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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

Eighth Session

Brasilia, Brazil, 5–9 October 2015

RESEARCH AND EDUCATION FOR AQUACULTURE DEVELOPMENT

EXECUTIVE SUMMARY

This working paper provides an overview of the state of aquaculture education and research and elaborates with examples how these can contribute better to the development of aquaculture. It provides a basis for discussion on whether FAO should facilitate/provide guidance on research and education for aquaculture development and, if so, in which areas and how?

The Sub-Committee is requested to:

Review and comment on the document and advice on future actions to be taken in assisting and improving research and education on aquaculture, in particular supporting efficient resource use and sustainable intensification of aquaculture.

INTRODUCTION

1. Aquaculture has been the fastest growing food producing sub-sector over the past three decades. It is now producing about 97.2 million tonnes per annum (including aquatic plants), equating to about 50 percent of all aquatic food[1]. It is one of the most promising food producing industries, from both socio-economic and food security perspectives[2]. It can help reduce poverty through employment and economic development opportunities.

[1]FAO. 2015a. Fishstat Plus, Vers. 2.32. Rome, FAO. (www.fao.org/fishery/ statistics/software/fishstat/en).
[2] Urdes, L-D., Diaconescu, C., Marin, M. and Dinita, G., 2013. The role of veterinary education in fostering aquaculture development. Procedia – Social and Behaviral Sciences. 106: 3091 – 3094.

2. Around 58 million people were directly employed in fisheries and aquaculture in 2012 and some 200 million are employed along the value chain. The livelihoods of 880 million depend on it[3]. In 2012, 39.4 million people were engaged in capture fisheries and 18.9 million in aquaculture.

3. Aquaculture is also an alternative to exploitation of natural aquatic resources and it has shown its ability to contribute to mitigating climate change impacts through the production of food types and commodities that emit low levels of greenhouse gases and sequester carbon. For example, the carbon footprint of Atlantic salmon, chicken, pork and beef are 2.9, 2.7, 5.9, 30.0 kg of CO_2 respectively per kg of the edible part of the product[4].

4. While capture fisheries has plateaued, aquaculture has driven the growth of the seafood sector, influenced product diversity, and found ways to address economic development and environmental conservation goals in diverse aquatic ecosystems[5]. Historically it has been heavily resource-based (land, water and labour), although more recently it has steadily become knowledge- and technology-driven.

5. There have been many innovations in management and technology for it to efficiently meet the needs for nutritional security, decent employment, and sustainable production. The widespread adoption of improved technologies by traditional farms in a number of countries has shown aquaculture's ability to improve productivity, contribute to the diversification of rural livelihoods, and generate employment and income in developing country agriculture[6] but not without constraints and challenges.

SHIFT FROM "PRODUCING MORE" TO "PRODUCING MORE WITH LESS"

6. Resource constraints, among other limitations, have shifted the thrust of aquaculture "from producing more", "to producing more with less". This reflects the multitude of challenges to sustained productivity stemming from the demand for more aquatic species, the diversity of systems and culture environments, increased incidences of diseases, the perceived threat of climate change, and the increasing competition for resources by different stakeholders and the conflicts that this competition may generate. These will not go away by themselves and new issues will compound them.

7. The history of agriculture, particularly the Green Revolution, has shown that well targeted investments in science and technology and manpower development (at all levels from scientists to farmers) can push the productivity frontier ahead of population growth. Returns on investment to research in cereals have been highly positive. In aquaculture, a good example is provided by the high

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[3] FAO. 2015b. The Blue Growth Initiative. Fisheries and Aquaculture Department. Rome, FAO. 47 pp.

