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COMMITTEE ON FISHERIES

SUB-COMMITTEE ON AQUACULTURE

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BUILDING RESILIENCE OF AQUACULTURE TO ENSURE FOOD SECURITY, NUTRITION AND LIVELIHOODS

Executive Summary

Although it is a millennia-old food production activity, aquaculture is increasingly exposed to a range of environmental, social, and economic disruptions that are increasing in both number and intensity. This paper reviews the role of aquaculture in building resilient aquatic food systems, capable to resist, absorb, accommodate, adapt to, transform and recover from those disruptions, as well as the approaches that can be employed to build aquaculture sector resilience. Given their importance for the future of the sector, three major stressors are considered in detail: pests and pathogens, climate change and natural disaster, and COVID-19.

Suggested action by the Sub-Committee

The Sub-Committee is invited to:

- Take note on the contribution of aquaculture to resilient food systems and encourage Members to share experiences on how aquaculture can further contribute to the transformation of our food systems;
- Review the current approaches to building aquaculture resilience and make suggestions for improving their effectiveness;
- Advise on priority actions for FAO to better support the transformation of aquaculture towards more resilient aquaculture-based food systems.

INTRODUCTION AND CONTEXT

1. **Aquaculture is exposed to a wide range of environmental, social, and economic disruptions**, including direct disruptions to on-farm activities, as well as indirect disruptions to inputs or value chains. Although it is a millennia-old food production activity that developed and evolved over the centuries in response to such stressors,[1,2] it is now increasingly impacted by more, and more-intense, slow long-term chronic stressors[3] as well as fast acute shocks,[4] or their combination.[5] The ability to respond, adapt to and recover from such disruptions is a necessary condition for the sustainability of future aquatic food production.[27]

2. Until now, the fast and regular growth of aquaculture production and trade has shown that the sector has been particularly resilient at the global level, although numerous cycles of 'boom-and-bust' have also frequently challenged its development at the local level.[6,7] Ecological limits, inbreeding depression, natural disasters, disease outbreaks and/or market problems have been among **the most frequent challenges to development of resilient aquaculture food systems** at this scale. More recently, new disruptions, such as climate changes or the pandemic of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) or COVID-19, have also emerged and have the potential of threatening the aquaculture sector globally.[8]

3. In 2021, **the Declaration for Sustainable Fisheries and Aquaculture** of the FAO Committee on Fisheries (COFI) emphasized the need to take action to ensure that the aquatic food systems remain resilient and meet growing demand for nutritious, safe and affordable food in the face of these pressures. Maintaining sustainable and resilient ecosystems, economies and societies that leave no one behind is a long-term request of FAO Members.[9]

4. **Resilience of aquaculture can be defined as** the ability of an aquaculture system exposed to changes, to resist, absorb, accommodate, adapt to, transform and recover from the effects of these changes in a timely and efficient manner, while preserving and restoring its essential basic structures and functions to continue providing livelihoods and sufficient, appropriate and accessible food to all.[10]

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[1] In this document, the term stressors refers to both shocks and stress. The IPCC AR5 also defines it as an "Events and trends, often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate related risk". www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf

[2] Beveridge, M.C.M. & Little, D.C. 2002. The history of aquaculture in traditional societies. In B.A. Costa-Pierce, ed. Ecological Aquaculture. The Evolution of the Blue Revolution. pp. 3–29. Oxford, UK, Blackwell.

[3] e.g. ever-increasing competition on natural resources such as water, wild fish used as feed, land, pollution of the environment, climate change; declines in the biodiversity that maintain environmental function.

[4] e.g. disease outbreak, extreme weather conditions, natural disasters, water pollution.

[5] Watkiss, P., Ventura, A. & Poulain, F. 2019. Decision-making and economics of adaptation to climate change in the fisheries and aquaculture sector. FAO Fisheries and Aquaculture Technical Paper No. 650. Rome, FAO. www.fao.org/3/ca7229en/CA7229EN.pdf

[6] Periods of rapid growth followed by collapse.

[7] You, W. & Hedgecock, D. 2019. Boom-and-bust production cycles in animal seafood aquaculture. Reviews in Aquaculture, 11(4), 1045-1060. https://doi.org/10.1111/raq.12278. Data on aquaculture production from 1950 to 2015 found that boom-and-bust cycles are far more common than would be expected for a mature industry

[8] Mangano, M.C. *et al.*, 2022. The aquaculture supply chain in the time of covid-19 pandemic: Vulnerability, resilience, solutions and priorities at the global scale. Environmental Science & Policy, 127: 98-110. https://doi.org/10.1016/j.envsci.2021.10.014

[9] FAO Committee on Fisheries. 2018. Report of the Ninth Session of the Sub-Committee on Aquaculture. Rome, Italy, 24–27 October 2017. FAO Fisheries and Aquaculture Report No. 1188. Rome, Italy. www.fao.org/3/I8886T/i8886t.pdf

[10] Adapted from the definition of UNDRR. 2017. Terminology. Geneva: United Nations Office for Disaster Risk Reduction and FAO www.fao.org/emergencies/how-we-work/resilience/en and Love *et al.*, 2021. Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system. Global Food Security, Volume 28, www.sciencedirect.com/science/article/pii/S2211912421000043

5. **Building resilience is now recognized as a multidimensional and multiscale development process.** This reflects an evolution of thinking around management of aquatic food production from a product-focused activity to one that gives more emphasis to the interactions between aquaculture, the community, the society and the environment, at the local, regional and global levels.[11]

6. Taking a **food systems approach**[12] recognizes that both stressors and their impacts are interconnected, and that the notion of complex dynamic processes that aptly describe the nature and dynamics of vulnerability, are at the core of approaches aimed at building resilience. Local and systemic stressors can amplify each other, or even mutually cancel each other out, while impacts can be direct or indirect. Their effects can be perceived over the short-term (e.g. farm destruction) or over the medium-to-long-term (e.g. increased occurrence of diseases, biodiversity loss). Localized conditions and cumulative impacts require coordinated and holistic, but case-by-case, approaches to building the systemic social-ecological resilience.[13,14]

7. **This paper reviews our current understanding of resilience in aquaculture**, the new challenges and opportunities facing the sector, to stimulate dialogue on what is required in terms of policy and innovative practices to build more efficient and resilient aquaculture.[15] It is based on the **four-pillars of the FAO resilience strategy**[16] which are to (1) Enable the environment (2) Watch to safeguard (3) Apply risk and vulnerability reduction measures and (4) Prepare and respond.[14]

THE ROLE OF AQUACULTURE IN BUILDING RESILIENT FOOD SYSTEMS

8. As stated by the UN Food Systems Summit, "food systems are complex, and are closely connected to, and significantly impact, human and animal health, land, water, climate, biodiversity, the economy and other systems, and their transformation requires a systemic approach."[17] The **paradigm of 'food systems'** is valuable in that it includes the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products. Aquaculture is a very highly diverse sector, in which resilience is not only governed by its own internal characteristics but also by the need to interface with, adapt to, or even conform to the governance systems of other sectors with which it shares risk in competing and using the same resources.[18] The (agri-)food system approach can be combined with social theories such as agrarian

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[11] FAO Committee on Fisheries. 2019. Report of the Tenth Session of the Sub-Committee on Aquaculture. Trondheim, Norway, 23–27 August 2019 FAO Fisheries and Aquaculture Report No. 1287. Rome, Italy. www.fao.org/3/ca7417t/CA7417T.pdf

[12] "*Food systems embrace the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal (loss or waste) of food products that originate from agriculture (incl. livestock), forestry, fisheries, and food industries, and the broader economic, societal, and natural environments in which they are embedded*." (Von Braun, J., Afsana, K., Fresco, L.O., Hassan, M. & Torero, M. 2021. Food Systems – Definition, Concept and Application for the UN Food Systems Summit. A paper from the Scientific Group of the UN Food Systems Summit https://sc-fss2021.org/)

[13] Ostrom, E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science 24 July 2009: Vol. 325, Issue 5939, pp. 419–422. https://science.sciencemag.org/content/325/5939/419

[14] www.fao.org/in-action/tropical-agriculture-platform/background/ais-a-new-take-on-innovation/en/

[15] Inputs to this document are informed by and build upon the learnings gained from the currently ongoing COVID19 pandemic, and role that aquaculture can play in mitigation of climate change.

