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联合国粮食及农业组织 Food and Agriculture Organization of the United Nations Organisation des Nations Unies pour l'alimentation et l'agriculture Продовольственная и сельскохозяйственная организация Объединенных Наций Organización de las Naciones Unidas para la Alimentación y la Agricultura منظمة الأغذية والزراعة للأمم المتحدة

# COMMITTEE ON FISHERIES

## SUB-COMMITTEE ON AQUACULTURE

## Tenth Session

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# AQUACULTURE INNOVATIONS, THEIR UPSCALING AND TECHNOLOGY TRANSFER TO INCREASE EFFICIENCY, COMBAT ENVIRONMENTAL DEGRADATION AND ADAPT TO CLIMATE CHANGE


## Executive Summary

Innovations in aquaculture include technologies that diversify economy and food production, improve production efficiencies at the hatchery or farm levels while mitigating environmental impact; technologies that mitigate the occurrence of animal diseases or parasites, or that reduce or eliminate the use of antibiotics to treat animals; advances in offshore or land-based recirculation technology; novel feed ingredients; reductions in carbon footprint through improved energy efficiency or regeneration; and social programs designed to improve living and working conditions at the farm or processing levels. Important efficiency gains can also be reached by reducing wastes and losses during production and post-harvest.

Aquaculture technology innovation was adopted to 1) develop and reform sector economy; 2) diversify livelihood and food production; 3) improve resource management efficiency; 4) combat environment degradation; and 5) adapt to climate change. Aquaculture technology innovations helped traditional aquaculture to better practice or establish an emerging sector for blue economy growth in many countries.

This document highlights the aquaculture technology innovation in increasing efficiency, combating environmental degradation and adapting to climate changes worldwide, with reference to the efforts and mechanisms of aquaculture technology innovation transfer and scaling up, particularly technical support from international organizations, regional cooperation and knowledge sharing, country pilot, research and localization among developing countries.




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| **Suggested action by the Sub-Committee** |
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| The Sub-Committee is invited to:<br><br>➢ Recognize the importance of aquaculture innovations in increasing efficiency, reducing environmental impact and combating climate change;<br><br>➢ Share experiences (including success stories and lessons learned) on aquaculture innovations;<br><br>➢ Provide advice and encourage the international community, and in particular existing aquaculture networks, to enhance collaboration on the synthesis, update and exchange of knowledge products on aquaculture innovations to increase resource efficiency and address environmental and climate change;<br><br>➢ Provide guidance and call for increased and dedicated financial resources for enhanced technical assistance for upscaling of innovations in aquaculture through various mechanisms, such as Technical Cooperation Programme, networking, South–South Cooperation, or Public Private Partnership. |

# INTRODUCTION

1. Aquaculture is a centuries-old activity that emerged and developed in full integration with the rural areas' traditional practices and farming systems. Over time, farmers' innovations[1] led to the development of quite complex aquatic food systems such as fish polyculture or Integrated Agriculture-Aquaculture.

2. The sector also witnessed major innovations in the twentieth and twenty-first centuries with new species, new technologies and new systems developed in new environments, leading aquaculture to become a key global food-producing industry. As aquaculture now plays a major role in the current and future provision of food, rural development, or poverty reduction (see COFI:AQ/X/2019/6), new challenges emerge: improving the low resource-use efficiency, coping with the disproportionate impacts of climate change and reducing the environmental degradation on the resource base.[2]

3. Innovations are needed to keep in line with the 2030 Agenda on Sustainable Development, especially Sustainable Development Goals (SDG) 1, 2, 3, 5, 6, 8, 9, 11, 12, 13, 14, 15, 16, 17,[3] but also with widely recognized international instruments, approaches and concepts such as the Code of Conduct for Responsible Fisheries (CCRF, see COFI:AQ/X/2019/3),[4] the Ecosystem Approach to Aquaculture (EAA)[5] and Agroecology.[6]

4. Climate change is another challenge for which aquaculture innovations will be needed. The 2015 Paris Climate Agreement recognizes the need for effective and progressive responses to the urgent threat of climate change, through mitigation and adaptation measures, while taking into account the particular vulnerabilities of food production systems. Global assessment of vulnerability provides a highly valuable indication of where aquaculture-related climate change effects may occur and where further research would be valuable for the development of climate-related innovation, but they should be complemented by more localized studies to provide stakeholders with the knowledge they need to develop their own strategies and implement their own innovations.[7]

5. Innovation and its enabling factors have been well studied. It can be the consequence of a carefully designed research or development process aimed at tackling some specific issues (e.g. remove constraints, avail of opportunities, improve efficiency or productivity etc.), the outcome of serendipity or the result of stakeholders' curiosity, needs, gained experience or cooperation.[8]

6. Aquaculture innovations include technologies that improve production efficiency at the hatchery or farm levels while mitigating environmental impact (e.g. reduced pollution, escaped fish, access to feed, predator management, wastes and losses reduction etc.); technologies that prevent the occurrence of animal diseases or parasites, or that reduce or eliminate the use of antibiotics or chemicals

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[1] "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)". OECD/Eurostat (2018), Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation, 4th Edition, The Measurement of Scientific, technological and Innovation Activities, OECD Publishing, Paris/Eurostat, Luxembourg. https://doi.org/10.1787/9789264304604-en

[2] FAO. 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Rome. Licence: http://www.fao.org/3/I9540EN/i9540en.pdf

[3] The 2030 agenda and the sustainable development goals: the challenge for aquaculture development and management, http://www.fao.org/cofi/38663-0a3e5c407f3fb23a0e1a3a4fa62d7420c.pdf

