Climate services for aquatic food systems in Asia and Africa: Current state, challenges, and opportunities to enhance at scale

2025

Credit: Peerzadi Rumana Hossain/WorldFish

Contents

Author
Peerzadi Rumana Hossain.

Citation
This publication should be cited as: Hossain PR. 2025. Climate services for aquatic food systems in Asia and Africa: Current state, challenges, and opportunities to enhance at scale. Penang Malaysia: WorldFish. Report: 2025-96.

Acknowledgments
This report on the future direction of climate services for aquaculture is produced under the CGIAR Science Program on Climate Action. Opinions stated in this narrative are those of author and do not necessarily reflect the views of the CGIAR program. We would like to thank all funders who support this research through their contribution to the CGIAR Trust Fund.

Contact
WorldFish Communications and Marketing Department, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia. Email: worldfishcenter@cgiar.org

Creative Commons License
This publication is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0), which permits non-commercial use, including reproduction, adaptation and distribution of the publication provided the original work is properly cited. To view this license, visit https://creativecommons.org/licenses/by-nc/4.0/

© 2025 WorldFish.

Design and production
Chua Seong Lee, Thavamaler Ramanathan, and Sabrina Chong, WorldFish.

Cover photo
Peerzadi Rumana Hossain/WorldFish.

Highlights

Climate risk management has become a national priority for many countries in Asia and Africa, such as Bangladesh, Zambia, and Malawi, with high vulnerability to climate impacts. Bangladesh is vulnerable to heatwaves, erratic and intense rains, and extremes such as cyclones and floods, while Zambia and Malawi are vulnerable to increasing frequency and intensity of floods and droughts together with rising temperatures.

Climate information and advisory services have supported operational and strategic risk management across various food systems, but they remain underinvested in aquaculture and largely unexplored in fisheries. As such, enhancing these services for aquaculture at scale and exploring such systems for fisheries are critically needed to de-risk value chains and build the resilience of the aquatic food systems sector. The capacity to deliver and access these services is highly uneven and inadequate across the aquatic food sector economy in the Global South.

One of the main challenges is the absence of real-time monitoring systems for pond water quality data, such as water temperature, dissolved oxygen, pH, and ammonia. These monitoring systems are necessary to sustainably operationalize decision support systems that can reach small-scale producers with data-driven, tailored, and context-specific climate services.

Strategic involvement of hydro-met services, fisheries departments, aquaculture institutes, and line ministries is essential for inclusive development, finance, policies, and execution of nationally determined contributions (NDCs). However, sectoral silos in the NDC process undermine effective climate action.

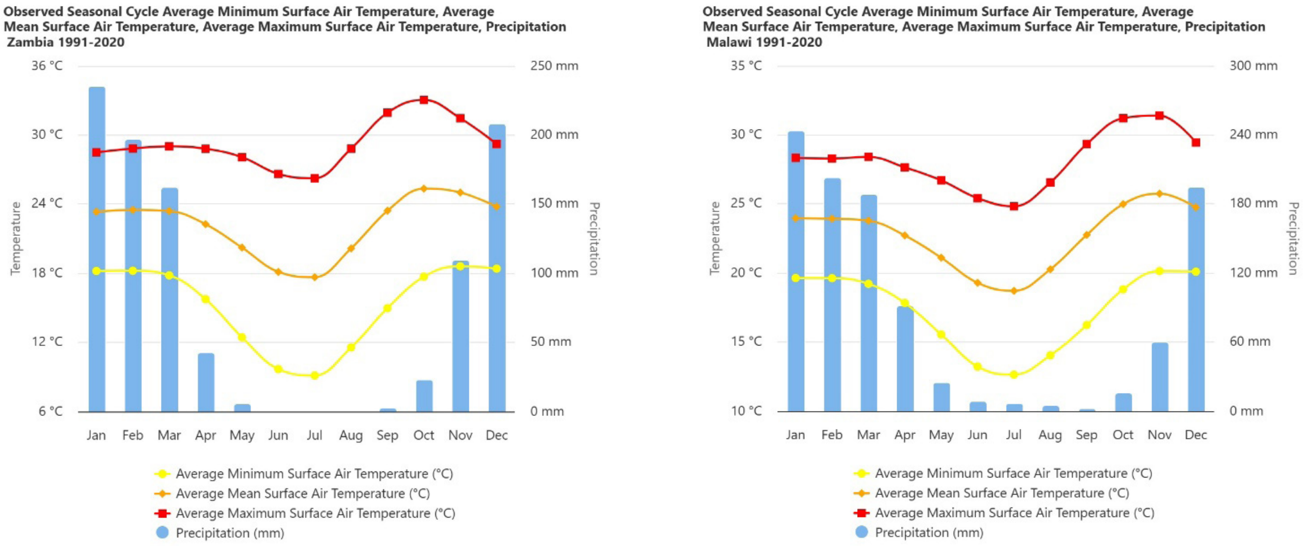
Climate change and aquatic food systems: Adapt and manage climate risks

Scientific evidence on rising atmospheric carbon dioxide (CO_2) concentrations and subsequent global warming is explicit. Marine and freshwater systems have already absorbed about 30% of this anthropogenic CO_2, with 93% of the consumed resultant heat (Reid et al. 2019). As a result, these critical systems for fisheries and aquaculture are undergoing drastic changes. For instance, offshore and coastal waters are experiencing expansion in low-oxygen zones (Breitburg et al. 2018). More pronounced acidification is another concern—a worrying phenomenon for fish and other lifeforms in the water—along with increasing temperature, uncertain precipitation patterns, frequent flooding, severe cyclones, intense drought, and a spate of other extreme weather events. These changes have significant impacts on aquatic ecosystems and the availability and sustainability of aquatic food resources (Tigchelaar et al. 2021). We illustrate this through observed climate impacts in three countries where WorldFish works: Bangladesh, Malawi, and Zambia.