[16] www.fao.org/emergencies/how-we-work/resilience/en

[17] www.un.org/en/food-systems-summit/vision-principles

[18] Partelow, S., Schlüter, A., Manlosa, A.O., Nagel & B. Paramita, A.O. 2021. Governing aquaculture commons. Reviews in Aquaculture (Advance online publication) https://doi.org/10.1111/raq.12622

change and transition theory in order to bridge results and insights. Doing so enables a more robust assessment of the social aspects of social-ecological transitions in the aquaculture sector and beyond.[19]

9. **Food security and nutrition issues are also very much at the heart of the dialogue on resilience**, fish being a key component of healthy diets, given their protein, poly-unsaturated fatty acids, and micronutrient profile. "There can be no transformation of food systems if we fail to include foods from water. We must put to use the vast potential of aquatic foods, many of which are super foods for women and young children".[20]

10. **However, the future of aquaculture rests on its ability to add resilience to world food supplies** whereas its reliance on terrestrial crops and wild fish, that could also be consumed directly by humans and provide essential nutrition for low-income households, its dependence on freshwater and land for culture sites, and its broad array of social and environmental impacts, diminish its ability to achieve this goal.[21] In the meantime, aquaculture, in particular when it is integrated with other activities, may also provide opportunities for improving water productivity in areas of worsening water scarcity, for reducing farmers' vulnerability to drought, for providing a source of high-quality protein to supplement crops, and for boosting overall production and profit. [22,23]

11. **The pathways that the sector will take will thus be very critical for aquaculture to add to the resilience of the global food system**, especially in terms of species and farm-types grown, ability to supply feed from sustainable supplies, grow-out system design and operation, and whether such development can offset the current negative externalities associated with terrestrial crop and livestock systems and capture fisheries. Since the adoption of the Code of Conduct for Responsible Fisheries[24] in 1995, FAO has consistently promoted the Ecosystem Approach to Aquaculture (EAA).[25] The EAA is a "strategy for the integration of the activity within the wider ecosystem such that it promotes sustainable development, equity and resilience of interlinked social-ecological systems."[26]

12. **The socio-cultural make-up of aquaculture food systems is also an important focus for building resilient aquatic food systems.** In particular, **greater consideration of gender** in aquaculture value chains means promoting gender-equal opportunities and substantive equality in aquaculture. Resilience also implies redressing disadvantage, addressing not only stigma and stereotyping in employment but also discrimination and abuse towards women, and accommodating differences including through removing structural impediments to inclusion.[27]

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[19] Bush, S. R., & M. J. Marschke. 2014. Making social sense of aquaculture transitions. Ecology and Society 19(3): 50. http://dx.doi.org/10.5751/ES-06677-190350

[20] Shakuntala Haraksingh Thilsted, 2021 World Food Prize Laureate http://blog.worldfishcenter.org/2021/05/aquatic-foods-are-essential-for-sustainable-healthy-diets-says-un-nutrition/

[21] Troell, M. Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., Folke, C., Arrow, K.J., Barrett, S., Crépin, A.S., Ehrlich, P.R., Gren, Å., Kautsky, N., Levin, S.A., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Walker, B.H., Xepapadeas, T. & de Zeeuw, A. Does aquaculture add resilience to the global food system? Proceedings of the National Academy of Sciences Sep 2014, 111 (37) 13257-13263. www.pnas.org/content/pnas/111/37/13257.full.pdf

[22] Allison, E.H., Andrew, N.L. & Oliver, J. 2007. Enhancing the resilience of inland fisheries and aquaculture systems to climate change. SAT eJournal-ejournal.icrisat.org 4 (1). https://hdl.handle.net/20.500.12348/1593

[23] Tran, N., Le Cao, Q., Shikuku, K.M., Phan, T.P. & Banks, L.K. 2020. Profitability and perceived resilience benefits of integrated shrimp-tilapia-seaweed aquaculture in North Central Coast, Vietnam. Marine Policy 120. https://doi.org/10.1016/j.marpol.2020.104153

[24] FAO. Code of Conduct for Responsible Fisheries Rome, FAO. 1995. www.fao.org/documents/card/en/c/e6cf549d-589a-5281-ac13-766603db9c03/

[25] FAO. 2010. Aquaculture development. 4. The ecosystem approach to aquaculture. FAO Technical Guidelines for Responsible Fisheries No. 5, Suppl. 4. Rome. 53 pp. www.fao.org/3/i1750e/i1750e00.htm

[26] Aguilar-Manjarrez, J., Kapetsky, J.M. & Soto, D. 2010. The potential of spatial planning tools to support the ecosystem approach to aquaculture. FAO/Rome. Expert Workshop. 19–21 November 2008, Rome, Italy. FAO Fisheries and Aquaculture Proceedings. No.17. Rome, FAO. 176 pp. www.fao.org/3/i1359e/i1359e00.htm

13. For aquaculture to contribute to resilient food systems, it must also pay more attention to the situations and roles of **youth, smallholders and artisanal farmers, fishers and fish farmers, pastoralists, forest users and indigenous peoples**, and, where necessary, it must challenge the *status quo*.[27] Aquaculture provides an opportunity to diversify livelihood options, which is believed to be vital to contribute to maintaining ecosystem resilience and building social systems resilience.[28] Horizontal collaborations has also been identified as promoting agility and visibility of aquaculture value chains during the COVID-19 pandemics, contributing to resilience.[8]

APPROACHES TO BUILDING AQUACULTURE RESILIENCE FOR FOOD SECURITY AND NUTRITION

Pillar 1: Enable the policy, institutional and legislative environment

14. Effective resilience depends on sustained **political commitment and investment** in: (1) Well-designed risk-informed policy, strategy and planning; (2) Effective and efficient risk informed legal and regulatory frameworks (covering land, water, seeds and inputs, as well as environment); (3) Supportive institutions (such as research, training and advice); and (4) Financial facilitation, flexibility and incentives.[29] Good policy and planning are the means to create such an enabling environment, as well as a framework that seeds and stimulates aquaculture enterprise, allows and facilitates sustainable development, identifies and removes bottlenecks, constrains unsustainable or unfair practices, and corrects market imperfections or inappropriate social constraints.[29,30,31]

15. However, the traditional limitation of **stakeholder participation** to a consultative role with minimal or ignored direct observations and anecdotal information is recognized as one of the weaknesses of current resource management institutions that needs to be addressed in the face of climate change and resilience building.[32] The measures selected for building resilience should be compatible with their livelihood objectives, strategies and assets. They should foster synergy in the governance of the aquaculture sector and in the other sectors, help avoid the maladaptation that results from competition

[27] Shanghai Declaration: Aquaculture for food and sustainable development. Global Conference on Aquaculture GCA +20. Aquaculture for Food and Sustainable development. Shanghai, China, 23-25 September 2021. https://aquaculture2020.org/declaration/

[28] Pant, J., Shrestha, M.K. & Bhujel, R.C. 2012. Aquaculture and resilience: Women in aquaculture in Nepal. p. 19-24. In: Shrestha, M.K. & Pant, J. (eds.) Small-scale aquaculture for rural livelihoods: Proceedings of the National Symposium on Small-scale Aquaculture for Increasing Resilience of Rural Livelihoods in Nepal. Institute of Agriculture and Animal Science, Tribhuvan University, Rampur, Chitwan, Nepal, and The WorldFish Center, Penang, Malaysia http://pubs.iclarm.net/resource_centre/WF_3460.pdf.