[4] http://www.globalsalmoninitiative.org/sustainability-report/

[5] Anon, 2014. National Aquaculture Research and Development Strategic Plan. National Program 106: Aquaculture. Agricultural Research Service, USDA. 22 pp.
http://www.nmfs.noaa.gov/aquaculture/docs/research/jsa_draft_aq_research_plan.pdf

[6] Ahmed, M. and Lorica, M.H., 2002. Improving developing country food security through aquaculture development – lessons from Asia. Food Policy, 27: 125-141.

economic return on investment (70 percent between 1988 and 2010 with an estimated net present value of US$368 million in constant 2001 prices)[7] in the development and promotion of GIFT8 tilapia.

8. In short, investments in research and education have been economically and socially beneficial by efficiently solving persistent problems, facilitating the solution of emerging problems, and catalyzing the development of innovations.

9. Producing more - "Use, improve and share known technologies to bring aquaculture on a par with livestock husbandry"- was the core of the scientific strategy advocated by the Kyoto Conference on Aquaculture of 1976 organized by the UNDP[9] and FAO. The Strategy had four cornerstones: (i) increase aquaculture production through transfer of proven technologies; (ii) undertake relevant adaptive research that facilitates increased production, leveraging basic and applied research though complementary activities with academic institutions; (iii) train senior personnel in planning and managing aquaculture development and production projects; and (iv) justify public expenditures for national aquaculture development projects.

10. Knowledge was collated from the allied disciplines, technology was borrowed from crop and animal husbandry and fisheries, and what rudimentary production techniques and traditional art (such as China's integrated aquaculture, India's polyculture and Norway's simple impoundment for salmon culture) that were available to farm fishs were improved on and infused with science, disseminated through practical training, and exchanged among countries.

11. Research was reoriented from disciplinary to multi-disciplinary to specific problem solving - focused on farming systems. Manpower development targets were set up by assessing the scientific, technical, management and production needs of the industry and matching the training programmes with those needs and priorities.

12. The early priorities were simple: produce more domesticate species and expand aquaculture development. Attention was given to producing visible and measurable results. For example, from 1978, through the adoption of an open policy for scientific advancement, Chinese aquaculture production leaped from 2.5 million tonnes in 1978 to 22.2 million tonnes in 1996 and to over 57.1 million tonnes in 20131. Its share in total fisheries production increased from 42.4 percent in 1978 to 60.8 percent in 1996 and 77.5 percent in 2013.

13. Cooperation among government institutions systematically transferred technical and management details of proven production practices through training, workshops, seminars, expert exchange and information. The training of national personnel and upgrading facilities created a multiplier effect for subsequent investments in R&D. The strengthening of regional and national capacities (that included trained people, upgraded facilities and more efficient operating and

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[7]Asian Development Bank. 2005. An impact evaluation of GIFT. http://www.adb.org/sites/default/files/publication/29623/ies-tilapia-dissemination.pdf

[8] Genetically improved farmed tilapia

[9] United Nations Development Programme

management systems) made it easier and more economical to execute subsequent research and training programmes.

14. The Strategy worked remarkably well. Aquaculture steadily grew. From the estimated annual output of 5.4 million tonnes in 1976, it sustained growth of 10 percent or more annually and had reached 33.8 million tonnes by 1996. It was over 97 million tonnes in 2013, with several countries now producing more fish from aquaculture than capture fisheries.

15. Producing more with less - "doing more from less" - was the core issue at the global review of aquaculture organized by FAO in Guangzhou in 200610. While technologies are improving, resources are becoming scarce and populations are increasing. The Global Conference on Aquaculture in 2010 also reconfirmed this[11]. To be sure, this is a universal problem felt and recognized by other industries long before 2006. It has been driving science, academia, industry and governments to devise ways that produce and deliver more goods and services using less resources and energy, convert waste to useful products, and emit less waste - guided by the principle that benefits are equitably shared. This is a simplified description of a knowledge-based socially responsible economy, and what this paper advocates the aquaculture sector should attain as soon as possible.