Located in the largest deltaic region in the world, Bangladesh is highly vulnerable to climate change because of a combination of geographical, environmental, and socioeconomic factors (World Bank 2022). It is the second-most climate vulnerable country for freshwater aquaculture and has the least ability to cope with the impacts of climate change for brackish water production (Barange et al. 2018; Cinner et al. 2018). The country's low-lying delta, dense population, and reliance on climate-sensitive aquatic food systems make it vulnerable to rising sea levels, extreme weather, and water-related disasters. These risks include cyclones, floods, droughts, sea-level rise, and changes in water salinity and temperature—all of which impact fish breeding, growth, and production. For instance, seasonal signatures of extreme heat can exceed the physiological tolerance level of aquatic plants, animals, and microorganisms; sudden temperature fluctuations can lead to mortality; dry and cold spells can trigger disease outbreaks; erratic or intense rainfall events can cause harvest losses; and floods and cyclones can damage or destroy aquaculture stock, gear, and facilities. However, being a deltaic country with the world's largest flooded wetland and the third-largest aquatic biodiversity in Asia also makes Bangladesh one of the most suitable regions for aquaculture and fisheries in the world (Shamsuzzaman et al. 2017). The prominence of aquatic foods in Bangladesh is reflected in a few key areas. Aquatic foods account for 60% of animal protein intake and contribute about 5% to the country's gross domestic product, while livelihood opportunities employ more than 10% of the population through fishing, aquaculture, handling, and processing. Therefore, managing climate risks in the aquatic food sector has become a national priority now for the country's continued development.

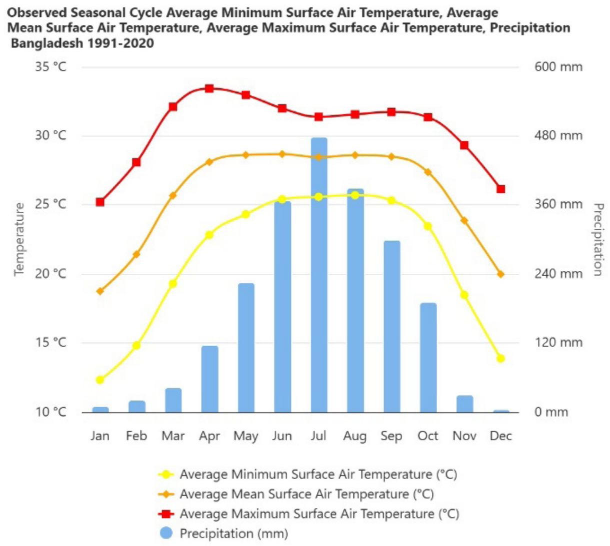
The scenario is similar for Zambia and Malawi. Climate variability and extreme weather—such as temperature changes, irregular rainfall, droughts, floods, and strong winds—significantly affect fisheries and aquaculture in both countries (Maulu et al. 2024). Declining rainfall and shorter, unpredictable rainy seasons further strain water resources vital for fish farming (Hossain et al. 2025). Droughts reduce water availability and quality, causing conflicts over water use among sectors. Rising water temperatures also harm fish health and increase the risk of disease. As such, smallholder fish farmers, who rely mostly on climate-sensitive systems like aquaculture and fisheries for their livelihoods, are highly vulnerable and at the forefront of such impacts because of their relatively limited adaptive capacity and knowledge of climate risk management measures (Muthoka 2024). Zambia, specifically, is the leading fish producer in Southern Africa and fifth in Africa by volume, with small-scale fish farmers meeting demand for affordable fish and reducing dependence on wild catch and imports. Therefore, building climate resilience of small-scale aquatic food producers with timely information and tailored advisory services in the Southern African Development Community (SADC) region is imperative to adapt and manage risks for food, nutrition, and livelihood security (Mohammed et al. 2021).

Figure 1. Observed seasonal cycle of average minimum, mean, and maximum surface air temperature and precipitation for Zambia and Malawi during 1991–2020.



Source: https://climateknowledgeportal.worldbank.org/

Figure 2. Observed seasonal cycle of average minimum, mean, and maximum surface air temperature and precipitation for Bangladesh during 1991–2020.



