Climate risk assessment framework for aquaculture

Monterey Bay Aquarium

September 2026

Summary

The climate risk assessment (CRA) framework for aquaculture, developed by the Monterey Bay Aquarium, is a free resource that evaluates how climate change affects aquaculture species, farmers, communities, and supply chains across regions. As aquaculture now provides over half of the world's aquatic animal food, effective climate adaptation is crucial but still underfunded and often ignored in national policies. The CRA offers a systematic approach to help users identify climate hazards that can negatively affect production and livelihoods and prioritize where intervention is most needed.

The framework serves a wide range of organizations, including government agencies, non-governmental organizations, private-sector actors, research institutions, and others that seek to understand and act on climate risk in aquaculture. It combines quantitative climate and spatial data with expert judgment and the knowledge of farmers and communities, balancing scientific rigor with practical constraints and community-led prioritization. Climate risk varies by geography, species, production method, and socioeconomic context, so users customize the framework to each application while keeping a consistent, systems-based approach.

The CRA moves users from identifying risks to setting action priorities. It helps users to assess climate hazards, exposure, and vulnerability; examines the responses that farmers, communities, and governments have already taken and how well they work; and prioritizes the adaptation and resilience actions needed across the immediate, near, and long terms. It also offers a starting point for identifying the public and private finance that adaptation requires. The output is a prioritized, system-specific view of climate risk that names responsible stakeholders and sets out next steps.

Users can apply the CRA on its own or alongside the Monterey Bay Aquarium Socio-Economic Learning Framework,[1] which deepens the social and equity dimensions of the assessment through community-led listening and learning.

---

[1] *Available at: https://www.montereybayaquarium.org/change-impact/our-conservation-work/global-ocean-conservation-programs/human-rights-social-equity/socio-economic-learning-framework*

Table of contents

Introduction 4

Our response 4

Intended users 5

Methodology 6

How to apply the climate risk assessment 8

Scope and scale 9

Data and methods 9

Rating and scoring elements 10

Step 1: Hazard identification 11

Step 2: Hazard and exposure analysis 13

Step 3: Vulnerability analysis 15

Step 4: Risk analysis 17

Moving from risk to adaptation and resilience priorities 19

Bibliography 20

Acronyms

CRA	Climate risk assessment
GIS	Geographic information system
IPCC	Intergovernmental Panel on Climate Change
RCP	Representative Concentration Pathway
FAO	Food and Agriculture Organization of the United Nations
SELF	Socio-Economic Learning Framework

Introduction

Aquaculture is the leading source of seafood globally, accounting for 53 percent of total aquatic animal production and over 59 percent of aquatic animal foods for human consumption (FAO, 2026).[2] Climate change poses significant and interacting threats to the aquaculture sector and to the communities and economies that depend on it (Brugere and de Young, 2015). These threats include rising air and water temperatures, altered rainfall patterns, shifts in water salinity, rising sea levels, more frequent and intense storms and flooding, drought, and ocean acidification. There are also the compounding effects of disease, harmful algal blooms, and disruptions to input production. Many regions where aquaculture is located are among the most exposed to these impacts. Climate impacts often fall hardest on small-scale producers, farm workers, and coastal communities, which often have limited capacity, savings, or access to finance to recover from shocks or invest in adaptation.

Despite these challenges, aquaculture receives limited attention, financing, or planning for climate adaptation and resilience. National adaptation plans and disaster risk strategies rarely consider aquaculture, and sector plans often fail to incorporate future climate impacts or to prioritize farmers and communities. This leaves the sector without the necessary early warning systems or risk-based guidance essential for effective adaptation. Moreover, adaptation financing for aquaculture remains far below the required level. A review of countries' nationally determined contributions and national adaptation plans estimated that the cost of adapting the aquatic food sector in developing countries will reach about $4.8 billion annually by 2030, with costs expected to increase sharply by 2050. However, public international adaptation finance to the sector averaged only around $0.2 billion per year from 2017 to 2021, highlighting a significant funding gap (FAO, 2024).

Our response

The climate risk assessment (CRA) framework for aquaculture was developed by the Monterey Bay Aquarium Global Programs to support responsible seafood practices and healthy oceans. It has four primary objectives:

- **Assess climate risk:** Examine the hazards, exposures, vulnerabilities, and the probability and scale of impacts on aquaculture production, farmers and their families, communities, and the wider sector.
- **Facilitate community-led adaptation:** Empower farmers and community groups to articulate their own priorities for climate adaptation and resilience.
- **Prioritize adaptation and resilience actions:** Determine the priority actions, innovations, and practices required to improve climate resilience and support adaptation for farmers, communities, and the wider sector across the immediate, near, and long terms.
- **Identify finance needs:** Serve as a starting point for identifying and prioritizing the private and public financing that adaptation and resilience require.

