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Montpellier, France, 25 August 2018

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PREPARATION OF THIS DOCUMENT

This report presents the results of the Special Session convened by the Food and Agriculture Organization of the United Nations (FAO) with support from Cirad (Centre de coopération internationale en recherche agronomique pour le développement) and NACA (Network of Aquaculture Centres in Asia-Pacific) during the joint World Aquaculture Society-European Aquaculture Society's International Conference AQUA 2018, Montpellier, France, 25 August 2018.

The report was prepared by Lionel Dabbadie, Austin Stankus, Xinhua Yuan and Matthias Halwart of FAO's Aquaculture Branch. Danielle Blacklock reviewed the document and provided useful improvements. Junning Cai provided useful World Aquaculture Performance Indicators (WAPI) illustrations.

The contributed papers are reproduced as submitted.

ABSTRACT

A workshop, aimed at collecting and documenting the diversity of integrated agriculture-aquaculture practices (IAA), was organized on 25 August 2018 in Montpellier during the International conference AQUA 2018 of the World and European Aquaculture Societies. The objectives were to clarify how an IAA implemented within an agroecological approach could help alleviating poverty and hunger, and to identify the knowledge gaps to be filled to ensure the sustainability of IAA. Twenty-five speakers presented background information and case studies in front of a full room.

The various case studies showed that traditional rice-fish culture continues to expand, especially in areas like Madagascar, China or the Lao People's Democratic Republic where improvements have been developed with local stakeholders and indigenous communities. In China, rice is increasingly integrated with new, high market value, fed species such as mitten crab, crayfish, turtle etc. In Guinea, rice-fish integration has been adapted to develop technologies that allow for the culture of rice in fishponds. However, traditional animal-fish integration sometimes tend to stagnate or regress (Brazil, some parts of Asia) despite its benefits. Aquaponics is developing in many areas, including Near East (Oman), Asia (Indonesia), Caribbean or Europe. Recirculating systems with integration to non-fed species is growing fast: “shrimp toilets” (Thailand), raceways in ponds (China), “aquamimicry” (Thailand), integrated cages (Viet Nam), and compartmentalization (Europe). Ecological engineering is also being used in China to recreate a spatial environment with an overall neutral environmental impact. In coastal areas, improved mangrove-shrimp farming is being tested by Viet Nam. IMTA is also being tested, but often still at a pilot stage, especially in Europe. Use of pro- and prebiotics is developing, but not all products are as efficient and the purpose of their use is highly diverse, in particular in India, Bangladesh and Kenya. Efficient water use is a driver for developing IAA, especially in desert and arid lands like Egypt or Oman.

Based on the case studies presented and the discussions that followed, recommendations were made, including the necessity to continue using agroecology to orient IAA development towards efficiency, to measure the environmental, economic and social performance of the improved systems, to define the transition paths to an upscaled sustainable IAA, or to produce some basic knowledge that is still lacking today. Special attention was paid to the constraints specific to small producers.

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ABBREVIATIONS AND ACRONYMS

ABW	Average Body Weight
ADG	Average Daily Growth
AFD	Agence Française de Développement
AHPND	Acute Hepatopancreatic Necrosis Disease
AIA	Aquaculture Intégrée à l'Agriculture
AIT	Asian Institute of Technology
AMR	Anti-Microbial Resistance
AMTI	Aquaculture Multi-Trophique Intégrée
APDRA	Association Pisciculture et Développement Rural en Afrique
BOD	Biological Oxygen Demand
CAFS	Chinese Academy of Fisheries Sciences
CBF	Community or culture-based fisheries
CFU	Colony-Forming Unit
CGIAR FISH	Research Program on Fish Agri-Food Systems of the Consultative Group for International Agricultural Research
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
COD	Chemical Oxygen Demand
COFI	Committee on Fisheries
CPHP	Commercial Prophylactic Health Products
CRSP	Collaborative Research Support Programme
DLF	Department of Livestock and Fisheries (the Lao People's Democratic Republic)
DNP	Direction Nationale de la Pisciculture
DOC	Duration of Cycle
DOF	Department of Fisheries
EPAGRI	Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
FFRC	Freshwater Fisheries Research Center
FOFIFA	National Center for Applied Research on Rural Development
FSy	Fermented soybean meal
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIAHS	Globally Important Agricultural Heritage Systems
GMO	Genetically-Modified Organism
HP	Horse Power
IAA	Integrated Agriculture-Aquaculture
ICLARM	International Center for Living Aquatic Resources Management
IIA	Integrated Irrigation-Aquaculture
IMAQulate	Immuno-Modulators in Aquaculture
IMSF	Integrated Mangrove-Shrimp Farming
IMTA	Integrated Multi-Trophic Aquaculture
INRA	Institut National de la Recherche Agronomique
IPRS	In-Pond Raceway aquaculture System
LFRB	Liquid Fermented Rice Bran
MAVIPI	Modelo Alto Vale do Itajaí de Piscicultura Integrada
MPAEM	Ministère des pêches de l'aquaculture et de l'economie maritime
N	Nitrogen
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	Non-Governmental Organization
P	Phosphorus
PDRPGF	Projet de Développement de la Rizi-Pisciculture en Guinée Forestière
PCR	Polymerase Chain Reaction

PL	Post-Larvae
PPGF	Projet de Pisciculture en Guinée Forestière
RAS	Recirculating Aquaculture System
SDG	Sustainable Development Goals
SFB	San Francisco Bay
SGR	Specific Growth Rate
SIS	Small Indigenous Species
SME	Small and Medium Enterprise
SQU	Sultan Qaboos University
SRA	Système de Riziculture Améliorée
SRI	Système de Riziculture Intensive
SRT	Système de Riziculture Traditionnelle
UNDP	United Nations Development Programme
UVI	University of the Virgin Islands
VAC	Vuon Ao Chuong
VC	Vinh Chau
WAPI	World Aquaculture Performance Indicators
WFP	World Food Programme
VSF	Vétérinaires Sans Frontières
WiA	Women in Aquaculture
WSI	Water Scarcity Regional Initiative
WSSV	White Spot Syndrome Virus
YHV	Yellow Head Virus

CONTEXT

1. Aquaculture now supplies more than half of the world's fish consumed and to meet global demand which is expected to reach 152 million tonnes per year by 2030, the sector will need to produce an additional 17 million tonnes. So far, the increase in production has been made possible by two means: the expansion of aquaculture production areas and the intensification of production methods. However, this has in some cases led to some undesirable environmental impacts at both the local and global levels, with the destruction of some important ecosystem services, as well as social conflicts between users of land and resources (especially water).

2. The integration of aquaculture and agriculture is not a recent innovation. Indeed, it is ancient, but in a context of increasing pressure on natural resources and land, aggravated by the uncertainties of climate change, it offers new opportunities to build more sustainable food systems through new practices that allow producing more, while also creating socio-economic and environmental benefits.

3. Agroecology is one of the new approaches that allows advancing the integration of aquaculture and agriculture. It involves applying ecological concepts and principles to optimize interactions between plants, animals, humans and the environment. By creating synergies, agroecology not only contributes to food production, food security and nutrition, but also to the restoration of ecosystem services and biodiversity, which are essential for sustainable agriculture. It can thus play an important role in building resilience and adapting to climate change.

4. In this context, the objective of the workshop was to assess the current state and prospects for agroecological development of Integrated Aquaculture in Agriculture, in order to determine if, under what conditions and how integrated aquaculture and agroecology can contribute to meeting current development challenges in the sector.

5. The workshop was held on the first day of the AQUA 2018 conference, 25 August 2018. Twenty-five speakers presented their communications to over 100 participants.

OPENING PRESENTATION (MATTHIAS HALWART)

6. Matthias Halwart (FAO) opened the workshop. After highlighting the diversity of aquaculture systems integrated with agriculture, he stressed that these practices offered the opportunity to inspire new and more sustainable food systems.

7. He also introduced the FAO Common Vision for Sustainable Food and Agriculture and noted that it calls for a reassessment of IAA systems. This new vision, endorsed by FAO Member States, is based on the recognition that it will be necessary to produce more, in view of population growth, but in a context increasingly constrained by scarce natural resources and the changes resulting from climate change. This vision, developed through extensive consultations and the mobilization of lead experts, proposes five key principles and emphasizes synergies and inter-sectoral practices. Agroecology on its side is based on ten principles: diversity, synergies, co-creation and sharing of knowledge, resilience, food culture and traditions, the circular and solidarity economy, recycling, efficiency, human and social values and responsible governance.

8. After stating the objectives of the workshop, Mr. Halwart concluded his intervention by officially opening the workshop.

HISTORY OF IAA AND AGROECOLOGY IN AQUACULTURE (PETER EDWARDS)

9. Peter Edwards, Professor Emeritus at the Asian Institute of Technology (Thailand) gave the first presentation, setting IAA and agroecology in their historical perspective. He began by recalling the definition of IAA: the integration of aquaculture with a crop and/or a livestock subsystem. IAA may be more or less intensive depending on the level of inputs it receives, it is direct when the inputs come from the farm or indirect when they come from outside.

10. Historically, rice-fish farming may date back 8 000 years in China and it is in this same country that polyculture of carp was developed a thousand years ago, after the breeding of common carp was prohibited because its Chinese name "li", was the same as that of Emperor Li.

11. Common carp was then introduced by sea to Japan (2000 years ago) and Indonesia (600 years ago), and by land to the Lao Peoples's Democratic Republic and Viet Nam (unknown date). For other Chinese carps, it was mainly during the 19th and 20th centuries that they were widely distributed throughout Southeast and South Asia.

12. Integration between rice and fish is often based on species with a low commercial value, but there are exceptions such as high value crustacean farming in rice fields in Bangladesh, China and Viet Nam. It remains a traditional activity, especially in the mountains, where the rice terraces are located (Zhejiang Province in China, North Viet Nam), but it is also currently promoted by various projects e.g. in the Lao People's Democratic Republic and Cambodia. However, there is a major trend towards converting rice fields into fish ponds throughout Asia, some involving IAA e.g. with ducks and horticulture in Viet Nam.

13. P. Edwards then referred to the traditional Chinese pond polyculture, emphasizing the central role of grass carp, which has been described as a "natural fertilizing machine" supported by two Chinese proverbs: "Take care of grass carp and other species will take care of themselves" and "one grass carp can feed two silver carps and one bighead carp".

14. Integration of fish with livestock has played an important traditional role in densely populated countries such as China, Indonesia and Viet Nam. However, since the 1990s, there has been a decline in IAA and an intensification through pellet-fed aquaculture systems. Today, the main direct livestock-fish systems encountered in Southeast Asia are poultry integrated with ponds. Among the indirect systems, integrated Indian carps farming produces 1 million tonne of rohu and catla in India. Fertilizers are broiler chicken litter and chemical fertilizers, while brans and oil cakes are also used as supplementary feed. Similar indirect IAA systems are found in Thailand and Viet Nam.

15. Research focused on establishing a scientific basis of how these systems work. Over the past forty years, recommendations have been formulated for different types of IAA for fertilization and supplementary feeding, and nutrients, oxygen and ammonia dynamics and various other design criteria.

16. P. Edwards then presented the experience of the Asian Institute of Technology[1] in promoting IAA to family farmers in Thailand. Following a diagnosis carried out in the late 1970s in Pathumthani province, two major groups of fish farmers were identified: commercial farmers mainly integrated with pigs and poultry, and small producers, rice farmers carrying out fish farming in excavations dug to raise the level of dwellings above flood level. The latter were the target of the Institute's assistance programmes. After various experiments (integration of duck and subsequently buffalo with fish), technical recommendations were formulated. Although the productivity of duck/fish integration was relatively high, competition from large agribusiness companies reduced the profitability of duck egg marketing. Thus, technical aspects should not be the only criterion used to design IAAs. Various factors including market (e.g.need to be considered in assessing the contribution of aquaclture to small-scale farming household income.

17. Based on this experience, P. Edwards made the following recommendations in conclusion:

- Rural households are increasingly motivated to raise fish for the income it provides rather than for their own subsistence;
- IAA should be financially attractive compared to other possible income-generating options, both on- and off-farm;
- IAA should be implemented as a SME (Small and Medium Enterprise);
- IAA should be intensified, but research on on-farm nutrient cycling is no longer a priority to make the activity attractive to rural households;
- The best option is probably indirect IAA, with the mobilization of inputs from outside the farm to augment the usually low on-farm nutrient base.

AGROECOLOGY AND ITS USE IN AQUACULTURE (MALCOLM BEVERIDGE)

18. Malcolm Beveridge presented agroecology and its application to aquaculture. After noting that this approach challenges the current dominant models of industrial agriculture by applying the concepts and principles of ecology to agriculture, he explored the various definitions of agroecology and selected

[1] More information is available at serd.ait.ac.th/aquaculture-and-aquatic-resources-management/

one: "... optimizing interactions between plants, animals, humans and the environment, while taking into account the social aspects that must be considered for a sustainable and equitable food system" as encapsulating many of the dominant ideas. Thus, "... by building synergies, agroecology can support food production, food security and nutrition while restoring ecosystem services and biodiversity that are essential for sustainable agriculture".

19. In the general framework of the 2030 Agenda and its 17 Sustainable Development Goals, FAO has developed a knowledge platform dedicated to agroecology and identified 10 elements that characterize agroecology approaches:[2]

1. "Diversity: diversification is key to agroecological transitions to ensure food security and nutrition while conserving, protecting and enhancing natural resources;
2. Co-creation of knowledge and transdisciplinary approaches for innovation: Co-creation and sharing of knowledge: agricultural innovations respond better to local challenges when they are co-created through participatory processes;
3. Synergies: building synergies enhances key functions across food systems, supporting production and multiple ecosystem;
4. Efficiency: innovative agroecological practices produce more using less external;
5. Recycling: more recycling means agricultural production with lower economic and environmental costs;
6. Resilience: enhanced resilience of people, communities and ecosystems is key to sustainable food and agricultural systems;
7. Human and social values: protecting and improving rural livelihoods, equity and social well-being is essential for sustainable food and agricultural systems;
8. Culture and food traditions: by supporting healthy, diversified and culturally appropriate diets, agroecology contributes to food security and nutrition while maintaining the health of ecosystems;
9. Responsible governance: sustainable food and agriculture requires responsible and effective governance mechanisms at different scales – from local to national to global;
10. Circular and solidarity economy: circular and solidarity economies that reconnect producers and consumers provide innovative solutions for living within our planetary boundaries while ensuring the social foundation for inclusive and sustainable development".

20. The application of agroecology in aquaculture emerged in the 1970s from the discipline of systems ecology and also drew heavily from traditional aquaculture systems, particularly in China.

21. It has since spread to other regions of the world, for example in Madagascar, where rice-fish farming is a traditional activity but where the production of this form of IAA increased by a factor of 15 during the late 1980s and 1990s, following a number of FAO interventions. In Viet Nam, the integrated production of vegetables, dairy cattle, and fish systems is often cited as an example of IAA. In Côte d'Ivoire, the acadja ponds (IAA that combines fish and small animal farming such as rabbits or chicken, with bamboos planted in the pond to promote the production of periphyton on which fish feed) raised many hopes in the 1990s but ultimately did not generate a sustainable development dynamic.

22. Agroecology is no longer only apparent in simple aquaculture technology-based systems. Integrated aquaculture/solar electricity production systems (e.g. Réunion) and aquaponics (e.g. United States) are beginning to appear. Marine salmon farming systems have been developed in Scotland and elsewhere in Northern Europe that incorporate co-stocking of lumpfish and wrasse to control sea lice.

23. Agroecology is thus developing rapidly due to concerns about the future of the global food system. It is based on a strong theoretical basis and applies to both developing and developed countries. Agroecology can also be applied in aquaculture, although progress has sometimes been slow. For agroecology-based aquaculture to be able to meet the challenges of the Sustainable Development Goals, it must:

- prove profitable and attractive to farmers, especially young farmers;

[2] More information can be found at http://www.fao.org/agroecology/home/en/

- facilitate ownership of the innovation process by stakeholders;
- take into account all impacts on ecosystem services.

24. To this end, FAO should integrate agroecology into the principles of its Code of Conduct for Responsible Fisheries and its Ecosystem Approach to Aquaculture. The aquaculture industry should also promote the adoption of agroecology principles through its certification processes.

SOCIAL DIMENSIONS OF IAA AND AGROECOLOGY (MIKE PHILLIPS)

25. After recalling why fish was important in terms of production, livelihoods, health, nutrition and also, of course, in economic terms, Mike Phillips quickly introduced Worldfish and the associated research programme. He then presented the work on integrated rice-fish systems that is being studied by using landscape approaches.

26. Rice-fish farming systems in South or Southeast Asia include a large number of diversified practices, with different agroecological interactions and different approaches at farm and landscape levels. The analytical framework used is the Sustainable Rural Livelihoods, which takes into account both the livelihoods and the resilience of the communities concerned.

27. As far as income is concerned, the results show a significant increase in income from conversion of rice paddies to rice-fish systems, due to fish revenues and productivity gains, particularly in Bangladesh and Myanmar. With regard to gender, studies have shown that when women have access to the same level of resources, farm yields are 20–30 percent higher, and the income gain would reduce the number of hungry people in the world by 12–17 percent.

28. In terms of nutrition, there is a considerable lack of knowledge, but rice-fish farming offers a potential in terms of accessibility to nutrient-rich foods, in terms of food diversity for nutritional benefits, and in terms of improving the quality of fish and rice.

29. Rice-fish farming systems are often practiced in highly vulnerable areas such as the deltas of South and Southeast Asia. Better fish management in these systems through diversification of production and productivity gains can increase the resilience of the people.

30. In terms of environmental impact, rice-fish farming improves the natural resources and ecosystem services through better management (fish, water storage during droughts, efficient use of water and nutrients, disease and pathogen management, pesticide use and better health, food security). The challenge at this level is the integrated water management at the landscape level.

31. At the global level, if 20 percent of the 163 million hectares of rice fields (32 million hectares) were to be converted to rice-fish farming, it would induce major social, environmental and economic changes, but before achieving this result, there is a need to better understand the impact pathways and the key actors involved.

ECOLOGICAL APPROACHES FOR BETTER MICROBIAL MANAGEMENT IN INTENSIVE SHRIMP FARMING (PATRICK SORGELOOS)

32. Patrick Sorgeloos began his presentation by listing the ten priorities for future technological innovations, identified in 2010 at the FAO Global Conference on Aquaculture, with two of them focusing on microbial management and integrated systems:

- domestication: total independence from natural stocks;
- improved and less costly methods of producing fry;
- better targeted selection of species;
- development of more efficient lines through genetic selection;
- better microbial management for sustainable production;
- better understanding of the immune systems of vertebrates and invertebrates;
- more integrated production systems with livestock and agriculture;
- coastal and offshore farms for food and energy production;
- total independence from fisheries for the supply of fats and proteins in aquaculture feed;

- better attention to the integration of re-seeding activities with fisheries management.

33. But today, scientific progress, particularly in molecular biology, has made it possible to go much further in understanding the management of bacteria in aquaculture, particularly with a view to preventing diseases of opportunistic pathogens.

34. Bacteria communicate with each other through extracellular signal molecules. When they reach a certain density or quorum, virulence genes are activated and they become pathogenic. Some, such as vibriosis, can have catastrophic effects on the aquaculture sector.

35. An aquaculture system is populated by neutral or beneficial bacteria, harmful bacteria and potentially harmful opportunistic bacteria. Biosecurity is essential to eliminate pathogenic bacteria. However, after disinfection, all bacteria are eliminated and a new colonization of the environment takes place, with two types of organism strategies: r-strategy and k-strategy. A succession of populations follows, until all the niches are occupied.

36. If stocking occurs too early, the microbial population may be dominated by growing (and therefore virulent) opportunistic bacteria, whereas if stocking were to be done later, the environment would be dominated by neutral or beneficial organisms.

37. A strategy to use "microbially mature" water can therefore pay off and several techniques are available: the green water system, the tilapia co-culture, the pro- and prebiotics, the bioflocs systems, the zero exchange systems, recirculated systems or systems integrated with non-fed species such as tilapia or macro-algae (e. g. shrimp-toilet ponds in which shrimp pond effluents are discharged before being released back into circulation). Polyculture could also promote bacterial stability.

38. These changes not only improve the health status of farms, but also improve the farm profitability as indicated by economic results before and after the outbreak of early shrimp mortality syndrome (EMS) or acute hepatopancreatic necrosis syndrome (AHPNS).

CURRENT PRACTICES AND PERSPECTIVES FOR IAA IN ASIA (DERUN YUAN)

39. IAA in Asia is diverse. It can be extensive (<1 tonnes/ha), semi-intensive (5–10 tonnes/ha) or even intensive (>10 tonnes/ha), although most systems are extensive and semi-intensive. It can also be practiced in open water (aquaculture-based fisheries), in excavations or trenches (rice/fish), in ponds, tanks, raceways or cages etc.

40. In Asia, the most common features of IAA systems are:

- a predominance of semi-intensive systems (rice-fish, crops-fish, livestock-fish, etc.);
- a predominance of omnivorous species;
- an incredible diversity;
- a trend towards intensification;
- new systems emerging.

41. Rice-fish farming is practiced in most Asian countries. Fish farming is carried out at the same time as rice cultivation, or alternately (rotation). Excavations or trenches are dug in the centre of the rice fields to serve as a fish refuge. The dominant species are omnivorous and production ranges from 100 kg to 1 tonnes/ha. One of the benefits of rice-fish farming is that the use of fertilizers and pesticides is reduced, by around 30 to 50 percent. The main constraints to its expansion are the public policies that restrict the conversion of rice fields to secure rice production, the economic attractiveness not always guaranteed, the adoption of new short-cycle rice varieties that require little water (and are therefore little fish-friendly), and the still widespread use of pesticides and fertilizers.

42. Rice-fish farming is particularly relevant for the poorest households, as it is a relatively accessible food source and means of improving incomes. Opportunities for intensification include better configuration of rice fields and better management to increase fish production. It is possible to diversify the technique, for example by breeding fish or producing fingerlings. It is also possible to integrate aquatic animals with a high market value such as crayfish, crabs, freshwater shrimp, lochs or rice field eels.

43. Other integrated crop-fish farming systems encountered in Asia include pond-dike farming systems, plant/fish rotations (forage or compost), mangrove-shrimp systems and new emerging systems such as plant-crayfish. The main constraints are the high opportunity cost of labour and land.

44. Animal-fish IAA systems are represented by semi-intensive ponds that are directly or indirectly integrated into terrestrial animal farms. They still dominate aquaculture production. The constraints include some health aspects such as avian influenza. At medium and large-scale, this practice is declining, but remains an effective means of reducing poverty, especially in its indirect form, as fertilizer inputs are an easy way to improve small-scale agricultural production.