16. Knowledge, its production, communication and use, has always been critically important to the development of aquaculture[11]. Policy-makers and stakeholders need to better understand knowledge processes such as knowledge translation (implementation), knowledge networks (e.g. the role of farmers' associations) and the use of knowledge platforms and negotiators, all aimed at more effective dissemination and adoption of knowledge. Knowledge management by most stakeholders will become increasingly critical to the sustainable development of aquaculture and attaining the goals set out in the Kyoto Conference on Aquaculture of 1976 and reinforced by the Bangkok Declaration in 2000[12].

17. There are good examples of doing more with less as an outcome of new knowledge. Farmers of Atlantic salmon over the last three decades have achieved significant improvement in feed efficiency (kg live weight gain/kg dry feed) from less than 0.3 in 1975 to about 0.85 in 2010[13].Similarly, the cost of feed per kg of Atlantic salmon raised in Norway decreased from US$3.5 in 1985 to US$1.5 in 2006, the result of improved feed quality and feed management[14]. Farmed salmon produces lower GHG emissions per kg than most other fed fish and shrimp species[15]. Other

[10] FAO Fisheries Department. State of world aquaculture 2006. FAO Fisheries Technical Paper. No. 500. Rome, FAO. 2006. 134 pp. http://www.fao.org/3/a-a0874e.pdf

[11] Davy, F.B., Soto, D., Bhat, V., Umesh, N.R., Yucel-Gier, G., Hough, C.A.M., Derun, Y., Infante, R., Ingram, B., Phoung, N.T., Wilkinson, S. & De Silva, S.S. 2012. Investing in knowledge, communications and training/extension for responsible 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. 569 – 625. FAO, Rome and NACA, Bangkok.

[12] http://www.fao.org/3/a-ad351e.pdf

[13] Kaushik, S.J. 2013. Feed management and on-farm feeding practices of temperate fish with special reference to salmonids. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture,* pp. 519 – 551. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

[14] Robb, D.H.F. and Crampton, V.O. 2013. On-farm feeding and feed management: perspectives from the fish feed industry. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture,* pp. pp. 489 – 518. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

[15] http://www.wri.org/events/2014/06/improving-productivity-and-environmental-performance

examples include the sharp decrease in the use of fishmeal (45 percent in 1995 to 25 percent in 2008, with predicted decreases to 12 percent in 2020) in salmon diets while increasing use of feed ingredients of terrestrial origin[16]. These technological improvements resulted from genetic, feed and nutrition research, and innovations[17]. Another case is the reduction of antibiotics use with the use of vaccines developed by research supported by targeted investments in health management (mostly in Norway). These innovations have been transferred to other countries by the private sector (e.g. to Chile).

STRATEGY FOR AQUACULTURE DEVELOPMENT BEYOND 2000

18. The Bangkok Declaration and Strategy on Aquaculture Development Beyond 2000[18] has 16 elements. Two of these are (a) Investing in people through education and training and (b) Investing in research and development. The recommendations for education and training included:

- participatory approaches to curriculum development;
- co-operation and networking between agencies and institutions;
- multidisciplinary and problem-based approaches to learning;
- modern training, education and communication tools, such as the internet and distance learning, to promote regional and inter-regional co-operation and networking in the development of curricula, exchange of experiences and the development of supporting knowledge bases and resource materials; and
- a balance of practical and theoretical approaches to train farmers and provide skilled and innovative staff to industry.

19. The suggested R&D strategy was to make efficient use of research resources and build the capacity of research institutions to be more responsive to development requirements through mechanisms such as:

- collaborative multidisciplinary research;
- stakeholder participation in research identification and improving linkages between research, extension and producers;
- collaborative funding arrangements between institutions, the public and private sector organizations;
- efficient communication networks;
- regional and inter-regional co-operation; and
- continuing efforts to build skills of researchers.