[2] *Figures are for the 2024 reference year.*

The CRA is a core component of the Aquarium's Sustainability Labs,[3] which partners with local communities, industry, scientists, and governments to co-design, test, and scale solutions to the intertwined environmental, social, and economic challenges facing small-scale aquaculture and fisheries. The CRA provides the risk analysis that grounds this work and helps provide small-scale producers and organizations with better access to the data, resources, and financing mechanisms needed to identify and implement adaptation solutions.

As climate change impacts and vulnerabilities vary by geography, species, production methods, adaptive capacity, and socioeconomic factors, the framework is designed to be customized for each application while maintaining a consistent, structured, and systems-based approach.

Intended users

The framework is intended for broad use by any organization working to build climate-resilient aquaculture, including: governments, non-governmental organizations, private-sector entities, research institutions, and others on a project basis.

[3] *Available at: https://www.montereybayaquarium.org/change-impact/our-conservation-work/global-ocean-conservation-programs/sustainability-labs*

Methodology

The CRA follows a risk-based analytical framework, consistent with international best practices for climate risk and vulnerability assessment. Climate risk reflects the interaction of hazard, exposure, vulnerability, and response, which together determine the likelihood and severity of impacts. Building on the models of the Intergovernmental Panel on Climate Change (IPCC) and the Food and Agriculture Organization of the United Nations (FAO), the framework combines climate data, socioeconomic and governance factors, environmental conditions, and local responses to evaluate the risk to aquaculture production (IPCC, 2014; Dabbadie, 2018). Climate risk is assessed both overall and by hazard through the interaction of four interconnected components: hazards, exposure, vulnerability, and response.The overlapping nature of the risk factors in the assessment framework is illustrated in Figure 1.

- **Hazards:** Potential occurrence of a natural or human-induced physical event or impact that may cause loss to infrastructure, livelihoods, services, and/or ecosystems.
- **Exposure:** Historical and projected exposure of species, habitats, farmers, communities, and supply chain hazards.
- **Climate risk:** Interaction of hazards, exposure, vulnerability, and impact severity, considering interdependent hazards, cascading effects, adaptive capacity, and uncertainty.
- **Vulnerability:**
  Sensitivity: Susceptibility to losses from climate impacts based on intrinsic and contextual factors and local perceptions.
  Adaptive capacity: Ability to respond to or recover from climate impacts based on environmental, governance, and socioeconomic factors.
- **Response:** Actions and investments to reduce sensitivity and build capacity for adaptation and resilience of farms, communities, and the overall production system.

Figure 1. The climate risk assessment framework.

The CRA assesses climate impacts using a systems-based approach that emphasizes how multiple climate drivers, together with the characteristics of the aquaculture system and its capacity to respond, shape risk outcomes at the farm, community, sector, species, and habitat levels, rather than in isolation. This assessment framework corresponds to the initial risk assessment step of the FAO's *Aquaculture Adaptation Framework for Climate Change* (Aqua-Adapt); its findings on hazards, exposure, vulnerability, and risk are intended to feed directly into the subsequent stages of adaptation planning, implementation, and monitoring (Soto and Garcia Sampaio, 2025).

How to apply the climate risk assessment

Climate risk varies significantly based on context and location. Therefore, the framework combines quantitative climate data and spatial analysis with expert judgment and local insights. The assessment follows a structured, systems-based approach that includes hazard identification, hazard and exposure analysis, vulnerability assessment, and risk evaluation, then translates findings into adaptation and reliance priorities and actions. The overall process is illustrated in Figure 2.