45. Pond recirculation systems are a way to treat water from intensive aquaculture by using filter feeder fish species, aquatic plants and/or shellfish that extract excess nutrients produced by the primary, intensively farmed, species. This makes it possible to reuse water in the system. The important elements for the system are the efficiency of land use and the cost compared to other alternatives. The system can be further improved and diversified but it is an environmental alternative to intensive monoculture.

46. IAA is also practiced in tanks or raceways. This is particularly the case for aquaponics, or tank- and raceways-in-ponds. They are a more sustainable alternative to conventional fed aquaculture systems, as they are mobile and flexible in terms of site selection. On the other hand, they require a certain amount of capital and raise the question of their profitability. They are also relatively complex technologically and potentially difficult for small producers.

47. Cage IAA is also practiced. In North Viet Nam and elsewhere, fodder and maize leaves are used to feed grass carp in cages. It is also practiced in the irrigation facilities of most countries, but agricultural pollution is a real constraint, which has led to its decline in China, for example. However, it remains an option in underutilized natural or agricultural water bodies, provided that carrying capacity is properly assessed. In eutrophic water bodies, cage culture can be considered without feeding. Large double-bottomed cages can also be used to facilitate the recovery of waste by pumping.

48. Finally, IAA is also practised in open systems, for example with fisheries based on aquaculture or for the production of aquatic plants through aquaculture effluents.

49. With regard to research and training needs, the general scientific principles of IAA are now well known and technologies are available; however, there is still knowledge to be acquired on the productivity and economic profitability of small farms. This requires a better understanding of the social dynamics, economic conditions and resources available to small producers. The other priority is to improve the sustainability of conventional intensive aquaculture. This requires assessing and documenting the ecological efficiency, economic viability and adoptability in different geographical contexts of new emerging IAA systems, respecting indigenous knowledge and farmer innovations; and designing new alternatives to unsustainable practices in intensive aquaculture through effective engineering approaches.

50. A major training effort has so far been made by many institutions, at international, regional, national and local levels, but it must be continued, especially for small producers, as IAA must continue to be promoted and implemented.

THE ACTIVITIES OF THE SONGHAI CENTRE IN AFRICA (GODFREY NZAMUJO)

51. The Songhai Centre promotes an alternative for agroecological and sustainable development in Africa. Based on the observation that conventional linear and mechanical approaches have failed, it recommends moving to a systemic approach. Therefore, the transition to integrated development systems should not be built on entities (animal, fish or culture), but on the organizational schemes to be developed and adopted so that these entities interact with their environment. Agriculture is by nature a systemic process with the potential to provide holistic responses to current challenges.

52. The approach is based on the construction of synergies, symbioses, complementarities, collaboration and supplementations. The objective is to design development trajectories where technologies are mobilized to create dynamic links and synergies between food production (crops, animals, fish, others), SMEs (value added, agri-food, construction) and marketing (retail, catering, export).

53. Within this general framework, aquaculture is one of the elements of the network that makes it possible to enhance the environmental capital of African water bodies, not only to produce food but also to generate ecosystem services that strengthen the productive capacity of the environment. Aquaculture is approached in a way that optimizes the interaction between its various trophic components, from the microorganisms that recycle nutrients to intermediate levels such as algae and plankton, and, finally, to fish. By optimizing these flows, the objective is to produce more with less.

54. The Songhai agroecological aquaculture system uses genetically improved fish strains, fish by-products and unconventional nutrient inputs such as crickets, algae, zooplankton, plant and animal by-products, or bacteria to produce high quality fish products and nutrient-rich water that can be used for crops or zooplankton production before being recycled into fish farming.

IAA AND AGROECOLOGY IN THE EUROPEAN UNION (JOËL AUBIN)

55. In 2015, the average consumption of aquatic products in the European Union was 23.1 kg/capita, of which 24 percent came from aquaculture. The production is almost entirely consumed locally, but this represents only 43 percent of the total. Fifty-seven percent is imported from non-European Union countries, in particular Norway. In terms of volume, the European Union is the 8th largest producer in the world, but with 1.5 percent, it lags far behind China (60.7 percent) and the other major producers of Asia (25.8 percent).

56. The traditional European aquaculture system is the freshwater pond polyculture. Introduced during the Middle Age, it was spread by monks to produce fish during the 120 days of Lent. Traditional production is either scattered throughout the territory or concentrated in particular regions. This system is by definition agroecological because it recycles nutrients in the food chain and is based on interactions: interactions between stocked and natural biodiversity, interaction at the landscape level and with agriculture.

57. The traditional production process, as described in the Dombes region, consists of 4+1 steps:

- pond filling with water and nutrients from the agricultural watershed;
- fish production and fertilization;
- pond drainage and fish harvesting;
- pond drying to promote mineralization of organic matter;
- this cycle is repeated 4 times, then an additional step is introduced, which consists in farming crops (cereals, etc.) inside the pond.

58. The current trend shows a decrease in the consumption of freshwater fish, some variability in yields and profit, a problem of bird predation, the development of new pond uses for more attractive activities such as recreation or hunting, the suspicion of environmental impact and some reduction in research support. All this lead to the abandon of the agroecological and integrated fish pond farming in favour of a fish monoculture based on exogenous food.

59. Unfortunately, it has several disadvantages: it is not integrated with other crops, it depends on external resources (food, energy), it is not the most effective in retaining nutrients and it generates many direct emissions that create a cost for producers, companies and/or ecosystems. There is a need to re-integrate monoculture aquaculture systems and design new systems based on new strategies.

60. The first one consists in conducting the farming by distinguishing different compartments. For example, a water treatment compartment is added downstream of an intensive fish farm. It has been tested with integrated marine algae, microalgae, *Salicornia* etc. Its advantage is that it generates co-products with an economic value, but so far it has remained at the experimental/SME stage.

61. An evolution of the system consists in separating the compartments in a recirculating system. This is the principle of aquaponics, which combines an aquaculture recirculated circuit with hydroponics technology. This system is currently supported by interest in urban agriculture, and many small-scale initiatives.

62. Another strategy is to separate the compartments to use primary production of fish effluents to feed secondary producers (oysters etc.). It is the land-based Integrated Multi-Trophic Aquaculture. The

practice is still at an experimental stage. In addition to microalgae, it is also possible to recycle organic matter by adding worms such as polychaetes or sea cucumbers to the system. This is also at the experimental stage.

63. An integrated multi-trophic aquaculture system tested in Hungary consists in combining an intensive aquaculture compartment with an extensive polyculture pond. Manure from intensive livestock farm fertilizes the pond, which recycles nutrients. It also increases the provision of ecosystem services.

64. Some systems are not compartmentalized. This is the case of the Integrated Multi-Trophic Aquaculture, which is at a pilot stage in the European Union. It consists of combining fish cages with macroalgae and mussel culture, and possibly also benthic organisms.

65. In coastal ponds, some fish farms combine fish with bivalves or microalgae. These include the combination of mullet, bream, oysters and sea lettuce (*Ulva* sp.) as well as an association of oysters and shrimps in Atlantic ponds. Such initiatives are still at the pilot stage too, but some SMEs are also experimenting with them.

66. In summary, there are many combinations possible, including the use of non-domesticated species. Exogenous feed allow fish produced in intensive systems to generate effluents rich in mineral salts, dissolved organic matter and particulate organic matter. Dissolved elements can be used by primary producers (phytoplankton, algae, and aquatic plants). Particulate organic matter can be used by secondary producers (zooplankton, insects), filter feeders (shellfish, fish) or benthophagous organisms (crustaceans, worms, echinoderms). Nevertheless, despite their diversity, most of the initiatives remain at an experimental or pilot stage, and most often for co-production from fish effluents. There are still few fully integrated initiatives.

67. Many issues still need to be resolved, including the design and sizing of systems, the assessment of their effectiveness, and a better understanding of the interactions between farmed species and those in the ecosystem. Priority actions must focus on economic relevance, acceptability to consumers, access to production sites, consistency of various legislations (fish, shellfish, algae), waste use legislation (e.g. “It is forbidden to feed animals with waste”) etc.

MALAGASY RICE-FISH FARMING (JEAN-MICHEL MORTILLARO)

68. In Madagascar, rice-fish farming, one of the oldest forms of integration of aquaculture with agriculture, was popularized by FAO in 1985 and then by the NGO “Association Pisciculture et Développement Rural en Afrique” (APDRA) from 2006. It is an activity with a great potential in the country, where rice is the main crop (1.2 million hectares) and staple food (150 kg/capita/year), although the national production does not meet the domestic demand. It also allows to diversify an often monotonous diet, particularly for low- and middle-income households, thus improving nutrition in rural areas.

69. Wild fish, most often wild tilapia, is traditionally harvested in irrigated rice fields. The farming technique used in Madagascar consists of stocking common carp fry in paddy fields, in raising the level of the side dikes and in digging a fish refuge inside the rice field. In terms of calendar, fish fry is generally produced at the end of the southern winter (between September and December), rice is planted in December and fish farming extends from January to June.

70. An experiment conducted over two years characterized by untypical rainfall (2016-2017: drought; 2017-2018: flood) showed an increase in rice yield in the presence of carps: +19 percent in 2016-2017 and +31 percent in 2017-2018. Fish recycle nutrients trapped in insects and weeds. Rice-fish farming also improves the resilience to climate change by allowing the dual use of water and land for rice and fish production.

71. A current challenge for Madagascar is to intensify the production by using crop residues or other locally available resources (leaves, termites, kitchen waste, animal excreta, etc.). However, a survey showed that the production obtained after adding inputs is far from being homogeneous, due to the diversity of rice culture practices (SRI: Intensive Rice System, SRA: Improved Rice System, SRT: Traditional Rice System, off-season rice), to the diversity of soils and to the diversity of agro-environmental conditions.

72. In Madagascar, integrated rice and fish farming is a profitable activity, because the price of fish on the local market is quite high (EUR[3] 2.5/kg) and the production costs of the integrated system are lower, but it also faces some constraints. The investment cost is high compared to the standard of living in rural Madagascar where the monthly income is about EUR 22. The labour needed to adapt a 400 m^2 rice paddy is worth EUR 16 and a 2 cm carp fry costs EUR 0.05 per piece (i.e. EUR 5 for stocking the whole rice field at a density of 0.25 fish/m^2). In addition, the rice-fish culture calendar requires high financial expenses in times where other spending are also needed: during the back-to-school season, or during December-February lean season, when farm crops have already been consumed and food must be bought.

73. Access to fry is another constraint, due to the remoteness of many rural areas, the poor road infrastructure and the low carp fry survival (on average, 2000 fry per female). Finally, the lack of public support, despite strategic plans to disseminate the SRI, is another constraint.

74. Current priorities for Madagascar are to reduce the investment costs, to improve the fry quality and availability, to optimize the competing uses of food and fertilizer by improving nutrient recycling, to improve the system efficiency by developing polyculture of native species and finally, to better understand the social constraints to the adoption of rice and fish farming.

THE USE OF PROBIOTICS IN AQUACULTURE (FRANCIS MURRAY)

75. The growing market for aquatic products is encouraging small aquaculture producers to intensify their farming systems. This often leads to animal health issues, which can eventually become major issues. With increasing restrictions on drug substances, antimicrobial residue problems and AMR (Anti-Microbial Resistance) legislation, the use of immuno-modulators, whether pre- or probiotics, has become commonplace but this trend has been accompanied by a confusing development with unjustified claims, poor quality assurance, and lack of clear recommendations for small producers.

76. Probiotics are living microorganisms that provide benefits for the health of organisms, when administered in adequate quantities with food (gut microbiome) or in the environment (in the water or the soil as bio-mediators). Prebiotics are substances that stimulate the growth of beneficial microorganisms (bacteria, fungi) in the intestine. Synbiotics are nutritional supplements that provide health benefits in combination with pre- or probiotics (selective growth, activation). Fermentation or biofloc technology are alternatives to commercial products.

77. The objectives of the IMAQulate (Immuno-Modulators in Aquaculture) project are to inventory and analyze some Commercial Prophylactic Health Products (CPHPs), to evaluate the cost-benefit in real conditions on farms, to develop new prebiotics and to communicate the information to small intensive producers, CPHP suppliers and official or regulatory control. The study was conducted in India, Bangladesh and Kenya and it included shrimp (*Litopenaeus vannamei* and *Penaeus monodon*), tilapia and pangasius farms. These countries and species have experienced a rapid growth and disease problems, particularly in areas where the farming was concentrated. The inventory of products used by farms was conducted by the Indian Coastal Aquaculture Authority. It shows that most of the farms use probiotics and immuno-stimulants.

78. The analysis of probiotics made it possible to establish a ranking of the risks associated with the different products, in particular by using criteria such as the presence of pathogens, the Colony Forming Units concentration (CFU/g), the antibiotic resistance or the contamination by antibiotics.

79. The survey of Indian farmers included 253 producers (137 small producers, 55 medium producers, 23 large/uncertified producers and 38 large/certified producers) and 47 hatcheries (4 small unregistered, 7 small, 26 medium and 10 large). In 2017, 100 percent of the large hatcheries, 88 percent of the medium-sized and 36 percent of the small ones used probiotics (5 brands with prices ranging from USD 14.5/kg to USD 51.1/kg), whether to treat water preventively or to treat diseases. However, the large and medium-sized hatcheries tend to use them to improve water quality, whereas the small ones are more likely to use them for therapeutic purposes. All probiotics were spread in water, none distributed with the

[3] EUR 1 = USD 1.1.

food. The farm survey also identified 89 products marketed by 45 manufacturers, but with two dominating the market.

80. This knowledge should be included in the quality certification approaches and standards, particularly with regard to risks and effectiveness of product. The specificities of the small producers must also be taken into account.

BIOMIMICRY IN AQUACULTURE (SALIN KR.)

81. Thailand has long been the world's leading shrimp exporter, but the production declined sharply in the 2010's due to the emergence of diseases, including Acute Hepatopancreatic Necrosis Disease (AHPND). Since 2015, farmers have implemented new strategies that have allowed the national production to start growing again.

82. To make aquaculture sustainable, action can be taken at several levels:

- At the input level, by disconnecting aquaculture feed from marine ecosystems, and not using antibiotics and chemicals;
- In the farming environment, by maintaining good water quality, without extreme variations and by minimizing or eliminating emissions;
- In terms of products, by-products and/or waste, by guaranteeing food quality and safety, animal welfare and zero waste.

83. Several systems have been developed: the Recirculated Aquaculture Systems, the Integrated Multi-Trophic Systems, the Bioflocs technology or Bio(Aqua)mimicry.

84. Biomimicry is the science that studies natural models and imitates nature to design ecologically sensitive production systems. J. Benyus identified nine principles that characterize natural systems:

- they operate on solar energy;
- they use only the needed amount of energy;
- they adapt the shape to the function;
- they recycle everything;
- they reward cooperation;
- they focus on diversity;
- they require local expertise;
- they limit excesses;
- they harness the power of limits.

85. In aquaculture systems, biomimicry acts at different levels:

- Many biotic and abiotic subsystems interact with feedback loops;
- Synergies make it possible to reduce emission of metabolic products, particularly ammonia;
- The result is a more efficient use of food and better sanitary conditions for fish/prawns;
- Regular energy inputs and management are needed to avoid collapses.

86. The first level of biomimetic functioning is the balance between autotrophic and heterotrophic compartments that perform different functions. Thus, water quality is more stable thanks to the development of biocolloids and live food. The feed used is fermented soya and the production method is a recirculating system that combines production ponds with treatment ponds. A central well is used to collect the mud and transfer it to an anoxic pond for treatment. Partitions favour sedimentation and fish species, bivalve molluscs or macroalgae to improve water quality. When satisfactory, it is returned to the production pond.

87. With such a system, it is possible to produce 10 tonnes of shrimp in 67 days in a 4 000 m^2 pond, with a 1.08 feed conversion rate. The production cost is USD 24 333, mainly consisting of feed (57 percent), electricity (13 percent), post-larvae (11 percent) and labour (11 percent).

88. Biomimicry in aquaculture is a farmer's innovation, which makes it possible to revitalize the sector by enhancing the value of abandoned ponds. It applies to both high and low density ponds, but

requires more land than traditional methods. The quality of the water is remarkable, as is the production of live food.

AQUAPONICS FOR DEVELOPMENT (AUSTIN STANKUS)

89. Aquaponics is a term that encompasses a set of techniques used for different purposes. It can be a hobby, an educational activity for children, youth or adults, or a real economic enterprise. Each of these purposes has different levels of risk, investment needs or operating methods, and the challenge is to clearly define, from the beginning, the objective assigned to aquaponics.

90. The technology is now well known. It consists of using nutrient-rich water from aquaculture farms to irrigate plants in a closed circuit. For consumers, it provides access to local production of a wide range of fresh products. For private companies, it is a proven and profitable technology that allows to supply niche markets. Finally, for development stakeholders and governments, it helps to generate livelihoods on a reduced surface area, with reduced water needs.

91. But aquaponics is not always easy to implement and there are a number of constraints to its adoption: the high initial investment cost; the complex techniques that involve mastering essential knowledge about fish, plants and bacteria, in addition to building, plumbing and greenhouse management skills; the business management is not simple because financial and market analyses are essential to profitability; the materials must be adapted to local conditions; the access to energy, well-trained human resources and inputs (including fry and seedlings) must be affordable and reliable; the access to premium markets is required; a favourable economic and regulatory environment is essential.

92. When these constraints are not taken into account, failures can occur. From 2012, FAO launched a pilot project in the Gaza Strip to install aquaponics systems for poor and fragile households, including women. At first, the project was a success, but at the end of the pilot phase, a number of households did not have the financial resources to continue buying the necessary inputs, whereas others lacked the technical knowledge to manage the various productions effectively. Finally, others had to give up when the supply of energy and fry became a concern because of the conflict. However, the failure is not complete, since it has shown the potential of the technology, so that the government has started providing support for the supply of fry and some small businesses are currently starting up.

93. There are also successes. The first example is Indonesia, which has dedicated a specific research programme to this activity, in conjunction with the rural extension services and farmers. At least 10 000 producers have been exposed to the aquaponics awareness campaign and an estimated 3 000 have invested. The model is unique, called Yumina (combination of the words fish and vegetable in Bahasa). It is totally different from the other models observed in the western countries. The principle is simple and uses only local materials, at low cost. The energy requirements are low and the system is resilient to power outages. In summary, this intervention fully integrates the constraints: low start-up cost, simple and uncomplicated system, local design, low energy need, use of existing experience in plant and fish farming, support from the government and regional partners.

94. Another good example is the ongoing FAO project in the Caribbean. The strategy was the following: as a first step, a regional training workshop was held on an existing farm for interested private farmers who later received support to build demonstration units. The option of working with the private sector provided the economic incentive to ensure that the momentum continues at the end of the project. Farmers have become the stakeholders responsible for rural extension and training. FAO also intervened to support exchanges with the hotel sector and key value-chain stakeholders to help farmers exploit profitable niche markets. The main lessons learned from this experiment are:

- That the technology transfer is not sufficient, exchanges between farmers and participatory approaches are also needed;
- That climate-smart and efficient techniques must be promoted through market connections;
- That aquaponics is easy, but that aquaponics managed as a business is difficult. Professionalism is essential.

95. Another interesting example about the Caribbean is the obligation to take into account the financial, environmental and social sustainability. When these three dimensions are taken into account, if

a locally-produced product has a lower total cost than an equivalent imported product, the local product should be selected. This consideration of the total cost is a key consideration for the promotion of circular economy and short value-chains.

96. FAO supports aquaponics and provides a number of technical guides. The main publication is a manual for small producers,[4] published in 2014 and widely downloaded since then. FAO also organizes trainings, including farmer-to-farmer exchanges, and sensitizes government officials.

97. In summary, the main messages are to clearly identify the objectives, and to also identify the places and communities that are most likely to benefit from a participatory needs assessment and feasibility analysis. If aquaponics does not seem to be the most appropriate solution, it should not be imposed. Awareness campaigns should be implemented though demonstration units, agricultural fairs, school systems, cooking competitions, etc. The connection with local markets should also be seeked. Finally, the known constraints must be explicitly taken into account during project and business planning, will full participation of beneficiaries and stakeholders.

AQUAPONICS IN OMAN (WENRESTI GALLARDO)

98. Oman is the third largest state of the Arabian Peninsula and it borders Yemen, Saudi Arabia and the United Arab Emirates. Sultan Qaboos University (SQU) is the country's leading university. Oman is currently developing its aquaculture sector. Together with mariculture, aquaponics is being considered for its potential to stimulate the national aquaculture production in a desert context where water resources are limited.

99. Aquaponics is the integration of aquaculture with hydroponics. This integrated system was designed in response to the problems arising from each of the two activities: in aquaculture, the water quality deteriorates over time and it is necessary to change it regularly by releasing wastewater into the environment; in hydroponics, it is necessary to ensure a constant flow of expensive nutrient salts, and to regularly drain the system. Thanks to aquaponics, it is possible to no longer dump water into the environment, ensuring the preservation of this resource.

100. Dr. Stephen Goddard initiated aquaponics research at SQU around 2010 and the Department of Marine Sciences and Fisheries continues the experiment with Dr. Wenresti Gallardo since 2014.

101. The presentation focusses on the 10 elements of agroecology: Diversity, Co-creation and knowledge sharing, Synergies, Efficiency, Recycling, Resilience, Human and social values, Food culture and traditions, Responsible governance, Circular and solidarity economy.

102. With regard to knowledge creation, SQU has produced many results, particularly on recirculating and non-recirculating systems, on optimal stocking densities, on the most appropriate plant crops for the different seasons, and on the production of high value-added species in greenhouses.

103. SQU is also involved in knowledge sharing, not only through scientific publications but also by organizing seminars and workshops. In August 2018, a Food Security workshop was organized by the Independent Learning Centre of SQU, with more than 40 participants, many of whom indicated that they wanted to build their own aquaponics system. Farmers-to-farmers meetings are also regularly organized. SQU participated in a FAO Oman study tour as part of the FAO Water Scarcity Initiative program to visit aquaculture and aquaponics farms in the Sultanate. Participants came from Egypt and Algeria to learn about the Omani experience, and Omani participants had benefited from a trip to Egypt and Algeria in 2017. This study tour concluded with a workshop at the university.

104. With the support of FAO Oman, local integrated and aquaponics farms are also being listed. So far, 14 aquaponics farms have been identified around Muscat, and there are also some other non-aquaponics integrated farms that use water from aquaculture farms to fertilize greenhouse crops.

105. With regard to responsible governance, the Ministry of Agriculture and Fisheries promotes aquaponics by providing recommendations to farmers, assisting the dissemination of knowledge among

[4] See Annex 4.

farmers with the support of FAO Oman and by providing subsidies. Mr. Ghassan Al-Bahrani is a farmer who has benefited from this support. Established in 2010 to produce greenhouse cucumbers, peppers, lettuce and basil, he started with two greenhouses and now owns 26 of them. In July 2017, he started an aquaponics system with the support of the Ministry, which provided him with 500 tilapia fry, aquaponics equipment, food and organic fertilizers.