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[16] Tacon, A.G.J., Hasan, M.R. and Metian, M. 2011. *Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects*. FAO Fisheries and Aquaculture Technical Paper No. 564. FAO. 87 pp

[17] Asche, F. and Roll, K.H. 2013. Determinants of inefficiency in Norwegian salmon aquaculture. Aquaculture Economics & Management, 17(3): 300-321

[18] NACA/FAO. 2000. Aquaculture Development Beyond 2000: the Bangkok Declaration and Strategy. Conference on Aquaculture in the Third Millennium, 20-25 February 2000, Bangkok, Thailand. NACA, Bangkok and FAO, Rome. 27 pp. http://www.fao.org/3/a-ad351e.pdf

EDUCATION: PRIORITY SETTING FOR FUTURE NEEDS AND STRATEGIES FOR IMPLEMENTATION

20. Education is the foundation for all development and interdisciplinary aquaculture education is the foundation for sustainable aquaculture development. China, for one, has greatly benefited from investing in education in key sectors including aquaculture19. Priorities for education need to be based on the future needs with well-defined strategies for implementation. However, the criteria for priority setting are often highly variable and uniform approaches are not always applicable or desirable. Some rules of thumb may however be observed include:

- Identify critical areas of and opportunities for future development;
- Encourage universities to re-orient aquaculture curricula to meet the sector's priority needs;
- Improve curricula and special programmes to train people for a holistic perspective of aquaculture and management that is required to devise solutions to actual problems;
- Education at all levels includes the ability to mitigate the social and environmental impacts of aquaculture;
- Develop alternative learning systems such as non-formal education and life-long learning (do not learn for learning's sake but learn how to adapt to changing circumstances). There are many alternatives for knowledge transfer other than formal education e.g. research in collaboration with farmers;
- Coaching systems are an important component of this kind of learning system and need to be coordinated within the knowledge networks.

21. The standardization of educational systems would ease mobility within the aquaculture labour market. But this risks losing the local nature and diversity of curricula/courses so that harmonization rather than standardization is more important to encourage diversity and innovation; what is best suited for each country is in the best interests of all others.

22. Collaboration and partnerships through consortia led by institutions of international renown as well as international networking are effective mechanisms for improving the quality of educational programmes. A consortium can be a mechanism for:

- streamlining research so that the same research is not repeated by different institutions;
- exchanging information and sharing experiences; and
- improving the appeal for prospective students to peruse a career in aquaculture and fisheries.

23. The Republic of Korea has established and is building up the Fisheries and Aquaculture University of the UN, and it would be worthwhile to explore ways of collaborating with it to enhance its contribution to global aquaculture Research and Education. It could be one of the leading institutions in a regional or global consortium.

[19]Nandeesha, M.C. 2003. Aquaculture Education in India – opportunities for global partnership. Aquaculture Asia, VIII (2): 26-31.

24. The private sector should be part of the consortium so that their manpower and technological needs are considered (often the private sector is unsure of what the educational institutions require from them). The demand for a particular educational offering can be driven by a business trend; students are motivated by job placement availability. Thailand saw a sharp student enrollment increase in aquaculture programmes during the shrimp boom in mid 1990s.

25. The fundamental issue here is that education (and research) caters to the market. The trend seems to be that educational institutions - even state-owned universities which are mandated to provide education and research as a public good - are increasingly market driven. This suggests a key strategy: the formation of partnerships among academia, private industry (including input and service providers, and producers) and the relevant government agency(ies) and institutions i.e. a consortium.

THE ROLE OF THE PRIVATE SECTOR AND PUBLIC-PRIVATE COOPERATION

26. Private sector has played a key role in research advancements and innovations. This has been noteworthy, particularly in nutrition and health. In nutrition, feed development and feed management; feed companies have invested significantly in research programmes - even though the results are not always widely shared. R&D investments, mostly by the private sector in developed economies, are driven by the high economic value and profitability of a product or service. The products of R&D should be shared with less developed countries and regions, and it has been done so in some cases. In health, improvements in vaccine development, diagnostics and therapy have significantly reduced disease related losses in aquaculture.

27. Technological advances in salmon farming have been adopted to improve efficiency in farming of other species such as Nile tilapia, Indian and Chinese carps, and catfish. Cooperation in research and training within the industry and industry and government can focus research to address aquaculture development needs; the private sector has acknowledged that joint research to improve feeding and FCRs can reduce pressures on the availability of feed ingredients, and improve productivity and the environmental performance of aquaculture.