[4] Code of Conduct for Responsible Fisheries http://www.fao.org/3/a-v9878e.pdf

[5] Building an ecosystem approach to aquaculture http://www.fao.org/3/a-i0339e.pdf

[6] The 10 elements of agroecology http://www.fao.org/3/i9037en/i9037en.pdf

[7] 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. FAO Fisheries and Aquaculture Technical Paper, 627. Rome. FAO. ISBN 978-92-5-130607-9 http://www.fao.org/3/I9705EN/i9705en.pdf

[8] Sanginga, P. C., Waters-Bayer, A. Kaaria, S., Wettasinha, C., Njuki, J. 2009. Innovation Africa: Enriching Farmers' Livelihoods. Earthscan, 2009 – 405p.

to treat animals (see COFI:AQ/X/2019/5); advances in farming system (e.g. offshore cages and land-based recirculation technology); novel feed ingredients; reductions in carbon footprint through improved energy efficiency or regeneration; and social programs designed to improve living and working conditions at the farm or processing levels.[9]

## AQUACULTURE INNOVATION TRENDS AND KEY ADVANCES

### Optimizing resources use

7. Aquaculture planning and management is key in optimizing resource use at a territorial level, and the introduction of spatial tools in this area[10] has been a major advance to support the location of aquaculture facilities based on the natural and geographic conditions, with efficient use of land/water resources, and limited impact on the environment. It integrates good practices for conversion of upland and wetland areas to ponds and impoundments, and improved governance of aquaculture practices,[11] as well as climate change provisions. Other innovations in this area include water, land and aquatic genetic resources utilization (see COFI:AQ/X/2019/2.1), aquaculture parks,[12] conservation zones, tenure licenses and permission systems that have improved resource management efficiency, minimized impact of aquaculture facilities on natural habitats, and allowed the efficient treatment of effluents.

8. Integrated aquaculture and other land/water efficient technologies are another strategy allowing for efficient resource use. In coastal areas where the use of marine and coastal resources by aquaculture raised concerns, integrated aquaculture with mangroves in Viet Nam,[13] deep-sea cage culture in the Gulf of Mexico, Norway and China,[14] mariculture platforms,[15] or Integrated Multi-Trophic Aquaculture (IMTA) in the Mediterranean Sea and the Atlantic Ocean[16] have attracted a lot of interest. In inland areas, the limited land availability and freshwater scarcity promoted fish farming in rice paddies, saline water aquaculture, aquaponics, using containers for fish culture[17] and in-pond raceway systems (IPRS),[18] etc.

9. Advancing Integrated Agriculture-Aquaculture (IAA) through agroecology encouraged more farmers to combine the production of rice and fish in Guinea and seaweed farming in Tanzania, where they encountered better stability and resilience of the system and a much lower environmental impact, so IAA plays an important role in the sustainable development of aquaculture in the future.

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[9] https://www.aquaculturealliance.org/blog/what-is-an-aquaculture-innovation/
[10] Aguilar-Manjarrez, J. Soto, D. Brummett, R. 2017. Aquaculture zoning, site selection and area management under the ecosystem approach to aquaculture, a handbook http://www.fao.org/3/a-i6834e.pdf
[11] Costa-Pierce, B.A., Bartley, D.M., Hasan, M., Yusoff, F., Kaushik, S.J., Rana, K., Lemos, D., Bueno, P. & Yakupitiyage, A. 2012. Responsible use of resources for sustainable aquaculture. In R.P. Subasinghe, J.R. Arthur, D.M. Bartley, S.S. De Silva, M. Halwart, N. Hishamunda, C.V. Mohan & P. Sorgeloos, eds. Farming the Waters for People and Food. Proceedings of the Global Conference on Aquaculture 2010, Phuket, Thailand. 22–25 September 2010. pp. 113–147. FAO, Rome and NACA, Bangkok. http://www.fao.org/3/i2734e/i2734e03a.pdf
[12] https://gia.org.br/portal/wp-content/uploads/2013/05/2013implementation.pdf
[13] http://www.snv.org/public/cms/sites/default/files/explore/download/mam_091014.pdf
[14] https://www.innovasea.com/
[15] https://www.mariculture-systems.com/
[16] http://www.idreem.eu/cms/what-is-imta/
[17] http://innovatedevelopment.org/2014/06/25/fishing-for-change
[18] https://ussoy.org/in-pond-raceway-system-a-technology-transfer-success-story/

## Aquaculture engineering

10. Aquaculture engineering focuses on the design of aquaculture facilities. Major innovations include pond design for optimizing production, animal wellbeing and biosecurity, secure offshore aquaculture projects, design of recirculating aquaculture systems (RAS) for land-based fish farming, and a range of engineering expertise for aquaculture feed mills, processing plants, etc. Engineering innovations have also emerged as non-medicinal treatment of parasites such as sea lice in salmon farming (e.g. polyculture with wrasses, laser rays, thermal treatments etc.).[19,20]

11. Farms for raising fish are getting larger, more secure, and are being sited further offshore. A Norwegian salmon farming operator, for example, is currently testing a deep-ocean cage system designed to accommodate 1.5 million salmons. The huge cage, named Ocean Farm 1, is mid-way through its year-long trial period, and is reporting good growth rates and low mortality.[21] Moreover, as fish farms move deeper into the high seas, the level of sophistication is increasing to promote autonomy using high definition cameras and submerged automatic feeders to reduce the need for human travel to and from the cages. Such experiments are currently being conducted with the Deep Blue 1 platform in China, the Aquatraz systems by Norwegian Seafarming Systems and the Aquapod containment system in USA.