106. For the social and human values component, one good example is the Al-Lezegh aquaponic farm, launched in 2010 with a funding from EarthWatch United Kingdom, various Omani and British people and the support of the University of Durham. This farm is unique because it uses the traditional *aflaj* irrigation system to bring water from the mountains to houses and farmland. Aflaj is communal and the group that manages it distributes water according to a predefined programme. The aquaponics farm receives water every five days. The advantage of this water is that it is not polluted. It is pumped into the aquaponic system and then circulates between fish tanks (tilapia) and plant crops (basil). Income from basil is higher than that from tilapia, both of which are sold locally. This experience should be communicated more to allow it to be sold in major hotels, restaurants, markets and stores.

107. Al-Arfan Farms is considered the largest aquaponic farm in Oman. This ultra-modern 600 m^2 greenhouse pilot unit is located 50 km from Muscat. The farm promotes its products as 100 percent natural and genetically modified organism (GMO)-free, and without chemical fertilizers and pesticides. Their vegetables are sold in Oman's main supermarkets and in hotels such as Al Bustan Palace, a hotel of the Ritz Carlton group.

108. In summary, aquaponics in Oman is developing well and is following the ten components of agroecology.

INTEGRATED MALAGASY AQUACULTURE (DIANA E. ANDRIA-MANANJARA)

109. Madagascar is the fifth largest island on the southeast coast of Africa, along the Indian Ocean and is experiencing strong population growth (+2.8 percent per year). With a per capita gross national product lower than USD 2/day, the country is ranked among the low-income countries. The majority of the population (64 percent) lives in rural areas and 77 percent are poor and food insecure. The agricultural sector is the main source of income (80 percent) and has a high aquaculture potential, with 150 000 to 160 000 ha of lakes and water bodies, as well as 200 000 ha of irrigated rice.

110. An important type of integrated agriculture system is rice and fish farming. It is an ancestral practice in Madagascar, but popularized by FAO around 1985 and by NGO APDRA since 2006. To date, 21 000 rice-fish farmers practice it on 20 percent of the exploitable rice areas. There is another form of rice-fish farming practiced on the coastal zone: the cultivation of rice in fish-stocked dams, with fish yields around 765 kg/ha.

111. The *tanjona* system is a new form of integrated crop-animal-fish aquaculture, recently identified in the marshes of the Antananarivo flood plain. Historically, *tanjona* are large mounds of land created by farmers in the middle of the marshes, in order to produce agriculture areas that cannot be flooded for vegetable and fruits production. At the beginning of the 2000s, some producers began building their mounds in such a way as to define a closed space in the centre that can be used as a fish pond. On the dikes, vegetable or horticultural crops are grown, as well as animals (ducks, dairy cattle, etc.).

112. A survey was conducted to describe the practices, which are extremely diverse. One example is a *tanjona* integrating fish (common carp and tilapia), duck and vegetable (cabbage). The fish production lasts between 6 and 12 months and the fish yield is 1.3 tonnes/ha. The vegetable production lasts 7 months, from May to November. Another example is a rice-fish (common carp and tilapia) integration with associated crops on the dikes (fruit and vegetables). The production lasts between 6 to 10 months (November to August) for fish and 12 months for crops. Integrated aquaculture provides a gross added value of 2 to 11 percent in a rice-fish system and 3 to 26 percent in a *tanjona* system. The additional income generated can be reinvested in food, savings, living conditions and education for children.

113. There is also traditional integrated animal-fish aquaculture, particularly on the west coast. The main species are livestock, pigs and chickens that provide fertilizers and feed through their droppings. Livestock farming near and above ponds also exists but are uncommon, mainly due to rural insecurity

and theft. An example of an atypical chicken-fish association in ponds is the use of droppings to produce worms, which are then used to feed fish. With a 15-month production cycle, it is possible to obtain a fish (common carp and tilapia) yield of 9 tonnes/ha.

114. The first advantage of integrated aquaculture is that it optimizes flows to generate household income and food in rural areas, which are sometimes isolated. This optimization of flows and synergies between productions notably makes it possible to increase rice production by 10 to 30 percent when carps are stored in irrigated fields.

115. However, there are a number of constraints. The first is the access to land, as small producers often do not have access to the best agricultural land. Theirs are often less productive and more vulnerable to climatic hazards (floods, drought). Climate hazards and climate change are precisely a second constraint, as Madagascar is one of the most vulnerable countries and there are concerns that floods (and subsequent loss of fish and rice, or destruction of dikes) and extreme droughts will become more frequent.

116. Another constraint is financial because the diversification of the system generates higher investment needs in labour and capital. Given the high seasonality of production, the period when fry purchases must be made coincides with the lean season (when food stocks are low or non-existent and where food must be purchased) and the back-to-school period. Productivity also remains low, which is a technical constraint, while praedial larceny (theft of cattle, fish and crops) has become a significant problem in some areas.

117. Among the prospects, there is, on the one hand, the government's awareness of the issues, particularly in the implementation of its blue growth strategy. There is also the need to make practical and technical improvements to integrated systems, and to support the dissemination of IAA in areas where it is not yet practiced, particularly those that are most vulnerable. Finally, there is also a need to better understand the impacts of IAA on households and public health.

118. In summary, integrated aquaculture is an important element for Malagasy households, especially the poorest. Its sustainable development will require the involvement of stakeholders and its dissemination will have to take into account socio-agro-climatic constraints.

GUINEAN PISCIRIZICULTURE (SIDIKI KEITA)

119. Guinea is a country of 11 million inhabitants, located on the West African coast, which borders Guinea Bissau, Senegal, Mali, Côte d'Ivoire, Liberia and Sierra Leone. Frequently referred to as "the water tower of West Africa", the country is drained by 1 161 rivers belonging to 23 catchment areas. It also has thousands of water bodies resulting from mining excavations. The country therefore offers significant aquaculture potential, both in continental water and along the 150 km coastline, and the country's highest authorities, including the President of the Republic, provide unfailing support for the development of this activity throughout the country, particularly in the savannah and coastal zones. A National Directorate of Fish Farming was created in 2011, and a National Agency for Guinean Aquaculture was established in 2018.

120. All kinds of aquaculture are possible in Guinea, but one of the most original and successful emerged in the Guinea Forest region in the late 1990s. This experience of integrated aquaculture where rice is grown in dam-ponds and fishponds is now becoming an example for other regions and other countries. It is implemented in the following way:

- First of all, an awareness-raising meeting is organized in the villages to present the concept and intervention approaches and strategies. Fish farmers are at the centre of the interventions and they participate at all stages.
- A topographical survey is carried out to guarantee to farmers that their investment in building farming structures (ponds, dikes) is of high quality. Particular importance is given to this aspect, considering the lifespan of these structures and its crucial role in farming performance. The dam-pond is by far the most common structure, as it maximizes the farming area by minimizing excavation work, and because the topography of the region is favourable with many small valleys located between small hills.

- The production cycle begins with the planting of the rice nursery (floating rice variety CK90) and a first water filling to degrade organic matter. The water level is then lowered to dry 80 percent of the pond in order to transplant the rice (between July and August). The water level is then gradually raised seven days after transplanting. This is when fish are stocked and grow-out starts. Partial harvests are regularly carried out to monitor the fish growth and eliminate unwanted fry and wild fish, especially zillii tilapias (from October). The rice is harvested between November and December and the fish between November and January. A second production cycle can then start in January-February, using off-season rice or no rice at all, for a final harvest in May-June.
- Fish farming is carried out in polyculture, in order to maximize the use of the pond's natural resources. The Nile tilapia *Oreochromis niloticus* (stocked at up to 1 fish/m^2) is the main species, the secondary one being the African bonytongue *Heterotis niloticus* (stocked at 1 fish/100 m^2) and other species (catfish *Heterobranchus isopterus*, predator *Hemichromis fasciatus* stocked at 1 fish for every 10 Nile tilapia). Manual sexing of tilapia is uncommon and limited to the most experienced fish farmers, so most farming is done with mixed sexes.
- The lack of commercial feed is compensated by the use of local agricultural by-products, including rice bran. Palm oil cakes are also used and some pig-fish farms (3 to 5 pigs) have been set up by some producers.

121. These interventions have resulted in a major increase in fish consumption at the local level. For example, in the Gbötöye district, a peri-urban area located 12 km from N'Zerekore, the capital of the region where the number of fish farmers increased from 1 in 1995 to 38 in 2015, fish consumption increased from 4 kg/capita/year in 1995 to 14 in 2015. As a comparison, over the same period, the consumption in Conakry decreased slightly with 23 kg/capita/year in 1995 and 22 kg/capita/year in 2015, whereas the national consumption slightly increased from 10 kg/capita/year to 11 kg/capita/year. Sixty-five percent of Gbötöye's fish is marketed and fish weighing from 150 g to 3 kg are sold between EUR[5] 1.5 and 3/kg.

122. The main constraints are the lack of public and private investment, the lack of national human resources in fish farming and the lack of technical capacity to support intensification. Demonstration units are also lacking, as well as aquaculture training facilities.

123. In terms of prospects, the National Economic and Social Development Plan aims to produce 7 000 tonnes of fish in 2020. Taking into account the basic concept of agroecological aquaculture, this will require the mobilisation of technical expertise and investments of up to EUR 30 million. The concept of *pisciriziculture* will have to be expanded and diversified so that the average yield increases from 0.9 tonnes/ha to 3 tonnes/ha. It will also be necessary to expand the production to Guinea's four natural regions, which will also involve diversifying fish farming technical models to adapt them to each socio-natural context, based on an individual or family fish farming entrepreneurship, with an emphasis on youth employment and the enhancement of women's participation in value chains. Research actions will also have to be carried out.

INTEGRATED ANIMAL-FISH AQUACULTURE IN SOUTHERN BRAZIL (MANOEL XAVIER PEDROZA FILHO)

124. In the 1980s, the *pesque-pague* recreational fishing establishments became extremely popular, both as a recreational activity and as a supply of fresh fish. The increased demand for farmed fish led to the development of integrated animal-fish systems in southern Brazil and to its professionalization during the 1990s, with the introduction of monosex tilapia, the opening of various processing units and the creation of EPAGRI Santa Catarina to provide rural extension.

125. In the state of Santa Catarina, the agricultural sector is mainly composed of small farms, 2 ha on average, with 90 percent smaller than 50 ha. Santa Catarina is also a traditional pig producing region and its integration with fish farming has emerged as a complementary activity to improve the income from pig production. There are now more than 13 000 fish farms, mainly in the upper Itajaí valley region.

[5] EUR 1 = USD 1.1.

126. The three principles of the southern Brazil IAA are:

- The polyculture, which makes it possible to enhance pig manure and unconsumed feed through structures on or near ponds.
- The stocking of species with complementary diets; the main species is determined by the market or the availability of food in the pond; the secondary species provides filtration and the complementary species, raised in small quantities, make it possible to enhance other food sources. In Santa Catarina, the common carp (*Cyprinus carpio)* and tilapia (*Oreochromis niloticus)* are the main or secondary species, depending on the case. Silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and bighead carp (*Aristichthys nobilis*) are the secondary species, while pacu (*Piaractus mesopotamicus*), cascudo (*Hypostomus affinis*), American catfish (*Ictalurus punctatus*), African catfish (*Clarias gariepinus*) and Jundiá catfish (*Rhamdia quelen*) are the complementary species.
- The recycling of nutrients, which acts as a catalyst for complex aquatic metabolism at three levels: production, consumption and decomposition.

127. The main objective of IAA is to reduce the fish farming production costs and to make economies of scale by sharing resources and labour with pig farms. The use of pig manure to fertilize ponds reduces production costs by up to 70 percent. For pigs, IAA improves the feed conversion index through improved thermal stability in winter or on the early morning, reduced ammonia concentration in the air and large water availability to allow pigs to bathe on the hottest days. Finally, from an environmental point of view, it is a rational use of manure.

128. In this traditional system, carps are the main species and food is exclusively provided by the environment (i.e. no commercial food). Controlling natural productivity is therefore fundamental to improve production with organic and mineral fertilizers. Productivity is low and duration of production is long, but production costs are also low. However, most of these operations are no longer in compliance with the new Brazilian Forest Code that was introduced in 2012, which requires a 30 m protection zone along watercourses that are larger than 10 m. Indeed, most of the traditional ponds were built to serve as water reservoirs by diverting the rivers to which they are therefore closer than that threshhold.

129. The development of IAA in the 1990s also prompted complaints from various environmental NGOs, as fish farming was accused of promoting the proliferation of the Borrachudo black fly (*Simulium pertinax*), of polluting watercourses and of being located in permanent protection areas. In response, the organization Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (EPAGRI) developed a new model by making improvements to water productivity and quality. This locally developed model was called MAVIPI, a Portuguese acronym of "Upper Itajaí Valley Fish Farming Model". The main differences between the traditional and MAVIPI models concern the use of a commercial feed in the final phase, the use of water aeration and the control of water quality through the control of the quantity of manure spread into the pond. Its main characteristics are:

- The species reared: tilapia (70 to 75 percent), common carp (10 to 15 percent), silver carp (7 percent), bighead carp (6 percent) and others (2 percent).
- The use of commercial feed at the end of the cycle.
- The integration with pigs, which partially replaces commercial feed.
- The compliance with legislation regarding the location and flow of water in and out.
- The use of mechanical aeration to oxygenate, homogenize the water column and better distribute manure in ponds.
- The controlled harvest carried out without lowering the water level to limit environmental impacts.

130. The MAVIPI system is more efficient in terms of productivity than the traditional system (13 tonnes/ha/year vs. 5 tonnes/ha/year). The cycle is also shorter (10 months vs. 14 months), but both remain longer and are less efficient than a tilapia monoculture farm (without fertilization:

22 tonnes/ha/year, 7 months). On the other hand, the average production cost is the lowest with the traditional system (BRL[6] 1.7 vs. BRL 2.6 for the MAVIPI system and BRL 3.7 in monoculture).

131. The main constraints that limit the expansion of pork-fish IAA in Brazil are the following:

- The system's limitations: IAA does not allow for the treatment of effluents from the largest or most intensive pig farms.
- The limited profit: the reduced production cost does not necessarily result in a higher profit.
- The consumer perception of IAA: outside the southern regions of Brazil, fish produced in IAA is not as popular.

132. In terms of prospects, IAA systems in southern Brazil have shown a decline in the number of producers, and an increase in the number of intensive producers using non-integrated systems. The technological intensification and concentration of Brazilian aquaculture capital has transformed the sector, which is becoming more competitive. Finally, some of the challenges faced by IAA producers are similar to those faced by small fish farmers in Brazil: low production volumes, high input costs, lack of quality and lack of processing. Producer organisations are crucial.

AQUACULTURE IN DESERTS AND ARID LANDS (VALERIO CRESPI)

133. Desert aquaculture refers to aquaculture activities in deserts and arid lands characterized by low rainfall (>250 mm/year), high solar radiation, high evaporation rate, and that use surface or subsurface water.

134. Twenty percent of the world's surface is occupied by arid areas, and this percentage is increasing. Over 300 million people, live in these areas, with 92 million in hyperarid deserts.

135. In these areas, variation between the daytime and nighttime temperature is high, rain is low, solar radiation and evaporation are high, surface water resources are limited, land is abundant and inexpensive, and there are large groundwater tables of fresh and brackish water. Aquatic resources are available in ponds or irrigation canals, freshwater or brackish lakes, groundwater, rivers or rainwater reservoirs.

136. The types of aquaculture that can be carried out are:

- irrigation ponds (small-scale);
- closed circuits in recirculation, including aquaponics;
- integrated aquaculture-agriculture systems on a small or large-scale;
- large-scale pond aquaculture systems;
- floating cages in artificial water bodies (e.g. dams, abandoned quarries etc.).

137. The adapted species are tilapia (*Oreochromis niloticus*, red hybrids, *Sarotherodon melanotheron*), African catfish (*Clarias gariepinus*), barramundi (*Lates calcarifer*), common carp (*Cyprinus carpio*), European seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*), shrimps (*Penaeus indicus* and *Penaeus vannamei*) and artemia (*Artemia salina*).

138. Successful desert aquaculture operations in Algeria include the *Pescado de la duna* farm in Ouargla, which produced 500 tonnes/year of African catfish (*Clarias gariepinus*) in 2017, the biofloc shrimp farm (*Penaeus vannamei*), as well as various IAA farms in the desert that produce between 700 and 1 000 tonnes per year. In Egypt, IAA production increased from 700 tonnes in 2010 to 2 200 tonnes in 2017. More than 100 farms have been created in desert regions.

139. FAO has been supporting the development of desert aquaculture since 2008 with a first project in Algeria. A technical workshop was held in Mexico in 2010 and recommendations were presented at various sessions of the Committee on Fisheries Sub-Committee on Aquaculture. Several technical projects have been implemented in Algeria, Ethiopia, the Gaza Strip, Jordan, Namibia, etc. and, at the regional level, the Water Scarcity Initiative has developed a regional strategy.[7]

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[6] BRL 1 = USD 0.26

[7] More information can be found at http://www.fao.org/3/a-au845e.pdf

140. In conclusion, the measures expected from governments are responsible governance (investment and incentives), spatial planning (water resource inventories and site selection), technical capacity building (e.g. farmer-to-farmer training) and infrastructure (roads, hatcheries, food factories, renewable energy). As a result, desert aquaculture can have many positive impacts:

- rational use of resources;
- improved food and nutrition;
- increase in technical capacity;
- job creation, especially for young people and women;
- reduction of rural-to-urban migration.

141. The aquaculture systems that seem to be the most appropriate in desert areas today are integrated systems that ensure the efficient use of resources, especially water, and are based on agroecological principles.

RESOURCE USE EFFICIENCY OF EGYPTIAN FARMS THAT PRACTICE AGRICULTURE-AQUACULTURE INTEGRATION (HARRISON CHARO KARISA)

142. Egypt has now become a major fish producer, and most of it comes from aquaculture, but the country's water resources are limited. Agriculture is the main consumer of water (>82 percent), and 95 percent of the land is irrigated, with a majority of water coming from the Nile RiverThis scarcity is likely to create conflicts of use, and aquaculture integrated with agriculture can provide solutions to limit them.

143. There are different ways in which aquaculture is integrated with agriculture: crops (mangoes, oranges, bananas, alfalfa, vegetables, grapes, rice, etc.), and livestock (e.g. chicken). Water for fish usually comes from irrigation canals or pumping, while in the case of plants, it comes from canals, fish ponds or fish tank effluents.

144. Experiments have been carried out to evaluate the performance of integrated systems, particularly in terms of sediment and nutrient accumulation in semi-intensive integrated ponds. In a first experiment, earthen ponds received chicken droppings or granulated feed at two stocking densities of 1 or 2 Nile tilapia (20–25 g)/m^2. The farming lasted 4.5 months and their potential for crops was also assessed by collecting sediment monthly.

145. In a second experiment, two integrated units were developed, each with three 200 m^2 earthen ponds, two 525 m^2 hybrid maize fields and a 3 horsepower solar water pump. At a first site, the initial average weight of fish was 1.1 g and the stocking density was 2 fish/m^2; at the second site, the weight was 30 g and the density was 2.5 fish/m^2. The ponds were fertilized with poultry droppings and rice bran at the beginning of the cycle (respectively 8 and 24 weeks on site 1 and 2), then a complementary feed (rice bran on site 1, commercial feed extruded with 30 percent protein) was used. Three treatments were compared at the hybrid maize plot level: T1: traditional system (100 percent commercial fertilization), T2: integrated system, T3: integrated system + 50 percent commercial fertilization.

146. The results show that sedimentation increased in all treatments, by about 3 cm, which shows that a large proportion of the nutrients are trapped in the sediments. This corresponds to about 100–300 kg of nitrogen, 1.8–5 tonnes of organic matter, 0.2–1.1 kg of phosphorus and 50–125 kg of potassium per hectare, which approximately match the recommended intakes for maize cultivation. Moreover, production is essentially the same in all three processes, and the economic analysis shows the economic potential of the integrated system, which is more economically efficient than each compartment taken separately. In terms of water use efficiency, the gross income per m^3 is between 8.5 (site 2) and 12.4 EGP/m^3.

147. In conclusion, aquaculture integrated with agriculture is the most economically efficient system. It allows the nutrients trapped in the sediment of the ponds to be reused, thereby reducing the use of commercial fertilizers in associated field crops. Optimization of the system will reduce production costs and improve the efficiency of use of the water resource.

SUPPORT FOR THE INTEGRATION BETWEEN AQUATIC PLANTS AND ANIMAL FARMING IN RICE FIELDS IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC (CHANTHABOUN SIRIMANOTHAM AND NICK INNES-TAYLOR)

148. The Lao People's Democratic Republic has a rich aquatic biodiversity, and rice fields form a sanctuary for a large number of aquatic organisms. They are essential for food security and nutrition, especially in the most remote rural areas. A survey of 50 families in 5 provinces showed that in 10 days they consumed 200 kg (30 percent) of plants, 326 kg of fish (49 percent) and 138 kg of other animals (21 percent).[8] Many small producers have tried to increase their production of aquatic animals (fish, crabs, shellfish, etc.), but this is generally difficult to implement. Indeed, it is generally necessary to build trenches, control predators and monitor thieves. Although technically logical, these measures involve significant household investments in time and money.

149. The objectives of the intervention at the level of the rice field ecosystem are to better understand the importance of aquatic resources for food security and nutrition, to develop an approach to conserve aquatic biodiversity, to find a simple and cost-effective way to improve the natural aquatic environment, and to increase the availability of safe and nutritious food.

150. At the institutional level, the objectives are to improve the understanding of poverty and nutrition, to increase the technical knowledge on small-scale aquaculture (at the provincial and district level), to improve approaches to work with communities (at the provincial and district level), and to develop processes for farmer experimentation, community learning and exchange of experiences.

151. One of the activities conducted was a survey of the relative preferences for aquatic products consumed in different provinces. Although there are differences, sometimes significant, fish is the most consumed (40–87 kg/10 families/10 days), followed by aquatic plants (2.5–77 kg/10 families/10 days). However, what is most significant is the economic importance of these resources. The monetary value of the rice fields' aquatic resources was higher (USD 256) than the value of the rice consumed by one person in one year (USD 200).

152. Experiments have been carried out to develop new rice and fish farming strategies. By 2018, 200 families had participated in these experiments. One strategy is to dig small service ponds made impermeable with a tarp to produce fry. The pond is large enough to allow substantive fish production, but not too large to be dug by hand. The small size of the pond also reduces predation, but the grow-out is done in rice fields. Many producers have integrated these ponds with vegetable crops on the side of the rice fields, and some use animal manure to fertilize the water.