28. Linkages among institutions in a country - It is now economical and efficient to manage a platform for sharing information among educational institutions in a country or a sub-region. With information technology making such linkages possible with minimal cost and effort, a network of institutions involved in aquaculture teaching and research would be useful.

29. Networking with farming communities - Ultimately farmers test the commercial viability of technologies – even though they come up with their own on-farm innovations. Networking with farmers can potentially provide profitable educational outcomes through the placement of students to gain valuable practical work experience, and as opportunities to undertake commercially orientated research and development programmes.

30. Networking within a region - Diversity and mobility are essential components for global capacity-building in education. Sharing resources between regions is just as important as within them.

Asia, for instance, has a number of specialized institutions in aquaculture and there is an opportunity to establish close linkages between these institutions. Japan has played a significant role in assisting several other countries in the region with expertise. Through SEAFDEC[20], Japan has provided significant support for the SEAFDEC Aquaculture Department in the Philippines.

31. The Asian Institute of Technology in Thailand has played a key role in the development of small-scale aquaculture technology in the region and in training researchers, managers, technicians, and producers from several countries. The FAO South South cooperation/partnership between different countries/organizations has been an extremely useful platform for networking and establishing close linkages between institutions/countries in different regions (e.g., Asia-Pacific including south Asia, Central Asia, sub-Saharan Africa, and Latin America and the Caribbean islands).

32. Networking in aquaculture education and research deserves special consideration in Sub-Saharan Africa (SSA), for many reasons. While SSA is home to several academic institutions with aquaculture research capacity, they tend to be geographically isolated with minimal networking and sharing of resources. Recent attempts have been made to promote networking between institutions to develop regional research and teaching capacity.

33. For example, under the auspices of the NEPAD-RFN programme (New Partnership for African Development - Regional Fish Node), the Bunda College of Agriculture, University of Malawi, has developed a regional aquaculture PhD training programme. The programme supports the training of students from Eastern, Central and Southern Africa to build and strengthen a network of researchers involved in refining and implementing projects to enhance fisheries, aquaculture production and biodiversity.

34. Other institutions include the Forum for Agricultural Research in Africa (FARA), the technical arm of the Africa Union Commission on matters concerning agriculture science, technology and innovation. Through its programme, Strengthening Capacity for Agricultural Research for Development (SCARDA), it aims to strengthen human and institutional capacity of African National Agricultural Research Systems. With the closure of the NEPAD fisheries desk, the African Union Inter-African Bureau for Animal Resources (AU-IBAR) has taken over the mantle for the Partnership for African Fisheries; its aquaculture working group is a potential mechanism for coordinating aquaculture research.

35. The Association of African Universities has identified the need to upgrade the curricula of African universities to ensure they deliver skills and professionals required by the labour market. This can be promoted as a collaborative area of work with the Southern African Regional University Association.

36. The SARNISSA (Sustainable Aquaculture Research Networks for Sub-Saharan Africa) project in southern Africa has effectively linked researchers, farmers and the private sector. It has not

[20] Southeast Asian Fisheries Development Centre

taken up a formal role of networking in aquaculture education, but has proved highly effective in promoting networking within the farming community and as an information and educational tool.

37. FAO has supported the establishment of Aquaculture Network for Africa (ANAF) which is modeled after NACA[21]. ANAF was conceived to facilitate the exchange of aquaculture information in the Sub-Saharan Africa and develop an informal, flexible and efficient network of regional experts for aquaculture development.

38. Consideration could be given to orientating curricula, research and special programmes of FAO towards Africa. A regional workshop can be organized, which is preceded and informed by a survey of the curricula and research programmes. The workshop would identify key areas for improvement. The results of the workshop could be used to initiate a regional network and programme on Science and Technology Innovation in Aquaculture. It could be integrated within the work programme of AU-IBAR.