12. RAS are also becoming more common as they allow for water recycling, waste reuse as fertilizer for agriculture with limited effects on their natural surroundings, thus reducing the environmental hazards for ecosystems and disease occurrences during farming. RAS can also reduce the carbon footprint of seafood by up to 50 percent,[22,23] and fish in these systems can be grown in a controlled and traceable environment without the use of hormones or antibiotics. These systems can be placed almost anywhere, including near urban centers. One test facility in Denmark,[24] built in 2011, has led to the largest RAS facility in the world in Miami, Florida. Called the Miami 'Bluehouse', the facility will rear Atlantic salmon. Another recent engineering innovation in the RAS field includes the air lift vacuum column that not only manages dissolved gas but also moves huge quantities of water at low energy cost and separates suspended matter from water.[25]

## Biology and genetics

13. Innovative practices with regard to species domestication or new species introduction have been observed to address the local market demand, or to develop stock enhancement (culture based fisheries and sea ranching). Today the majority of farmed species have been domesticated although this is relatively recent for most species, especially when compared to the species used in terrestrial agriculture. The biological characteristics of a species can determine its adaptability to diverse rearing systems and influence traits such as robustness or resilience, reproduction in captivity, trophic level of feeding and feeding plasticity. Genetic technologies can be used to modify commercially important traits of aquaculture species (see COFI:AQ/X/2019/2.1).

14. Genetics and genomics is thus an area where innovation has huge potential and this potential is being further advanced by improved understanding, over recent decades, of the –omics (e.g. proteomics,

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[19] FAO. 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger & D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. http://www.fao.org/3/CA3129EN/CA3129EN.pdf

[20] https://globalsalmoninitiative.org/en/what-is-the-gsi-working-on/biosecurity/non-medicinal-approaches-to-sea-lice-management/

[21] https://www.salmar.no/en/offshore-fish-farming-a-new-era/

[22] https://www.fastcompany.com/3068608/replacing-farms-with-fish-farms-the-odd-solution-to-both-hunger-and-cli

[23] https://aquaculturemag.com/2018/08/28/technological-innovation-in-aquaculture/

[24] https://atlanticsapphire.com/about-us

[25] http://www.coldep.com/en/

transcriptomics, metabolomics) in which our increased knowledge of the biological functioning of organisms is enhancing our capacity to further adapt these organisms to our food production systems. Genetic-related innovations in aquaculture include selective breeding[26] for new characters such as fast growth, specific pathogen resistance (SPR), the ability to grow on plant-based feeds,[27] cold tolerance, stress resistance or feed efficiency (FE).[28,44] Adaptation to aquaculture breeding of new methods such as the marker assisted breeding, BLUP[29] estimated breeding, molecular marked breeding[30,31,32] has provided a fast and reliable approach.

15. The successful cryopreservation of gametes (sperms and eggs) and embryos offers new commercial opportunities with unlimited production of seed and fry along with potentially healthier and better conditioned fish and genetic management of broodstock. It can also assist in the *ex situ* conservation of the genomes of threatened and endangered species.

16. Chemical or environmental sex reversal,[33] genetic sex control,[34] chromosomic set manipulation (YY breeders,[35] triploids,[36] etc.) or intraspecific/interspecific/intergeneric hybridization[37,38] have been applied in several cultured species, such as tilapia, flounder, carp, etc.

17. Genome modification such as transgenesis and gene editing has also been applied in several species for experimental purpose but a transgenic salmon is the only genetically modified fish approved for human consumption[39] to date. New omics technologies have the potential to deeply impact production and management of fish genetic resources. In particular, CRISPR[40]-cas9 can add novel traits of enhanced growth, cold tolerance, disease resistance, etc.

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[26] https://doi.org/10.1111/raq.12202

[27] Le Boucher, R., Quillet, E., Vandeputte, M., Lecalvez, J. M., Goardon, L., Chatain, B., ... & Dupont-Nivet, M. (2011). Plant-based diet in rainbow trout (*Oncorhynchus mykiss* Walbaum): Are there genotype-diet interactions for main production traits when fish are fed marine vs. plant-based diets from the first meal?. Aquaculture, 321(1-2), 41-48.

[28] https://doi.org/10.1111/raq.12202

[29] Best Linear Unbiased Prediction

[30] De Verdal, H., Komen, H., Quillet, E., Chatain, B., Allal, F., Benzie, J. A., & Vandeputte, M. (2018). Improving feed efficiency in fish using selective breeding: a review. Reviews in Aquaculture, 10(4), 833-851. https://doi.org/10.1111/raq.12202

[31] Beardmore, J.A.; Porter, J.S. Genetically modified organisms and aquaculture. FAO Fisheries Circular. No. 989. Rome, FAO. 2003. 38p. http://www.fao.org/tempref/docrep/fao/006/y4955e/Y4955E00.pdf

[32] Application of genetic technologies in aquaculture development and management http://www.fao.org/3/mc856e/mc856e.pdf

[33] Baroiller, J. F., & D'Cotta, H. (2018). Sex control in tilapias. In: Sex Control in Aquaculture. Hanping Wang, Francesc Piferrer, Songlin Chen (eds). John Wiley & Sons, 888 p.

[34] Mair, G. C., Abucay, J. S., Beardmore, J. A., & Skibinski, D. O. (1995). Growth performance trials of genetically male tilapia (GMT) derived from YY-males in Oreochromis niloticus L.: On station comparisons with mixed sex and sex reversed male populations. Aquaculture, 137(1-4), 313-323

[35] Mair, G. C., Abucay, J. S., Beardmore, J. A., & Skibinski, D. O. (1995). Growth performance trials of genetically male tilapia (GMT) derived from YY-males in Oreochromis niloticus L.: On station comparisons with mixed sex and sex reversed male populations. Aquaculture, 137(1-4), 313-323.