Source: https://climateknowledgeportal.worldbank.org/

Climate impacts are escalating, and climate services must accelerate

Extreme weather events—such as more fequent and intense heatwaves, heavy rainfall, droughts, floods, and tropical storms—are becoming more frequent and severe because of climate change. However, many vulnerable countries across the Global South lack the financial resources, infrastructure, and knowledge to adapt effectively, leading to a growing adaptation gap. Given this, climate services, early warning systems, climate safety nets, and adaptation policies are more critical than ever to build resilience, improve risk perception, facilitate behavioral changes, and enhancing planning. Context-specific climate services provide actionable climate-related information to support decision-making and planning across various food systems. However, there is a scarcity of decision support systems and tools to generate, translate, transfer, and communicate tailored climate data, information, advisories, risk management strategies, early warnings, and safety nets to aquatic food producers, value chain actors, vulnerable communities, and government organizations, and this, in turn, limits the capacity of stakeholders to effectively make decisions and adapt to climate change impacts (FAO 2019; WordFish 2020; Hossain et al. 2024; Kondowe et al. 2025). To close this gap, it is essential to enhance climate services for aquatic food systems at scale, especially those that are highly feasible and have potential synergies with mitigation (IPPC 2023; Lee et al. 2024). These services support sustainable development by addressing climate risks and enabling long-term planning, and they are essential for advancing climate-resilient development and reducing losses and damages from climate-induced risks. In this line, the Global Framework for Climate Services (GFCS), a UN–led initiative coordinated by the World Meteorological Organization (WMO), aims to strengthen the production, delivery, and use of climate information and services to support decision-making in climate-sensitive sectors. This global coordination mechanism needs to be considered for national frameworks for climate services (NFCS) to operationalize climate services at the country level, to promote co-production of climate services involving users, scientists, and policymakers, and to encourage integration of climate services into policies, planning, and investments.

Climate services landscape for fisheries and aquaculture in the Global South: Recent developments and challenges

South Asia: Bangladesh

The current scenario for climate information services (CIS) in Bangladesh's aquaculture and fisheries sector shows growing demand to manage climate risks, like temperature and rainfall variability. Still, significant gaps remain in both availability and accessibility. Initiatives are underway to create decision support systems to provide actionable, tailored information to fish farmers to reduce disease outbreak, stress, mortality, and financial losses (WorldFish 2020). However, those initiatives lack a fully operational CIS platform for fisheries and aquaculture that delivers actionable, species-specific advisories (Hossain et al. 2021).

To address this, a significant pilot study developed a decision framework using temperature and rainfall thresholds for four key fish species backed by an air–water temperature model to generate risk information and advisory services with a five-day lead time for pond aquaculture (Mohammed 2024). Additionally, a seasonal approach to climate risk management for aquaculture was also explored, with a one-month lead time, as forecasted information before the specific risk season, like summer and monsoon, particularly the number of expected days of warm and heavy rain, are critical for strategic decision-making (Montes et al. 2022). Economic forecasts of climate-induced losses in aquaculture in Bangladesh showed that the potential economic value of aquacultural CIS could be up to USD 14 million a year, if 10% of the damage can be offset by appropriate services through a range of multisector efforts to establish and extend these services to farmers at scale (Islam et al. 2024). These collective research results identified policy opportunities and informed policy dialogues in Bangladesh (Hossain, Ahmed & Barman 2023). Although there is increasing recognition of CIS's potential to reduce climate-related losses, the sector lags behind crop agriculture in implementation. For instance, government bodies like the Department of Agricultural Extension and Agriculture Information Service have already developed the Bangladesh Agro-Meteorological Information System (BAMIS) portal to disseminate dedicated agricultural climate services. Ongoing projects and research aim to develop tailored, reliable services, but there remain major challenges in data scarcity, inadequate delivery infrastructure, limited capacity, and dissemination.

Southern African Development Community region: Zambia and Malawi

In the SADC region, CIS for fisheries and aquaculture are evolving, but significant gaps persist in the availability and accessibility of such services tailored specifically for aquatic food production. Although the value of CIS for managing climate-related risks is increasingly recognized, application within the aquatic food systems sector lags behind the agriculture sector (Moyo 2025). For instance, the Fund for the Promotion of Innovation in Agriculture (i4Ag), as part of the special initiative Transformation of Agricultural and Food Systems, developed and implemented E-PICSA, a digital climate service for smallholder agriculture farmers in Zambia and Malawi. Efforts are underway to address these shortcomings, notably through collaborations with international partners. Given the importance of the blue economy in the SADC region, there is an emphasis on using digital CIS not only to mitigate economic loss and damage but also to secure food, nutrition, and livelihoods. Through the Program for Improving Fisheries Governance and Blue Economy Trade Corridors in SADC Region (PROFISHBLUE), WorldFish, jointly with partners, developed a digital climate information system for Malawi and Zambia called Blue Resilience. This work identified that targeted analysis of climate vulnerabilities, risks, and adaptation options for the fisheries and aquaculture sector is still widely lacking. This hampers the effective inclusion of CIS as risk managing measures in national and regional plans, policies, strategies, and climate commitments. In addition, access to and use of CIS among smallholder farmers in rural areas remain limited. Reliance on digital systems requires internet access and smartphones, knowledge and skills are inadequate, and there is no weather-based insurance to effectively mitigate risks and protect against losses.

Recent developments of climate services in these three countries (Table 1) are at an initial stage in comparison with guidance from the GFCS (Table 2). Several points for immediate consideration at the national level range from integrating climate services into national aquaculture and fisheries policies, reducing gaps in localized data and forecast delivery systems, developing technical capacity among smallholder farmers, and connecting fragmented donor coordination and funding mechanisms.