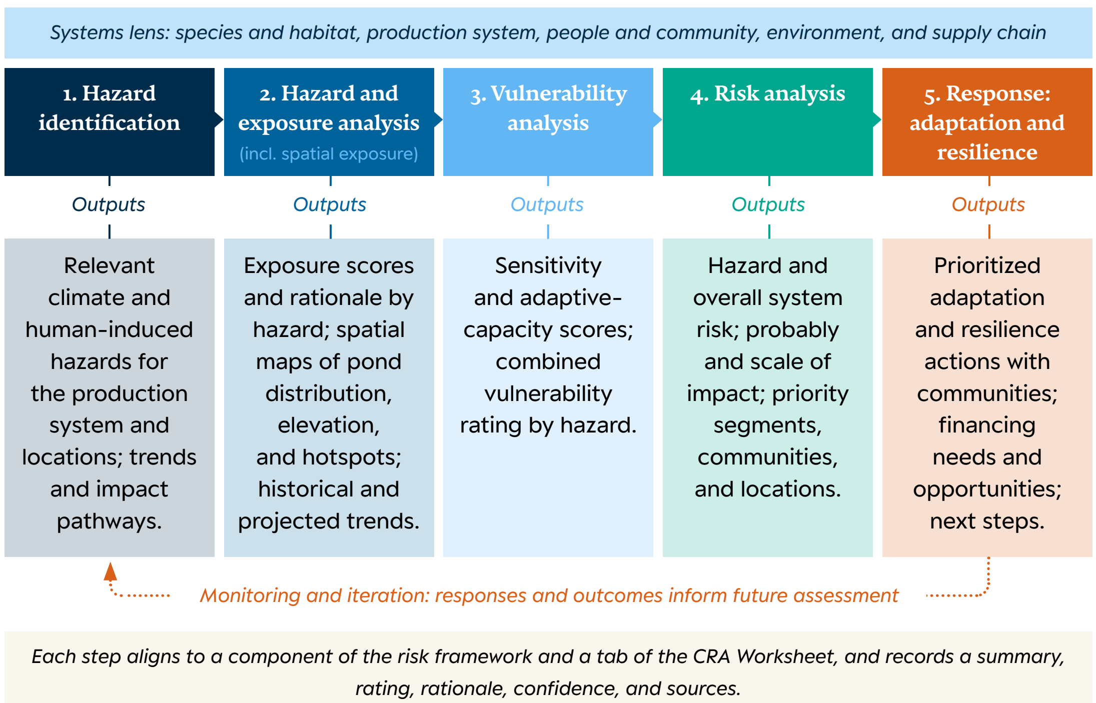

Figure 2. The climate risk assessment process.

Although the assessment is presented sequentially, it is iterative. Insights gained later in the process may influence earlier steps, such as farmers' adaptation efforts, which can either reduce or increase vulnerability and risk. Additionally, findings from the vulnerability analysis can provide further insights into hazard identification at the local level. The assessment is also flexible; the level of detail, data sources, and methods can be tailored to the specific production system, location, available resources, and timeframe. Before beginning the assessment, the Aquarium recommends defining the scope and scale, identifying the target audience and intended use of the outputs, and determining the essential data and information needed by those users.

Scope and scale

The assessment framework is adaptable and can be used at various scales, from individual farms and communities to entire regions or sectors. It can be adapted to apply to one species or multiple species and production systems, depending on the context. Using a systems approach, it considers species, habitats, production methods, people, communities, environmental factors, and supply chains as interconnected components. Additionally, it can focus on specific supply chain segments, such as inputs, transportation, or processing. Many insights from one assessment are often applicable more broadly, as risks and vulnerabilities tend to be shared across similar production systems and climates within a country or sub-region.

Data and methods

The CRA integrates quantitative climate and spatial data with community feedback and expert insights, employing a flexible mixed-methods approach tailored to the user's needs and resources. However, the Aquarium suggests the following methods:

- **Literature review** of published research to define hazard thresholds, interpret indicators, and characterize exposure, sensitivity, and adaptive capacity.
- **Climate hazard analysis** utilizing historical and projected data from climate and disaster databases, standardized climate indices, and global and regional circulation models. Where available, it incorporates local climate hazard data and models downscaled to the specific area.
- **Geographic information system (GIS) mapping** to visualize the spatial variation of exposure and risk, overlaying hazard layers with pond distribution, elevation, coastal proximity, and hydrological features.
- **Socioeconomic data and information** from baseline surveys, Socio-Economic Learning Framework (SELF) application,[4] or other studies to provide context on local perceptions of exposure and impact, levels of adaptability, and initial coping responses.
- **Key informant interviews** with industry representatives, researchers, and climate experts to validate desk research and provide context on local exposure, impacts, and adaptation.
- **Focus group discussions** with farmers and community members to capture variation and priorities based on their perception and experience of hazard exposure, impacts, and adaptation responses. Focus group discussions are often conducted in two stages: an initial session to elicit perceptions and a validation session to confirm and prioritize findings.

The CRA complements the Aquarium's SELF, an interactive tool examining small-scale producers' lives, livelihoods, and priorities across nine well-being and equity elements. Together, they offer a comprehensive view: SELF highlights social, economic, and equity factors that affect household responses to climate hazards, while the CRA identifies hazards, exposure, and vulnerabilities that threaten livelihoods. Users can integrate climate questions into SELF discussions, map community

---

[4] *Available at: https://www.montereybayaquarium.org/change-impact/our-conservation-work/global-ocean-conservation-programs/human-rights-social-equity/socio-economic-learning-framework*

assets against perceived climate stressors, and score CRA outcomes during workshops. Integrating CRA and SELF can shift decision-making to those most affected, improve assessment accuracy, and help identify actions to reduce climate risk and strengthen livelihoods.