153. The key principles of the approach are to strengthen the local ownership, giving it an essential role during the planning, to work with structured but adaptive processes and finally to place capacity building (agricultural advisors and farmers) at the heart of the intervention. The process developed by the Department of Livestock and Fisheries (DLF) takes these elements into account. To help improve food and nutrition security, it lists several processes and associated responsibilities. At the central and provincial levels, a support process provides technical knowledge and facilitation of interventions. As for the processes of learning, experimentation and communication, they are conducted at the community level. Where the community considers it possible, dissemination is implemented by the community and district authorities. A follow-up at each step allows the processes to be evaluated and adapted.

154. Thus, significant gains can be made in terms of poverty reduction. Within a year, farmers manage to produce enough fish to feed their families (with an average production of 27 kg of fish/person/year). It reduces the time women and children spend fishing, and provides a constant supply of nutritious food. The communities produce enough fry to allow aquaculture development as well. As for development donors, their return on investment is only one year, which allows for a more effective use of international aid.

[8] See Appendix 4

ECOLOGICAL ENGINEERING OF RECYCLING PONDS (XINGGUO G. LIU)

155. Chinese aquaculture provides a huge quantity of aquatic products, but uses a large amount of resources (e.g. 3 to 13.4 m^3 of water/kg of fish produced; 4.5 m^3 on average). Aquculture is also responsible for greenhouse gas emissions, while also being vulnerable to pollution, such as heavy metals, hormones or antibiotics.

156. Farmers' demands for technologies include:

- improving the aquaculture environment;
- adjusting the livestock structures;
- introducing new production and processing methods;
- increasing the efficiency in the use of resources;
- ensuring the quality of aquatic products and improving the overall production efficiency.

157. To meet this demand, the option chosen was to mobilize ecological engineering to design pond aquaculture based on polyculture of multi-trophic species. The aim is to design a natural ecosystem in which energy and nutrients are managed in a balanced way.

158. The RPAS system (Raceway in Ponds Aquaculture System) is therefore based on ecological principles that allow the system to comply with environmental regulations through coordinated management of biological processes and the environment. The main elements of the RPAS system are: an artificial marsh, ecological ditches where floating plants are grown, ecological slopes, ecological ponds, fluidized bed biofilters and a rice system for the reuse of aquaculture effluents. Fish ponds are connected to ecological ditches, ecological ponds, artificial marshes and rice fields. Polyculture is based on herbivorous carp (45 percent by weight) and bream (40 percent by weight as the main species). Silver carp, bighead carp and crussiun carp (Carassius carassius) are the secondary species (15 percent by weight). The biomass at stocking is 0.15 kg/m^3.

159. Water quality in the system is managed by solar machines that improve sediment quality, and by surface aerators. The whole system is managed automatically using a number of sensors. The water quality in terms of nutrients (nitrogen, phosphorus, chemical oxygen demand) and biological composition (phytoplankton) is monitored by analyses and the fish production is increased by 8.5 percent, with a feed conversion rate reduced by 8.2 percent.

160. The water consumption was also reduced by 63.6 percent, and nitrogen, phosphorus and chemical oxygen demand emissions were reduced by 87.8 percent, 91.7 percent and 78.1 percent, respectively. As far as heavy metals are concerned, the artificial marsh makes it possible to retain 99 percent of them.

161. The system has already been distributed to various Chinese sites in Tinshan, Xinbang, Zhujiao, Shatianhy, Wuxi, Zhuangqiao and in the deltas of the Yangtze and Pearl River. It is used both in the arid northwest of China and on the coasts to the east or near major cities (for recreational purposes).

162. The compartmentalization of species within the pond itself improves nutrient use and ecological efficiency, thus increasing production. It is also possible to have a sequentially compartmentalized system, especially for the production of breams. In this case, effluent collection is centralized. Another system uses *Penaeus* shrimp farms in a greenhouse. This allows several batches of shrimp to be raised simultaneously. In the Yangtze region, it is thus possible to produce three batches each year, at a density of 3 to 5 kg/m^3.

163. Monitoring the biomasses of the various biological organisms in the pond of traditional systems, compartmentalized ponds and sequential ponds shows that the effectiveness of nutrient transfer in the latter is highest. The omnivory index and diversity index of the sequential ponds were higher than those of the other two ponds, and the connection index of the ponds was higher than that of the traditional ponds. The index of the separate ponds is also higher than that of the traditional pond. The two hybrid ponds are superior to traditional ponds in terms of maturity. Through ecological engineering, it is therefore possible to change the ecological vulnerability of ponds and improve the diversity of the system.

164. Current priorities should focus on the study of pond eco-aquaculture, on the development of mechanized facilities equipped with digital technology and on the design of management methods with high ecological efficiency, capable of producing high quality products.

IMPROVEMENT OF CARP PRODUCTION IN SEMI-INTENSIVE PONDS BY PERIPHYTON PRODUCTION (SUNILA RAI)

165. Polyculture of carp, with or without small indigenous species (SIS) is widely practiced in Asia, but can be intensified by improving substrate nutrition. Indeed, in most pond production systems, only a small fraction of the nutrient inputs (30 percent) is converted into harvestable biomass. The remainder is lost to sediment, effluent and the atmosphere. Improving periphyton growth in ponds is one way to increase the production of natural foods.

166. The periphyton performs other useful functions as well. In particular, it contributes to the oxygenation of the water and the fixation of the pond's nutrients. Experimentation was carried out in a farming environment from 20 April to 28 December 2014. The stocking density was 2 fish/m^2 and polyculture consisted of silver carp (20 percent), bighead carp (5 percent), grass carp (30 percent), common carp (15 percent), rohu (20 percent) and mrigal carp (10 percent). The substrates to allow periphyton growth extended over 2 percent of the pond surface.

167. Two treatments were tested: the first without substrate and the second with substrate. Exogenous food was distributed at 3 percent of the biomass. The fertilization was based on urea (470 g/100 m^2/week) and diammonium phosphate (350 g/100 m^2/week). The additional food consisted of rice bran and mustard oil cake (1:1).

168. The results showed a significant increase in fish production of 8 percent (4.31 tonnes/ha/year vs. 4.04) and a slight decrease in the feed conversion rate (FCR, 3.2 vs. 3.3) in the treatment with substrate and periphyton. Economically, costs were slightly higher with the substrate, but gross revenue was 5 percent higher and the gross margin increased by 7 percent as a result of the periphyton.

169. Another experiment was carried out from 24 August 2014 to 28 March 2015 to design new periphyton stimulation systems. Four treatments were compared: carp fed without substrate, carp+SIS fed without substrate, carp+SIS fed with half ration and a substrate (bamboo) and carp+SIS not fed with substrate (bamboo). The density of carp was 15 000 fish/ha and that of SIS 50 000 fish/ha. The normal feeding rate was 2 percent of the biomass and the surface area of the pond covered with substrate was 1 percent.

170. The best net yield of carp and carp+SIS was obtained in the pond receiving half ration of feed (5.5 tonnes/ha/year) and that of SIS in the normal fed carp+SIS treatment (0.21 tonnes/ha/year). The FCR for this treatment was also much lower than in ponds without substrate (1 vs. 2.4). Economically, the highest costs were measured in the two ponds without substrate, while the most interesting incomes and benefits were obtained in the pond with substrate and half ration (NPR 8 355 and 5 558/100 m^2/210 days respectively).[9]

171. In conclusion, polyculture of carp and polyculture of carp and small indigenous species with bamboo substrate and reduced feeding to 1–1.5 percent of biomass per day is an option for small producers. However, this technique should also be considered for commercial producers.

MANGROVE-SHRIMP INTEGRATION IN VIET NAM (PHAN THANH LAM)

172. Cà Mau province is home to Viet Nam's largest mangrove area, but its total surface decreased from 400 000 ha in 1960 to 73 000 ha in 1990 owing to a combination of factors:

- use of herbicides during the Indochina War;
- conversion of mangroves to agriculture (rice plantations from 1975 to 1979) and aquaculture (shrimp ponds from 1995 to 2008);

[9] NPR 1 = USD 0.01.

- urban development.

173. Coastal resources are now threatened by rapid and unregulated growth in the fisheries sector, coastal agriculture, maritime transport and ports, oil and gas exploitation and tourism development. These also threaten the provision of ecosystem services such as biodiversity, nutrient recycling and carbon storage provided by mangrove forests, and negatively impacts the livelihoods and food security of coastal communities.

174. Integrated mangrove-shrimp farming systems (IMSF) combine forestry and shrimp farming (*Penaeus monodon*) with crabs and/or fish. Using these systems could be a good way to prevent mangrove loss and adopt conservation measures if the forest is well managed.

175. In Viet Nam, IMSF are regulated by provincial governments in order to maintain a mangrove-to-water surface ratio of at least 60 percent. They are characterized by no or low food and fertilizer use, passive water exchange and low production.

176. There are currently three types of mangrove-shrimp integrated systems in ponds: integrated systems in which the mangrove covers a large part of the pond, associated systems in which the mangrove covers part of the pond and separate systems that include the ponds built next to the mangrove. The IMSF do not have sedimentation tanks or ponds, as all their ponds are used for shrimp grow-out.

177. At the technical level, the first step is the preparation of the pond and the stocking. Farmers pay little attention to the pond preparation tasks, as only about 30 percent of them perform operations such as water storage or treatment before stocking. On the other hand, most clean their ponds from their sediments after each cycle. Most are also unaware of the origin of their post-larvae (PL) and do not performing a disease testing before purchase and seeding (87 percent of farms surveyed). Shrimp mortality rates (> 95 percent at harvest) are higher in integrated mangrove-shrimp farms due to the uneven quality of post-larvae, as their selection is an important factor in production efficiency. Shrimp PLs are generally stocked directly in the ponds (80 percent of the farms surveyed) although about 20 percent of the farms surveyed use a pre-growing pond. Stocking density of integrated mangrove shrimp farms is generally lower than traditional pond culture and includes regular harvesting and partial stocking.

178. The integrated mangrove-shrimp system does not use shrimp feed. Farms are often located in coastal areas and estuaries, so the water source used for shrimp ponds comes mainly from the mouths of rivers and coastal channels, with some farms receiving water from primary and secondary channels. Water exchanges are limited and farms most often use the “partial drainage and water replacement” method (84 percent of farms surveyed). The main reason for this limited water exchange is related to environmental conditions and the risk of epidemics, as most farms do not wish to use river water to avoid disease occurrence. Water exchanges depend on tides, they are generally carried out every two weeks or every month, and it is generally an opportunity to obtain wild shrimp and natural feed. Farms with large ponds can only partially exchange water, about 20 to 40 percent of the volume.

179. Most farms have designed their own drainage systems and do not treat their wastewater, which is discharged directly into rivers or canals that are also used for filling. However, the emptying is not complete because the large ponds cannot be completely emptied. The water is therefore partially reused for the next harvest. On the other hand, the ponds are cleaned and the mud is placed on the dikes after each harvest.

180. Discharges of untreated wastewater and sludge, particularly during outbreaks of shrimp diseases, can contribute to their spreading. In addition, poor water quality such as high concentrations of biological oxygen demand (BOD) or chemical oxygen demand (COD) is a favourable condition for pathogenic microorganisms.

181. In fact, most farms faced a mortality problem during their past production cycles. The losses had several causes, including pathologies (> 70 percent of farms surveyed), extreme weather conditions and the quality of PLs. White spot syndrome virus (WSSV), yellow head virus (YHV) and vibriosis are the three main diseases affecting shrimp.

182. The farms carry out about 5 cycles per year and the storage density of the PLs is between 16 and 24 PL/ha. The production ranges from 487 to 616 kg/ha/year, mainly consisting of monodon shrimp (36–

38 percent), wild shrimp (12–20 percent), crab (14–27 percent) and fish (25–27 percent). It is sold mainly to collectors (69–83 percent).

183. Value chain analysis shows that farmers recover 55 percent of the gross value addition, collectors 15 percent, wholesalers 11 percent and processors 18 percent. In terms of net value addition, these percentages are 78-14-6.4 and 1.2 percent. A cost-benefit analysis was carried out for an integrated mangrove-shrimp farm. The main costs are generated by monodon PLs and labour to clean up the ponds. In terms of revenue, shrimps are the main contributor (VND 55 million) followed by wood (22 million) and crabs (13 million).[10]

184. There are three technical factors that must be taken into consideration to improve agricultural practices and production:

- Farmers should select and purchase quality PLs and carry out pre-growing to improve survival rates.
- The stocking density of 10–15 PL/m^2/year is recommended for the integrated mangrove-shrimp model. With such a stocking density, shrimp can grow without exogenous feeding, and thus meet the criteria for organic certification.
- Probiotics should be applied in shrimp ponds to control water quality and stimulate natural feeds that support shrimp growth.

185. This study identified the main constraints of integrated production and showed that small farms face a higher level of obstacles than large farms. Nevertheless, Viet Nam remains the largest producer of monodon shrimp and the integrated low-density mangrove-shrimp system, with no exogenous feeding and fewer chemicals, is a less risky and more sustainable alternative. It is therefore potentially certifiable as organic production. Most farms are small in size, which must therefore be taken into account in the future development of aquaculture, whether through vertical or horizontal coordination.

ARTEMIA PRODUCTION IN COASTAL PONDS IN ASIA (LIYING SUI)

186. The four main species of *Artemia* are: *A. franciscana* in America, *A. persimilis* in South America, *A. salina* around the Mediterranean basin and in South Africa, *A. urmiana* in the Near East, *A. sinica* in China and *A. tibetiana* in Tibet. Parthenogenetic *Artemia* is distributed from the Mediterranean basin to South Africa, the Near East, South Asia, China and Australia. Its life cycle includes an ovoviviparous loop where adults produce nauplii when environmental conditions are favourable, and an oviparous loop with production of cysts and duration eggs when conditions become unfavourable.

187. *Artemia* nauplii and adult biomass is characterized by its size, high protein content, methionine content and fatty acid content, which make it a feed of choice for fish and other aquatic animals. To produce one million mangrove crab post-larvae, 30 kg of *Artemia* cysts are needed, only 3 kg for tiger shrimp and vannamei shrimp, 3 kg for cobia (for 5 000 50-day-old fry) and 10–13 kg for freshwater shrimp.

188. Until 1991, world production was coming almost entirely from the Salt Lake City salt lake, but from 1992 onwards, production from the Commonwealth of Independent States and from China from 1995 onwards started to compete with it. During the period, production increased irregularly, as did the price, to around USD 50/kg dry weight in 2015 (vs. less than USD 10/kg in 1995). The current demand is strong, and the production should be sold at a better price. The quality of the cysts must also meet the market demand, whether for niche markets or local markets.

189. In 1986, Patrick Sorgeloos described a production method based on the natural presence of *Artemia* in solar salt production. Seawater is pumped into a first aquaculture basin and used to raise conventional aquatic organisms until salinity reaches 50 g/l. It is then transferred by gravity to a second basin, where the ovoviviparous cycle of *Artemia* starts, with permanent recruitment up to 100 g/l. This continues up to 150 g/l but without recruitment. When the environment reaches this level of salinity, *Artemia* shifts to the oviparous life phase, and cysts accumulate in the basins, especially if they are

[10] VND 10 000 = USD 0.45.

subjected to a prevailing wind direction. At 250 g/l, *Artemia* mortality is followed by salt precipitation. To ensure sufficient production, it is necessary to control algal bloom and provide nutrients to halophilic microorganisms. The production of *Artemia* also benefits the yield and quality of the salt.

190. This is why aquaculture is often integrated into salt marshes: *Artemia* (cysts and biomass) and salt production are carried out during the dry season, while aquaculture of various species is carried out in the wet season. Various other case studies exist, for example the intensive production of *Artemia* cysts in Viet Nam, Vinh Chau and Bac Lieu. Salt is produced between November and April (*Artemia* from January to July, salt from March to April). The original strain of *A. franciscana* type SFB (San Francisco Bay) has evolved into a strain now called Vinh Chau (VC), which has different characteristics from the mother strain, particularly in terms of temperature tolerance. The feeding of *Artemia* is based on conventional fertilization (chicken droppings, low quality fishmeal, urea, phosphate fertilizer) in order to produce green water, or on biofloc technology using organic carbon sources (e.g. tapioca) to induce the growth of heterotrophic microorganisms.

191. Another case study concerns Thailand. The country produces 500–1 000 kg/ha/day, or more than 600 tonnes per year for a value of USD 700 000. Seventy-five percent is intended for the local market of fish and shellfish hatcheries and nurseries. Twenty-five percent is exported frozen at USD 2/kg. Production is based exclusively on the use of ami, a by-product of the industrial production of monosodium glutamate (<100 l/ha/day). *Artemia* is harvested manually with nets, by light attraction or semi-automatically. They are cleaned and stored in a net cage for later sale.

192. Another example is the extensive production of *Artemia* in ponds and the improvement of stocks in the salt marshes of Bohai Bay in China. It is the largest sea salt production site, with 40 million tonnes in 2015 and an area of 1 500 km^2. The commercialization of *Artemia* cysts began in the 1980s. Bohai Bay cysts are famous for their higher hatching rate and nutritional value. However, cyst production has dropped from 800–1 000 tonnes per year to 300–400 tonnes/year within a decade. Pond production management therefore focuses on improving stocks by inoculating *Artemia* and extensive management to reduce fertilization and labour.

193. The socio-economic benefits are multiple. In South Viet Nam, more than 500 salt workers produce 40 tonnes of cyst per dry season. The income generated is USD 4 000–7 500/ha. Household income is multiplied by 2.5–3 compared to that of a household that only produces salt. The local availability of *Artemia* cysts can be a catalyst for the development of marine fish and shellfish aquaculture. In terms of human nutrition, *Artemia* omelette is a substitute for shrimp, fish and crab cakes.

194. Future prospects concern the appropriate management of *Artemia* population dynamics during production cycles in terms of ecological characteristics of ponds, in order to better predict the future yields, particularly in the context of climate change. The impact of *Artemia* inoculations must be assessed and minimized to comply with international agreements to protect local *Artemia* biodiversity. New initiatives are emerging in Southeast Asia and African countries. Although feasibility studies have been carried out or are ongoing through north-south or north-south-south cooperation with local research partners, international organizations should pay more attention to it.

THE RAPID DEVELOPMENT OF INTEGRATED RICE-FISH, RICE-MITTEN CRAB AND RICE-CRAYFISH AQUACULTURE IN CHINA (YONGXU CHENG)

195. The Chinese tradition of farming fish in rice fields is ancient. There are traces of it over 2000 years ago in Hanzhong in Shanxi province and in Chengdu, Sichuan province. In June 2005, the Qingtian rice and fish farming system in Zhejiang province was listed by FAO as one of the first five systems on the list of "Globally Important Agricultural Heritage Systems" (GIAHS).

196. With the support of governments and agencies, the rice-fish co-culture model began to develop rapidly in the early 1980s and technological innovations made it possible to move from a fish-rice co-cropping to an integrated system of rice and aquatic animals. In 1983, 4 413 ha were in production and yielded 36 300 tonnes. In 2000, the area increased to 1.53 million hectares and the production reached 746 000 tonnes. Since 2010, the area has declined slightly (1.32 million hectares) but production has increased to 1.24 million tonnes thanks to a steady increase in yields (61.9 kg/667 m^2 vs. 32.5 and 5.5 in 2000 and 1983 respectively).

197. Three characteristics distinguish the traditional rice-fish co-culture model from the integrated rice- aquatic animals system:

1. The species reared are not only the common carp, but also species with a higher economic value such as mitten crab, crayfish, loach or softshell turtle.
2. The need to provide balanced granulated feed to aquatic animals, whereas in the traditional system, no exogenous feed is provided.
3. The safety of food and aquaculture animals is better taken into account.

198. Moreover, the rice yield is not lower than in the traditional system. Geographic distribution shows that highest yields are observed in the band from Sichuan/Yunnan in the west to the coast of the China Sea in the east (> 68 402 tonnes in 7 provinces). It is also in the same area where the land farmed is the largest (>77 123 ha in 7 provinces).

199. The integrated crab-rice system is mainly found in Heilongjiang, Jilin, Liaoning, Ningxia, Zhejiang, Chongming Shanghai County, Jiangsu, Hebei, Hubei and Yunnan. The rice seedling cultivation technique alternates thick and narrow lines. Stubble control technology also extends the crab rearing period, and high quality feed is used for the crabs.

200. The integrated crayfish-rice system is mainly found in Hubei, Anhui, Jiangsu, Hunan, Zhejiang, Yunnan and Sichuan. In a rotation model, rice planting and crayfish farming do not overlap in space and time, so damage caused by rice cultivation techniques to crayfish is avoided. This is probably the reason for the success of this system in recent years.

201. Fertilization is based on two principles: a formula to adapt the quantities spread to the needs determined by a soil analysis, and a segmented fertilization technology, which is based on a bottom fertilization supplemented by regular additional fertilizer inputs. New pest and weed control measures are also being used, especially insect traps and insect nets. Biological control is also widely employed to reduce and control weeds. The most important innovation has been to dig canals and refuge ponds inside the rice fields, where animals can seek refuge during the harvest or in the dry season. The width and depth of the refuge channels are 1.5–4 m and 1–1.5 m respectively, so that their total area does not represent more than 8–10 percent of the surface area of the rice field. Other innovations include the layout of fields, dikes and screens, the alternate planting of narrow and wide rows, or the use of high quality larvae and feed.

202. Research shows that the integrated rice-crab farming model has many advantages, particularly in terms of:

- improvement of soil fertility and texture;
- maintenance of the zoobenthic diversity with adequate crab density;
- competition for light and nutrients reduced through weed control, which also reduces the use of chemical herbicides;
- the system provides shelter for crabs and maintains the water temperature near its optimum.

203. The rice and crayfish rotation system also requires a number of innovations, including the development of fields, dikes and screens, winter management when all straws return to the field, bamboo bottom cages and the testing of suitable rice varieties.

204. Technical standards have been developed for the integrated rice-aquatic animal system (SC-T 1135.1-2017), which must be adhered to.

205. Rice yields in lowland areas are always higher than 500 kg/667 m^2, and in mountain areas they are never lower than those of a rice monoculture. The total surface area of the refuge areas is generally less than 10 percent of the surface area and the net income per unit area increases by 50 percent on average, compared to a rice monoculture carried out under the same conditions. The use of fertilizers and pesticides per unit area is reduced by 30 percent. No antimicrobial substances are used.

206. Of all the models, the rice-crayfish system has developed the fastest. In 2016, total crayfish production was 852 300 tonnes and 1 million tonnes in 2017. The cultivated area was 570 000 ha in 2017 and is expected to exceed 800 000 ha in the near future. The economic value of the crayfish market is

RMB 268.5 billion, of which RMB 48.5 billion is from farming. [11] In 2017, the area under cultivation with crayfish-rice represented 71 percent of the total surface area of crayfish farming and 47.5 percent of the surface area of integrated rice and aquatic animal systems.