Additionally, technical and procedural advancements like remote monitoring, modeling, prediction, scenario development, task team formulation, and national frameworks and coordination are all needed to scale the implementation of CIS for aquaculture. The collective challenge for aquaculture climate services in Bangladesh, Zambia, and Malawi is the lack of tailored services, with current efforts primarily focusing on land-based agriculture. Other challenges include limited collaboration among government, the private sector, nongovernmental organizations (NGOs), and communities. This has led to fragmented and less effective interventions and a gap in research to integrate localized forecasts with farm-level data, particularly pond conditions, water quality, or species-specific needs for precise decision-making (Table 3). Additionally, there are institutional weaknesses such as inadequate infrastructure, particularly a weather observation station shortage at the lowest administrative level and limited skills in using updated forecast models to generate localized forecasts for delivering effective climate services. There are also financial constraints for enhancing aquaculture climate services at scale, and limited access to resources both soft and hard like appropriate technologies, financial instruments, training, and input materials—all of which are essential for effective use of climate services. An example of this is weather index insurance, an automated, climate-triggered financial safety net for farmers. Although it is found around the world, it remains nascent in Bangladesh, with pilot schemes underway and further development needed to scale impact. In Zambia, it holds promise for climate risk protection, but scaling requires tailored climate services, improved aquaculture-specific data, and strong partnerships across government, insurers, and the aquaculture sector. Social challenges are common, especially the digital divide caused by poor internet coverage in rural remote areas, lower smartphone penetration, and gendered gaps in line with access to capacity development initiatives. Another key challenge for pilot developments is the absence of business models needed to maintain digital climate services platforms in the long run, with no clear transition to national ownership after the short-cycled project.

Table 1. Recent developments of climate services for aquatic food systems in Bangladesh, Zambia, and Malawi.

Aquatic food systems	**Progress summary**	**Status**		
		Bangladesh	**Zambia**	**Malawi**
Aquaculture	Introductory dialogues with relevant stakeholders and value chain actors	Major work done	Major work done	Major work done
	Relevant information identified to tailor climate services	Major work done	Major work done	Major work done
	Climate analytics of historical data	Inadequate	Inadequate	Inadequate
	Climate impacts and risk modeling	Absent	Absent	Absent
	Decision tree development	Major work done	Major work done	Major work done
	Seasonal climate services	Inadequate	Absent	Absent
	Air–water temperature model	Inadequate	Inadequate	Inadequate
	Internet of Things (IoT) for water quality parameters	Absent	Absent	Absent
	Prototype development and validation	Major work done	Major work done	Major work done
	Decision support system	Inadequate	Inadequate	Inadequate
	AI integration (chatbots and voice-based systems)	Absent	Absent	Absent
	Capacity building	Inadequate	Inadequate	Inadequate
	CIS for value chain actors	Inadequate	Inadequate	Inadequate
	Delivery mechanism	Inadequate	Inadequate	Inadequate
	Economic evaluation	Absent	Absent	Absent
	Impact assessment	Inadequate	Absent	Absent
	Scaling readiness	Inadequate	Inadequate	Inadequate
	Weather risk index–based aquaculture insurance products	Absent	Absent	Absent
Fisheries	Introductory dialogues with relevant stakeholders and value chain actors	Absent	Major work done	Major work done
	Relevant information identified to tailor climate services	Absent	Major work done	Major work done
	Climate analytics, impacts and modeling	Absent	Absent	Absent
	Decision support system	Absent	Absent	Absent
	Risk preparedness capacity	Absent	Absent	Absent
	Climate risk informed services and safety nets	Absent	Absent	Absent

Absent	(white)
Inadequate	(light blue)
Major work done	(dark blue)

Table 2. Global Framework on Climate Services (GFCS) guidance and key implications for aquatic food systems.

GFCS guidance for fisheries		Key implications at the national level
Inclusion as a climate-sensitive food sector	Consider fisheries a priority for food security.	Fisheries and aquaculture should be incorporated into national and regional climate service planning.
Stakeholder engagement	Emphasize aquatic food producers' (e.g. fish farmers, fishers) engagement for tailoring information in line with their needs.	The climate services for fisheries and aquaculture must be co-developed with fishers, aquaculture operators, extension services, value chain actors, etc., for effective use.
Observation and monitoring	Strengthen observing systems, including hydroclimatic and environmental variables relevant to aquatic food systems.	For fisheries and aquaculture climate services, this means IoT-enabled water quality monitoring for data-driven precise decision-making and predictive modeling.
Modeling, prediction, and scenarios	Advance climate modeling and prediction at seasonal to decadal scales, and produce climate projections for decision support.	Fishery and aquaculture systems should be integrated into oceanographic, ecosystem, and hydrological and climate models so that forecast products incorporate likely impacts and risks (i.e., changes in productivity, disease outbreak, species distribution, etc.).
Climate services products tailored to the sector	Develop specialized climate products, like drought outlooks, risk maps, species threshold, etc., rather than generic products.	Specialized products might include weekly weather forecasts for operational decision-making, seasonal forecasts of temperature and rainfall for strategic decision-making, salinity intrusion risk, flood or drought risk affecting inland aquaculture, sea level rise impacts, etc.
Capacity building	Place high priority on capacity development, both at the institutional and user level, to ensure sustainability.	All value chain actors of the aquatic food sector need to be trained in climate data, interpretation, adaptation planning, and how to use climate services for managing risks.
Integration into adaptation	Support NAPs and other climate adaptation frameworks.	Fisheries and aquaculture adaptation strategies should incorporate climate services in decision-making, such as where to site farms, when to stock, which species, risk mitigation, etc.
Coordination and institutionalization	Establish NFCS and coordinate across sectors.	Line ministries, fisheries and meteorological departments, and oceanographic centers should be part of NFCS for collaboration and inclusion in national climate service planning.
Task teams and specific initiatives	Set up a task team for climate services – fisheries (TT4CS-F).	The TT4CS-F initiative can bring aquaculture and fisheries into the climate services fold at the national level.

Table 3. Challenges for tailored aquaculture CIS in Asia and Africa.