The Aquarium recommends that the assessment be carried out by an interdisciplinary core team, reflecting the focus on climate and weather, spatial analysis, socioeconomics, and aquaculture. A typical team combines a team lead and climate expert to guide the assessment and lead the hazard and scenario analysis; a GIS specialist to develop hazard, exposure, and vulnerability maps and conduct spatial analysis; a socioeconomic adviser to assess sensitivity, adaptive capacity, and community dimensions; and an aquaculture expert to interpret species- and system-specific sensitivities, production practices, and adaptation options. The core team can be supported as needed by enumerators and partners, who support field surveys, focus group discussions and key informant interviews, and by data analysts, who process survey and climate data and support scoring and quality control.

Rating and scoring elements

Exposure, sensitivity, adaptive capacity, and the resulting vulnerability and risk are each scored using structured criteria applied by the assessment team, informed by expert knowledge, data, and local information. Each hazard is scored against several criteria on a four-point scale (Low = 1, Moderate = 2, High = 3, Very high = 4), and the criteria are averaged to produce a rating for that component and hazard. The individual component ratings feed into the risk analysis in sequence. Vulnerability for each hazard is the average of its sensitivity and adaptive capacity ratings. Hazard risk is then derived by integrating the exposure and vulnerability ratings for that hazard, informed by the assessor's judgment and the underlying data. Finally, the hazard-level risk ratings are integrated into an overall system risk.

Average scores map to overall ratings as follows:

- Very high (3.5 or above)
- High (3.5 to 2.5)
- Moderate (2.5 to 1.5)
- Low (below 1.5)

Where an average score falls near the boundary between ratings, the assessor may record a combined rating that reflects both levels (for example, High to Very high), and the rationale for any such adjustment is documented. Where information is insufficient to score a hazard, its impact, or the combined vulnerability, the assessor records an insufficient information designation and flags the need to gather more data before scoring.

Confidence ratings

To account for uncertainty in the data and information used to score exposure, vulnerability, and risk, the user records a confidence rating for each score. Confidence ratings allow users to identify data and information gaps and areas of uncertainty, which in turn highlight priorities for expert review and future research. Confidence is scored against five criteria as shown in Table 1 (High = 5, Medium = 3, Low = 1) and averaged.

Table 1: Confidence ratings for each hazard score.

Criteria	High = 5	Medium = 3	Low = 1
Reputable source	Published academic journal, climate institute reports, or climate expert	Industry articles or opinion pieces with limited sourcing for claims	No, unknown, or unclear
Date (recency)	Last 5 years	5 to 15 years	Over 15 years
More studies with same or similar results	Yes, reputable	Yes, industry articles or opinion pieces	No, unknown, or unclear
Specificity to target area	Specific to the target area or issue	Target province in the country	Region in the country or country level
Methodology	Participatory and data-driven	Limited participation or on-the-ground validation	Data models only

A further check records whether the rating has been validated externally by experts (Yes, Partially, or No/Unknown). The resulting confidence level guides interpretation: a High rating indicates the score is likely accurate with consistency across data and studies; Medium indicates some inconsistency or uncertainty about location or system differences, warranting validation by external experts and with farmers and communities; and Low indicates very uncertain information that needs further attention and validation. The team seeks additional input on any score with a Medium or Low confidence rating.

Step 1: Hazard identification

The initial step involves identifying climate hazards relevant to the focus aquaculture species, location, and communities experiencing or at risk of experiencing impacts. This can also include human-related hazards such as land subsidence and water pollution, which can exacerbate climate hazards when relevant. Hazards are described using indicators relevant to aquaculture, such as average and extreme temperatures, hot day frequency, rainfall amount and intensity, drought conditions, effective sea-level rise, and salinity intrusion.

Standardized climate indices, such as those developed by the Expert Team on Climate Change Detection and Indices, can be used (Zhang et al., 2011). Examples include the highest daily temperature of the year, the percentage of days when the temperature exceeds the 90th percentile, and the maximum rainfall over 1-day and 5-day periods. The Standardized Precipitation-Evapotranspiration Index is also used to assess drought.

The assessment team should identify potential pathways through which these hazards impact the aquaculture system, industry, or community. These pathways depend on factors such as the type and location of production, such as freshwater, brackish water, mariculture, or offshore cage farming. The examples shown in Table 2 are illustrative rather than exhaustive; users can modify by adding or removing hazards and indicators specific to their context.

Table 2: Examples of potential pathways through which hazards impact the aquaculture system, industry, or community.