[29] FAO. 2017. The 2030 Agenda and the Sustainable Development Goals: The challenge for aquaculture development and management, by John Hambrey. FAO Fisheries and Aquaculture Circular No. 1141, Rome, Italy. www.fao.org/3/i7808e/i7808e.pdf

[30] Brugère, C., Ridler, N., Haylor, G., Macfadyen, G. & Hishamunda, N. Aquaculture planning: policy formulation and implementation for sustainable development. FAO Fisheries and Aquaculture Technical Paper. No. 542. Rome, FAO. 2010. 70 p. www.fao.org/3/i1601e/i1601e00.pdf

[31] GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection), 2001. Planning and management for sustainable coastal aquaculture development. Rep. Stud. GESAMP, (68): 90 p. www.fao.org/3/y1818e/y1818e.pdf

[32] Poulain, F., Himes-Cornell, A. & Shelton, C. 2018. Chapter 25: Methods and tools for climate change adaptation in fisheries and aquaculture In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 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

over resources and lack of cross-sectoral governance, and provide the opportunity to incorporate policy that reduces the adverse impacts of aquaculture.[33]

Pillar 2: Watch to safeguard

16. **Understanding and monitoring risks** and **early warning systems** are also needed to plan, detect, forecast and, when necessary, issue alerts relating to impeding stressors or hazards (such as diseases, weather). The alerts effectively contribute to build resilience, reduce risk occurrence and are based on information of possible chronic and acute impacts on the aquaculture sector. The alerts must be communicated clearly and quickly to vulnerable people to facilitate immediate actions for better preparedness, response and prevention.[16,36,34]

17. **Global assessments of aquaculture vulnerability** are becoming more common and accessible but in order to permit the identification and application of risk and vulnerability reduction measures, they must be complemented by **investigations at more localized levels**, where specific aquaculture practices, environmental conditions and interactions with stakeholders and communities are taken into account. Unfortunately, quantitative or semi-quantitative vulnerability assessments are as yet rare for food systems, let alone aquaculture. The sector is often assessed together with fisheries or agriculture and in coastal or watershed-based studies. Nonetheless, an increasing number of studies describe various elements of vulnerability of some aquaculture species and systems that should contribute to more formal assessments.[35]

18. **Not all aquaculture systems are equally vulnerable or resilient** to the various stressors or hazards, and safeguard systems in place must acknowledge and cope with this diversity. Traditional aquaculture systems have certainly been among the most resilient aquaculture systems so far, as rural farmers have perfected their farming systems over the years, decades and centuries to maximize the resilience of their households and the security of their livelihoods.[32,36] Yet, they now face new constraints among which include increased land competition, water quality, water scarcity, emerging diseases and climate change. Similarly, the availability of farming areas is becoming limiting in many regions for cage systems, in both freshwater and coastal areas. Mass mortalities resulting from over capacity are also becoming more common.

Pillar 3: Apply risk and vulnerability reduction measures

Farm location

19. The closure and relocation of production sites, using risk-based siting and spatial planning, may be an option to reduce vulnerability, especially for cages operators, or inland farms in flood-prone areas,

[33] FAO, 2017 Building climate-resilient fisheries and aquaculture in the Asia-pacific region. FAO/APFIC Regional Consultative Workshop. Bangkok, Thailand, 14–16 November 2017, www.fao.org/publications/card/en/c/CA5770EN/

[34] FAO, 2018. Building climate resilient fisheries and aquaculture in the Asia-Pacific region. Asia-Pacific Fishery Commission Thirty-fifth Session (APFIC). Cebu, the Philippines, 11-13 May 2018 www.fao.org/publications/card/en/c/CA0077EN/

[35] Soto, D., Ross, L.G., Handisyde, N., Bueno, P.B., Beveridge, M.C.M., Dabbadie, L., Aguilar-Manjarrez, J., Cai, J. & Pongthanapanich, T. 2018. Chapter 21: Climate change and aquaculture: vulnerability and adaptation options. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 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

[36] Poulain, F. & Wabbes, S. 2018. Chapter 23: Impacts of climate-driven extreme events and disasters. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 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

to move to less exposed areas. Compliance with the recommendations made on **spatial planning for aquaculture** should allow to reduce significantly the risks, provided that accurate data are available.[37] This will imply collecting big datasets, analysing them and developing new accurate and fine-grain spatial models, which could lead to the development of a brand new specialized sector for start-ups of the “OceanTech”.[38]

20. However, farm relocation as a risk and vulnerability management measure applies mainly for new farms to be established. Building resilience of aquaculture should also take into consideration the numerous existing farms and provide practical guidance on how to modify and improve farm designs and facilities for better resilience.

Farm design and facilities

21. **Flexible facility designs** that can be adapted to a certain range of conditions should be preferred. Designs of infrastructure that use renewable energy and implementation of management practices that minimize resource use, waste and environmental impacts should be favoured. Investment in **protection, stronger cage and mooring systems, on-farm depuration facilities and controlled environments production systems** (for example RAS, ponds) and water-efficient or climate-smart facilities for water storage (for example deeper ponds) are another way of reducing current vulnerability.

22. With the expected increase in **extreme weather events**, the number of escapes from aquaculture is anticipated to rise, generating economic losses and creating hazard for the surrounding environment and ecosystems. Minimizing impacts of escapes can be achieved by regulating the movement of non-native aquatic germplasm, certification of cage and farming equipment, capacity development of farmers and implementation of management measures, including spatial planning to identify flood-prone areas. Investment in new climate-smart collective infrastructure (like dams, dikes, channels) may also help to reduce the occurrence of uncontrolled flooding and salinity intrusions, in addition to improving water storage.[66,68]

23. Integrated or closed systems may allow to rely less on external resources and subsequently, to contribute to higher resilience. Beyond the traditional integrated aquaculture, new technologies emerge to propose high-efficiency systems, yet their sensitivity to technical disruption still needs to be improved.[39] Integrated systems have also recently been suggested as a resilience strategy to the COVID-19 crisis, due to their buffering characteristics on some components of the economic distress, such as, for example on job losses.[8]

24. A major innovation in recent years has been the emergence of technologies such as the Recirculated Aquaculture Systems (RAS), which enabled the farming of many species with limited impact and dependence on surrounding ecosystems.[40,41] The energy needed to maintain suitable water quality has long been seen as a constraint to its mainstreaming, however a recent study using Life Cycle Assessment concluded that RAS production is possible without major energy trade-off and that RAS