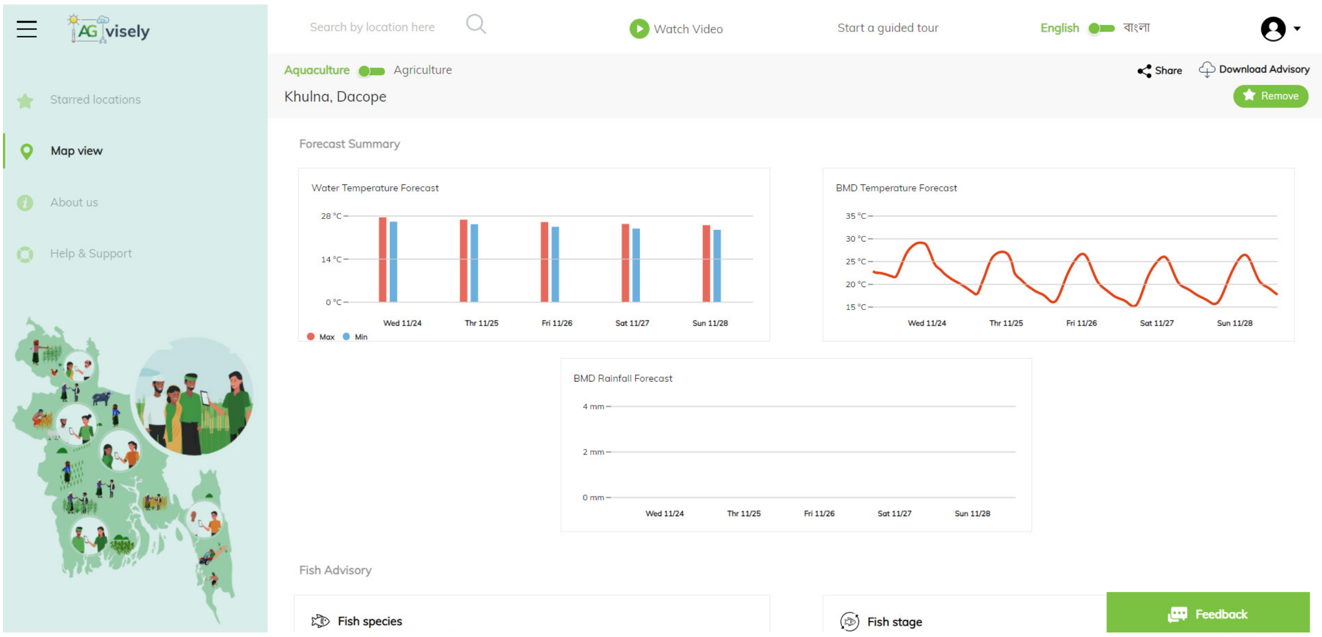
<table>
<tr><th>Challenges</th><th>Bangladesh</th><th>Zambia</th><th>Malawi</th></tr>
<tr><td>Institutional and policy</td><td>• Fragmented coordination and weak collaboration within and among public and private sectors
• Lack of skilled labor in extension services and local administration
• Inadequate infrastructure and investment
• Weak communication and monitoring channel</td><td colspan="2">• Limited institutional capacity (infrastructural, technical, and financial) to design and implement effective aquaculture CIS
• Scarcity of data on the specific needs of aquaculture CIS
• Lack of integration of climate services into national fisheries strategies
• Limited interagency collaboration
• Dependence on external expertise</td></tr>
<tr><td>Technical and data</td><td colspan="3">• Insufficient data availability for accurate climate assessment and decision-making
• Limited localized forecasting tailored to specific aquaculture zones
• Poor integration of climate information with farm-level data systems
• Lack of data-driven analytics and predictive modeling to support adaptive management</td></tr>
<tr><td>Socio economic</td><td>• Low adaptive capacity of small-scale fish farmers
• Lack of knowledge, skills, and resources
• Gendered gaps to access CIS tools and training
• Inequitable resource distribution
• Trust and adoption
• Uneven digital literacy</td><td colspan="2">• Limited awareness and understanding
• Lack of local buy-in
• Poor internet coverage in rural remote areas along with less smartphone penetration
• Low digital literacy and skills to access decision support systems and interpret climate services
• Weak extension services</td></tr>
<tr><td>Financial</td><td>• High initial investment needed to develop and deploy climate services
• Limited access to credit for small-scale fish farmers
• Low willingness to pay
• Funding gaps for training and outreach
• Absence of climate risk insurance for aquaculture
• Very few donor-backed pilots, though testing, evaluating impacts, further improvement, adoption and scaling underfunded</td><td colspan="2">• Limited access to formal credit
• Mostly regional and international aid with minimal local investment
• Fewer insurance products tailored to aquaculture, though lack of knowledge and financial resources to manage climate risks</td></tr>
</table>

Digital ecosystems for aquaculture climate information and advisory services in Bangladesh, Zambia, and Malawi

Agvisely–Aquaculture

Agvisely–Aquaculture was developed to help extension officers at Bangladesh's Department of Fisheries provide fish farmers with tailored, context-specific, and translated climate advisories so that they could make informed decisions to mitigate climate-related risks. In this line, a decision framework was developed that focused on temperature and rainfall thresholds of four economically important and widely cultured fish species, particularly for the grow-out phase (Hossain et al. 2021). When a threshold is forecasted to be passed, an automatic system provides location-specific management advice for listed fish farmers through SMS. This digital system integrates gridded weather forecasts from the Bangladesh Meteorological Department, processed to the upazila level using WRF algorithms, along with water temperature data from reference ponds. Automated data processing, including air-to-water temperature translation, generates timely advisories. The Bangladesh Fisheries Research Institute and the Department of Fisheries both reviewed and endorsed this framework. However, the key technical barrier for the sustainability of this process is the absence of automated data input systems from the pond water environment to translate the air temperature forecasts into water quality parameters like pH, dissolved oxygen, hydrogen sulfide (H_2S), ammonia (NH_3), etc., for adaptive management decisions.