Hazard	Key indicators	Potential impact pathways
Increased air and water temperature	Mean temperature annual maximum daily temperature frequency of extreme heat days; seasonal temperature shifts.	Metabolic and heat stress; reduced feed intake and growth; higher mortality during peak heat; increased disease susceptibility; algal blooms and oxygen depletion; shortened grow-out windows.
Change in precipitation and flooding	Shifts in total and seasonal rainfall; rainfall variability; extreme rainfall (maximum rainfall over 1-day and 5-day periods); flood frequency and extent.	Pond flooding and overflow; embankment erosion; sudden freshwater influx causing salinity and pH shocks (osmotic stress); disease outbreaks; infrastructure damage.
Drought and water availability	Drought frequency, duration, and intensity (e.g., Standardized Precipitation-Evapotranspiration Index); groundwater levels; freshwater access; competition over water use.	Water scarcity; hypersalinity from evaporation; reduced water exchange; degraded water quality; production disruption; conflict over water resources.
Effective sea-level rise	Cumulative effective sea-level rise (global rise plus local land subsidence); tidal inundation extent; storm-surge history and projections.	Permanent and tidal inundation of ponds; saltwater intrusion into water sources; loss of productive land; damage to infrastructure.
Salinity intrusion	Extent, frequency, and duration of saltwater intrusion, estimated from coastal proximity, elevation, and river-flow conditions; dry-season salinity trends.	Osmotic stress and mortality; altered plankton and nutrient dynamics; water quality degradation; disruption of integrated systems (e.g., rice–aquaculture); salinization of soil and groundwater.
Extreme weather events	Frequency and intensity of storms, typhoons, and cyclones; heavy-rain and high-wind events; projected changes in cyclone rainfall.	Physical damage to ponds and infrastructure; production loss; disruption to inputs and broodstock supply and to market access.
Land subsidence	Subsidence rates (GPS or leveling surveys); groundwater-level decline; frequency of forced pond abandonment.	Amplifies effective sea-level rise and inundation; worsens salinity intrusion; often irreversible loss of farmland.
Water pollution and contamination	Pollutant concentrations (e.g., heavy metals, biochemical and chemical oxygen demand); contamination incidents; compliance failures.	Acute mortality events; chronic sub-lethal effects and reduced growth; market rejection; amplified by climate extremes that mobilize pollutants.

Step 2: Hazard and exposure analysis

After identifying relevant hazards, users should analyze both hazards and exposure to evaluate the importance and emerging trends of key climate threats affecting the aquaculture system, farmers, and communities. Climate projections need to include one or more emissions scenarios, with the Representative Concentration Pathway (RCP) 4.5 as a moderate, stabilizing pathway that serves as the primary reference for medium-term adaptation (IPCC, 2021). If resources permit, users can also assess RCP 8.5, a high-emissions scenario that acts as a stress test for worst-case situations and long-term planning. These pathways describe the emissions trajectories used across successive IPCC assessments; more recent assessments pair them with the Shared Socioeconomic Pathways, which set out the societal conditions under which each trajectory could unfold (ClimateData.ca, n.d.).[5]

Selecting climate models

The analysis should include a mix of general circulation models for their structural diversity and extensive historical data, the delta-change approach to compare future projections against a baseline period, adjusting for systematic biases, and statistical downscaling to increase accuracy:

- **Choosing a mix of general circulation models:** No single model is definitive, so the user should combine models with different underlying assumptions and strong records of reproducing past climate data to capture a realistic range of outcomes rather than a single model's blind spot (Tebaldi and Knutti, 2007).
- **Delta-change approach:** Raw general circulation model output often runs slightly too warm, too wet, or out of season in the present day. The delta-change approach avoids this by taking the change a model projects between a baseline period and a future period, then applying that change to observed local climate (Teutschbein and Seibert, 2012).
- **Statistical downscaling:** General circulation models run on a coarse grid, often 100 km or wider, which lacks the resolution for a specific set of farms, a district, or a stretch of coast. Statistical downscaling relates the coarse output to fine-scale observed climate on a high-resolution reference grid, then translates the projection to the local level where decisions are made (Permana, 2026).

Climate data and sources

Exposure and potential impacts are assessed by comparing historical data with future projections across specific time horizons: a historical baseline (such as the last 20 years), a near-term period (around 5 to 20 years), and a mid-term period (approximately 25 to 40 years). Historical data establish past exposure levels and initial adaptation efforts, while future trends reveal the potential for increased

[5] *The underlying scenarios are defined in IPCC (2021).*

exposure and the necessity for further adaptation and investments. The datasets employed will differ depending on the region and the hazards being evaluated, but typical sources include:

- **Downscaled climate projections** such as the NASA Earth Exchange Global Daily Downscaled Projections, WorldClim (derived from the Coupled Model Intercomparison Project Phase 6), the Climate Hazards Group InfraRed Precipitation with Station data, and the Copernicus Climate Data Store provide temperature, precipitation, and derived hazard indicators under multiple scenarios (Thrasher et al., 2022; Fick and Hijmans, 2017; Funk et al., 2015).
- **Water and disaster risk data** such as the World Resources Institute Aqueduct water risk atlas, the World Bank Climate Change Country Profiles, and the Emergency Events Database.
- **Spatial and elevation data** such as digital elevation models (e.g., the Shuttle Radar Topography Mission or national equivalents), satellite imagery for pond mapping, national geospatial and land subsidence datasets, and hydrological network data.
- **Country- and region-specific** climate vulnerability indices, sector assessments, and national adaptation plans.