[36] Peruzzi, S., & Chatain, B. (2000). Pressure and cold shock induction of meiotic gynogenesis and triploidy in the European sea bass, Dicentrarchus labrax L.: relative efficiency of methods and parental variability. Aquaculture, 189(1-2), 23-37.

[37] De Verdal, H., Rosario, W., Vandeputte, M., Muyalde, N., Morissens, P., Baroiller, J. F., & Chevassus, B. (2014). Response to selection for growth in an interspecific hybrid between Oreochromis mossambicus and O. niloticus in two distinct environments. Aquaculture, 430, 159-165.

[38] West, J. L., & Hester, F. E. (1966). Intergeneric hybridization of centrarchids. Transactions of the American Fisheries Society, 95(3), 280-288.

[39] https://aquabounty.com/

[40] Clustered Regularly Interspaced Short Palindromic Repeats

## Nutrition and feeding

18. Feeds are a major ingredient in aquaculture, being the main factor and source of performance, profit and environmental impact[41,42]. Innovations in this area include oil from microalgae as a fish oil alternative that contains the levels of high-quality omega-3 fatty acids (DHA and EPA) required by most fish species. Large agribusinesses are developing fish feeds by a process that places bacteria in fermentation tanks and feeds them methane. Fast-growing insects, such as black soldier flies, that feed on food waste or cereal by-products are another excellent sustainable source of protein for fish feeds, and have already been approved for use in aquafeeds by the EU (FDA approval in progress).[43]

19. The study on fish nutrition (formulation, flesh composition, probiotics and gut microbiota etc.) provide innovations in fish feed production, such as alternatives to fishmeal using more sustainable sources of proteins such as plant meals, bacterial meals or insect meals, use of local ingredients or recycling by converting CO2 or methane or organic wastes into feed ingredients, use of carbon monoxide and hydrogen feedstock from coal gasification, extruded and floating feed, mathematical modelling and nutrigenomics in feed formulation etc.

20. Fish feeding innovation, e.g. computer-aid distribution, functional feed, such as medicated feeds, first feed and feeds by growth stages etc., can thus lead to major gains and in salmon farming, for example, De Verdal *et al*. (2018) calculated that a 2–5 percent improvement in feed use efficiency would save 42.9–107 million USD per year.[44]

## Biotechnology

21. Aquatic biotechnologies having both basic and spin off applications, can play pivotal roles in promoting productivity, boosting efficiency, and ensuring sustainability in aquaculture. The key facets of the culture cycle (involving growth, nutrition, health and reproduction) can be optimized through biotechnological applications including enhancement of growth rate and feed conversion efficiency, nutrition and product quality, stress modulation, vaccination, disease resistance, modern disease diagnostics and treatment, genetic selection, transgenesis, etc.

22. Nanotechnology has opened up a new horizon for the analysis of biomolecules, development of non-viral vectors for gene therapy, as a transport vehicle for DNA, protein or cells, targeted drug delivery, clinical diagnosis, disease therapeutics etc. Biotechnological interventions have shown great promise in applying the tools of bioremediation and probiotics in environmental management of effluents, toxicants and pathogens. The present and prospective use of biotechnology would lead to development of smart and high performing fish.

23. Naturally-occurring microorganisms play a key role in aquatic environments, as they can fulfil a wide range of roles, including recycling nutrients, degrading organic matter and protecting fish against infections. Application of Effective Microbial (EM), biofilter, probiotics in water quality management has high performance in environment and optimum living habitat.[45]

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[41] Robb, D.H.F., MacLeod, M., Hasan, M.R. & Soto, D. 2017. Greenhouse gas emissions from aquaculture: a life cycle assessment of three Asian systems. FAO Fisheries and Aquaculture Technical Paper No. 609. Rome, FAO. 110 pp. http://www.fao.org/3/a-i7558e.pdf
[42] Hasan, M.R. & Soto, S. 2017. Improving feed conversion ratio and its impact on reducing greenhouse gas emissions in aquaculture. FAO Non-Serial Publication. Rome, FAO. 33 pp. http://www.fao.org/3/a-i7688e.pdf
[43] http://www.fish20.org/images/resources/Fish2.0-FISHFEED-Investor-Insights.pdf
[44] De Verdal, H., Komen, H., Quillet, E., Chatain, B., Allal, F., Benzie, J. A. and Vandeputte, M. (2018), Improving feed efficiency in fish using selective breeding: a review. Rev Aquacult, 10: 833-851. doi:10.1111/raq.12202
[45] Fishes 2018, 3, 33; doi:10.3390/fishes3030033

24. Vaccination is another innovation likely to produce major economic benefits. Vaccination has been recognised as an essential route to the reduction in use of antibiotics within the aquaculture industry in the UK and Norway.[46] For example, an economic analysis of vaccination against *Streptococcus agalactiae* in tilapia farms in Brazil proved that vaccinated fish would benefit from a +60-80 percent increased survival and exhibit +5-10 percent feed conversion ratio, this leading to significant savings, sales and profit.[47]

## Digital and Information and Communication Technology (ICT)

25. The future is digital for food systems, farming systems, health and the environment. These areas are increasingly driven by data and high tech innovations using new technologies, sensors, robotics and artificial intelligence, which will drive technical developments for different aspects related to aquaculture, such as the use of autonomous underwater vehicles in managing fish cages, individually tailored feeding, personalised fish health; genetics profiling, new food products, and efficient monitoring of the anticipated effect of climate and environmental changes.