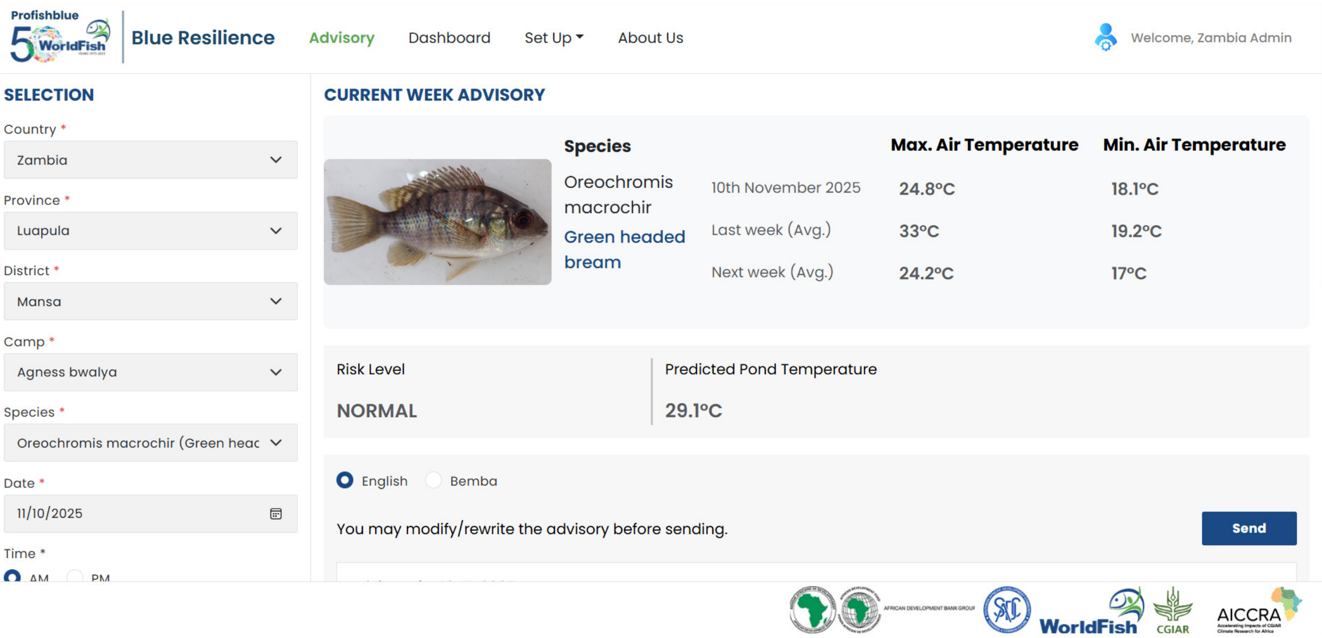
Figure 3. Agvisely–Aquaculture, a digital climate services system for aquaculture in Bangladesh.



Blue Resilience

Building on the knowledge and experience from Bangladesh, Blue Resilience was tailored to Zambia and Malawi. This digital system generates climate-risk information for two fish species, and communicates advisory services to fish farmers and extension officers so that they can make climate-informed decisions, paving the way for climate risk management initiatives for aquatic foods in the SADC region (Hossain et al. 2025). Blue Resilience has been shared with the Department of Fisheries in both countries and with the SADC Secretariat. The CIS platform is still in the initial stages and requires testing and evaluation for impact. Moreover, as a pilot, this development focused only on two provinces in Zambia and one region in Malawi, so the geographic scope needs to be extended.

Figure 4. Blue Resilience, a digital climate services system for aquaculture in Zambia and Malawi.



How national hydro-met services, fisheries departments, and line ministries strategically can contribute to NDCs

NDCs by each party of the Paris Agreement are required every five years to prepare, communicate, and update covering two tracks: (1) increasing resilience and adaptation capacity, and (2) low-emission pathways and net zero emissions by 2050. In this regard, NDCs 3.0 are already being prepared; however, the national source of authoritative weather, water, and climate science information in their respective countries has often not been involved in the process of development or implementation (WMO, 2024). Moreover, climate-sensitive sectors like fisheries and aquaculture, which are important for food, nutrition, and livelihood security at the national level as well as for the global agenda, particularly for SDG 13 (climate action) and SDG 14 (life below water), are either absent (e.g., NDC 3.0 Zambia) or not properly addressed for just transition (e.g., NDC 3.0 Bangladesh). Therefore, national hydro-met services, fisheries departments, and line ministries need to be involved in the whole NDC process to accelerate implementation by breaking silos. Doing so will result in co-production and co-design of transformational risk management measures, long-term adaptation pathways maps, and mitigation plans based on climatic and non-climatic contributing factors and high-quality datasets.