207. An economic calculation was carried out in Anhui province in 2014, 2015 and 2016 with 347 farmers totalling 13 500 mu.[12] Crayfish and rice yields were 125/600 kg/mu in 2014, 140/600 kg/mu in 2015 and 150/NA kg/mu in 2016 respectively, generating revenues of RMB 3 750/1 620 per mu in 2014, RMB 4 760/1 560 per mu in 2015 and RMB 2 250/NA per mu in 2016. The corresponding costs amounted to RMB 1 500/800 per mu in 2014, RMB 2 000/760 per mu and RMB 2 250/NA per mu. The net revenue was therefore RMB 3 070 (2 250/820) per mu in 2014, RMB 3 560 (2 760/800) per mu in 2015 and over RMB 3 000 per mu in 2016.

208. The integration of rice with mitten crab is another practice observed, particularly in Liaoning province, which hosts a demonstration unit in Panjin. The total surface area is currently 5 200 mu, or 347 ha.

209. The farming of softshell turtles is also practiced. The turtle yield in the Qingxi model allows to obtain 200 kg of turtles/mu (value higher than RMB 270/kg) and 620 kg of rice (RMB 36–98/kg). The revenue is RMB 26 000/mu and the net profit is RMB 9 600/mu. Economic monitoring in Zhejiang province has yielded the following results:

Year	Total (ha)	Turtle yield (kg/mu)	Rice yield (kg/mu)	Average net income (RMB/mu)
2014	900	135.2	419.7	10 270
2015	1 027	118	409.9	8 443
2016	1 253	111	340	9 340

210. In summary, for a rice-aquatic animal farming system, for each mu:

- the rice-crayfish model generates a profit of RMB 1 456 (+258 percent);
- the rice-turtle model generates a profit of RMB 13 744 (+2 290 percent);
- the rice-crab model generates a profit of RMB 2 484 (+351 percent).

211. As far as further development of these systems is concerned, the challenge is to strengthen the technology, since today, integrated rice-aquatic animal systems cover 1.468 million hectares, or only 4.5 percent of the surface area of rice fields in China. For further growth, the need are:

- strengthen research to learn the theoretical basis and formulate technical recommendations for developing integrated rice-aquatic animal systems;
- accelerate the demonstration and promotion of models and technologies;
- strengthen brand building strategies and promote integrated agricultural development as part of an entrepreneurial approach.

INTEGRATED RICE-FISH SYSTEMS AND WORK WITH INDIGENOUS AND LOCAL COMMUNITIES IN YUNNAN PROVINCE (YANNI XIAO)

212. Yunnan is located in the extreme southwest of China. It covers an area of about 394 000 km^2 and has a population of 45.7 million in 2009. It is the most biologically and culturally diverse province of China. It is drained by 6 major river systems: the Yangtze, the Pearl River, the Mekong River (Lancang), the Red River, the Salween River (Nujiang) and the Irrawady. The freshwater fish fauna is diverse, with more than 620 species, 580 of which are native. It is also one of the least developed provinces of China, with a higher number of counties affected by poverty than other provinces. The poverty reduction plan includes five major projects to improve infrastructure.

[11] RMB 1 = USD 0.15.
[12] 1 mu = 667 m^2.

213. The autonomous prefectures of Honghe Hani and Yi are located in the south-southeast central part of Yunnan province. Their names derive from the Red River (Hong) and the two main ethnic minorities: the Yi and the Hani.

214. The Honghe Hani rice terraces cover an area of one million mu, and their history is 1 300 years old. It is an agricultural and cultural innovation that results from particular geographic and climatic circumstances. During its 37th session on 22 June 2013, the World Heritage Committee included the Honghe Hani terraces in its World Heritage List.

215. But in terms of sustainable development, many problems are observed. The level of economic development is limited, the rural infrastructure is scarce, and the economic benefits of rice cultivation are low. The geographical constraints of terraced fields also make their mechanization complicated and the result is that the willingness of local people to continue in the agricultural sector is decreasing. The phenomenon of abandoned land is beginning to appear. Some farmers switch to sugar cane or vegetables in terraced fields.

216. The Hani's terrace crops and ecological environment have now suffered greatly and to provide solutions, the Yunnan Zhonghai Freshwater Fisheries Research Center (FFRC) and the Chinese Academy of Fisheries Sciences (CAFS) have initiated supporting activities. The first postdoctoral research station was established in Honghe County. It studied and conducted an in-depth investigation on the protection and sustainable development of Hani's terraced fields.

217. It appears that the "integrated rice-fish system" is of crucial importance for the protection and development of Hani's terraced fields. An industrial freshwater fishing industry has been created, which includes all activities from larval selection, genetic improvement, breeding, processing to the sale of the finished products. The management model used associates the government, business, farmers, extension and markets.

218. A training programme has also been set up in Honghe County to establish cooperatives and communities of agricultural professionals using standardized practices. A system of cooperation on common stocks has been established, as well as a buy-back system that guarantees a minimum price.

219. Between 2016 and 2017, 160 million fry were stocked into the fields of the Hani terraces, covering an area of 22 000 mu. Thirteen cities are concerned, 112 village committees, 336 villages and 2 000 households. Ten thousand people have been lifted out of poverty, and new initiatives are under consideration. For example, in 2018, the rice-bullfrog system was initiated.

220. In response to these actions, on 15 June 2017, FAO recognized the Hani terraces as a Reference Centre for Integrated Rice and Fish Systems, while in March 2017, the Secretary and Deputy Secretary of the Yunnan Provincial Party Committee came to Honghe County to show their support.

221. The integrated rice-fish system of the FFRC and Zhonghai is just beginning. The objective is to extend this experience to new rice fields. Appropriate aquatic species and fish fry should also be introduced in different regions, focusing on the benefits of the rice-fish farming system.

GENERAL DISCUSSION

222. A general discussion was held after after the presentations, which was active and lively. It showed that IAA is dynamic with a multitude of low technology approaches. Moreover, the discussion suggests that agroecology is a way of embracing innovation. Several themes were discussed, including the following:

- If agroecology can contribute to making IAA more sustainable, it is important to measure it holistically: what is its impact on nutrition, the environment and ecosystem services? What is its economic performance? What is its social contribution?
- What strategies should be implemented to accelerate the IAA adoption and its scaling up? A debate focused on the question: "Should we export models that have proven their value (for example, should we disseminate the Asian experience in Africa) or should we favour the emergence of local systems?". Whatever the answer, local, human and cultural values must be taken into account.

- It is imperative to involve the other sectors interested in IAA, in particular the rice farmers.
- It was agreed that further research on a number of technical (including the role of specific micro-organisms in preventing aquaculture diseases, the management of nutrient flow at the territorial level rather than only at the pond or farm level) and socio-economic issues is needed. There is also a need to better describe the impact of IAA on ecosystem services and to define the biological and aquaculture basis for diversification of production (with new high value-added species).
- It was also mentioned that there is a need to better describe the transitions from conventional intensive aquaculture to IAA and agroecology, as well as the pathways to impacts or the specific constraints of the key stakeholders (especially small-scale farmers).
- Finally, it was stressed that the specific constraints of small-scale farmers with limited resources should be better described.

CONCLUSION

223. The workshop was concluded with remarks made by Árni M. Mathiesen (FAO) and Elisabeth Claverie de Saint-Martin (CIRAD). Ms Claverie de Saint-Martin deeply thanked FAO for organizing this workshop and recalled the importance and challenges of agroecology.

APPENDIX 1 - MEDIA COVERAGE

- Cirad's press release, that was widely covered by international media in French, English, Spanish and Italian (general and specialized press)

  - In French

www.cirad.fr/actualites/toutes-les-actualites/communiques-de-presse/2018/l-agro-ecologie-pour-relever-le-defi-d-une-aquaculture-durable

  - In English

www.cirad.fr/en/news/all-news-items/press-releases/2018/agroecology-to-meet-the-challenge-of-sustainable-aquaculture

- Three original articles:
  - Science et Vie (French Science Magazine)

www.sciencesetavenir.fr/nature-environnement/a-montpellier-le-salon-aqua2018-explore-de-nouvelles-pistes-pour-transformer-l-aquaculture_126969

  - La Croix (French national daily newspaper)

www.la-croix.com/Sciences-et-ethique/Environnement/Laquaculture-solution-alimentaire-bientot-durable-2018-08-31-1200965320

  - The Fish Site (English news website)

thefishsite.com/articles/agroecology-session-set-for-aqua2018

- Radio interview to France Info (broadcasted on August 25)

- Twitter feed:

twitter.com/search?q=WeRaquaculture

- Participants' interviews:
  - Sidiki Keita

twitter.com/Cirad/status/1034085423860121601

  - Diana Edithe Andria-Mananjara

twitter.com/Cirad/status/1034730308296486912

  - Derun Yuan

twitter.com/Cirad/status/1034841534477295617

  - Mike Phillips

twitter.com/Cirad/status/1034803162513858560

  - Wenresti Gallardo

twitter.com/Cirad/status/1034699459756740608

- FAO movie on YouTube platform

www.youtube.com/watch?v=rwdH813SehU

APPENDIX 2 - PROGRAMME

Time	Presenter and topic
08.30	**Matthias Halwart** : Welcoming remarks
08.45	**Peter Edwards** : History of IAA and agroecology in aquaculture
09.00	**Malcolm Beveridge** : Agroecology and its application to aquaculture
09.15	**Michael Phillips** : Social dimensions of IAA and agroecology
09.30	**Patrick Sorgeloos** : Ecological approaches for better microbial management in intensive shrimp farming
10.00	**Yuan Derun** : Regional overview of the ongoing work and priorities in Asia
10.15	**Godfrey Nzamujo** : The work at Songhai on integrated systems, and a regional overview of the ongoing work and priorities in west Africa
10.30	**Joël Aubin** : IAA and agroecology in aquaculture: views from Europe
10.45	**Jean-Michel Mortillaro** : Ecological basis of integrated systems: example of Madagascar rice-fish farming
11.00	**Francis Murray** : Interim policy recommendations for effective use of probiotics in aquaculture emerging from field work in India, Bangladesh and Kenya
11.15	**Salin KR** : Biomimicry in aquaculture
11.30	**Austin Stankus** : Aquaponics for development, an example from the Caribbean
11.45	**Wenresti G. Gallardo** : Aquaponics in Oman
13.30	**Diana Edithe Andria-Mananjara** : Malagasy integrated aquaculture (rice-fish farming, tanjona)
13.45	**Sidiki Keita** : Guinean Fish-Rice culture
14.00	**Manoel Xavier Pedroza Filho** : Integrated animal-fish farming in Southern Brazil: practices, challenges, opportunities and difficulties
14.15	**Valerio Crespi** : Desert aquaculture
14.30	**Harrison Charo Karisa** : Practices and resource use efficiency of Egyptian farms applying aquaculture-agriculture integration
15.00	**Chanthaboun Sirimanotham** : Strengthening integrated aquatic plant and animal farming in the rice fields of the Lao People's Democratic Republic
15.15	**Xingguo Liu** : Raceway-in-pond aquaculture system
15.30	**Sunila Rai** : Increase fish production in semi-intensive ponds through enhancing periphyton growth
15.45	**Thanh Lam Phan** : Integrated mangrove-shrimp farming in Viet Nam
16.00	**Liying Sui** : Brine shrimp production from coastal salt ponds
16.15	**Yongxu Cheng** : Rapid development of integrated rice-fish, rice-mitten crab and rice-crayfish farming in China
16.30	**Yanni Xiao** : Improving livelihoods of indigenous and local communities through integration of fish in terraced rice fields in Yunnan, China
16.45	Question and Answer Session
17.45	Closing remarks **Elisabeth Claverie de Saint-Martin**, DG Research and Strategy, CIRAD **Árni M. Mathiesen**, ADG-FI, FAO

APPENDIX 3 - PICTURES

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Figure 1: The workshop was a Special Session of the International Conference AQUA 2018 #WeRaquaculture organized in Montpellier (France) by the World and European Aquaculture Societies.

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Figure 2: Austin Stankus and Matthias Halwart (FAO).

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Figure 3: Patrick Sorgeloos (Ghent University and AQUA 2018 Conference chair).

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Figure 4: Fr. Godfrey Nzamujo (Songhaï Center).

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Figure 5: Derun Yuan (NACA).

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Figure 6: Yanni Xiao (YZFC).

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Figure 7: Jean-Michel Mortillaro (Cirad).

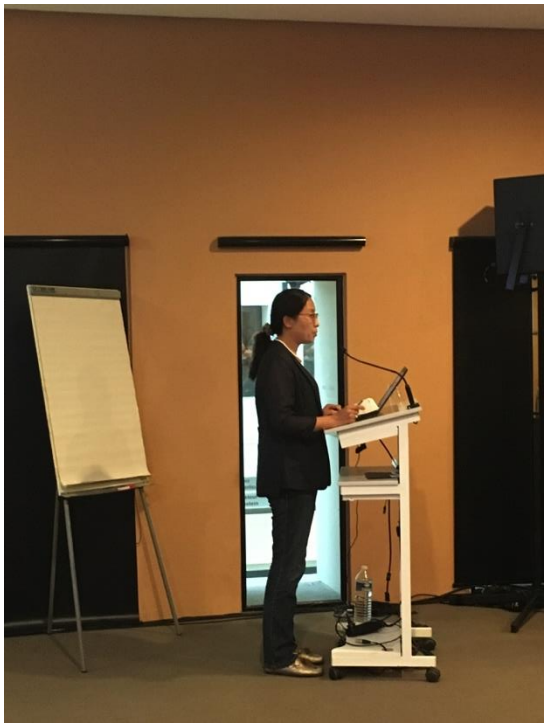

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Figure 8: Liying Sui (Tianjin University).

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Figure 9: Nick Innes-Taylor (FAO) and Chanthaboun Sirimanotham (The Lao People's Democratic Republic department of Livestock and Fisheries).

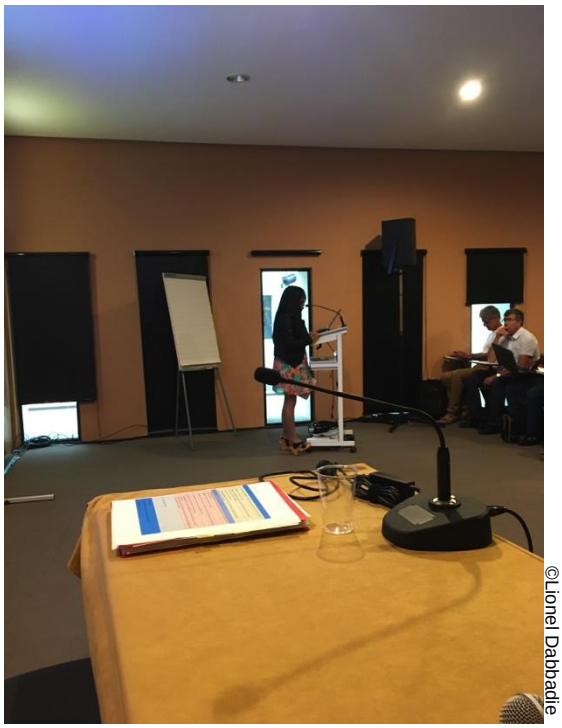

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Figure 10: Diana Andria-Mananjara (FOFIFA).

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Figure 11: Austin Stankus (FAO).

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Figure 12: Harrison Charo Karisa (Worldfish).

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Figure 13: Matthias Halwart (FAO) and Lionel Dabbadie (Cirad-FAO) co-chairing the discussion session.

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Figure 14: The Assistant Director-General of FAO in charge of Fisheries and Aquaculture Árni M. Mathiesen and the Director General in charge of Research and Strategy at CIRAD, Élisabeth Claverie de Saint-Martin gave the closing remarks.

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HISTORY OF INTEGRATED AGRICULTURE-AQUACULTURE (IAA) AND AGROECOLOGY IN AQUACULTURE

Peter Edwards

Abstract

Integrated agriculture-aquaculture (IAA) is a traditional and widespread practice in Asia. Asian IAA comprises diverse cultured species and systems. It was developed and disseminated by farmers and local communities using on-farm and/or locally available resources. Culture systems include rice fields, ponds and cages.

Definitions of agroecology in relation to aquaculture are followed by an historical overview of IAA. Examples of traditional farmer practices and their characterization in and outside China are presented.

Considerable research and development has elucidated the scientific basis of IAA. Some of the major institutions involved in IAA research and the elucidated principles of pond-based IAA, pond dynamics, and design criteria for livestock/fish integration are outlined.

Attempts to promote IAA for small-scale farming households are discussed with research and development (R&D) at the Asian Institute of Technology (AIT) presented as a case study.

The future relevance of IAA for small-scale farming households and for IAA to lower the cost and improve the adverse environmental impacts of modern aquaculture are considered.

1. Definitions

A relatively simple definition of IAA is, “aquaculture is linked up with plant crop and/or livestock subsystems on a farm”; or more formally, “an output from one subsystem in an integrated farming system which otherwise would have been wasted becomes an input to another subsystem resulting in greater efficiency of output” (Edwards, Pullin and Gartner. 1988). Two types of IAA have been recognised: on-farm or direct integration; and indirect integration with off-farm products and by-products of agro-industry as inputs, leading to an even more comprehensive definition of integrated farming involving IAA as well as other types of integration with aquaculture, “concurrent or sequential linkages between two or more human activity systems (one or more of which is aquaculture), directly on-site, or indirectly through off-site needs and opportunities, or both” (Edwards, 1998).

IAA is based on extensive and semi-intensive culture using natural and/or supplementary feed. Extensive culture depends on natural food in the culture facility without intentional fertilisation by humans. Natural food is increased by fertilisers in semi-intensive culture stage 1; semi-intensive stage 2 has an energy supplement at low fish biomass as natural food is high in protein; and semi-intensive stage 3 has denser feed at higher fish biomass with both energy and protein supplement (Edwards, Lin and Yakupitiyage, 2000).

Natural food produced *in-situ* in the culture facility is high in protein that comprises plankton and benthos (insect adults and larvae, and molluscs). Aquatic macrophytes do not occur in well-managed culture facilities. While the absence of aquatic macrophytes is the case in traditional fish ponds, most mitten crab (*Eriocheir sinensis*), red swamp crayfish (*Procambarus clarkii*) and some river prawns (*Macrobrachium* spp.) ponds in China have a surface area coverage of more than 60 percent of aquatic macrophytes to provide shelter, extra food, and improve water quality (Wenbo Zhang, personal communication). A fertilised pond is

dominated by phytoplankton producing “green water” although zooplankton and bacteria are also active in the food web.

Supplementary feeds that nutritionally complement natural food are agricultural by-products e.g. rice bran, broken rice, and waste vegetables; domestic waste food e.g. from the household, restaurants or factory canteens; volunteer (wild) or cultivated terrestrial vegetation e.g. grass and weeds, and wild or cultivated aquatic macrophytes e.g. duckweed (*Lemna* spp., *Spirodela polyrhiza* and *Wolffia arrhiza*), water spinach (*Ipomoea aquatica*) and pond weeds; and agro-industrial by-products from factories e.g. rice bran, broken rice, oil cakes and waste noodles, and sometimes pelleted formulated feed. However, some IAA systems have intensified through use of pelleted feed, especially towards the end of grow-out to increase the growth rate and size of harvested fish as larger fish usually fetch a higher farm gate price.

2. Historical overview

Integrated farming probably evolved in China due to a historically high population density and a decline in wild fish (Edwards, 2004). The origins of aquaculture are lost in antiquity. Rice/fish culture is perhaps the most basic and the oldest type of IAA as lowland rice grows in a swamp, which is a suitable environment for fish. Recent archaeological evidence indicates possible co-evolution of agriculture and aquaculture 8 000 years ago in China by sophisticated farming societies with cultivation of rice with other “aquacultural crops” e.g. water chestnut (*Trapa* sp.) and foxnut (*Euryale ferox*) for nut-like fruits. Agronomists have refered to “aquacultural societies”.

The earliest written record is culture of common carp (*Cyprinus carpio*) in ponds, Fan Li, 2 500 years ago. The earliest evidence for rice/fish is clay models from the Han dynasty (205-220 CE) with water chestnuts and common carp with a written record from the Wei dynasty (220-265 CE) of small fish with yellow scales and a red tail grown in rice fields in Sichuan province. A high-value red-coloured common carp stocked in rice fields in the mountains of Zhejiang Province has a 1 000 year history (Edwards, 2006; Lu and Li, 2006). More recent history is the culture of common carp being forbidden during the Tang dynasty (618-906 CE) because the name for common carp, li, was the same as the surname of the Emperor, Li. There are records of collection and transportation of Chinese carp fry in the Song dynasty (960-1276); and detailed accounts of Chinese carp polyculture in the Ming dynasty (1368-1644).

China has had a major impact on the establishment of IAA in some other Asian countries both historically and more recently through Chinese-inspired foreign initiatives, and joint Chinese/foreign initiatives (Edwards, 2004). Common carp was most likely distributed first as it was a revered fish, formed part of the diet and was easy to breed. The species was introduced initially to Japan by sea nearly 2 000 years ago; and to Indonesia probably during 14th century sea voyages; and by land by the Dai (Tai) ethnic minority who migrated southwards from Sichuan to Southeast Asia. Traditional rice/common carp culture still occurs today in mountain valleys in Yunnan (Wenbo Zhang, personal communication), Guizhou, Zhejiang, Fujian and Jiangxi (Hu *et al.*, 2016) and in Northern Lao People's Democratic Republic and Northern Viet Nam (Le *et al.*, 1995); and common carp remains a major cultured species today in Indonesia.

Chinese carp polyculture was probably introduced into the Red River Delta, Northern Viet Nam at an undetermined date by land using wild seed of carps from the Red River. In the late 19th to mid-20th century there was annual transportation of Chinese carp seed from the Pearl River to Malaya (present day Malaysia and Singapore) and Thailand where Overseas Chinese farmed the fish in IAA. IAA probably developed less than a century ago in other regions of Indonesia and Central and Southern Viet Nam, and in other countries of Southeast Asia and South Asia.

IAA was introduced into South Asia initially in Nepal in the 1970s (Woynarovich, 1980) and subsequently into Bangladesh by former US Peace Corps who had served as pond labourers for

Woynarovich in Nepal when they were aquaculture consultants (William Collis, personal communication).

3. IAA systems

3.1. Rice/fish integration

Rice fields are trenched to provide deeper water for the fish with culture either concurrent with rice or rotational. Fish stocked in the rice field consume natural food, including rice pests with a range of yields from 100-250 kg/ha; with supplementary feeding production may approach 1 tonne/ha or more depending on the area of the field converted to the trench or pond, and the amount of feed given to the fish.