26. A computer assisted aquaculture decision making system can help to decide the proper culture cycles with input based growth performance under climate and environment changes. There is bio-economic modelling for improving aquaculture performance, a User-Friendly Tool for Investment Decision Making in Aquaculture (UTIDA), assisted farmers to optimise the performance of aquaculture under different hypothesis.[48,49] Mobile phone apps are developed to manage production process, monitor remotely, facilitate marketing, such as e-commerce and online marketing.

27. Innovation around farming infrastructure is critical as sensors and related data-derived services are targeting farm efficiency. Recent developments of ICT applications include air-based drones or aquatic robots, aquatic sensors and video cameras for inspecting equipment and moorings, real-time monitoring of water quality, environment and fish, and assisting in the optimization of land-base and sea-cage farm operations. Installing the aquaculture management system UmiGarden device on a fish crawl, enables livestreaming of fish swimming behaviour to realize school remote monitoring at any time, through sensors and a management software layer. The Umitron device has an edge computing function so that it can optimize feeding costs by analyzing the school of fish.[50]

## Standards and certification

28. In terms of production and marketing of aquaculture products, one major innovation in recent years has been the development of market-led regulatory schemes based on setting standard requirements for farmers to follow and aimed at mirroring the production level expectations of remote consumers (remote in both geographical and cultural senses).[51] Experiences on the development of government surveillance, third party certification, commercial accreditation and aquaclubs proved

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[46] Norwegian Ministries, Norwegian Government's National Strategy against Antimicrobial Resistance, Norwegian Ministry of Health and Care Services, 2015-2020 Publication number: I-1164
[47] Marina K.V.C. Delphino, Rafael S.C. Barone, Carlos A.G. Leal, Henrique C.P. Figueiredo, Ian A. Gardner, Vítor S.P. Gonçalves, 2019. Economic appraisal of vaccination against Streptoccocus agalactiae in Nile tilapia farms in Brazil. Preventive Veterinary Medicine 162: 131-135. Doi:10.1016/j.prevetmed.2018.12.003
[48] http://www.fao.org/3/i8442en/I8442EN.pdf
[49] http://www.fao.org/fishery/statistics/software/utida/en
[50] https://thebridge.jp/en/2018/06/umitron-jpy920-funding
[51] Mialhe, F., Morales, E., Dubuisson-Quellier, S., Vagneron, I., Dabbadie, L., & Little, D. C. (2018). Global standardization and local complexity. A case study of an aquaculture system in Pampanga delta, Philippines. Aquaculture, 493, 365-375. https://doi.org/10.1016/j.aquaculture.2017.09.043

successful for improving farm management, information sharing and relationships with other stakeholders in the supply chain.[52,53]

29. The CCRF, developed by FAO almost twenty-five years ago, is probably one of the first records of inter-governmentally agreed principles in support of sustainable development of aquaculture. Relevant provisions have been further elaborated by several FAO Technical Guidelines for Responsible Fisheries,[54] but also by many collective or private guidelines describing Good Aquaculture Practices (GAP), suggesting practical improvements in practices such as species, stocking density, water quality management, diseases prevention, transportation, feeding, postharvest or business models. Best aquaculture practice (BAP) guidelines provide improved practices based on science, lessons and experiences, but also on the objectives of their promoter. Biosecurity, risk analysis[55] and prudent approaches[56] are recommended, especially with regards to transboundary movements of live aquatic animals.[57,58]

30. GlobalGAP, AquaGAP and BAP certification and the addition of Aquaculture Stewardship Council (ASC) shows commitment to environmentally responsible Pangasius production in Viet Nam, control over fish meal and fish oil sources, and social responsibility. The application of good practices aims to improve seed quality, feed quality and production standards, with an emphasis on food safety, traceability, animal health, environmental protection and social standards. Larger companies have fully integrated operations, enabling them to control every stage of the production process.[59]

## UPSCALING AND TECHNOLOGY TRANSFER

31. The difference between a promising technology or process and an innovation is contingent on its successful transfer and upscaling.[60] It is now recognized that the way the agendas of different stakeholders are represented during the technology development affects the “appropriateness” of new technologies and their subsequent adoption.[61,62] As a response to this, farmers’ participation has emerged