These sources are supplemented with published secondary literature, species- and system-specific thresholds, and primary information gathered through interviews, surveys, and expert consultation.

Exposure ratings

It is important to review existing research at this stage to set appropriate thresholds, understand what the indicators mean, and connect climate trends to potential impacts and risks in aquaculture, including how different species tolerate heat and salinity. The user then rates exposure for each hazard against four criteria (Table 3).

Table 3: Calculating exposure ratings.

Criteria	Very high = 4	High = 3	Moderate = 2	Low = 1
Intensity or severity	Catastrophic disruption	Major disruption	Moderate to minor disruption	Limited or insignificant disruption; low intensity or severity
Time scale	Immediate disruption or exposure	Gradual, high or increasing intensity over a short period (under 10 years)	Gradual, increasing over time, or high intensity but not expected for over 10 years	Disruption or exposure not expected within 20 years
Expected scale or level of exposure	Complete or near-complete (over 90 percent) of target area	Large share (over 50 percent) of target area	Medium share (under 50 percent) of target area	Localized to particular areas (under 20 percent)
Frequency	Very frequent or constant exposure	Annual, seasonal, or frequent exposure	Every other year or influenced by other phenomena (e.g., El Niño, La Niña)	Occasional or incidental exposure

Option: Spatial exposure analysis

A GIS-based hazard exposure analysis can be a useful supplementary approach when data and resources permit. Alternatively, exposure can be qualitatively assessed through secondary reports, district data, and perceptions from farmers and experts. Spatial exposure using GIS involves mapping and scoring indicators for each defined area—such as district, sub-district, or zone—where finer scales may limit data accuracy. This spatial data is combined with survey-based exposure metrics: pond area derived from satellite imagery; mean pond elevation (lower levels indicating higher exposure); coastal proximity (closer indicating higher risk); population density relative to pond area; and water-system dependency and flood history. Hazard layers are overlaid to generate maps illustrating pond locations, elevation, and proximity to hazards, which are then validated through farmer interviews and focus groups. Data sources include aquaculture plans, district statistics, land-use records, satellite imagery, digital elevation models, and hydrological datasets, which are analyzed using GIS tools.

Step 3: Vulnerability analysis

Vulnerability analysis assesses how prone the aquaculture system, farmers, and communities are to hazards, as well as their capacity to manage and recover from impacts. It consists of two components: sensitivity, which measures the extent to which species, production systems, people, and ecosystems are affected by a hazard, and adaptive capacity, which reflects the ability to anticipate, withstand, and recover from these impacts. The user evaluates each component using literature thresholds, spatial indicators, and data from surveys, focus group discussions, and key informant interviews. Since vulnerability is complex and cannot be fully quantified, the analysis can combine both indicators with expert insights and local knowledge.

Sensitivity

Sensitivity captures how susceptible the species, production systems, people, and ecosystems are to harm from each hazard. The literature review provides thresholds linking hazards to species performance, while survey data provide empirical validation through observed stress, disease incidence, and production impacts. Sensitivity is assessed across several dimensions:

- **Species and system:** Species-level thresholds such as thermal and salinity tolerance and disease susceptibility, and system characteristics such as farming intensity, stocking density, pond design, and reliance on shared water sources.
- **People and community:** The economic, social, and cultural dependence on aquaculture, including the share of income and employment derived from the sector and the importance of the species to the region by volume and value of production, employment, exports, and share of gross domestic product.
- **Environment and ecosystem:** Baseline conditions such as water quality and habitat status that can amplify or buffer climate impacts.

Sensitivity is scored for each hazard using the sensitivity criteria, with farmers' and communities' perceptions recorded as one of the criteria (Table 4).

Table 4: Calculating sensitivity ratings.

Criteria	Very high = 4	High = 3	Moderate = 2	Low = 1
Intensity or severity of impact	Catastrophic impact	Major impact	Moderate to minor impact	Limited or insignificant impact; low intensity or severity
Expected scale of impact	Complete or near-complete (over 90 percent) of target area	Large share (over 50 percent) of target area	Medium share (under 50 percent) of target area	Localized to particular areas (under 20 percent)
Perception (farmers and communities)	Top one or two main concerns identified in multiple studies	A concern but not top priority, or inconsistent across studies	Identified by a minority of respondents; believe they can adapt	Not a priority or not identified

Adaptive capacity

Adaptive capacity is the ability of the aquaculture sector, supply chain, and communities to reduce or recover from the impacts of climate hazards. Assessing adaptive capacity considers three main factors:

- **Aquatic food system:** Production status, disease prevalence, water quality conditions, habitat and ecosystem buffers, and stakeholder awareness and skills
- **Governance:** Policy environment, climate monitoring, early warning systems, integration of climate data into sector planning, and adaptation and resilience initiatives
- **Socioeconomic factors:** Such as income sources, access to finance and insurance, social infrastructure and services, farmer organizations, knowledge transfer, and disaster recovery programs.