Although capture of wild fish in rice fields is likely as old as rice farming, rice/fish farming has never been common or widespread. It has been practiced traditionally in only a few areas of some countries: in the mountains of Southeast China (Edwards, 2006; Lu and Li, 2006); in mountainous areas in Northern Lao People's Democratic Republic and Northern Viet Nam (Le *et al.*, 1995); and in Java, Indonesia (Edwards, 2009a). Only about 1 percent of the world's rice fields have been estimated to be stocked with fish (Halwart and Gupta, 2004).

Rice/fish farming occurs sporadically throughout Southeast Asia although rice/fish culture occurs throughout Viet Nam; some farmers in the Mekong River Delta in Southern Viet Nam culture low-value fish such as common carp, kissing gourami (*Helostoma temmincki*), rohu (*Labeo rohita*), silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia (*Oreochromis niloticus*) concurrently with rice. Culture of high-value giant river prawn (*Macrobrachium rosenbergii*) has been developed recently in well-watered trenched rice fields in southern Viet Nam; post-larvae are raised concurrently with rice and then in rotation after rice harvest as rains flood the field (Nguyen *et al.*, 2006). Culture of giant river prawn has been developed recently in trenched rice fields with an abundant water supply in southwest Bangladesh (Nandeesha, 2003; Ahmed *et al.*, 2013). Post-larvae are nursed in trenches in rice fields and then raised concurrently with rice as rains flood the field. Culture of high-value crustaceans has also been developed in China recently, concurrently with rice in trenched rice fields: river prawns (*Macrobrachium nipponensis* and *M. rosenbergii*), mitten/hairy crab (*Eriocheir sinensis*), and the red swamp crayfish (*Procambarus clarkii*) (Miao, 2010; Edwards, 2014a).

Although rice/fish farming has been promoted widely, the degree of sustainable adoption has been rather limited in the main rice growing areas of Bangladesh (Nandeesha, 2004; Nabi, 2008) and the Philippines (Horstkotte-Wesseler, 1999). Rice fields were traditionally used to produce culturally favoured small fish (50-100 g) for domestic consumption in Java, Indonesia but the development of running water pond culture in the 1960s and 1970s lead to a boom in rice/fish culture to provide fingerlings for stocking the ponds as well as the more recent development of cage culture in reservoirs in the 1970s and 1980s (Costa-Pierce and Hadikasumah, 1990). Although rice fields became a major source of fingerlings, the practice of rice field nursing declined significantly in Cianjur, a major nursing area, because a nursery pond converted from a rice field produced double the number of fingerlings than a rice field (Edwards, 2009a). The sustainability of traditional rice/fish farming in the mountains of Northern Viet Nam was questioned (Edwards *et al.*, 2000)

Capture and culture of fish in rice fields have probably both diminished over recent decades in Asia. High yielding varieties of rice require water less than 20 cm deep, have a shorter growing period than traditional rice varieties and fish, and use of pesticides has increased. Theft of fish from rice fields is widespread as they are often considered as a common property resource, and are difficult to guard distant from the farmer's dwelling. It also requires considerable time and labour to dig trenches and raise the height of rice field dikes; and to maintain adequate water for fish in the dry season and prevent loss of fish through monsoon season flooding. Rice/fish

integration is likely to become further constrained by new rice technology promoting less water use.

Most fish from rice fields are consumed by the farming household. While there may be a relatively low return on producing small fish in rice fields, such fish may provide an important source of animal protein, healthy fats, vitamins and minerals for poor farming households (Halwart, 2006). Consequently, there have been considerable efforts to promote rice/fish integration during recent decades although sustainable adoption has been limited following withdrawal of project financial technical and logistical support (Horstkotte-Wesseler, 1999; Nandeesha, 2004; Nabi, 2008). Rice fields as nurseries to produce fingerlings may be more attractive because farmers can more readily earn income through sale of fingerlings. Nursing common carp and Nile tilapia fry in irrigated rice fields in Northwest Bangladesh has been demonstrated and the practice spread without further project support (Barman and Little, 2006; Haque *et al*., 2010); the extent of sustainable adoption is being investigate (D.C. Little, personal communication).

Most fish ponds in Asia have been converted from rice fields as pond culture is more profitable than rice/fish farming (Edwards, 2015). Rice field conversion to ponds or pond/dike systems in the Red River Delta, Viet Nam, at least doubled the return from rice; and fish and fruit production were more stable with less chance of flooding and thus less risk, with thousands of hectares converted from rice fields to ponds (Le Thanh Luu, personal communication).

3.2. Pond-based IAA

3.2.1. China

Integrated farming has a long history in China where traditional family-level integrated farms were widespread in the Yangtze and Pearl River basins before the development of communes and collective agriculture in the 1950's.

Pond-based IAA was developed in China empirically by trial-and-error by farmers. The traditional Chinese system of carp polyculture had several on-farm linkages (Figure 1).

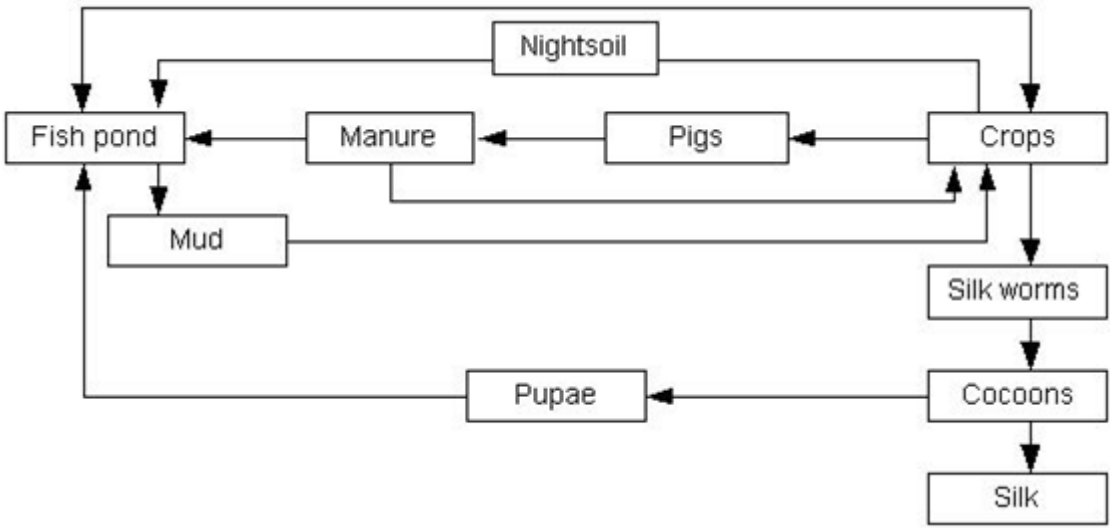

Figure 1: Traditional Chinese integrated farm (Edwards, Pullin and Gartner, 1988; Edwards, 1993).

Fertilisers included livestock manure, mainly pig, as well as human manure or nightsoil, for crops and pond; vegetation or green manure for crops and pond; and pond mud for crops. Supplementary feed for fish was provided by wild grass from on and around the farm; and by waste from vegetables grown for humans and pigs. Mulberry was grown for leaves to feed

silkworms and silkworm pupae were a traditional high-protein fish feed. Pig manure and nightsoil were used to fertilise rice, vegetables and the fish pond in decreasing importance; feed requirements of pigs were met before feeding fish. Pond mud was used to fertilize crops grown on pond dikes as ponds fertilised with green manure and fed grass as green fodder for grass carp (*Ctenopharyngodon idella*) developed thick deposits of organic-rich sediments that required periodic removal. Few on-farm resources were used for the fish pond due to intense competition from crops and pigs on resource-poor, small-scale farms. The main input to the pond was wild grass of low nutrient value so extrapolated annual fish yields were low, probably only 1-2 tonnes/ha. Estimated fish production in 1949 was 383 000 tonnes from 208 000 ha of fish ponds or an average of 1.8 tonnes/ha (Hoffmann, 1934).

Farmers managed the pond using 'farmer bioassays': natural food production indicated by water colour and light transparency; and adequate dissolved oxygen for fish indicated by the differential surfacing behaviour of fish, especially the most sensitive bighead carp (*Hypophthalmichthys nobilis*) and the most resistant common carp (Edwards, 2004).

The most complex IAA were developed in China during the era of communes and they reached their peak of complexity in the 1980s with intensification through direct and indirect integration (Figure 2) (Edwards, 1982; NACA, 1989; Mathias, Charles and Hu, 1994; Symoens and Micha, 1995; Chen, Hu and Charles, 1995). Nutrient flows were greatly increased through manure from increased numbers of integrated livestock, especially pigs that were farmed mainly for their manure to fertilise the pond, and transport of urban nightsoil as pond and crop fertilisers. Silkworm pupae wastewater was also used as a pond fertiliser. Improved grasses were grown on pond dikes to feed grass carp and aquatic macrophytes were cultivated on ponds and in nearby canals e.g. duckweed, water hyacinth (*Eichhornia crassipes*) and water spinach. Wild feed organisms such aquatic macrophytes and snails for black carp (*Mylopharyngodon piceus*) were harvested from nearby lakes; and wheat and rice bran, and soybean and rapeseed cakes, were used as supplementary feed. There was also increasing use of chemical fertilisers and pelleted feed.

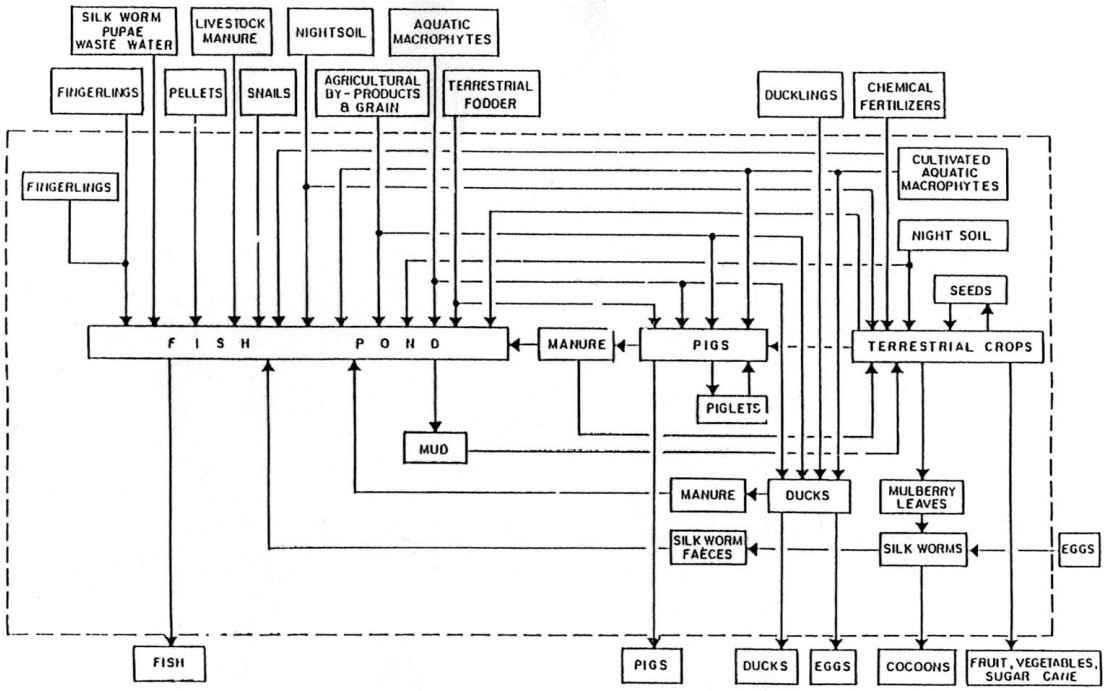

Figure 2: Links in large-scale integrated farms in China in the early 1980s. A composite diagram with all linkages identified from a survey of 10 farms (Edwards, 1982).

Large-scale Chinese IAA farms became less integrated following privatization, with a reduction in the number of subsystems (Miao, 2007). Crops were eliminated except for grass used mostly for feeding relatively high-value grass carp broodstock. Livestock integration with aquaculture was mostly replaced by more efficient and profitable large-scale, industrial-scale livestock production. Pond fertilisation during fish grow-out declined with increasing intensification of pond aquaculture through use of pelleted feed so less manure was required as the ponds had excess nutrients from the residual fertiliser effects of feed (Miao and Liang, 2007; Miao and Yuan, 2007). There has been a rapid increase in use of commercial feed with more than 10 000 aqua-feed mills today in China (Zhang *et al.*, 2013). In the major Chinese carp farming areas more than 95 percent of farmers used manufactured feeds although some still used home-made feeds from rice bran, soybean cake and wheat bran. However, some livestock/fish farms do remain in China, particularly small-scale duck/fish integration in Southern China (Edwards, 2008a).

The centuries old integrated mulberry dike/pond system has disappeared from the Pearl River Delta with an increase in intensive monoculture of high-value fish, giant river prawn and soft shelled turtle (*Pelodiscus sinensis*) from the late 1980s (Yee, 1999; Edwards, 2008a). It has also disappeared from the Yangtze River Delta where there is a 1-km2 park of a mulberry dike/pond system in Huzhou district, Zhejiang province as an agriculture heritage reserve although it was not really in production during a recent visit (Wenbo Zhang, personal communication).

3.2.2. IAA in Southeast Asia

Similar IAA to traditional Chinese pond-based IAA occur in two other historically densely populated countries, Viet Nam and Indonesia, and may have a long history.

Traditional IAA in Viet Nam is called VAC, an acronym from the Vietnamese words for garden, pond and pig sty. A polyculture of carps is raised in household-level ponds in association with livestock and crops (Le *et al.*, 2002). Most households keep one to several pigs, and small herds of scavenging chickens or ducks, which may be caged at night. Livestock quarters for pigs and poultry are constructed adjacent to or near the pond so that washings and urine may be flushed or drained into the pond. There may be a garden and/or an orchard with annual and perennial crops grown to provide household food and produce for the local market. Some farmers grow high-value ornamental plants on pond dikes for sale. Pond water is used to irrigate crops. Leaves of vegetables are used to feed grass carp. Grass and other wild vegetation and chopped banana trunks are also used to feed grass carp. Pond silt is removed annually to fertilise fruit trees and/or to provide a nutrient-rich layer of soil to cultivate vegetables. Extrapolated fish yields are 3-4 tonnes/ha.

As the traditional VAC system has fairly low yields, farmers now practice improved VAC with addition of Nile tilapia and pelleted feed to supplement traditional pond inputs. However, pelleted feed is mainly used to fatten fish towards the end of grow-out as it would not be profitable to use throughout the growth period.

VAC is recognised for household food security and increasingly as a source of income. The Vietnamese Government has recently introduced a policy of agricultural diversification that allows conversion of poor quality land such as low-lying and frequently flooded rice fields that do not provide an adequate household income for small-scale farmers to fish ponds.

A wide range of traditional integrated systems occurs in West Java, Indonesia both small- and large-scale (Edwards, 2009a). Feedlot livestock/fish integration at varying scales (poultry/fish and small-scale goat/fish) is also widespread.

The most common type of IAA in Asia is feedlot livestock/fish integration using manufactured formulated feed for the livestock: pig/fish, chicken/fish, duck/fish, and dairy cattle/fish integration (Little and Edwards, 1997, 1999, 2003). The fertilised pond has high natural food

production because of nutrient-rich manure from well-fed livestock and may also receive spilled livestock feed. Some pig farms may depend on agro-industrial by-products from food factories and waste food from factory canteens. Fish yields may be as high as 5-15 tonnes/ha/year, depending on management. Feedlot livestock/fish is typical of suburban areas with access to agro-industrial products/by-products. Feedlot livestock/fish in rural areas is often associated with rice mills as the miller usually retains the rice bran as a charge for milling the rice which enables livestock to be raised in an intensive way.

Feedlot livestock/fish farms are widespread in Thailand. Most farmers in Central Thailand where feedlot livestock/fish integration is common began as livestock farmers and dug the pond initially for soil to raise the land to construct the livestock quarters to minimize the risk of flooding. Following the outbreak of bird flu fish farmers were not allowed to purchase day old chicks to integrate with fish. The Thai Government allowed the continued integration of egg-laying poultry with fish as the eggs would not be exported like broilers but the chicken houses had to be screened from contact with possible virus carrying wild birds (Edwards and Mohan, 2007). There has been a recent decline in feedlot/livestock IAA with tilapia, the major freshwater species today raised in ponds with indirect IAA using feedlot chicken manure as fertiliser and rice bran as supplementary feed.

Traditional polyculture of Indian major carps in Bangladesh was extensive but semi-intensive fish culture has been introduced through projects in the past three decades (ADB, 2005). Farmers attain extrapolated annual fish yields of 3 -5 tonnes/ha in well-managed ponds using on-farm and locally purchased manures, brans and oil cakes. Important introductions of exotic fish were grass carp fed with on-farm vegetation such as grass, banana leaves and duckweed, and filter-feeding silver carp which comprises a major part of the harvest as it grows rapidly in green water ponds. There has been a shift from little use of any type of feed, to use of on-farm feed resources such as cow manure and rice bran (direct integration), to purchase of the latter (indirect integration), to purchase of formulated pelleted feed without any integration (Hernandez *et al.*, 2017).

The State of Andhra Pradesh is called the ‘fish bowl’ of India because it produces nearly 1 million tonnes of Indian major carps, mostly rohu (*Labeo rohita*) and catla (*Catla catla*). Production is mainly an indirect IAA based on local off-farm by-products such as feedlot chicken manure and inorganic fertilisers, and brans and oil cakes as supplementary feeds (Nandeesha, 2001; Ramakrishna, 2007; Edwards, 2008b; Abraham, Sil and Vineetha, 2010). Carp farmers were reluctant to use commercial pelleted feed as they believed that indirect IAA fertiliser and supplementary feed were superior. A majority of the farmers in Andhra Pradesh were large-scale whereas in West Bengal farms were mostly small-scale integrated with duck rearing and horticulture (Abraham, Sil and Vineetha. 2010). Feedlot poultry are sometimes raised on or near the pond in both Bangladesh and India.

Pond fertilisation has not been widely practiced in Myanmar (Belton, Bush and Little, 2015; Belton, Filipski and Hu, 2017). It has been estimated that about 80 percent of Burmese aquaculture production is indirect integration based on off-farm rice bran and peanut cake, the remainder using pelleted feed. Feedlot livestock/fish integration has been present for several years on a small-scale but poultry/fish has expanded recently on indirect integrated, large-scale farms.

In addition to small-scale VAC, feedlot livestock are more recently commonly raised in Viet Nam, especially meat ducks, on small fenced areas of the pond and on the dikes.

IAA has never been widespread in The Philippines with the most common freshwater fish, tilapia, being mostly pellet-fed (ADB, 2005).

Fish ponds provide a source of water to irrigate crops so cultivation of plants on pond dikes is widespread, mostly for human food, although old or damaged leaves are fed to herbivorous fish or used as green manure. Dike cropping of vegetables is widespread in the Mekong Delta, Viet

Nam (Nhan *et al.*, 2007). Giant gourami (*Osphronemus goramy*) is raised in the Mekong Delta, Viet Nam, integrated with crop production as feed for the herbivorous fish; and giant gourami is fed on elephant ear plant (*Alocasia macrorrhizos*) leaves and water spinach in Indonesia (Edwards, 2009a).

There is some small-scale integration of the herbivorous silver barb (*Barbonymus gonionotus*) with soft plants such as water spinach in rural areas in Thailand. Pond dikes are also commonly used to raise fruit and vegetables in Bangladesh (Ahmed, 2007; Jahan *et al.*, 2015). Crops can also be cultivated specially for fish feed but it is labour as well as land intensive with a ratio of land:fish pond ranging from 1-2:1 so that at least equal to twice the area is required to grow fodder as to raise fish in the pond. It is also labour intensive to collect wild vegetation. Further constraints are the food conversion ratio of vegetation is also high (a low feed conversion efficiency) as plants are mostly water with only about 20 percent dry matter and some plants also contain anti-nutritional chemicals (Castanares *et al.*, 1992). Pond mud may also be removed once the pond becomes shallow to fertilise dike crops but as this is labour intensive it is seldom carried out, especially in the humid tropics.

Reviews covering crop/fish integration are Edwards (1980, 1987) and Prein (2002).

3.3. Cage-based IAA

Small-scale cage farming occurs in Northern Viet Nam with grass and maize leaves used to raise grass carp. The system was probably introduced from Southern China where it is reported to have occurred also.

4. Research and development

4.1. Institutions

There has been an enormous amount of research over the last four decades to develop a scientific understanding of IAA with voluminous documentation as traditional Chinese aquaculture lacked a scientific basis. According to Chen (1934) writing about Chinese carp polyculture, ‘although these claims and beliefs are not supported by any scientific data or explanation, they are yet the results of thousands of years of experience’.

Research was carried out in the 1950s and 1960s at the Tropical Fish Research Institute, Malaya (modern day Malaysia); and in the 1970s to the 1990s to mention only a few of the key research institutions, at Dor Research Station, Israel; at the International Center for Living Aquatic Resources Management, ICLARM, now the WorldFish), at INRA and Cirad, France (Billard, 1980; Dabbadie, 1996); and at the Asian Institute of Technology (AIT), Thailand.

Pond fertilisation and feeds for Chinese carps were studied in Malaya. In Israel according to Wohlfarth (1979), “we experimented with the Chinese type of management… we used polyculture and manure only”. Schroeder (1978) carried out research on Chinese inspired polyculture in Israel and later in China at the Asia-Pacific Regional Research and Training Centre for Integrated Fish Farming, Wuxi and wrote that the fish pond is “a sunlit rumen wherein mineral and organic fractions of feeds and fertilizers are converted by autotrophic and heterotrophic activities… the food base for fish growth”.

ICLARM (renamed WorldFish) held a major international conference on IAA in 1979 (Pullin and Shehadeh, 1980) and researched livestock/fish culture in The Philippines and as well as IAA in Africa, especially in Ghana and Malawi.

In France, considerable research was conducted on traditional pond polyculture and fertilisation (Billard, 1980). Similar work was conducted in Africa, including considering periphyton-based aquaculture potential in rural Ivory Coast (Dabbadie, 1996).

The Asian Institute of Technology researched the scientific basis of fertilized "green water" ponds in the tropics (Colman and Edwards, 1987; Edwards, 1993), and latterly in cooperation with Collaborative Research Support Programme (CRSP), resulting in the major publications by Egna and Boyd (1997) and Knud-Hansen (1998). The CRSP pond dynamics research carried out on sites in Central and North America, East Africa and Southeast Asia elucidated the physical, chemical, and biological processes that interact in pond culture systems, considering the people who depend on these systems. Research at AIT also included various livestock/fish systems, and especially with relevance for small-scale farming households (Edwards, 1983, 1986; Edwards and Little, 1995; Little and Edwards, 1997, 1999). A survey was conducted of feeds and feeding strategies for aquaculture in Lower Mekong River basin countries (Edwards and Allan, 2004a, b). Li and Yakupitiyage (2003) modelled the nutrient dynamics of the semi-intensive pond system.