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[37] Aguilar-Manjarrez, J., Soto, D. & Brummett, R. 2017. Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture. Full document. Report ACS113536. Rome, FAO, and World Bank Group, Washington, DC. 395 pp. http://documents.worldbank.org/curated/en/421101490644362778/full-document
[38] www.blue-cloud.org/demonstrators/aquaculture-monitor
[39] FAO. 2019. Report of the Special Session on Advancing Integrated Agriculture Aquaculture through Agroecology, Montpellier, France, 25 August 2018. FAO Fisheries and Aquaculture Report No. 1286. Rome www.fao.org/3/ca7209en/CA7209EN.pdf
[40] www.fao.org/fao-stories/article/en/c/1371489/
[41] www.undercurrentnews.com/report/land-based_salmon-handbook/

may play a more important role in a future, environmentally-sustainable food system.[42] However, they are also very demanding and much more sensitive to any technical dysfunction than traditional systems, as the huge biomass creates a major demand for oxygen or good water quality. Until fully resilient technical solutions, materials and designs can be offered, preparedness and redundancy of equipment and circuits (water, air) are vital to avoid massive losses in emergency situations.[43]

25. In Asian shrimp aquaculture, two opposed scenarios of resilient systems were also identified. In the first one, the farming techniques for small-scale producers are integrated into intertidal areas in a way that the ecological functions of mangroves are maintained and shrimp farming diseases are controlled. In a second one, problems of disease and effluent are eliminated in closed recirculation ponds behind the intertidal zone controlled by industrial-scale producers. [44]

Water scarcity management practices

26. Aquaculture consumes water to compensate for the losses by seepage and evaporation, for water renewal and for producing the ingredients used in fish feed production. **Its water footprint depends on the species farmed and the production system used**[45,46] but systems that reuse water compare very favourably with terrestrial crops and livestock production (400 l/kg for fish in RAS vs. 3 900 l/kg for chicken, 4 800 l/kg for swine or 15 500 l/kg for beef).[47] However, aquaculture can also be a source of water pollution through eutrophication.[48,49,50] Reduced availability and quality of freshwater may lead to increased competition among water users. Water consumption by aquaculture can be reduced by a series of technological or managerial innovations, including intelligent aquaculture.[51]

27. **At global or national level**, options proposed to build resilience of aquaculture with regards to water include:

a) Community-based flood control and irrigation facilities with pond-dike cropping.
b) Development of brackishwater aquaculture.

[42] Bergman, K., Henriksson, P. J., Hornborg, S., Troell, M., Borthwick, L., Jonell, M., Philis, G., Ziegler, F. 2020. Recirculating aquaculture is possible without major energy tradeoff: Life cycle assessment of warmwater fish farming in Sweden. Environmental science & technology, 54(24), 16062-16070. https://pubs.acs.org/doi/abs/10.1021/acs.est.0c01100
[43] Murray, F. Lewis, N.D. & Divakaran, G.S. 2021. Assessment report on Recirculated Aquaculture Systems. Gap Assessment, Innovation and Value-added Engineering. FAO Project UTF/UAE/009/UAE Baby 2 – Supporting Sustainability and Innovation in the UAE Aquaculture sector, FAO, Abu Dhabi, UAE. 145 p.
[44] Bush, S. R., P. A. M. van Zwieten, L. Visser, H. Van Dijk, R. Bosma, W. F. De Boer & M. Verdegem. 2010. Scenarios for resilient shrimp aquaculture in tropical coastal areas. Ecology and Society 15(2): 15. www.ecologyandsociety.org/vol15/iss2/art15/
[45] Pahlow, M., van Oel, P.R., Mekonnen, M.M. & Hoekstra, A.Y. 2015. Increasing pressure on freshwater resources due to terrestrial feed ingredients for aquaculture production. Science of The Total Environment 536: 847-857. https://doi.org/10.1016/j.scitotenv.2015.07.124.
[46] Verdegem, M.C.J. & Bosma, R.H. 2009. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. Water Policy, 11, 52-68.
[47] Joyce, A., Goddek, S., Kotzen, B. & Wuertz, S. 2019. Aquaponics: Closing the Cycle on Limited Water, Land and Nutrient Resources. In: Goddek S., Joyce A., Kotzen B. & Burnell G.M. (eds) Aquaponics Food Production Systems. Springer, Cham. https://doi.org/10.1007/978-3-030-15943-6_2
[48] Halwart, M., van Dam, A.A. 2006. Integrated Irrigation and Aquaculture in West Africa: Concepts, Practices and Potential. Food and Agriculture Organization of the United Nations. Rome, Italy. www.fao.org/3/a0444e/A0444E00.htm
[49] Verdegem, M. C. J. & R. H. Bosma. Water withdrawal for brackish and inland aquaculture, and options to produce more fish in ponds with present water use. Water Policy 11: 52–68 (2009). https://doi.org/10.2166/wp.2009.003
[50] Ahmed, N., Ward, J. D., Thompson, S., Saint, C. P. & Diana, J. S. (2018). Blue-green water nexus in aquaculture for resilience to climate change. Reviews in Fisheries Science & Aquaculture, 26(2), 139-154. www.tandfonline.com/doi/abs/10.1080/23308249.2017.1373743
[51] Li, D. & Li, C. 2020. Intelligent Aquaculture. J World Aquaculture Society 51:808-814 https://onlinelibrary.wiley.com/doi/epdf/10.1111/jwas.12736

c) Mangrove restoration and integrated mangrove-shrimp cultivation.
d) Expansion of mariculture to release pressure on freshwater.[50]

28. **At farm level**, new or more effective water management schemes must be promoted and mainstreamed, for example: no water renewal, greenwater technology, bioflocs, and/or water recirculation. The following water management adaptation practices have been reported in India:[52]

a) Pumping of freshwater to cool down the temperature of fish ponds or use of oxygen tablets during higher summer temperatures.
b) In case of drought, early harvest, irrespective of the fish growth, and use of bore wells to maintain water level. Adjustments in the farming calendar may need to shift to shorter production cycles.
c) Using mesh-like structures in pond bunds to prevent fish escapes during floods, or pumping out of water to lower water level.

29. **Introducing multisector water management** with new integrated agricultural (such as integrated irrigation-aquaculture) or non-agricultural activities (like power generation with solar panel over the ponds providing both energy, income and shade).

Farmed organisms

30. About 580 aquatic species are currently reported as farmed all over the world, representing a wealth of genetic diversity both within and among species.[53] **This diversity of species and farmed types is critical to resilience, yet in practice, very few species dominate production**.[54] Finfish farming is the most diverse subsector in terms of species, but the 20 most important species still account for 83.6 percent of the total production. Compared with finfish, fewer species of crustaceans, molluscs and other aquatic animals are farmed.[55]

31. **Building aquaculture resilience through diversification** is a way to adapt to climate changes, but also to satisfy the rising demand for seafood, offering social benefits to small-scale farmers. It can be implemented by (i) increasing the number of species being farmed, (ii) increasing the evenness of farmed species and (iii) increasing the diversity within currently farmed species by developing new farmed types.