[52] A qualitative assessment of standards and certification schemes applicable to aquaculture in the Asia–Pacific region, http://www.fao.org/3/ai388e/AI388E00.htm
[53] Padiyar, P.A., Phillips, M.J., Bhat, B.V., Mohan, C.V., Ravi, B.G., Mohan, A.B.C. & Sai, P. 2008. Cluster level adoption of better management practices in shrimp (P. monodon) farming: an experience from Andhra Pradesh, India. In: M.B. Reantaso, C.V. Mohan, M. Crumlish & R. Subasinghe, eds. Diseases in Asian Aquaculture VI. Fish Health Section, Asian Fisheries Society.
[54] FAO. 2011. Technical Guidelines on aquaculture certification. http://www.fao.org/3/a-i2296t.pdf
[55] Arthur, J.R. and Bondad-Reantaso M.G. 2012. Introductory training course on risk analysis for movements of live aquatic animals. FAO SAP, Samoa. 167p. http://www.fao.org/3/a-i2571e.pdf
[56] Bondad-Reantaso, M.G., Arthur, J.R. & Subasinghe, R.P., eds. 2012. Improving biosecurity through prudent and responsible use of veterinary medicines in aquatic food production. FAO Fisheries and Aquaculture Technical Paper. No. 547. Rome, FAO. 207 pp. http://www.fao.org/3/ba0056e/ba0056e.pdf
[57] FAO. 2007. Aquaculture development. 2. Health management for responsible movement of live aquatic animals. FAO Technical Guidelines for Responsible Fisheries. No. 5, Suppl. 2. Rome, FAO. 2007. 31p. http://www.fao.org/3/a-a1108e.pdf
[58] Arthur, J.R.; Bondad-Reantaso, M.G.; Subasinghe, R.P. Procedures for the quarantine of live aquatic animals: a manual. FAO Fisheries Technical Paper. No. 502. Rome, FAO. 2008. 74p. http://www.fao.org/3/a-i0095e.pdf
[59] Miriam Greenwood, Seafood Supply Chains: Governance, Power and Regulation, Routledge, 2019
[60] Valvåg, O.R. Technology transfer through networks: experiences from the Norwegian seafood industry. FAO Fisheries Circular. No. 1004. Rome, FAO. 2005. 14p. http://www.fao.org/3/a-a0012e.pdf
[61] Asopa, V.N., Beye, G. 1997. Management of agricultural research: A training manual. Module 8: Research-extension linkage. Alternative research and extension systems technology transfer models. Rome: FAO. http://www.fao.org/3/W7508E/w7508e0d.htm
[62] FAO. 2018. Upscaling climate smart agriculture. Lessons for extension and advisory services. Occasional papers on innovation in family farming. Rome: FAO. 66 p. http://www.fao.org/uploads/media/Climate_Smart_Agriculture_draft08.pdf

and more inclusive thinking approaches have been developed.[63] The knowledge flows and interactions between the various stakeholders in the Agricultural Innovation System (AIS) as well as the capacity development by which new arrangements are developed for specific local contexts, are particularly important.[64]

32. One example of successful technology transfer and upscaling is the development of *Pangasius* farming in Viet Nam. In the mid-90s, the main species farmed in floating cages was *Pangasius bocourti*, “ca ba sa” in Vietnamese, for an annual production of 15 000 tonnes. Unlike *P. hypophthalmus* (“ca tra”), another Vietnamese catfish farmed mostly in ponds and which had been artificially bred for many years, no artificial propagation of *P. bocourti* had ever been reported and the fish farmers were dependent on an annual catch of 20 million fingerlings from the river.[65] Shortly after a successful research achieved the first controlled breeding of *P. bocourti*,[66] the national production of Viet Nam started to increase exponentially, reaching almost 1.3 million tons in 2017, but the main farmed species shifted from *P. bocourti* to *P. hypophthalmus*. This highlights the complexity of innovation processes and the importance of serendipity. It seems that the research conducted on *P. bocourti* did not just achieve the induced breeding of the species but also indirectly unlocked other barriers to aquaculture development of *P. hypophthalmus.*

## National development strategy

33. A national innovation system (comprising of a consortium of industry, academia, government and the producers’ association) dedicated to the marine shrimp culture industry established in Thailand in the early 1990s is an example of an innovation cluster at national level to develop solutions to a set of problems.

34. Countries with a tradition of aquaculture have developed their own national development strategy on sustainable aquaculture development. Based on technology development and strong research and development capacities, they carried out aquaculture technology innovations to meet the sustainable development goals.

35. These governmental targets can be noted as key factors in the increased priority of aquaculture technology in China starting in 2010. Technology development for preventing water pollution caused by feed for aquaculture was promoted for environmental protection in China’s 12th Five-Year Plan (2011–2015).[67] Furthermore, the Chinese government set a high priority on aquaculture technology development in the 13th Five-Year Plan (2016–2020) for national progress. This plan promotes the development of new aquaculture technologies among research institutes and universities.

36. The industry collaboration covers not only the technical nature of the problem but the policy, regulatory, management and capacity building aspects. China, the largest aquaculture producer, carried out a national strategy on aquaculture innovation through establishment of Agricultural Technology Innovation System. The system has covered five major economic species groups in China, i.e. carps, tilapia, shellfish, shrimps and flounder. In the 13th Work Plan, China promotes environment-friendly aquaculture technology innovations, such as ecological aquaculture, open recirculation system and rice-

[63] Impact of Research in the South https://impress-impact-recherche.cirad.fr/
[64] Making Agricultural Innovation Systems (AIS) Work for Development in Tropical Countries http://www.fao.org/uploads/media/sustainability%20paper.pdf
[65] Cacot, P., Legendre, M., Dan, T. Q., Tung, L. T., Liem, P. T., Mariojouls, C., & Lazard, J. (2002). Induced ovulation of *Pangasius bocourti* (Sauvage, 1880) with a progressive hCG treatment. Aquaculture, 213(1-4), 199-206. https://doi.org/10.1016/S0044-8486(02)00033-9
[66] Cacot, P. (1999). Étude du cycle sexuel et maitrise de la reproduction de *Pangasius bocourti* (sauvage, 1880) et *Pangasius hypophthalmus* (sauvage, 1878) dans le delta du Mékong au Viêt-Nam. Doctoral dissertation. Institut national d'agronomie de Paris Grignon, Paris, France: 317 p.
[67] China Agriculture Yearbook, 2015, http://english.agri.gov.cn/service/ayb/201701/W020170105346858276040.pdf

fish farming integration. It is reported that the total area of integrated rice-fish farming systems reached 2 million Ha in 2018. The Chinese practices illustrate the effectiveness of organizing science-industry-government cooperation to focus on a problem. It points to the need for an institutionalized (in contrast to ad hoc or project driven) linkage of the major players in an industry to address broad, specific, persistent as well as emerging issues.