Research on supplementary feeding was reviewed by De Silva (1993) and De Silva and Davy (1992). Yakupitiyage, Edwards and Wee (1991) reported on a specific study on the effect of rice-bran as a supplementary feed for fish in a duck-fish integrated system.

General publications relating to IAA and in particular for small-scale farming households are by Little and Muir (1987); Edwards, Pullin and Gartner (1988); Edwards, Little and Demaine (2002); Edwards (1997, 1999); Edwards and Demaine (1997); and Prein (2002).

4.2. Principles of pond-based IAA

As China has played such a major role in the development of IAA it may be useful to outline six major features or characteristics of Chinese integration which may be considered as principles, as follows:

- integration with other human activity systems (agriculture and animal husbandry, hence IAA, as well as sanitation and local agro-industry);
- polyculture of an outstanding diversity of carps with various spatial and feeding niches in the pond;
- waste (or rather by-product) reuse (wild volunteer vegetation, livestock manure, nightsoil, brans and oilcakes, soybean, and silk and distillery processing wastes);
- nutrient reuse/multiple use;
- water reuse/multiple use; and
- production of high-protein natural food *in situ*.

4.3. Pond dynamics

There is a relationship between a natural pond ecosystem and three traditional aquaculture systems (Edwards 1993). Two of the three systems are IAA systems: the macrophyte or vegetation-fed system, and the manured or excreta-fed system. The fish-fed system is not commonly a component of IAA as carnivorous fish are usually raised in intensive monoculture and traditionally fed forage fish although carnivorous fish may be stocked in polyculture to control prolific breeding of tilapias in IAA systems.

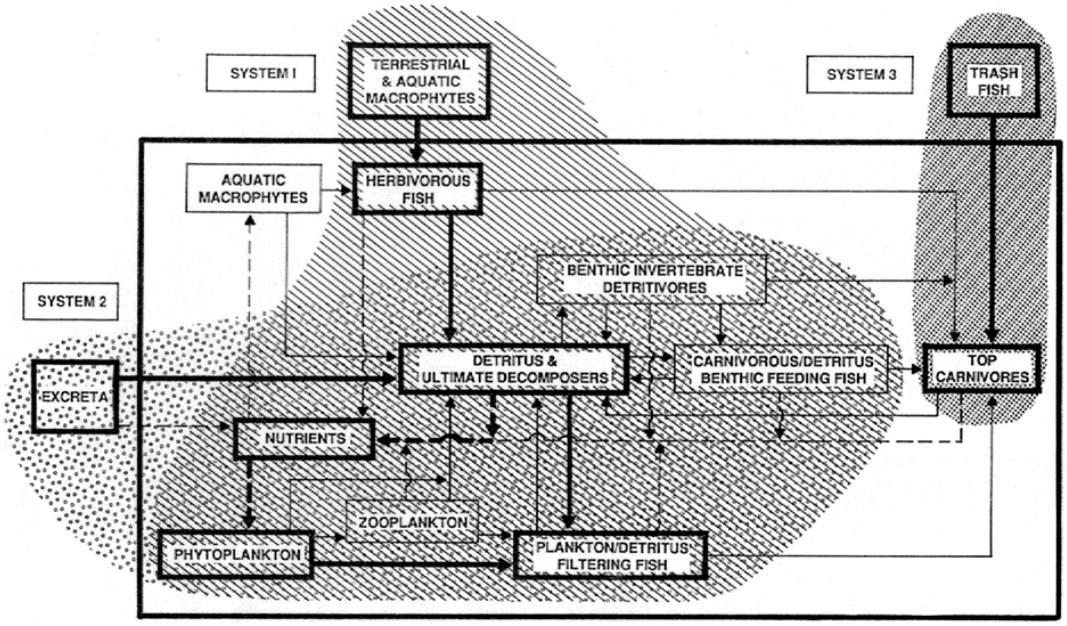

Figure 3: The relationship between a natural pond ecosystem and three traditional aquaculture systems (Edwards, 1993).

Thus there are two possible feeding pathways in IAA:

- a vegetation-fed system; vegetation is rarely present in a well-managed pond because its growth is inhibited by reduced light from phytoplankton in the water column; inefficient digestion by herbivorous fish fertilises the pond with fish manure which produces plankton for filter-feeding fish and benthos for pond bottom feeding fish;
- a manured system; manuring produces plankton and benthos.

It is necessary to consider fish pond dynamics in relation to nutrient and organic matter loading rates:

- there is a diurnal dissolved oxygen (DO) cycle with increasing nutrient input; the first limiting factor at night is DO; and the second limiting factor is un-ionized ammonia, the concentration of which also depends on pH and temperature and should be <0.5 mg/l;
- the optimal organic matter loading rate is about 100 kg dry matter/ha/day; a large bacterial oxygen demand from respiratory breakdown of organic matter leading to pond deoxygenation may occur if the loading rate is too high;
- the optimal nutrient loading rates are about 4 kg nitrogen (N) and 1-2 kg phosphorous (P)/ha/day; there is also a need for adequate carbon; bacterial respiration of organic matter should provide the minimum of at least 20 mg total alkalinity/l.

High quality manure from feedlot pigs and poultry should produce about 3-5 tonnes tilapia/ha/3-4 month crop but low quality grazing buffalo manure would produce only 0.5-1 tonne/ha/3-4 month crop. Low fish yields with buffalo manure were because of the high organic matter load to provide adequate N and P, giving rise to a low DO (Edwards, Pacharaprakiti and Yomjinda, 1994; Edwards *et al.*, 1994; Shevgoor, Knud-Hansen and Edwards, 1994). Tannins in the ruminant manure also stained the pond water brown, limiting light penetration for photosynthesis.

Nutrient budgets for semi-intensive ponds have indicated that only 10-15 percent of N and P were removed in harvested fish, 2-6 percent remained in pond water while 80-90 percent "disappeared" within the pond system but mostly probably remained in pond sediments

(Colman and Edwards, 1987; Edwards, 1993). Further research on recycling nutrients is warranted.

4.4. Design criteria for livestock/fish integration

Livestock/fish integration is an indirect IAA depending on off-farm formulated feed (Figure 4). While livestock production is intensive and based on off-farm nutritionally complete feed, fish production is semi-intensive as it is based on inefficient digestion of feed nutrients, thus providing a high nutrient level fertiliser for fish production. Crop production is usually minor or absent as the two main commodities are livestock and fish.

The rationale behind recycling livestock manure in aquaculture is approximately 72-79 percent of N and 61-87 percent of P in feed fed to livestock is recovered in their manure and urine (Edwards, 1993). There are variations in their amount and composition of manure which depend on species and total live weight of the animal. As a general rule livestock fed high quality feed have a high concentration of nutrients in their manure. A major factor is inclusion of urine as it can be up to 40 percent of the total wet weight of manure. Inclusion of foreign materials such as soil, litter or bedding will decrease the nutrient content. Spilled feed will increase the nutrient content. Management of manure is also important as loss of N (20-90 percent) depends on the method of collection and handling to minimise volatilization of ammonia. Loss of P is less than N as the former is not volatile. Manure should be used fresh to minimise N nutrient loss. There is minimal possibility of transmission of disease to humans because of the high diurnal pH resulting from photosynthesis activity in manured green water ponds (Little and Edwards, 2003).

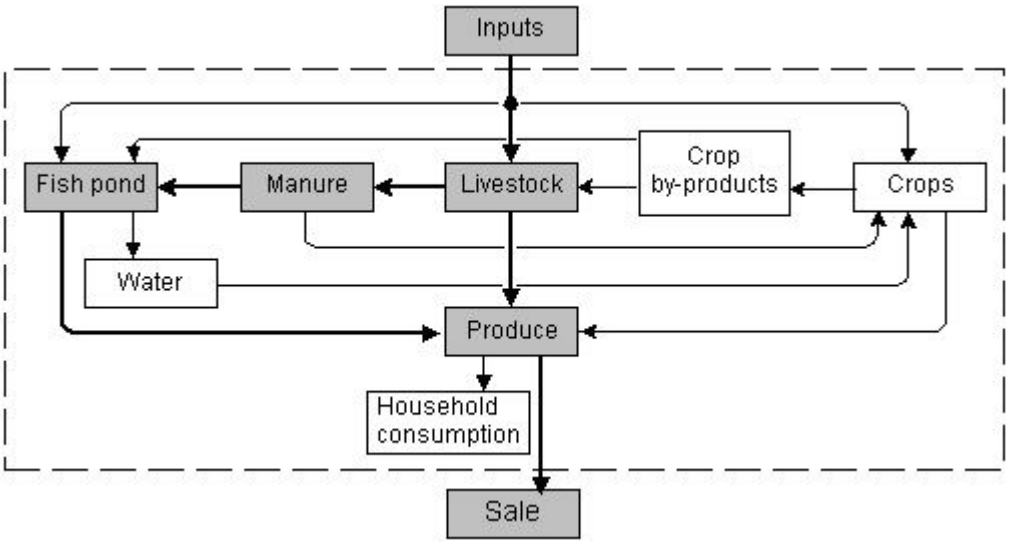

Figure 4: Crop, livestock and fish interactions in a feedlot/livestock IAA system (Edwards, 1993).

Principles of application and distribution of manure are:

- frequent, daily up to twice-weekly for manure;
- small doses which are related to frequency to give the optimum loading rates expressed as kg/ha/day or kg/ha/week;
- wind induced water movement helps to distribute manure in small to medium sized ponds but manure needs to be distributed by boat in large ponds;
- the best time is mid-morning when DO is high and rising.

Enclose the livestock, at least partially, to collect manure, although this is not feasible with few, scavenging livestock. Large ruminants and flocks of poultry are usually kept in a paddock at

night to avoid theft which facilitates partial manure collection. Feedlots lead to more efficient livestock production and available manure but there is a need to collect feed which requires labour and/or to purchase feed which may be unavailable or costly.

The livestock quarters are best located on, next to or near the pond to minimise manure transportation which may have a high moisture content and be heavy and bulky. There is trade and transport of manure in most countries, especially for crop production, so manure should be available for purchase for indirect IAA.

Poultry are light animals so their quarters can be constructed on the dike, or over the pond. Advantages of being located over the pond are it facilitates manure distribution, no extra space is required as it is above the water surface, and there is less chance of disease as there is no manure accumulation and good air circulation. Disadvantages of being over the pond are a higher construction cost, no flexibility of manure use, and stress to birds in cool and/or windy weather which may lead to disease, even in the tropics. There are special considerations for ducks as they can be housed on a floating raft on the pond water surface (Edwards, 1986). If the duck house is on stilts over the water, there should be a ramp for the ducks to access the pond. Earthen pond dikes should be bricked or duck access prevented by a fence to prevent their erosion by ducks descending into and clambering out of the pond.

Ruminant and pigs are heavy livestock so their quarters are best built on the dike to minimise construction cost. Quarters should have a sloping brick or concrete floor connected to a pipe or channel leading to the pond. A sump to collect wastes should be installed if flexibility in manure recycling is needed for example to also fertilise crops, or with seasonal fish culture.

The maximum manure loading rate is the amount of manure that pond bacteria and phytoplankton can digest/unit area/unit time. Phytoplankton blooms from excessive fertilisation lead to a night-time anaerobic water column. Excessive manuring also leads to the accumulation of organic matter on the pond bottom causing the development of anaerobic conditions. Maximum loading rates of 100-200 kg manure dry weight/ha/day correspond to livestock numbers/ha of 2 000-4 000 poultry weighing 2 kg each, 100-200 pigs weighing 100 kg each, and 15-30 cows weighing 500 kg each. However, these numbers should only be used as a general guide as local conditions may require that they be adjusted.

A wide range of livestock is available for IAA but livestock rearing is culture specific. Hindus, Muslims and Jews do not raise pigs or eat pork. The purpose of raising livestock may vary: draught, food, income, and as a ‘bank’ to save money. Major determining factors in introducing new livestock species are feeds, marketing, and competition between small-scale and large-scale vertically integrated agro-industrial sectors. Livestock prices may be cyclical, especially pigs so fish may contribute to total net profit of IAA when pig prices are high and cover much of the net loss of pig raising when pig prices are low.

5. Promotion of small-scale IAA

5.1. Constraints

IAA has been promoted in recent decades in many Asian countries in an attempt to improve the welfare of small-scale farming households. A major difference with traditional aquaculture in China in the past is limited indigenous technical knowledge (ITK) in most areas of the tropics in recent times.

The major constraints include:

1) improved awareness of the impact of IAA on society, environment and economy;
2) lack of know-how and guidance on adoption to local conditions;
3) business plan/production chain and marketing of products;
4) technical service and support.

Small-scale farms usually have a poor resource base with limited inputs and limited outputs. Major transactions between subsystems on small-scale farms are between crop, mostly rice, and livestock subsystems, with the fish subsystem poorly developed or absent (Figure 5). Traditionally most produce would have been consumed by the household for subsistence rather than sale although farming household increasingly raise fish for sale in Asia (Edwards, Little and Yakupitiyage, 1997).

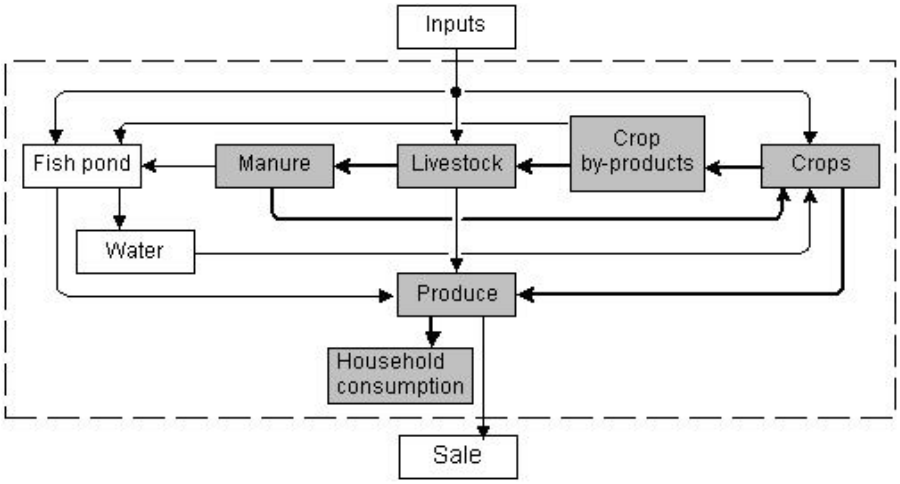

Figure 5: Most interactions on small-scale farms are between crop, mostly rice, and livestock subsystems, with the fish subsystem poorly developed or absent (Edwards, 1993).

Small-scale ponds may be fertilised with livestock manure but there is usually insufficient as most farms are resource-poor. It is difficult to collect manure for aquaculture as pigs and poultry usually scavenge for food on small-scale farms and if they are confined or housed for manure collection then they have to be fed with feed collected manually or purchased. Large ruminants (buffalo and cattle) are penned/corralled at night near the house to prevent theft so it may be possible to collect some manure although scavenging ruminant manure is poor fertiliser as outlined above. Further constraints to manuring ponds is it may be labour intensive, there may be alternative uses as a crop fertilizer or as fuel in the Indian sub-continent, and the pond may be used as a domestic water supply. There are also constraints in use of plants as outlined above. The most common supplementary feed is rice bran which is an on-farm by-product if rice is milled by the farming household; rice bran is an off-farm by-product if retained by the miller as a charge for milling the paddy and needs to be purchased by the farmer.

Fish yields are usually low because of limited nutritional inputs and are further constrained by stocking small fingerlings which may be predated by carnivorous fish. Fish ponds newly constructed are often turbid due to suspended inorganic particles or silt reducing light penetration. This may cause the farmer to lose interest in aquaculture because of little to no fish growth with the eventual result that the pond becomes a ‘weed-filled hole’ as the water later clears with settling of suspended particles and light penetrating to the pond bottom allows emergent aquatic macrophytes to grow and choke the pond water volume.

5.2. AIT case study

Research into small-scale aquaculture at AIT began in the late 1970s with a survey of farmer practice in Pathumthani province, a major fish farming province north of Bangkok where the institute is located (Edwards *et al.*, 1983). Two major groups of fish farmers were identified:

- successful medium to large-scale farms which were mostly integrated with feedlot livestock;
- small-scale rice farmers with ponds created from excavation of soil to raise the level of the house but who had little to no knowledge of aquaculture.

It therefore seemed logical to attempt to introduce scaled-down feedlot livestock/fish to small-scale rice farmers who expressed interest in fish farming (Edwards, 1983, 1986). Research was carried out on the AIT campus initially to develop the requisite technology for duck/fish integration, and subsequently pond fertilisation with buffalo manure and inorganic fertilizers, nursing fish in "hapa" nets to make more predator-resistant fingerlings, making the water green and feeding the fish with available resources, and mass spawning of tilapia and all-male production. Technologies researched on-station on AIT campus were subsequently trialed with farmers and "promising recommendations" were extended. The AIT Outreach programme was initiated in 1989 in cooperation with the Thai Department of Fisheries (DOF) with the aim to reduce poverty among small-scale farmers in Northeast Thailand (Edwards *et al.*, 1991; Edwards and Demaine, 1998).

Fish farmers in the on-farm trials of duck/fish integration in Central and Northeast Thailand were subsidized as the technology was under development and the researchers did not want the farmers to be subjected to risk should the trial fail. Each farming household was provided with a 200 m^2 pond, materials for them to construct the duck house, 30 ducks, fingerlings and duck formulated feed. Although extrapolated net yields were an impressive 8-9 tonnes fish/ha/year (110-120 kg fish/pond/8 months culture period), most systems collapsed and were abandoned after withdrawal of project support. Economics of duck rearing was marginal through competition from large-scale and often vertically integrated companies; and there were marketing problems with input supply for feeding ducks and fingerlings to stock the pond, and marketing 20-25 duck eggs daily in the village as it was impractical to link into a marketing chain.

Feedlot livestock/fish for small-scale farmers continued to be promoted uncritically by development agencies to improve the welfare of small-scale farmers on resource-poor farms but AIT research clearly demonstrated that feedlot livestock/fish is more than likely to be a mismatch of technology to resource base. As small-scale farmers in Northeast Thailand had buffaloes for ploughing rice fields, buffalo manure was then researched as a pond fertiliser as manure was available on the farm. Buffalo manure was a poor pond fertilizer with extrapolated production of only about 2 tonnes/ha/year for reasons outlined above.

As both duck and buffalo manure had proved to be unsuitable for small-scale farms, a baseline survey was carried out in a 'back-to-basics' exercise to determine what potential pond inputs were available in various local agroecologies in Northeast Thailand although these proved to be few (Demaine *et al.*, 1999). The only seed available from local nurseries were 2-3 cm fingerlings readily predated by wild carnivorous fish so hapa nursing was trialed in farmers' ponds. An Outreach recommendation was to use only low inputs of buffalo/cattle manure at a maximum rate of 50 kg dry matter/ha/day and in combination with other inputs. Green water was produced in the pond by fertilization with buffalo manure supplemented with urea. Although yields increased 3-5 times above the farmer baseline to an average extrapolated 1.6 tonnes/ha/year, it still only contributed to a minor 6.5 percent of total farm income. Further on-farm trials used urea and TSP at optimum fertilization rates and although yields increased 2-3 times to an average extrapolated 4-5 tonnes/ha, it only comprised 15.9 percent of total farm income (Edwards *et al.*, 1996). Subsequent research confirmed the difficulty of on-farm IAA in resource poor North Thailand without off-farm nutrient inputs (Pant, Demaine and Edwards, 2001, 2004, 2005).

6. Future relevance of IAA

6.1. Small-scale farmers

It is a major challenge to increase the productivity and profitability of small-scale farms, with ever decreasing farm size, through IAA. Three approaches to intensify production are:

- increased efficiency of use of relatively limited existing and/or potential on-farm resources through better water and nutrient management. When land availability/cost is not a problem (e.g. unused small valleys in some West African countries), small-scale farmer fish production may be increased by creating larger extensive water bodies like the traditional European medieval ponds (L. Dabbadie, personal communication);
- production of more valuable produce (crops, livestock or fish); and
- increased flow of off-farm resources.

Research continues on IAA with the aim of increasing fish production by maximizing nutrient cycling within the pond based on natural pond productivity. Two examples are improved polyculture to more effectively use pond niches; and periphyton on solid substrates placed in the pond (Azim *et al.*, 2005; Azim and Little, 2006; Bosma and Verdegem, 2011; Browdy *et al.*, 2012; Costa-Pierce *et al.*, 2012; Diana, 2012; Milstein, 2005). However, the relatively small increase in fish production by these interventions is unlikely to make IAA significantly more attractive to farmers (Bostock *et al.*, 2010).

There must be a significant increase in nutrients to permit a significant increase in produce (Figure 6) (Edwards, 1997). Intensification could be achieved by either indirect integration using off-farm fertilisers such as feedlot poultry manure and supplementary feeds such as brans and oil cakes; or by using more expensive pelleted feed.

There is a need to consider human ecology or sociology in the promotion of IAA as farmers throughout the developing world are increasingly motivated to raise fish for income rather than only for household subsistence and have diverse livelihood portfolios on- and off-farm (Rigg, 2006). More value could be added to IAA products as they may be perceived as organic with lower chemical fertilizer input. Intensification of fish production would lead to IAA becoming a more meaningful livelihood option for small-scale farmers through increased income from sale of fish. Although there may be small but significant contributions towards household nutrition and income from most current IAA practices, farming households need to intensify aquaculture for it to become a small to medium enterprise (SME) to provide significant household income (Edwards, 2014b).

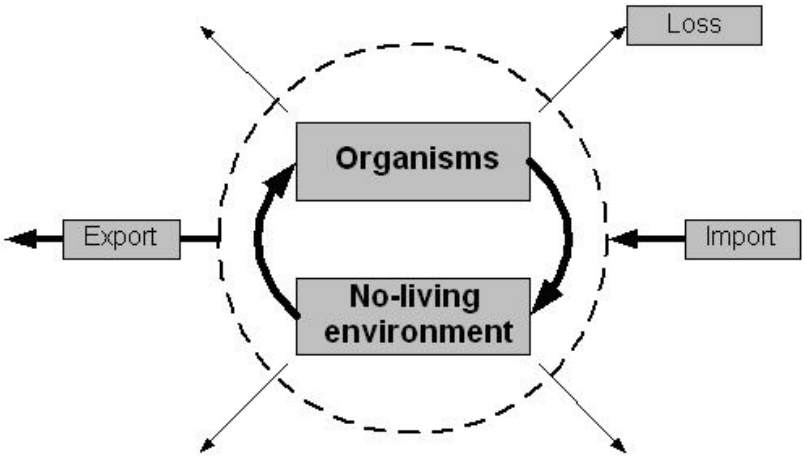

Figure 6: There is a need to increase the input of off-farm nutrients as significant output of produce requires significant inputs of nutrients (Edwards, 1997, 1998).