32. At the level of the farmed organisms, applying risk and vulnerability reduction measures may over the medium-to-long term require **shifting to new species or farmed types**[56,22] that are more

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[52] Adhikari, S. *et al.* 2018. Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India." Journal of Fisheries Sciences 12.1: 16-21. www.researchgate.net/profile/Subhendu-Adhikari-2/publication/324444952_Adaptation_and_Mitigation_Strategies_of_Climate_Change_Impact_in_Freshwater_Aquaculture_in_some_states_of_India/links/5c6a5318a6fdcc404eb7466d/Adaptation-and-Mitigation-Strategies-of-Climate-Change-Impact-in-Freshwater-Aquaculture-in-some-states-of-India.pdf

[53] FAO. 2019. The State of the World’s Aquatic Genetic Resources for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture assessments. Rome, Italy. www.fao.org/3/CA5256EN/CA5256EN.pdf

[54] Metian, M., Troell, M., Christensen, V., Steenbeek, J. & Pouil, S. 2020. Mapping diversity of species in global aquaculture. Reviews in Aquaculture, 12(2), 1090-1100. https://onlinelibrary.wiley.com/doi/abs/10.1111/raq.12374

[55] FAO. 2020. The State of World Fisheries and Aquaculture 2020. Sustainability in action. Rome. https://doi.org/10.4060/ca9229en (page 29)

[56] “Farmed aquatic organisms that could be a strain, hybrid, triploid, monosex group, other genetically altered form, variety or wild type”. FAO. 2019. The State of the World’s Aquatic Genetic Resources for Food and Agriculture. FAO Commission on Genetic Resources for Food and Agriculture assessments. Rome. www.fao.org/3/CA5256EN/CA5256EN.pdf

tolerant to changes of water quality, to high temperature, to higher salinity, or less sensitive to diseases. The species and strains more efficient at using feed will be preferred, as well as the species with a wide spectrum of tolerance, as they will be more likely to cope with a wide range of uncertain environmental variations. Diversifying the farmed species and systems may also be a good strategy to cope with a wide range of uncertainties.[84]

33. Similar results may be achieved by investing in selective breeding for thermal or saline tolerance, for disease resistance or for feed conversion efficiency and capacity to use plant-based feeds. Selective breeding in oysters, for example, is likely to be an important global mitigation strategy for sustainable shellfish aquaculture to withstand future climate-driven change to ocean acidification. Indeed, oyster families selectively bred for fast growth and families selected for disease resistance can alter their mechanisms of calcite crystal bio-mineralization, promoting resilience to acidification.[57] Specific treatment at the early stages of farmed organisms can also contribute to build higher resilience. Predation can be a major source of mortality in bivalve aquaculture but it is possible to induce predatory defences under industry conditions by exposing larvae to predator cues in the hatchery.[58]

Feeds and unfed aquaculture

34. **Shift to novel commercial feed formulation**, especially for carnivorous species, should be considered, as well as the introduction of better on-farm feeding practices and monitoring in order to increase the performance and resilience of the farming. Trade-offs may have to found. For example, the feeding of a high fat diet increases growth in juvenile barramundi, but also reduces its tolerance to extreme water temperatures.[59]

35. Even though important sources of fishmeal and fish oil are vulnerable to climate change, increased use of fish processing wastes and rapid developments in novel feedstuffs is likely to mean that the issue is only of importance for aquaculture in the short to medium term.[77] **Nonetheless, feed provision in aquaculture** derived from both food-grade and non-food-grade agricultural products needs to be efficiently and responsibly sourced. Compliance with the provisions of the Code of Conduct for Responsible Fisheries and the FAO Technical Guidelines for Responsible Fisheries should be enforced.[24,60]

36. Investing in unfed aquaculture of molluscs or aquatic plants also offers an important food source with minimal inputs and increased resilience with regards to aquaculture feeds. It can also substantially increase the production of nutritious aquatic food with a lower environmental impact, and sometimes enhance capture fisheries by creating artificial habitats.[61]

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[57] Fitzer, S. C., McGill, R. A., Torres Gabarda, S., Hughes, B., Dove, M., O'Connor, W. & Byrne, M. 2019. Selectively bred oysters can alter their biomineralization pathways, promoting resilience to environmental acidification. Global change biology, 25(12), 4105-4115. https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.14818

[58] Belgrad, B.A., Combs, E.M., Walton, W.C. & Smee, D.L. 2021. Use of predator cues to bolster oyster resilience for aquaculture and reef restoration. Aquaculture 538. https://doi.org/10.1016/j.aquaculture.2021.736553.

[59] Isaza, D.F.G., Cramp, R.L., Smullen, R., Glencross, B.D. & Franklin, C.E. 2019. Coping with climatic extremes: dietary fat content decreased the thermal resilience of barramundi (*Lates calcarifer*). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 230, 64-70. www.sciencedirect.com/science/article/pii/S1095643318301892

[60] FAO. 2011. Aquaculture development. 5. Use of wild fish as feed in aquaculture. FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 5. Rome, FAO. 2011. 79p. www.fao.org/documents/card/en/c/f6737048-85bc-57ca-a98d-33fb3d84dbcc

[61] Costello, C., L. Cao, S. Gelcich *et al.* 2019. The Future of Food from the Sea. Washington, DC: World Resources Institute. Available online at www.oceanpanel.org/future-food-sea

Markets and social acceptability

37. The highly valued international trade in aquatic products is concentrated in relatively few species groups, such as salmonids, seabass, sea bream, shrimps/prawns, tilapias and catfishes while the major import markets are in Europe and North America. **Vulnerabilities at production or exportation sites can impact livelihoods at each stage of the global supply chain** from farmers, processors, transport, and retail distribution. Market stressors are among the most common vulnerabilities for aquaculture.[7]

38. The management of **fish quality after harvest** is important to avoid a reduction in nutritional value, economic value or food safety issues, leading to rejects and financial loss to farmers.[62] Measures to prevent or minimise the decrease in quality of fish after harvest can be implemented by promoting the siting of fish farms close to fish market, or vice versa, by using appropriate cold storage for preservation and/or by employing appropriate processing to a more shelf-stable form (e.g. drying, smoking, canning).

39. **Improving public perceptions** of the sector will be instrumental to develop the aquaculture market resilience over the long-term.[63] Aquaculture is still at an early stage of development, and despite many improvements in its production processes towards more sustainability, there is a "perception gap" between how aquaculture is actually done and the public understanding of the sector. To address public concerns more effectively, more social science studies are needed to better understand the public and consumer perceptions of aquaculture in different regions. The perception of local communities where aquaculture is taking place is also very important to develop under-exploited products such as the resilient unfed aquaculture.[61]

Livelihoods and safety nets

40. **Farmers can generally cope with small and recurrent risks** by adopting best management practices and self-reliance strategies such as the diversification of farm activities (fish, plant crops, orchards) or the diversification of the sources of income (on-farm and off-farm). However, they are often not able to manage the less frequent but more severe losses resulting from diseases, theft, floods and drought, water pollution by herbicides and pesticides used nearby, storms and swells, and/or climate change–induced perils. When they suffer such disastrous losses, as may be more and more frequently the case, the entire value chain and local economy can be affected.