37. Recognizing the importance of aquaculture planning for development, African countries increasingly developed national aquaculture development strategies. The New Partnership for Africa's Development (NEPAD), recently transformed to the African Union Development Agency, is an economic development program of the African Union. Many individual African states have also established national NEPAD structures responsible for liaising with the continental initiatives on economic reform and development programs. FAO and partners assisted many African countries that have developed or are developing specific aquaculture strategy documents or plans. Such sector-specific plans help to create awareness of the importance of and to define targets for the aquaculture sector.[68,69]

38. One example of successful upscaling of aquaculture as a result of a national strategy is the rice-fish farming in Madagascar. Following several decades of unsuccessful attempts to develop pond fish farming, from 1985 FAO started implementing a series of projects[70] that completely changed the situation. Instead of promoting fish pond farming, they focused on improving traditional rice-fish integration. New technologies where developed and promoted, by stocking common carps instead of wild fish, by digging a refuge canal and by strengthening the side dykes, reportedly allowing to produce up to 200-300 kg of fish per hectare while increasing rice yields by 10 to 30 percent. The involvement of the private sector for supplying the fry market was also promoted. All these activities had a major impact on the national fish production that increased 10- to 15-fold, from 200 tonnes before 1990 to over 2 500-3 000 tonnes/year a decade later.[71]

39. In some countries (the Republic of Benin, the Republic of Cameroon, the Republic of Côte d'Ivoire, the Republic of Ghana, the Republic of Kenya, the Federal Republic of Nigeria, the Republic of Uganda, the Republic of South Africa, the Republic of Zambia) there is an ever increasing use of ICT including mobile phones for marketing to reduce the information asymmetry between traders and producers to the benefit of the latter. There has been an overall increase in the use of new communication tools by professionals and many stakeholders' groups to access information to improve the output of their operations.[72]

40. The private sector has played a key role in research advancements and innovations. Research and development investments, mostly by the private sector in developed economies, are driven by the high economic value and profitability of a product or service. In some cases the products of research and development have been successfully shared with less developed countries and regions. In animal health, for example, improvements in vaccine development, diagnostics and therapy have significantly reduced disease related losses in aquaculture. The private sector has acknowledged the importance of joint research with government, academia, international agencies and non-governmental organizations

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[68] Brugere, C., Aguilar-Manjarrez, J., Halwart, M.2009. Formulation of a development plan for sustainable aquaculture in Cameroon. FAO Aquaculture Newsletter 43: 24-25

[69] Moehl, J.; Halwart, M.; Brummett, R. Report of the FAO-WorldFish Center Workshop on Small-scale Aquaculture in SubSaharan Africa: Revisiting the Aquaculture Target Group Paradigm. Limbé, Cameroon, 23–26 March 2004. CIFA Occasional Paper. No. 25. Rome, FAO. 2005. 54p.

[70] MAG/76/002, MAG/82/014, MAG/86/005, MAG/88/005, MAG/92/004, MAG/058/6023

[71] Dabbadie L., Mikolasek O. 2017. Rice-Fish Farming in the Malagasy Highlands, Twenty Years after the FAO Projects. FAO Aquaculture Newsletter (FAN) 56 (April 2017): 33-36. http://www.fao.org/3/a-i7171e.pdf

[72] FAO. 2017. Regional review on status and trends in aquaculture development in sub-Saharan Africa – 2015, by Benedict P. Satia. FAO Fisheries and Aquaculture Circular No. 1135/4. Rome, Italy. http://www.fao.org/3/a-i6873e.pdf

to improve fish seed and feed supply, which in turn can reduce pressures on the availability from local markets, and improve productivity and environmental performance of aquaculture.

## Technical support from International Organizations

41. Facing the increasing challenges in resources use, environmental degradation and climate changes, many country authorities request technical support from international organizations, such as FAO, IFAD, CGIAR, and NGOs, etc.

42. The Technical Cooperation Programme (TCP) was created to enable FAO to make its know-how and technical expertise available to member countries upon request, drawing from its own resources. The TCP provides assistance in all areas pertaining to FAO's mandate and competence that are covered by the Strategic Framework to respond to governments' priority needs. FAO has actively accelerated the technology transfer and upscaling of aquaculture innovations to its member countries through TCPs. Carp breeding in Kyrgyzstan, tackling shrimp disease in Viet Nam, seaweeds and milkfish culture in Zanzibar or "Doing aquaculture as a business" capacity building in Africa are just few examples where FAO assisted country authorities in adopting aquaculture technology innovations to benefit farmers, farmers' organizations, and the fishery economic sustainable development. TCP projects also indirectly affect aquaculture development as in the case of adopting spatial planning for marine cage culture in Iran, and adapting to climate smart aquaculture in Peru.

43. The South-South and Triangular Cooperation (SSTC) program covers South-South Cooperation (SSC) and Triangular Cooperation (TrC). These programs have proven effective in creating jobs, building infrastructure and promoting trade in countries across the global South. They seek to boost a broad framework for collaboration among developing countries and offer a complementary model to the traditional relationship between donors and recipients. As SSC plays a greater role than ever before in tackling food insecurity, global demand for Southern development solutions that have been tested and proven effective is at an all-time high. It has been established in Namibia, Uganda, South Africa, etc. on the breeding centre, pellet feedmill, rice-fish farming, and transferred aquaculture technology innovation from Brazil, China and Viet Nam etc. to other developing countries.