Adaptive capacity is rated overall and, where relevant, by hazard (Table 5). It uses an inverted scale so that greater ability corresponds to a lower score and therefore lower vulnerability.

Table 5: Calculating adaptive capacity ratings.

Rating	Description
Very high ability = 1	Very high ability, already showing multiple adjustments and adaptation, with limited negative factors impacting the ability to adapt.
High ability = 2	Already showing ability and willingness to adapt to changes; multiple positive internal and external factors, with some negative elements.
Moderate ability = 3	Some ability, with more negative factors than positive influencing adaptive capacity.
Low ability = 4	Very limited capacity or willingness to adapt; multiple negative factors impacting capacity.

Response: Adaptation and resilience

Before moving to the risk analysis, the user identifies the responses that farmers, communities, governments, and other actors have already taken in response to climate hazards and assesses how well those responses have worked. The analysis then assesses effectiveness: whether a response has reduced exposure, sensitivity, or vulnerability, and for whom. Some measures lower risk and strengthen livelihoods at the same time. Others can fall short, reach only some households, or prove maladaptive, meaning they reduce risk in the short term while increasing exposure or vulnerability over the longer term or shifting it onto others. Understanding which responses work, which do not, and why enables the assessment to build on what communities already do well and to prioritize the actions, investments, and innovations most likely to reduce risk across the immediate, near, and long terms. Consistent with the framework's community-led approach, farmers, farmers' organizations, women-led groups, and local institutions help identify and prioritize these actions and record them in community action plans.

Step 4: Risk analysis

The risk analysis combines hazards, exposure, vulnerability, and adaptation or resilience strategies to assess the likelihood and severity of impacts. The user starts by analyzing specific climate hazard risks and then integrates them into an overall climate risk system, considering both probability and impact level. The user must identify the compound and cascading effects among different hazards, as climate change impacts aquaculture production and communities through complex interactions.

The risk analysis should also identify key dependencies between the aquaculture system and the larger ecosystem, economy, and social structures, since these can heighten exposure and potential impacts. This requires examining how these elements interact and influence each other, including relevant interdependencies such as:

- **Water competition and conflict:** Climate-driven water scarcity can prompt farmers to extract more groundwater, accelerating land subsidence and fueling conflict with agriculture, industry, and domestic users.
- **Economic sectors:** Interactions between aquaculture and sectors such as tourism, agriculture, and manufacturing.
- **Infrastructure systems:** Water supply, energy, and transportation systems that are interlinked and can propagate disruption.
- **Non-climate stressors:** Stressors such as industrial pollution and coastal development can compound climate hazards, degrading water quality and habitat and further reducing adaptive capacity.

As part of the risk analysis, the user scores risk across five classes, from Insufficient information to Very high, facilitating comparisons across hazards and locations (Table 6). When presenting risk outputs, the user can group hazards by their risk profile—such as critical compounding risks (very high exposure and vulnerability), gradual-onset risks (high exposure with high or moderate vulnerability), and potentially significant risks (high exposure with uncertain vulnerability, requiring further research). An optional approach is to incorporate risk quantitatively by standardizing and combining hazard, exposure, and vulnerability indices into a composite risk score.

Table 6: Calculating risk analysis ratings.

Rating	Description
Insufficient information	• More information is needed to understand exposure to the hazard, its potential impact, or the combined vulnerability.
Low	• Confidence that exposure or potential impact from the hazard is limited historically and in the near-term. • The hazard is not a critical risk for the application and location. • Adaptive capacity of the species, farmer, and community reduces impacts.
Moderate	• Some exposure and impact in recent trends or potential in the near-term for increased impacts, warranting monitoring and future inclusion in planned but less immediate focus. • Exposure and effects are limited in scope, location, or geography. • Adaptive capacity limits but does not prevent all impacts.
High	• Recent trends show increasing exposure and impact, and projections indicate increasing vulnerability and impact in the near-term (5 to 20 years). • Impacts may be gradual rather than acute, and/or vulnerability is high but focused on a few locations in the production region. • Adaptive capacity and actions have helped to reduced impacts but will be limited as exposure and compounding hazards increases.
Very high	• Clear evidence of exposure to hazards in recent years with significant and escalating impacts; projections showing high probability of increased exposure and severity impacts in the near-term. • Multiple climate and human-induced hazards are interconnecting and causing compounding and cascading impacts. • Vulnerability affects many farmers, communities and supply chain segments, and adaptive capacity is limited.