41. **Appropriate financial and insurance services are thus imperative** to improve the resilience of aquaculture farmers and the society as a whole by preventing bankruptcy occurring after such losses.[64] Although it is still an immature sector in aquaculture, relative to other food producing sectors, the development of a cooperative indemnity insurance scheme, tailored to the needs of a fish-farming community is an option where commercial proposition is not available.[65]

42. In addition, small farmers are highly susceptible to the volatile market system and instability of fish prices. They have a lower capacity to comply with stringent environmental regulations and

[62] www.fao.org/flw-in-fish-value-chains/loss-and-waste-scenarios/en/
[63] FAO. 2016. Report of the Workshop on Increasing Public Understanding and Acceptance of Aquaculture – the Role of Truth, Transparency and Transformation, Vigo, Spain, 10–11 October 2015. FAO Fisheries and Aquaculture Report No. 1143. Rome, Italy. www.fao.org/3/i6001e/i6001e.pdf
[64] FAO. 2020. Aquaculture insurance for small-scale producers FAO's Blue Growth Initiative. Blue finance guidance notes. Rome, Italy. www.fao.org/3/ca8663en/CA8663EN.pdf
[65] Watson, J.R., Armerin, F., Klinger, D.H. & Belton, B. 2018. Resilience through risk management: cooperative insurance in small-holder aquaculture systems. Heliyon 4 (2018) www.cell.com/heliyon/fulltext/S2405-8440(18)30450-X

requirements on food production standards. The development of a modernized value chain that would contribute to enhancing the competitive advantage of small producers in new world business is urgently needed.

Pillar 4: Prepare and respond

43. Preparedness refers to the knowledge and capacities necessary to effectively anticipate, respond to, and recover from the stressors impacting aquaculture, including through the proactive management of risks and farmers empowerment. Preparedness and contingency planning are undertaken to support effective and efficient response to stressor occurrence.[16,66]

44. All relevant stakeholders (including the vulnerable and marginalized) must be identified beforehand through a stakeholder analysis and co-opted into preparedness planning. The core of aquaculture resilience being the resilience of farmers, particularly small scale farmers, there is need to elaborate plans on how to empower them for better resilience.

45. **Contingency plans and response planning for policy and management action must be in place prior to occurrence of the stressor**. Training and capacity development must be provided to relevant stakeholders in policy and management issues as part of preparedness, based on existing capacities and expected needs, and using appropriate delivery mechanisms. FAO is currently finalizing a Fisheries and Aquaculture Response in Emergencies (FARE) training to be available soon on the Organization’s e-learning platform.[67]

46. **Management information systems and data collection mechanisms** must be established as part of disaster preparedness. Relevant information (including local knowledge) is used to inform risk assessments, contingency planning, and response preparedness strategies. Management information systems are resilient, and measures are taken to ensure that they will continue to function and be accessible during emergencies, that they are based on appropriate technology, and that they are cost-effective.[66]

47. The process of disaster emergency response, rehabilitation and reconstruction in aquaculture can also be an opportunity for “**building back better**”, by addressing some of the weaknesses and issues in the sector.[68]

BUILDING RESILIENCE TO SPECIFIC STRESSORS

Pest and pathogens

48. Under-the-water health management of aquatic species presents huge challenges due to the fact that they are often not readily visible and they live in a complex and dynamic aquatic environment.

49. Since the 1970s up until the decade 2000, new pathogens emerged approximately every three to five years and caused significant diseases to farmed and wild populations of aquatic species, without warning. In most cases, losses were economically substantial. Four important drivers of disease emergence in aquatic species are: (1) trade, introductions and transfer of live aquatic species and their products; (2) little knowledge of pathogens and their hosts; (3) poor enforcement of health management and control of diseases of aquatic species; and (4) ecosystem change.

[66] Cattermoul, B.; Brown, D. & Poulain, F. (eds). 2014. Fisheries and aquaculture emergency response guidance. Rome, FAO. 167 pp. www.fao.org/3/i3432e/i3432e.pdf

[67] https://elearning.fao.org/

[68] Brown, D. & Poulain, F. (eds). 2013. Guidelines for the fisheries and aquaculture sector on damage and needs assessments in emergencies. Rome, FAO. 114 pp www.fao.org/3/i3433e/i3433e.pdf

50. It is generally considered that a disease emerges when a pathogen meets a susceptible host in a conducive environment. The pathway to exotic disease[69] emergence includes introductions and transfers and occurs more commonly into new geographical localities.[70] Similarly, the pathway to endemic disease[71] emergence includes stress-related factors such as poor husbandry, stocking with species outside their natural geographic range or with rapid growth *vs.* disease tolerance traits, and environmental changes.

51. The lack of, inadequate, or poorly-implemented biosecurity strategies at the farm, sector and national levels are another driver of disease emergence; low capacity for emergency response; weak implementation of international standards; weak enforcement of regulatory frameworks; low incentive for disease reporting; mismatch between research agendas and farmer/commodity sector needs; and weak public-private sector partnerships for sharing responsibilities.

52. Changes to the farming aquatic ecosystems through direct human activity and indirect impacts (e.g. climate change, global pollution) are made more complicated by the physiology of aquatic species. As environmental factors change near the tolerance levels for hosts and disease agents, poikilothermic species will encounter constraints to adaptation, emergence of pathogens, and changing geographic ranges of wild stocks, microbes and parasites.

53. Building resilience to disease occurrence requires a series of actions from the local to the global level. During the Tenth Session of the Sub-Committee on Aquaculture of the FAO Committee on Fisheries, FAO introduced a new initiative, the Progressive Management Pathway for Improving Aquaculture Biosecurity (PMP/AB), which was welcomed by the Members. The PMP/AB proposes a cost-effective management of risks caused by pathogens in aquaculture through a strategic approach at enterprise, national and international levels with shared public-private responsibilities.[72]

54. Building resilience to disease occurrence at farm level may imply investing in ecological approaches providing a more effective and resilient microbial management of the water. Disinfecting the water is not the best approach for minimizing the risk of pathogenic disease occurrence. On the contrary, the reduction of unwanted bacteria by disinfection should always be followed by a selective enhancement of desirable microbes.[73,74]

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[69] Previously unknown in the species or the geographic area they grow in

[70] e.g. white spot disease of shrimp in the Kingdom of Saudi Arabia and Australia, koi herpesvirus disease in Iraq, multinucleate sphere X disease in Canada, epizootic ulcerative syndrome in the Democratic Republic of Congo and Malawi, infectious myonecrosis virus disease in India and Malaysia, infectious spleen kidney necrosis virus disease in Ghana.

[71] Known to exist in the species and area grown in, but considered to be manageable due to limited outbreak occurrences or using production husbandry measures

[72] Preventing and Managing Aquatic Animal Disease Risks in Aquaculture through a Progressive Management Pathway. Committee on Fisheries - Sub-Committee on Aquaculture, Tenth Session, Trondheim, Norway, 23–27 August 2019. www.fao.org/3/na265en/na265en.pdf

[73] FAO 2019. Report of the Special Session on Advancing Integrated Agriculture-Aquaculture through Agroecology. Montpellier, France, 25 August 2018. FAO Fisheries and Aquaculture Report No. 1286. Rome. www.fao.org/3/ca7209en/CA7209EN.pdf

[74] Sorgeloos, P. & De Schryver, P. 2020. Ecological Approaches for Better Microbial Management in Intensive Shrimp Farming. FAO Aquaculture Newsletter 61: 43-44. www.fao.org/fileadmin/user_upload/COFI/VirtualDialoguesCOFI34/13_SorgeloosDeShryverMicrobialManagementFAN61.pdf

Climate change and natural disasters[75,76]

55. **Aquaculture may either exacerbate or help** to create solutions to one of the biggest challenges of our time – climate change.[77] Fish ponds have the potential to be a carbon sink, with their sediments holding much higher organic carbon than soils in other widespread habitats. [78,79] Culture-based fisheries can also be used to address climate change-aggravated issues of recruitment in wild stocks, requiring minimal feed use or other types of care.[77] Unfed aquaculture can provide useful and practical applications to boost carbon sequestration globally.[80,81] Moreover, they deliver many other ecosystem services and biodiversity benefits along the objectives of Agenda 2030, in addition to producing aquatic food.[80,27]

56. Vulnerability assessments of aquaculture to climate change show that a number of countries in both high and low latitudes are highly vulnerable. In general, **vulnerability is directly associated with governance**, from national to farm level. Consequently, global assessments of vulnerability must be complemented by investigations at more localized levels, where specific aquaculture practices, environmental conditions and interactions with stakeholders and communities are considered.