44. Partnerships and Public Private Partnership (PPP) are at the heart of FAO's mission to help build consensus for a world without hunger. The effectiveness and credibility of the Organization as a policy-making forum and unique multilingual centre of excellence, knowledge and technical expertise depends to a considerable degree on its ability to work and develop strategic partnerships. Only through effective collaboration with governments, civil society, private sector, academia, research centres and cooperatives, and making use of each other's knowledge and comparative advantages, can food insecurity be defeated. FAO-EU partnership on Mediterranean Aquaculture Integrated Development – MedAID, Ecosystem Approach to making Space for Aquaculture – Aquaspace, etc.

## Regional level

45. Networking is one option to facilitate knowledge sharing and diffusion. FAO has supported the formation of networks for aquaculture in many regions, such as the Network of Aquaculture Centres in Asia Pacific (NACA), the Aquaculture Network for Africa (ANAF), the Network of Aquaculture Centres in Central and Eastern Europe (NACEE), the Micronesian Association for Sustainable Aquaculture (MASA), The Aquaculture Network for the Americas (RAA). There are also inter-regional networks for the promotion of aquaculture innovations, such as the Fishery and Aquaculture Innovation Platform (FAIP), the Norwegian Seafood Federation, etc. These networks were established to improve communication between research societies and industry, developed to play an important role as to what priorities should be given for research and exchange programmes related to the sector. Another long-

term effect of the network collaboration was that the seafood industry gradually developed a more positive attitude towards research and development in general.[73]

46. A Consortium is another important approach to promote aquaculture innovations in the region or across the regions. There are worldwide consortia in aquaculture, such as the Green Aquaculture Intensification in Europe (GAIN), ASEM Aquaculture Platform and ASEAN-China Consortium for TVET Cooperation (ACCTC). Social networking is a special case of networking that can offer aquaculture entrepreneurs and workers opportunities for sharing knowledge and staying connected with families and social groups, which is of particular importance when they are out at sea or need to migrate for fishing/farming activities.

47. One emerging difficulty for innovation transfer and upscaling is the growing uncertainties with regards to climate and other global changes.[74] Capacity development is one of FAO's core functions under "Technical support to promote technology transfer and build capacity" and it has the potential to provide solutions. It is the "process whereby people, organizations and society as a whole unleash, strengthen, create, adapt and maintain capacity over time". It has traditionally been associated with knowledge transfer and training of individuals, yet it is a complex, non-linear and long-term change process in which no single factor (e.g. information, education and training, technical assistance, policy advice etc.) can by itself be an explanation for the development of capacity.[75] Aquaculture innovation transfer has been implemented in various areas through Farmers-Field-Schools.[76,77]

48. Feed Innovation Network (FIN) locations are proposed for the Americas, China, and Southeast Asia. FIN locations can guide ingredient evaluation for local species, and share performance data in an ingredient database. Regional meetings and conference calls will be held periodically to offer a forum for knowledge exchange.

## Knowledge products and sharing

49. FAO as a knowledge hub is devoted to synthesizing aquaculture technology innovations into knowledge products, such as web-based knowledge and tools, videos, books, proceedings, posters, hand books, manuals, portable training kits, etc. It is also devoted to facilitating exchange among Members through the organization of global or regional symposia on agriculture innovations, policy dialogue, conference and workshops to gain awareness of aquaculture innovations, exchange of good practices and pilot project for demonstrations. Another dimension is that FAO publishes knowledge products for wide and easy access, making important publications available in all UN languages and available for translation into local languages.

50. International and national organizations and agencies, such as the CGIAR agencies, government agencies, academia and universities, technical demonstration stations and vocational schools publish many knowledge products on aquaculture innovations and often aim to increase the human resources in the private sector and the number of smallholder commercial fish farmers with enhanced aquaculture knowledge and up-to-date practical skills. Information is often dispersed and scattered and particularly in cross-cutting innovation platforms and knowledge hubs aquaculture could still be much better

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[73] Valvåg, O.R. Technology transfer through networks: experiences from the Norwegian seafood industry. FAO Fisheries Circular. No. 1004. Rome, FAO. 2005. 14p, http://www.fao.org/3/a-a0012e.pdf

[74] 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. FAO Fisheries and Aquaculture Technical Paper, 627. Rome. FAO. ISBN 978-92-5-130607-9 http://www.fao.org/3/I9705EN/i9705en.pdf

[75] Corporate strategy on capacity development. http://www.fao.org/3/a-k8908e.pdf

[76] Halwart, M., Settle, W. 2008. Participatory training and curriculum development for Farmer Field Schools in Guyana and Suriname. A field guide on Integrated Pest Management and aquaculture in rice. Rome, FAO. 122p. http://www.fao.org/3/a-ba0031e.pdf

[77] Building capacity for integrated rice-fish systems through the regional rice initiative and South-South Cooperation http://www.fao.org/3/a-i7239e.pdf

represented and linked.[78] Collaboration and partnerships can enhance wider access to knowledge products on innovation with benefit for more stakeholders. FAO encourages more exchange and sharing of knowledge on aquaculture innovations.

## GUIDANCE SOUGHT

51. The Sub-Committee is invited to:

- Recognize the importance of aquaculture innovations in increasing efficiency, reducing environmental impact and combating climate change;
- Share experiences (including success stories and lessons learned) on aquaculture innovations;
- Provide advice and encourage the international community, and in particular existing aquaculture networks, to enhance collaboration on the synthesis, update and exchange of knowledge products on aquaculture innovations to increase resource efficiency and address environmental and climate change;
- Provide guidance and call for increased and dedicated financial resources for enhanced technical assistance for upscaling of innovations in aquaculture through various mechanisms, such as TCP, networking, SSC, or PPP.

[78] E.g. the Tropical Agriculture Platform http://www.tapipedia.org/search/tap