RESEARCH: A STRATEGY FOR SETTING PRIORITIES

39. Considering the diversity of aquaculture practices and systems in the world, the prioritization of research issues by region may be the better option and FAO can facilitate the regional initiatives in identifying researchable issues after assessing the regional needs. Nevertheless, a number of globally important researchable issues can be flagged:

- technically advanced, environmentally compatible, and sustainable production systems;
- domestication and improved productivity of species of economic importance;
- development of culture species and novel products with strong market demand; and
- exploiting competitive advantages through the integrated use of water and feed resources for production of public goods and enhanced environmental services, such as healthy foods, strong populations of wild stocks, and healthy ecosystems[5].

40. The research strategy underpins these current priorities, which have varying degrees of importance across regions and sub-regions:

- Integration of aquaculture development with environmental conservation;
- modeling environmental impacts; improved spatial planning/integrated resource planning and ecosystems approach to aquaculture; optimization of farming practices;
- Genetics to increase productivity, meet consumer demands and protect natural populations;
- Breeding/genetic improvement programmes (i.e. for enhanced growth, disease resistance, product quality); management of genetic resources within cultured and wild stocks; assessing and modelling genetic risks and controlling introductions of non-native species and non-native genotypes;
- Health management and biosecurity;

[21] Network of Aquaculture Centres in Asia-Pacific

- Characterize disease causing agents/parthenogenesis; develop vaccines, drugs and probiotics; improved disease detection and diagnostic assays / surveillance protocols; improved stock health monitoring and biosecurity protocols;
- Improve aquaculture production efficiency and well-being;
- Intensification of production systems; establish stressors in culture systems and associated mitigation measures; enhance growth and survival with improved culture technologies;
- Improve aquatic nutrition, feeding and feed management;
- Optimization of species and size-specific feed formulations; fishmeal/fish oils replacements; improved feed manufacturing technologies; optimized feed management practices;
- Increase supply of nutritious, safe, quality seafood;
- Improved processing and post-harvest technologies; product safety through improved diagnostics (e.g. bacteria, toxins, residues) and product quality monitoring; improved shelf life; food policy, legislation and regulation;
- Develop innovative aquaculture production systems including reduction of environmental footprint;
- Cost effective production systems and technologies - Recirculation Aquaculture Systems, Integrated Multi-Trophic Aquaculture Systems, improved effluent treatment systems;
- Integrate economic and social sciences in aquaculture research and innovation system;
- Improved understanding of value chains and actors; economic modeling and maximizing economic returns and social welfare; markets and trade; certification; social resilience; knowledge networking; equity and gender issues.

41. Networking in research - Networking in research would facilitate synergies between institutions. Setting up of technology development platforms can be considered for different production sectors to identify who is doing what, in which countries, and identify future needs. A good place to start would be the various international symposia that attract scientists, farmers, private sector suppliers etc. Reviewing existing research networking is another option to glean some lessons and guidelines:

- WorldFish, Globefish, COPESCAALC[22], NACA,WIOMSA[23] are some of the organizations engaged in research networking. Is there need to evaluate the effectiveness and impact of some of these network arrangements?
- FAO can facilitate networking among these organizations, work with different universities in the regions as well as assist Member countries to identify regional priorities and private sector needs for aquaculture development;
- How can universities be engaged in applied research? This would require significant funding.

NATIONAL INNOVATION SYSTEMS (NIS)

42. Investment in proactive education and research is essential for the sector to meet its development needs and for it to meet societal needs. In this regard, establishing and strengthening National Innovation Systems for Aquaculture can be an effective means to meet the challenges of knowledge-based aquaculture development.