Moving from risk to adaptation and resilience priorities

This assessment aims to shift from merely identifying risks to actively guiding actions and investments that enhance resilience and support adaptation efforts for farmers, communities, and the aquaculture system. Building resilience involves a holistic perspective that connects environmental health, farming practices, community well-being, and institutional support. Since climate risks and resilience differ considerably across production systems, adaptation strategies must be customized to specific species and systems, reflecting the priorities of local farmers and communities. Based on the locally led model of the Sustainability Labs, this approach allocates resources to local innovators, communities, farmers, and adaptation champions, emphasizing low- and no-regret actions that strengthen resilience and income. It also safeguards farmers, workers, and communities with social safety nets, livelihood support, and disaster response. The final assessment should present a prioritized, system-specific action plan, identify responsible stakeholders, and outline next steps for research, consultation, and partnership building.

Bibliography

Brugere, C. and de Young, C. “Assessing climate change vulnerability in fisheries and aquaculture: Available methodologies and their relevance for the sector.” FAO Fisheries and Aquaculture Technical Paper No. 597. Rome: FAO, 2015.

CARE. “Climate Vulnerability and Capacity Analysis (CVCA) Handbook (2nd ed.).” CARE International, 2019.

ClimateData.ca. “Understanding Shared Socio-economic Pathways (SSPs),” n.d. https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

Dabbadie, L. et al. “Effects of climate change on aquaculture: Drivers, impacts and policies”. In: *Impacts of Climate Change on Fisheries and Aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome: FAO, 2018.

Fajardo, J., Corcoran, D. and Roehrdanz, P.R. “GCM compareR: A web application to assess differences and assist in the selection of general circulation models for climate change research.” *Methods in Ecology and Evolution*, 11(5), 656-663, 2020.

FAO. “The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action.” Rome: Food and Agriculture Organization of the United Nations (FAO), 2024.

Fick, S.E. and Hijmans, R.J. “WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas.” *International Journal of Climatology*, 37(12), 4302-4315, 2017.

Funk, C. et al. “The Climate Hazards Infrared Precipitation with Stations (CHIRPS).” *Scientific Data*, 2, 150066, 2015.

Handisyde, N., Telfer, T. and Ross, L. “Vulnerability of aquaculture-related livelihoods to changing climate at the global scale.” *Fish and Fisheries*, 18(3), 466-488, 2017.

IPCC. “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.” Geneva: Intergovernmental Panel on Climate Change (IPCC), 2014.

IPCC. “Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.” Cambridge University Press, 2021. https://www.ipcc.ch/report/ar6/wg1/

Maraun, D. et al. “Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user.” *Reviews of Geophysics*, 48, RG3003, 2010.

Monterey Bay Aquarium. “Sustainability Labs, Global Ocean Conservation Programs,” n.d. https://www.montereybayaquarium.org/change-impact/our-conservation-work/global-ocean-conservation-programs/sustainability-labs

Monterey Bay Aquarium. “Socio-Economic Learning Framework (SELF).” Global Ocean Conservation Programs, n.d. https://www.montereybayaquarium.org/change-impact/our-conservation-work/global-ocean-conservation-programs/human-rights-social-equity/socio-economic-learning-framework

Permana, D.S. “Evaluation and ranking of NEX-GDDP-CMIP6 models based on monthly precipitation climatology over Indonesia.” *Frontiers in Climate*, 8, 1748663, 2026.

Soto, D. and Garcia Sampaio, F., eds. “Aquaculture Adaptation Framework for Climate Change (Aqua-Adapt): A tool to support the development and implementation of strategies to improve aquaculture’s resilience to climate change.” FAO Fisheries and Aquaculture Technical Papers, No. 739. Rome, FAO, 2025. https://doi.org/10.4060/cd6476en

Tebaldi, C. and Knutti, R. “The use of the multi-model ensemble in probabilistic climate projections.” *Philosophical Transactions of the Royal Society A*, 365(1857), 2053-2075, 2007.

Teutschbein, C. and Seibert, J. “Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods.” *Journal of Hydrology*, 456, 12-29, 2012.

Thrasher, B. et al. “NASA Global Daily Downscaled Projections, CMIP6 (NEX-GDDP-CMIP6).” *Scientific Data*, 9, 262, 2022.

Zhang, X. et al. “Indices for monitoring changes in extremes based on daily temperature and precipitation data.” *Wiley Interdisciplinary Reviews: Climate Change*, 2(6), 851-870, 2011.