yeh, S.-Z., DiNardo, G., & Chang, Y.-J. (2013). An ensemble analysis to predict future habitats of striped marlin (*Kajikia audax*) in the North Pacific Ocean. *ICES Journal of Marine Science*, 70(5), 1013-1022.
- Su, N.-J., Sun, C.-L., Punt, A.E., Yeh, S.-Z., DiNardo, G., & Chang, Y.-J. (2015). Environmental influences on seasonal movement patterns and regional fidelity of striped marlin *Kajikia audax* in the Pacific Ocean. *Fisheries Research*, 166, 59-66.

Technical Reports

- Fukuda, H., Hoyle, S., Stewart, I., and Ahrens, R. (2024). International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) Western and Central North Pacific Striped Marlin Assessment Consensus Peer Review. ISC/24/ANNEX/11. Presented at the 24th Meeting of the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean, Victoria, Canada, June 19-24, 2024
- IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report.
- Japan Meteorological Agency. (2024). RSMC Tokyo-Typhoon Center. Retrieved from https://www.jma.go.jp/

Other

- ADRA International (2020). URL: https://adra.org/worst-cyclone-to-ever-hit-fiji-cuts-power-water-and-communication
- Geography Realm. (2024). Storms in the Western Pacific Ocean. Retrieved from https://www.geographyrealm.com/storms-western-pacific-ocean/
- ICIS (2022). https://www.icis.com/explore/resources/news/2020/09/03/10548390/typhoon-maysak-forces-port-closures-as-it-makes-landfall-in-busan-south-korea/
- Pacific Island Climate Adaptation Science Center. URL: https://pi-casc.soest.hawaii.edu/research/research-projects/inundation-risk-for-majuro/
- Pacific RISA (2021). URL: https://www.pacificrisa.org/places/republic-of-the-marshall-islands/
- PMC (Climate change and coastal resiliency of Suva, Fiji). URL: https://pmc.ncbi.nlm.nih.gov/articles/PMC9838293/
- Port Technology International (2022). URL: https://www.porttechnology.org/news/busan-halt-ops-as-super-typhoon-impacts-asian-supply-chains/
- ScienceDirect (2024). "The effects of tropical cyclone on the container shipping network". URL: https://www.sciencedirect.com/science/article/abs/pii/S1361920924004061
- Spennemann, Dirk H.R. Typhoons in the Marshall Islands. URL: https://marshall.csu.edu.au/Marshalls/html/typhoon/typhoon.html

- WorldFish (2024). "New Study Uncovers How Climate Change Is Deepening Labour Risks in Industrial Fisheries". URL: https://www.worldfishcenter.org/blog/new-study-uncovers-how-climate-change-deepening-labour-risks-industrial-fisheries