57. Climate change can have direct and indirect impacts on aquaculture both in the short-term and the long-term. Longer-term climate-driven trends (e.g. increases in temperature and salinity) are more readily addressed as there is time to plan and implement adaptation measures. Short-term extreme weather events and other natural disasters are less predictable and induce more severe impacts to aquaculture. Severe weather episodes can damage infrastructure, increase incidence of escapes, and cause lost production from disease, parasites or harmful algal blooms.

58. Aquaculture farmers will bear the full force of climate change impacts through less stable livelihoods, changes in the farming technologies and species farmed, and rising risks to their health, safety and homes. [82] Ultimately, it is at the farm level that vulnerability reduction efforts should converge; vulnerability assessments should be as fine-grained as resources allow in order to be relevant

[75] Cochrane, K., De Young, C.; Soto, D. & Bahri, T. (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper. No. 530. Rome, FAO. 2009. 212p. www.fao.org/fileadmin/user_upload/newsroom/docs/i0994e.pdf

[76] Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & 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

[77] Beveridge, M.C.M., Dabbadie, L., Soto, D., Ross, L.G., Bueno, P.B. & Aguilar-Manjarrez, J. 2018. Chapter 22: Climate change and aquaculture: interactions with fisheries and agriculture. *In*: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 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

[78] Gilbert, P.J., Taylor, S., Cooke, D.A., Deary, M.E. & Jeffries, M.J. 2021. Quantifying organic carbon storage in temperate pond sediments. Journal of Environmental Management 280: 111698. https://doi.org/10.1016/j.jenvman.2020.111698

[79] Taylor, S., Gilbert, P.J., Cooke, D.A., Deary, M.E. & Jeffries, M.J. 2019. High carbon burial rates by small ponds in the landscape. Front Ecol Environ 2019; 17(1): 25–31. https://doi.org/10.1002/fee.1988

[80] MAF and FAO. 2007. Aquatic biodiversity and human nutrition – the contribution of rice-based ecosystems. Ministry of Agriculture and Forestry, Lao PDR and Food and Agriculture Organization of the United Nations, Rome, Italy. www.fao.org/3/i3841e/i3841e.pdf

[81] Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A., Lucente, D., Mair, G., Miao, W., Potin, P., Przybyla, C., Reantaso, M., Roubach, R., Tauati, M. & Yuan, X. 2021. Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. FAO Fisheries and Aquaculture Circular No. 1229. Rome, FAO. https://doi.org/10.4060/cb5670en

[82] IPC Global Platform. Fisheries and Aquaculture in a changing Climate. UNFCCC COP-15 in Copenhagen, December 2009. www.ipcinfo.org/fileadmin/user_upload/en/KCCO-28-05-2009-2/ENG-Brochure-LR.pdf

to farmers. Capacity building in addressing vulnerability and improving adaptation to climate change, especially among target stakeholders, is an investment that more than pays for itself.

59. Vulnerability reduction depends on the broader adaptation measures beyond the aquaculture sector and there is a strong need to integrate aquaculture management and adaptation into watershed and coastal zone management. Moreover, adaptation to climate change can be a complex undertaking and poses many challenges, especially as the demands by various sectors on common resources often result in user conflicts. There is a greater level of human control over aquaculture[83], which enables the sector to better manage risks. However, the same degree of control makes it critical to have a properly planned and coordinated, well-governed and equitable adaptation strategy. This stresses the need for precise identification and characterization of the nature of hazards from climate change, predicting and assessing the risks that the hazards drive, and their impacts. The types of hazards spawned by climate change are physical, chemical and biological.

60. Several adaptation measures are available to mitigate impacts of negative changes or increase resilience: better feeds and feeding practices; understanding the relationship between species and habitat based on optimal thermal limits, dissolved oxygen, pH and salinity levels; combined climate change impacts on resources, physical assets, livelihoods, and health; understanding how climate change impacts on food systems may lead to changes in demand. FAO also developed an Adaptation Toolbox for stakeholders and decision makers.[32] Adaptation measures must be considered in accordance with multisector National Adaptation Strategies. Regional adaptation plans are also needed for transboundary water bodies.[84]

61. However, it must be noted that there are important gaps in current knowledge and understanding of scientific, institutional and socio-economic aspects of the aquaculture sector and the likely impacts of climate change. These gaps hinder the effectiveness of adaptation. Better implementation of the Code of Conduct for Responsible Fisheries[85] and the Ecosystem Approach to Aquaculture[25] would provide a good foundation for success and effectiveness.

62. The authorities should thus adopt new tools for coping with uncertainties while supporting new governance schemes and conflict resolution schemes, in which aquaculture stakeholders are involved, in particular to ensure equitable access to water during water shortage periods. They should also support social protection strategies based on accurate vulnerability assessments. Finally, they should also prepare contingency plans, as well as emergency and disaster responses.[66,68]

Lessons learned from the COVID-19 global outbreak

63. The COVID-19 pandemic has caused unprecedented disruptions of social interactions, affecting both the supply and demand for food.[8] These disruptions to jobs, income and food supply magnified and exacerbated existing inequalities. Lessons from the pandemic provided a unique opportunity for real structural change that can make food systems more efficient, resilient, healthy, sustainable, and equitable.

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[83] De Silva, S.S. & Soto, D. 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. In: K. Cochrane, C. De Young, D. Soto & T. Bahri, eds. Climate change implications for fisheries and aquaculture: overview of current scientific knowledge, pp. 151–212. FAO Fisheries and Aquaculture Technical Paper No. 530. Rome, Italy. FAO. 2017.
[84] Dabbadie, L., Aguilar-Manjarrez, J., Beveridge, M.C.M., Bueno, P.B., Ross, L.G. & Soto, D. 2018. Chapter 20: Effects of climate change on aquaculture: drivers, impacts and policies. In: Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-Smith, S. & Poulain, F., eds. 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
[85] www.fao.org/documents/card/en/c/e6cf549d-589a-5281-ac13-766603db9c03/

64. Although the aquatic food system as a whole has been able to perform its key functions, its fragilities have been exposed.[86] Each stage of the aquaculture supply chain appeared susceptible to being disrupted or stopped by measures arising from COVID-19 restrictions. Delayed harvests resulted in increasing levels of live fish stocks, creating higher costs for feeding as well as risks of fish mortalities. Some farmers also faced difficulties in obtaining seed, feed or other production inputs (for example, vaccines, oxygen). Cash flow and access to credit was another challenge because of the additional costs incurred in the absence of revenue, especially if aquaculture clients were also affected by the crisis and they delayed payment for past deliveries.