National climate information and services activities could contribute to an inclusive NDC formulation and implementation process through better climate-informed adaptation and funding. These activities include developing and delivering timely, accessible, and applicable context-specific information for climate relevant policy planning, and advisory services for operational and strategic decision-making, Additionally, relevant stakeholder engagement should be at the forefront of the nationally led process to unlock finance and rethink national climate and investment plans in order to turn commitment into action and, thus, impactful NDC.

Mainstreaming aquatic food systems and climate information services in national climate strategies

While NDCs remain central to countries' climate commitments, effective climate action for aquatic food systems requires mainstreaming fisheries, aquaculture, and CIS across the wider landscape of national climate strategies, including NAPs, sectoral policies, and development plans. Experience from countries such as Bangladesh and Zambia shows that aquatic food systems are either insufficiently detailed or weakly operationalized in updated NDCs, despite their importance for food, nutrition, livelihoods, and ecosystem health. Strengthening collaboration among national hydro-meteorological services, fisheries departments, and line ministries is therefore essential to break institutional silos and enable the co-production and co-design of climate-informed adaptation, mitigation, and just transition pathways. Integrating high-quality climate data and tailored CIS into fisheries and aquaculture planning can support transformational risk management, unlock climate finance, and translate national climate commitments into inclusive and impactful action aligned with SDGs 13 and 14.

Way forward

Implement the 3Cs: Co-creation, capacity building and cross-sectoral collaboration.
Empathy-driven development and participatory design ensure that climate services are purpose-driven, contextually relevant, inclusive, responsive, and accessible for practical use. In addition, building capacity and/or climate literacy at both the institutional and user level is essential to support informed decisions, sustainable practices, and climate adaptation. Sustaining digital aquaculture climate services and addressing climate risks holistically requires cross-sectoral collaboration, including public–private partnerships and integration across fisheries, ICT, and meteorological departments.

Integrate intelligent monitoring for precise decision-making.
In order to transform the current aquaculture climate-services landscape, it is essential to build a digital ecosystem that integrates IoT-enabled multiparameter sensors for real-time monitoring of dissolved oxygen, pH fluctuations, and thermal gradients across culture ponds followed by analysis, modeling and simulation. Such digital twins would deliver localized, actionable insights to enable precise decision-making in aquaculture.

Adopt AI technologies to improve service quality and delivery.
AI creates promising opportunities to enhance climate services for use in underserved and climate-vulnerable sectors like aquaculture and in countries with severe climate risks like Bangladesh and Zambia. The focus should be on empowering local communities to better cope with the impacts of climate change and building lasting resilience. AI could be used in aquaculture climate services, equitable and community-centered outcomes, such as data-driven analytics for decision-making, organized local knowledge into actionable insights, enhancing the advisory tools/apps for real-world use for broader adoption.

Explore weather index–based insurance for aquaculture as a climate-smart financial instrument.
Weather index–based insurance for aquaculture offers a promising climate-resilient financial safety net for vulnerable fish farming communities, leveraging climate data to enable timely payouts amid extreme weather events. However, scaling requires overcoming data and regulatory challenges to design insurance indices and payout triggers.

Bridge hard and soft investments gap for climate resilient aquaculture.
Hard investments such as aerators, nets, cages, and pumps, and soft investments like climate information services and advisory support are interdependent and essential for climate-smart aquaculture. Physical assets enable climate-information application and advisory services that optimize asset use for resilience and informed decisions.

Develop a sustainable business model to deliver climate services.
Delivery systems for climate services are central to scaling and sustaining them over time. A clear way forward is to move from project-based delivery toward market-aware, institutionally anchored, and user-valued business models.

Ensure that development of climate services for aquaculture is socially inclusive.
Scaling aquaculture climate services effectively and sustainably depends on embedding social inclusion. Achieving socially inclusive aquaculture climate services requires participatory, equity-driven approaches that integrate local knowledge, ensure accessible and tailored information, build capacity among marginalized groups, and embed gender equity into climate risk management.

Build a stage for testing, validation, and further improvement.
Assuming the usefulness of any climate services upfront is risky. It is important to test, validate, and iterate them into the climate service delivery pathway, treating services as *learning systems* rather than finished products. As such, it is necessary to ensure an adaptive, evidence-driven scaling pathway (i.e., pilot → validate → iterate → scale) so that climate services are demonstrably useful, trusted by farmers, and worth sustaining over the long term.

Embed aquaculture climate services into national policies and strategies for broader impact.
Including aquaculture climate services into national policies and strategies is vital to effectively manage risk, provide safety nets, secure financial stability for farmers and the economy, promote sustainable practices, and protect national food security.

References

Barange M, Bahri T, Beveridge MCM, Cochrane KL, Funge-Smith S and Poulain F, eds. 2018. Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome: FAO. 628 pp. www.fao.org/3/i9705en/i9705en.pdf

Breitburg D, Levin LA, Oschlies A, Grégoire M, Chavez FP, Conley DJ, Garçon V, Gilbert D, Gutiérrez D, Isensee K et al. 2018. Declining oxygen in the global ocean and coastal waters. *Science* 359(6371):eaam7240. doi: 10.1126/science.aam7240

Cinner J, Adger W, Allison E, Barnes M, Brown K, Cohen P, Gelcich S, Hicks C, Hughes T, Lau J et al. 2018. 2018. Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change*, 8(2):117–23. https://www.nature.com/articles/s41558-017-0065-x

[FAO] Food and Agriculture Organization. 2019. FAO's work on climate change – Fisheries & Aquaculture. Rome: FAO.