[22] Commission for Inland Fisheries and Aquaculture of Latin America and the Caribbean
[23] Western Indian Ocean Marine Science Association

43. A national system of innovation has been variously defined by OECD[24,25] with the most recent definition being "that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies" [26].Ideally, the NIS should comprise:

- Universities: basic, applied research, education;
- R&D Centers and Institutions: applied and adaptive research and training;
- Private sector: equipment and machinery manufacturers, feed and drug/feed additive producers - commercial application of innovations, production and supply of inputs;
- Farmer associations: on farm trials, feedback to industry and to R&D institutions; traders - wholesalers and retailers: feedback on product and services acceptability;
- Consumer groups or associations: feedback on needs satisfaction;
- Civil society organizations: sometimes representing consumers;
- Government: incentives to investments in innovation, policy and regulations.

44. 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[27].Its programme began with broodstock development and the genetic improvement of black tiger shrimp, Peneaus monodon. This became institutionalized into the Shrimp Genetic Improvement Center for development of genetically selected SPF28 black tiger shrimp.

45. This illustrates 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. The industry collaboration covers not only the technical nature of the problem but the policy, regulatory, management and capacity building aspects.

REGIONAL AND GLOBAL LINKAGES FOR AQUACULTURE INNOVATION

46. All regions have educational institutions, Research and Development centers, private research establishments devoted to aquaculture, with aquaculture as part of their mandates or working on areas that produce technology which aquaculture can benefit from or train people in disciplines the aquaculture sector can employ them for. Some have capacities for basic research and high-level

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[24] Organisation for Economic Co-operation and Development
[25] OECD. 1997. National Innovation Systems. Centre Français d'Exploitation du Droit de Copie (CFC), 3, rue Hautefeuille, 75006 Paris, 48 pp. http://www.oecd.org/science/inno/2101733.pdf

[26] Metcalfe, J.S. 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives. *In* P. Stoneman, ed. *Handbook of the Economics of Innovation and Technological Change,*pp. 409–512. Blackwell Publishers, Oxford (UK)/Cambridge (USA). 583 pp.
[27] READI. 2014. ASEAN Research Landscape in Aquaculture: Opportunities for Investments and Cooperation in Science and Technology. REGIONAL EU-ASEAN DIALOGUE INSTRUMENT. 59 pp. http://readi.asean.org/news/155-asean-research-landscape-in-aquaculture-opportunities-for-investments-and-cooperation-in-science-and-technology
[28] Specific pathogen free

training in science and technology, others have intermediate capacities and are geared towards applied and adaptive research, and some have the mandate to adapt research for local application. Most of them include personnel training for research, extension, management and production.

47. Through various frameworks, there are numerous regional and inter-regional collaborations in S&T (including manpower training), encompassing various funding arrangements. These include ASEAN, APEC[29], SAARC[30], CARICOM[31], SPC[32], FEAP[33] etc.).

48. The broad role of FAO in this international ecosystem of research and education in aquaculture and allied fields would be to offer a focus to their programmes. That focus could be the current global (and FAO) advocacy of Blue Growth. Many of these institutions have developed their capacities or have been working on programmes to address climate change issues. They would also have sharpened their expertise for research that contributes to production intensification, and mitigation of risks and environmental impacts. The FAO Blue Growth Initiative (BGI) would provide the signals for their individual programmes on S&T, but more importantly for their collaborative programmes.

49. If BGI was unpacked, in other words its components were laid out separately, one or more of these would likely be in line with the ongoing progammes, interests or capacities of the global, regional and national entities with mandates in aquaculture or allied fields. The strategic action would be to establish collaboration with these entities to strengthen or fill up the gaps through inputs in research and/or education - in the particular areas that are of their interest and contribute to the BGI.

50. The above outlined role of FAO extends to the development of NIS for Aquaculture. It can be used to encourage the formation or provide assistance in strengthening national clusters of institutions (academia, government, industry) to develop into an NIS for Aquaculture, with their S&T programmes becoming attuned towards the BGI.

[29] Asia-Pacific Economic Cooperation
[30] South Asian Association for Regional Cooperation
[31] Caribbean Community Secretariat
[32] Secretariat of the Pacific Community
[33] Federation of European Aquaculture Producers