65. Some supply chains, market segments, companies, small-scale actors and civil society have shown initial signs of greater resilience than others, while COVID-19 has also highlighted the vulnerabilities of certain groups working in- or dependent on the seafood sector. One emerging adaptation observed globally has been to develop direct retail sales, through internet ordering and home delivery or aquaculture drive-in. Another adaptation has been to process and freeze fish that have reached their commercial size, to keep them in cold storage. Concerns also emerged during the COVID-19 crisis regarding the safety of aquaculture products (salmon, shrimp), leading to temporary market disruptions.[87]

66. A recent study found that the primary causal factors of supply shortage and shrinkage of demand were the main causes inducing negative impacts. The limited options to transport products emerged as the weakest link in the aquaculture value-chain whereas when market stage was the second most vulnerable link facing severe disruptions due to the closure of local, national and international markets as well as the stopping of the HoReCA (hotel, restaurant and catering) channels.[8]

67. Many workers in the aquaculture sector operate in informal markets with no social insurance. These small-scale farmers and workers are the most vulnerable to disruptions. Social protection has been a key response adopted by governments to alleviate the socio-economic impacts of COVID-19 restrictions. Countries with social protection systems in place were those most able to respond rapidly to the impacts of COVID-19 by tweaking existing social protection programmes. The main type of social protection measures governments took to alleviate income losses in fisheries and aquaculture was temporary cash and in-kind transfers. The second most used type of programme was input subsidies.[88]

THE ROLE OF FAO AND GOVERNMENTS

68. For aquaculture to enhance the resilience of aquatic food systems, government policies need to provide adequate incentives for resource efficiency, equity, and environmental protection.[21] In particular, in order to meet the Sustainable Development Goals and the target of zero hunger, resilience measures need to support food security and livelihoods whilst ensuring food production systems can respond to chronic pressures and recover from shocks. FAO supports countries by providing policy recommendations, technical advice, and capacity building, in line with the four pillars of the Organization's resilience strategy and the past recommendation of the Subcommittee on Aquaculture.

69. Key recommended actions by FAO, Governments and/or partners for building resilience to stressors that can disrupt aquaculture production and fish supply chains include:

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[86] FAO and Worldfish. 2021. Aquatic food systems under COVID-19. Rome. www.fao.org/publications/card/fr/c/CB5398EN/

[87] Bondad-Reantaso, M. *et al.* 2020. Viewpoint: SARS-CoV-2 (The Cause of COVID-19 in Humans) is Not Known to Infect Aquatic Food Animals nor Contaminate Their Products https://doi.org/10.33997/j.afs.2020.33.1.009

[88] FAO 2021. The role of social protection in the recovery from COVID-19 impacts in fisheries and aquaculture. Rome. https://doi.org/10.4060/cb3385en

a) **Understand changes**. Monitoring the drivers of changes and stressors to identify early the new risks, mitigate their impact and control their spread.
b) **Promote knowledge exchange** by creating platforms to ensure wider dissemination and adoption of resilient and adaptive practices (including the Guidelines for Sustainable Aquaculture) and **inclusive networks** for collaborative research and development efforts among all stakeholders.[89]
c) **Take a broad systems approach and integrate**. The Shanghai Declaration, unanimously adopted by the participants of the Global Conference on Aquaculture Millennium +20 on 24 September 2021, calls for integrating aquaculture with the natural environment, with agriculture, capture fisheries, forestry, tourism, renewable energy and other sectors, and within agri-food systems for increased resilience.[27] In recent years, the idea of integrated aquaculture has often been considered as a mitigation approach to curb the excessive quantities of nutrients and organic matter generated by intensive aquaculture activities. This has led to the emergence of approaches such as the Integrated and Multitrophic Aquaculture (IMTA) or the Raceway-In-Ponds (RIPS).[90,91]
d) **Consider area-based management and spatial planning**. Improved spatial planning for identification of appropriate sites for aquaculture can reduce vulnerability to external stressors and identify potential conflicts with other resource users. It should make use of the latest information technologies for modelling spatial interactions and helping stakeholders better forecast their adaptation strategies.[92]
e) **Focus on value-chains**. Supporting food supply chains by avoiding disruptions in the movement and trade of fish and fish products beyond international food safety and quality assurance requirements can ensure that food systems function smoothly in the face of natural disasters and crises. Having a holistic view of the whole value chain requires balanced focus on both ends of the value chain. For example, effort on activities to promote the benefits of fish consumption and strengthen end demand such as school feeding programmes and consumer awareness of the health benefits of seafood should mirror efforts on building productive and resilient farmed fish production.[93]
f) **Leverage innovation**. Building resilient food systems will require effective innovations to reduce the overall vulnerability, and not replace one stressor by another. Recirculating Aquaculture Systems, for example, are less susceptible to climate change but may be more vulnerable to supply chain disruptions that block access to farm inputs (e.g. feed, seed, oxygen) or sales to end-consumers. Although they are part of the technical solutions, they also highlight the need that innovation for resilience needs to be holistic and system-wide.
g) **Digitization of the aquaculture sector** should be promoted, with new and climate-smart low cost technologies (e.g. e-commerce using digital platforms) that facilitate the interface between the producers and the consumers, or support precision aquaculture. The digital tools to support small farmers should also be widely developed to facilitate better access to reliable and trustworthy information on farm input prices, availability of input suppliers, or technical support on the responsible use of the farm inputs.
h) **Recognize gender in aquaculture**. Recognize the specific opportunity and role in resilience, but also the vulnerability of women, as food producers, processors, vendors and family caregivers in aquaculture value chains. The impact of natural disasters and crisis

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[89] Towards Sustainable Aquaculture Guidelines www.fao.org/blogs/blue-growth-blog/towards-sustainable-aquaculture-guidelines/en/

[90] FAO. 2019. Report of the Special Session on Advancing Integrated Agriculture Aquaculture through Agroecology, Montpellier, France, 25 August 2018. FAO Fisheries and Aquaculture Report No. 1286. Rome. www.fao.org/3/ca7209en/CA7209EN.pdf

[91] www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b4-fisheries/b4-case-studies/case-study-b4-2/en/

[92] FAO and World Bank. 2010. Aquaculture zoning, site selection, and area management under the ecosystem approach to aquaculture, Policy Brief, Rome. www.fao.org/3/i5004e/i5004e.pdf

[93] FAO & WFP. 2018. Home-Grown School Feeding. Resource Framework. Synopsis. Rome, 36 pp. www.fao.org/3/ca0474en/CA0474EN.pdf

such as COVID-19 on women should be considered at local, regional and global level, while improved access to support mechanisms should be secured for women along the fish value chain.

i) **Support access to investment**. Developing assistance packages and contingency plans with specific aquaculture measures that assist small and medium enterprises and those communities most vulnerable to food disruptions, to be included in National Aquaculture Plans.

GUIDANCE SOUGHT

70. The Sub-Committee is invited to:

- Take note on the contribution of aquaculture to resilient food systems and encourage Members to share experiences on how aquaculture can further contribute to the transformation of our food systems;

- Review the current approaches to building aquaculture resilience and make suggestions for improving their effectiveness;

- Advise on priority actions for FAO to better support the transformation of aquaculture towards more resilient aquaculture-based food systems.