Hossain PR, Amjath-Babu TS, Krupnik TJ, Braun M, Mohammed EY and Phillips M. 2021. Developing climate information services for aquaculture in Bangladesh: A decision framework for managing temperature and rainfall variability-induced risks. *Frontiers in Sustainable Food Systems 5:*677069. doi: 10.3389/fsufs.2021.677069

Hossain PR, Kakwasha K, Maluwa A and Mumba P. 2024. Introduction to digital climate information services for aquatic food systems in Malawi: A dialogue-cum-training workshop report. Penang, Malaysia: WorldFish. Workshop report: 2024-25. https://hdl.handle.net/20.500.12348/5970

Hossain PR, Tilley A, Kondwe J, Longobardi L, Oladejo SO, Stander H, Kuruganti P, Kakwasha K, Mudege N and Siamudaala V. 2025. Development of digital fisheries information systems and knowledge sharing platforms for managers and value chain actors. Penang, Malaysia: WorldFish. Report: 2025-46. https://hdl.handle.net/20.500.12348/6590

Hossain PR. 2022. Gender-inclusive innovations for aquatic food systems transformation. Penang, Malaysia: WorldFish. https://hdl.handle.net/20.500.12348/5118

Hossain PR, Ahmed R and Barman BK. 2023. Digital climate information and advisory services for de-risking aquatic food systems. Penang, Malaysia: WorldFish. Policy brief. https://hdl.handle.net/20.500.12348/5750

[IPCC] Intergovernmental Panel on Climate Change. 2023. AR6 Synthesis Report. Geneva: IPCC. https://www.ipcc.ch/report/ar6/syr/

Islam S, Hossain PR, Braun M, Amjath-Babu TS, Mohammed EY, Krupnik T J, Chowdhury AH, Thomas M and Mauerman M. 2024. Economic valuation of climate induced losses to aquaculture for evaluating climate information services in Bangladesh. *Climate Risk Management 43:*100582.

Kondowe J, Hossain PR, Mudege N, Kakwasha K and Victor S. 2025. Introduction to digital climate information services for aquatic food systems in Zambia: A dialogue–training workshop report. Penang, Malaysia: WorldFish. Workshop report: 2025-10. https://hdl.handle.net/20.500.12348/6475

Lee H, Calvin K, Dasgupta D, Krinner G, Mukherji A, Thorne P et al. 2024. Climate change 2023 synthesis report summary for policymakers. Geneva: IPCC. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

Maulu S, Hasimuna OJ, Chibesa M, Bbole I, Mphande J, Mwanachingwala M et al. 2024. Perceived effects of climate change on aquaculture production in Zambia: Status, vulnerability factors, and adaptation strategies. *Frontiers in Sustainable Food Systems* 8:1348984.

Mohammed EY, Hossain PR, Lau J, Wahab MA, Beveridge MCM and Marwaha N. 2021. Accelerating climate resilience of aquatic food systems. Penang, Malaysia: CGIAR Research Program on Fish Agri-Food Systems. Program Brief: FISH-2021-16. https://hdl.handle.net/20.500.12348/4921

Mohammed EY. 2024. We need to scale up climate innovations for aquaculture resilience.

Montes C, Acharya N, Hossain PR, Babu TA, Krupnik TJ and Hassan SQ. 2022. Developing a framework for an early warning system of seasonal temperature and rainfall tailored to aquaculture in Bangladesh. *Climate Services* 26:100292. doi: 10.1016/j.cliser.2022.100292

Moyo M, Mpofu N, Dube T, Mutenje M and Kakwasha K. 2025. Climate information services, climate-smart agriculture, and farmer adaptation in Zambia. https://hdl.handle.net/10568/178600

Muthoka M, Ouko KO, Mboya JB, Ndambuki MN, Outa N, Ogello E et al. 2024. Socio-economic impacts of climate change and adaptation actions among smallholder fish farmers in Sub-Saharan Africa. *Aquaculture, Fish and Fisheries* 4(3):e182.

Reid GK, Gurney-Smith HJ, Flaherty M, Garber AF, Forster I, Brewer-Dalton K et al. 2019. Climate change and aquaculture: Considering adaptation potential. *Aquaculture Environment Interactions* 11:603–24.

Shamsuzzaman MM, Islam MM, Tania NJ, Al-Mamun MA, Barman PP and Xu X. 2017. Fisheries resources of Bangladesh: Present status and future direction. *Aquaculture and Fisheries* 2(4):145–56.

Tigchelaar M, Cheung WW, Mohammed EY, Phillips MJ, Payne HJ, Selig ER et al. 2021. Compound climate risks threaten aquatic food system benefits. *Nature food* 2(9):673–82.
doi: 10.1038/s43016-021-00368-9

[WMO] World Meteorlogical Organization. 2024. State of climate services 2024: Five-year progress report (2019–2024). WMO-No. 1363. Geneva: WMO. https://climahealth.info/wp-content/uploads/2024/11/20241106_WMO_2024-State-of-the-climate-services_en.pdf

World Bank. 2022. Country climate and development report for Bangladesh. Washington DC: World Bank. https://www.worldbank.org/en/news/feature/2022/10/31/key-highlights-country-climate-and-development-report-for-bangladesh

WorldFish. 2020. A training dialogue report: Introduction to climate services for aquaculture. CGIAR Research Program on Climate Change, Agriculture and Food Security. Capacitating farmers and fishers to manage climate risks in South Asia. Penang, Malaysia: WorldFish. Program Report: 2020-04. https://hdl.handle.net/20.500.12348/4062


Credit: Harun Ur Rashid/WorldFish