Traditional IAA does have environmental advantages as it uses local resources rather than globally traded animal and plant meals; and livestock manure can be readily disposed of through integration with fish with excess nutrients mostly tied up in sediments that could be used to fertilize crops. Furthermore, it is the best entry point for poor farmers to farm fish to

gain experience before considering intensification as it is relatively low cost with minimal risk and may be considered as the "first step on the ladder of intensification" (Edwards, 2009b).

6.2. Modern aquaculture

A recent and accelerating trend in Asian aquaculture is a decline in the share of most IAA to the total production, with delinking integrated fish, crop and/or livestock subsystems or enterprises. Intensification is taking place through increased use of formulated feed and specialization or monoculture. So called "modern" aquaculture has a higher cost of investment but produces more profit than traditional IAA although at greater risk. A primary driver of intensification in Asia is the desire of households, including small-scale farming households that dominate Asian aquaculture in terms of number of farms if not in total production, to improve their livelihoods and increase income. Small-scale farming households are usually multi-generational and generally have diverse livelihood portfolios (Rigg, 2006); they compare the income generation of various options both on- and off-farm, including that of aquaculture which would likely need to be financially attractive to be sustainable.

However, agroecology does have a role to play in the future development of aquaculture. The principles of agroecology are still highly relevant to manage the transitions to more adaptive, efficient and resilient integrated systems (Halwart, Dabbadie and Beveridge, 2019). There are traditional IAA which thrive today as well new systems that deserve a more thorough assessment. Perhaps the best example is the farming a red coloured variety of common carp in stream-fed terraced rice fields in mountainous Qingtian County, Zhejiang Province, China that has a documented history of 1 200 years (Edwards, 2006; Lu and Li, 2006; Hu *et al.*, 2016; Ren *et al.*, 2018). The fish have a high market value because of their special taste with local households and restaurants involved in ecotourism (FAO, 2016). The system has been listed by FAO, UNDP and GEF as a 'globally important indigenous agriculture heritage system'. While more widespread dissemination of the system appears unlikely because of its special situation as a localized tourist site, more recently developed integrated culture of high value crustaceans in well-watered rice fields in Bangladesh, China and Viet Nam as outlined above has potential for considerable expansion.

Some of the principles of traditional IAA practice could be used to make 'modern' aquaculture more environmentally friendly as well as to reduce production costs (Edwards, 2014b, 2015). Examples are:

- nutrient and water reuse with intensive aquaculture effluents used for crop irrigation and aquaponics;
- Chinese polyculture with 80 percent pellet-fed fish integrated with 20 percent filter feeding fish;
- pellet-fed caged fish integrated in a pond in which fingerlings are nursed on 'green water' produced from caged-fish fish wastes;
- reduction of feed costs, especially in nursing and early grow-out when fish are small, by using 'green water' rather than formulated feed; and,
- biofloc systems in which feed costs are reduced and the water quality improved by the production of protein-rich natural food from the addition of low-cost carbohydrate-rich supplementary feed to N-rich fish wastes which otherwise would require treatment.

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AGROECOLOGY AND ITS APPLICATION TO AQUACULTURE

Malcolm Beveridge and Lionel Dabbadie

1. Introduction

With world hunger rising again after decades of decrease since the 1990s, there are growing concerns that the increasingly dominant high-input, resource-intensive model of food production has created massive problems of deforestation, water scarcities, soil depletion, greenhouse gas emission and biodiversity loss and cannot deliver sustainable food or agriculture production (FAO, 2017). Critical parts of our food systems are becoming ever more capital-intensive, vertically integrated and concentrated in fewer hands. It is argued that what is required is nothing short of a transformation towards a more holistic approach to food production and its governance.

The term 'agroecology' was first used in the 1920s to refer to "... *the application of ecology to agriculture*".[13] Half-a-century later McKay (1983) coined the term "ecological aquaculture", which he defined as "... *the application of ecological principles to aquaculture*". This is synonymous with the original definition of agroecology, further refined a few years later by Alteri (1995) ("... *the application of ecological concepts and principles to the design and management of sustainable agroecosystems*"). In his Preface to the multi-authored volume on ecological aquaculture produced at the beginning of the 21st century Costa-Pierce (2002) elaborated ecological aquaculture as "... *a model that uses ecological principles and ecosystems thinking as the fundamental organizing paradigm for the development of aquaculture",* closely paralleling the prevailing view of agroecology at the beginning of the present century.

Interest in agroecology grows apace, its original focus extending in scale from the plot and farm level to entire food production systems, and attracting interest from stakeholders across the social, economic and natural sciences as well as from policy makers (Wezel *et al.*, 2009). The diversity of interpretations is captured by FAO in a database of some 20 definitions and in the organisation's current working definition:

"Agroecology is based on applying ecological concepts and principles to optimize interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system. By building synergies, agroecology can support food production and food security and nutrition while restoring the ecosystem services and biodiversity that are essential for sustainable agriculture. Agroecology can play an important role in building resilience and adapting to climate change".

The concept encompasses many not entirely consistent visions. Baatard *et al. (*2013) propose a grid highlighting the areas in which different current concepts of agroecology differ. It can be with regard to the challenges assigned to agroecology by their promoters, to the knowledge, concepts and disciplines mobilized, to the thematic and spatio-temporal scope of the system considered, to the principles and levers of action used, to the agroecology stakeholders put forward, to the possible reference to ethics or to the sources of inspiration and geographical anchoring. FAO has focused on the common ground shared by the various proponents, to formulate 10 interdependent agroecology elements (Table 1) in order to operationalize an agroecological approach among member countries to create large-scale transformation of food and agricultural systems to achieve Zero Hunger and other Sustainable Development Goals (SDGs).

Our Introduction provides context and complements a series of case study-based presentations on agroecology and aquaculture. We consider how an agroecological approach is being - and could further be - applied to aquaculture and how novel aquaculture technologies offer potential solutions to

[13] See the FAO database on agroecology www.fao.org/agroecology/knowledge/definitions

sustainability issues in aquaculture. We begin by briefly considering the key issues around aquaculture and sustainability.

2. Aquaculture and sustainability issues

Aquaculture production has grown rapidly in recent decades and since 2014 has supplied the majority of fish consumed by humans in the world (FAO, 2018a). The prevailing discourse is that for the foreseeable future aquaculture will be the primary source of increases in aquatic food supplies needed to meet the demands of a growing and increasingly wealthy human population (FAO, *ibid*). However, there have also long been concerns about the environmental and social impacts of the sector (Beveridge, Ross and Kelly, 1994, Naylor *et al.*, 2001; Béné *et al.*, 2016). Accompanying increases in production, for example, has been an intensification of production methods, including an increasing reliance on commercial, pelleted feeds that utilise scarce fishmeal and fish oil resources (Tacon *et al.*, 2013; Little *et al.*, 2016; FAO, 2018a) and increases in the prevalence of aquatic disease (Subasinghe *et al.*, 2001). Conflicts have arisen between aquaculture and other sectors, particularly over competition for space in coastal areas, in the use of agricultural land (Aguilar-Manjarrez *et al.*, 2017) and fresh water, especially in relation to aquaculture feed production (Gephart *et al.*, 2017). There are concerns about the sustainable use of aquatic genetic resources for aquaculture (FAO, 2019). Climate change is also likely to adversely impact on future aquaculture production (Dabbadie *et al.*, 2018), further fuelling concerns about the sustainability of the sector, its abilities to meet the anticipated gap between demand and supply of aquatic foods and its impacts on climate change and the environment.

3. Aquaculture and agroecology

Ecological aquaculture initially drew heavily on systems ecology, which emerged in the late 1960s and 1970s (see Odum, 1983), and the pioneering work on development of aquaculture at the New Alchemy Institute, Massachusetts, United States of America,[14] which combined systems ecology thinking with technologies new and old in order to develop production systems that both relied on and conserved ecosystem services. Pioneers found much to emulate in the traditional types of integrated aquaculture still being practiced in Asia (e.g. rice-fish culture, waste fed aquaculture; see, for example, Little and Muir, 1983; Edwards, Demaine and Little, 2002). More recently, agroecological elements have both been applied to conventional aquaculture (e.g. stocking lumpfish (*Cyclopterus lumpus*) or wrasse [Labridae] in Atlantic salmon (*Salmo salar*) cages to control sea lice and replace use of pesticides; Powell, *et al.*, 2017). New technologies, fully rooted in agroecology, have also emerged including recirculation aquaculture systems (RAS; e.g. Badiola *et al.*, 2018), aquaponics (Sommerville *et al.*, 2014), periphyton-based aquaculture (Dabbadie, 1996; Azim *et al.*, 2005; Figure 1) and Integrated Multi-Trophic Aquaculture (IMTA; e.g. Granada *et al.*, 2016).

[14] See, for example: newalchemists.files.wordpress.com/2015/01/solar-aquaculture-primer-by-eab1.pdf

Figure 1: Example of periphyton-based aquaculture pond with integrated chicken farming experimented in Côte d'Ivoire in 1993 by using bamboo sticks.

FAO's ten interdependent agroecological elements are shown in Table 1 and demonstrate the wide applicability of the approach to aquaculture.

4. Discussion

Agroecology has an increasingly strong theoretical base, encompassing not just production but entire food systems, with implementation being driven by empirical evidence from scientific, on-farm trials and feedback from participatory stakeholder workshops. However, it is one of several emerging approaches to counter the prevailing model by which the USD 5 trillion global food system operates. Others include conservation agriculture, organic agriculture permaculture and climate smart agriculture. Baatard *et al. (*2013) propose a comparison of these approaches and how they differentiate from - and might also strengthen and coexist with - agroecology. All aim to develop sustainable food systems that produce nutritious foods that meet the needs of consumers, that value culture and small-scale farms and that generate equitable benefits throughout value chains. However, some are based on primarily on principles that should be respected (e.g. agroecology) whilst others focus on meeting certain objectives (e.g. climate-smart agriculture).

While critics maintain that such approaches, while perhaps worthy, won't feed the world a recent Opinion Piece in the New York Times reports on a number of large-scale on-going investments as evidence that agroecology is becoming mainstream.[15] This includes investments of USD 2.3 billion of public funds in Andra Pradesh, India, over the next five years to convert six million farmers to "zero-budget natural farming" (farming that does not rely on credit or purchased inputs) and USD 1 billion to French farmers to adopt agroecology by 2025.

As summarised in Table 1, all of the FAO elements of agroecology are applicable to aquaculture and that aquaculture can be incorporated into many agriculture systems to help strengthen agroecological elements. But how prevalent is agroecology in aquaculture? It is difficult to say but probably the majority of aquaculture production addresses at least some elements, although little of present-day production subscribes to more than a handful. As highlighted by Edwards (elsewhere, this volume) traditional types of aquaculture, practiced in Asia for centuries, embodied many of the agroecology elements that FAO promotes. However, prevailing economic drivers – rising costs of land and labour, affordability of feed,

[15] The full article is available at www.nytimes.com/2018/06/26/opinion/farming-organic-nature-movement.html

cheap energy - have been steering farmers towards aquaculture monocultures and intensive production methods to increase profits per unit land use.

While there is no doubt that the application of agroecological elements in aquaculture can improve sustainability, a number of issues must be addressed if it is to be mainstreamed in the sector. Foremost is the question of whether agroecological practices can be readily adopted without compromising on profits. There needs to be the kind of concerted effort seen in agroecology to implement coordinated, large-scale and scientifically robust trials to determine impacts of agroecological practices on key sustainability indicators. Stakeholders must assume ownership of the process to ensure that technologies meet their needs, that there is an equitable sharing of risks and benefits throughout value chains, and to ensure rapid and sustained uptake of innovations. Agroecological aquaculture must also prove attractive to youth, increasingly disenfranchised from much of present-day food production (FAO, 2014). Novel, more technological approaches to aquaculture, such as RAS, periphyton-based aquaculture, aquaponics, IMTA, integrated mangrove-shrimp culture, may prove more attractive to youth. Finally, environmental services need to be fully costed in food production systems and the system of subsidies changed to reflect this. Only then will policy makers consider changing policies and governance to promote an agroecological approach.

Aquaculture practitioners often view the world from an aquaculture-centric perspective. However, governments, whose primary mandate is to ensure the health and welfare of its people, must take a broader perspective. Growing awareness of the potential of the Blue Economy and Blue Growth (FAO, 2018c) to provide a range of economic, social and environmental benefits is beginning to influence the development of coherent policies across sectors and may help foster an enabling environment for agroecological approaches to aquaculture. For example, in Ireland farmed Atlantic salmon production has fallen substantially in recent decades. The national strategic plan for sustainable aquaculture has ambitions to grow cage farming of Atlantic salmon, but rather than trying to compete on price with much larger producing countries, it is being encouraged to conform to the country's ambitions to be one of the most important producers of high quality, organic foods in the European Union and complement tourism.[16] It thus seeks to encourage the development of small, sensitively sited, family-owned organic salmon farming and seafood processing businesses, embodying many of the principles of agroecology. Tourists undertaking the Wild Atlantic Way are encouraged to engage with artisanal aquaculture producers – seaweed, oysters, mussels and salmon - as part of the experience.[17] Other European Union national aquaculture plans show similar integration within a Blue Economy framework and include agroecological elements.

Guidance is required to support policy makers in developing the aquaculture sector in their countries. The Ecosystem Approach to Aquaculture (EAA), developed in 2008 to promote '…integration of aquaculture within the wider ecosystem such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems' (FAO, 2010; Brugère *et al.*, 2018), provides a highly relevant framework on which to build cohesive guidance on an agroecological approach to aquaculture.

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[16] For more information www.agriculture.gov.ie/media/migration/seafood/marineagenciesandprogrammes/nspa/NationalStrategicPlanSusAquaDevel181215.pdf

[17] For more information: www.ireland.com/en-gb/

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Table 1: FAO elements of agroecology and their applicability to aquaculture. Modified from the FAO website on agroecology (**www.fao.org/agroecology/knowledge/10-elements/en/**)

Elements	Description	Applicability to aquaculture
Diversity	Diversification is key to agroecological transitions to ensure food security and nutrition while conserving, protecting and enhancing natural resources	Diversification of on-farm agriculture production by culturing fish, such as tilapias, carps, and catfish, freshwater giant prawn, molluscs, aquatic plants. Applicable farm to landscape scale.
Co-creation and sharing of knowledge	Agricultural innovations respond better to local challenges when they are co-created through participatory processes	Highly applicable. Co-development and sharing of aquaculture technologies that meet the needs of farmers, communities and wider society.
Synergies	Building synergies enhances key functions across food systems, supporting production and multiple ecosystem services	Aquaculture can be designed to generate (e.g. provision of nutrients) and enhance ecosystem services (e.g. provision of water in farm ponds) as well as consume them.
Efficiency	Innovative agroecological practices produce more using less external resources	Some types of aquaculture can utilise agricultural wastes (chicken manure, rice bran) as direct/indirect sources of feeds; aquaculture wastewater can be used to grow salad and other crops in aquaponic systems.
Recycling	More recycling means agricultural production with lower economic and environmental costs	Aquaculture can be incorporated into farming systems to utilise wastes from crop and livestock production or to supply nutrient enriched wastewater for irrigation (e.g. desert aquaculture, Egypt)
Resilience	Enhanced resilience of people, communities and ecosystems is key to sustainable food and agricultural systems	Diversification of agriculture systems to include aquaculture can help build resilience of people, communities and ecosystems to external shocks, including climate change.
Human and social values	Protecting and improving rural livelihoods, equity and social well-being is essential for sustainable food and agricultural systems	Development of aquaculture sector strategies and implementation plans should be co-developed with stakeholders, thereby ensuring these elements are comprehensively addressed (e.g. FAO strategic national plans, Africa).
Culture and food traditions	By supporting healthy, diversified and culturally appropriate diets, agroecology contributes to food security and nutrition while maintaining the health of ecosystems	While aquaculture produce can play a role in a healthy and diverse diet, production in any location tends to be reliant on a relatively small number of species, often exotic. However, interventions can and are being made to focus on farming of indigenous species.
Responsible governance	Sustainable food and agriculture requires responsible and effective governance mechanisms at different scales – from local to national to global	The same arguments apply to the sustainable development of aquaculture.
Circular and solidarity governance	Circular and solidarity economies that reconnect producers and consumers provide innovative solutions for living within our planetary boundaries while ensuring the social foundation for inclusive and sustainable development	The same arguments are equally valid in an aquaculture context.

CURRENT PRACTICES AND FUTURE PROSPECTS FOR INTEGRATED AGRICULTURE AND AQUACULTURE IN ASIA - A REGIONAL REVIEW

Derun Yuan, Peter Edwards, Matthias Halwart

Abstract

Conventional intensive aquaculture has often been associated with low efficiency of resource utilization and negative environmental impacts. Competition with other food production sectors for water, land and other resources poses the question as whether it can continue to sustain an aquaculture growth rate about 6 percent as it has done in the past three decades. Integrated agriculture and aquaculture (IAA), an old farming practice fast evolving and diversifying in the past three decades, with agroecological approaches that have a number of system merits is expected to be a renewed growth point of aquaculture, to contribute to food security and nutrition for the world growing population in facing resource scarcity, environmental pressure and impacts of climate change. This paper is a general overview of the major IAA systems in several Asian countries today - status, some details of current practices, and development trends. The prospects for future development, including opportunities and constraints are outlined. IAA in Asia displays an amazing diversity in terms of farming activities, system components, operation intensity, and species cultured, and shows potential in increasing productivity and improvement of profitability. Well-configured IAA is able to provide system alternatives to conventional intensive monoculture with possible better ecological efficiency and environmental integrity. IAA continues to be relevant to poverty alleviation, rural nutrition and improvement of farming productivity and probably profitability of resource-poor small-scale farms. IAA should be further researched, fine-tuned, and promoted as an important production strategy for world food supply.

1. Introduction

Aquaculture has been growing steadily in the past three decades with an average annual growth rate of about 8 percent from 1985 to 2016 and 5.8 percent from 2001 to 2016. [18] The global fish production reached 80.0 million tons in 2016, providing over half of the world's fish consumed (FAO, 2018).[19] In the context of the need to increase food fish production one cannot ignore the contribution that aquaculture *per se* has made to this end.

The continuing increase of production has been fuelled, to a large extent, by the expansion of the pellet-fed intensive aquaculture and an increase of farming area. However, the question has often been asked as to whether intensive aquaculture that requires and competes for limited natural resources such as land and water, can continue to sustain an annual growth rate of 6 percent as it has done in the past two decades. In addition, various intensive forms of aquaculture have been frequently questioned for their ecological efficiency due to inefficient food conversion by often mono-cultured organisms, resulting in waste of otherwise valuable nutrients and causing undesirable environmental impacts at the local and global levels, with the degradation of some important ecosystem services. Competition for natural resources such as land and water has also been a factor that induced social conflicts between users, corrupting social harmony in farming communities.

In the wake of the population growth and increase of fish consumption in human diets, there has been increasing realisation and acknowledgement of the importance of food fish as a source of nutrition and its role in food security at large (Committee on World Food Security, 2014; Béné *et al.*, 2015). There was also an associated call for increasing food fish production to minimise the widening gap between

[18] The actual annual growth rates are adjusted with the annual production increments and averaged over the years.
[19] The amount excludes the production of aquatic mammals, crocodiles, alligators, caimans, seaweeds and other aquatic plants.

supply and demand. It is expected that an additional 27 million tonnes of fish will be needed by 2030 (FAO, 2016).

Integrated agriculture-aquaculture (IAA) is a traditional and widespread practice in Asia, with its ecological advantages and social-economic importance. In an IAA farming system, the agriculture and aquaculture components often mutually benefit from each other, and utilize nutrients more efficiently than the agriculture and aquaculture alone with similar resource inputs and operation intensity. The ecological merits of a typical IAA practice may include one or many of the followings:

- biological pest/weed control;
- nutrient resuspension/recycling by aquatic animals benefiting crop production such as the case in rice-fish culture;
- removal and harvest of waste nutrients from aquaculture by plants;
- use of wastes from feedlots/poultry houses as fertilizers to sustain fish growth in semi-intensive aquaculture ponds;
- multiple uses of water and land, better system stability and resilience, and less negative environmental impacts.

Most traditional IAA systems are semi-intensive, demand low intensity of feed/nutrient inputs, and consume no or little unrenewable energy, and therefore have less greenhouse gas emission and ecological footprint. Traditional IAA in Asia has been developed and disseminated by farmers and local communities. It is highly contextualized according to locally available resources and social-economic settings, playing important roles in rural livelihoods, food security, human nutrition, and development of rural economy.

Considerable research and development has elucidated the scientific basis of IAA. Many new innovative IAA technologies and systems have been recently developed and practiced, which have shown great potential to improve sustainability of aquaculture. IAA continues to dominate production in Asia although science/industrial-based aquaculture technology using agro-industrially formulated feed is expanding rapidly, both geographically and in production. It is expected that IAA, potentially a more resilient food production system than monoculture, will be a renewed growth point of aquaculture, contribute to food security and nutrition for growing world population in facing resource scarcity, environmental pressure and impacts of climate change.

Agroecology is one of the new approaches to revisit aquaculture-agriculture integration. It consists of applying ecological concepts and principles in order to optimize interactions between plants, animals, humans and the environment, as well as social aspects. By creating synergies, agroecology contributes not only to food production, food security and nutrition, but also to the restoration of ecosystem services and biodiversity, which are essential for sustainable agriculture. It can play an important role in building resilience and adapting to climate change.

2. Scope of the regional review

This is a general overview of the major IAA systems in several Asian countries today - status, some details of current practices, and development trends. It should be noted that the types and extent of the diverse IAA systems in Asia are not recorded in official national or FAO statistics. Segregated production data on IAA, if they are available, are not readily accessible. Information on the technical specifications of some “emerging” systems has yet to be disseminated widely. Thus, the information is extracted from available published literatures, field experiences of authors, personal communication and internet. Some information still needs verification by national aquaculture personnel and field survey. The prospects for future development, including opportunities and constraints are outlined.

3. Definitions and characterization of IAA

Edwards (2019) defines integrated farming involving aquaculture as “aquaculture linked up with plant crop and/or livestock subsystems on a farm”. The linkage between two or more human activity systems (one or more of which may be aquaculture), can be either direct, with the activities linked on-site, or indirect through distant activities connected by transport, and with activities linked in terms of time either in parallel (at the same time) or sequentially (alternately, at different times).

The majority of IAA systems in Asia are extensive and semi-intensive. However, some recently emerging IAA systems can also be intensive in terms of aquaculture production.

Extensive systems depend on natural food produced within the system without nutritional inputs provided to aquaculture animals intentionally by humans. Natural food consists of some macrophytes, plankton suspended in the water column (bacterioplankton, phytoplankton and zooplankton) and benthos in sediments (insect larvae and adults, snails and worms) and is usually high in protein (50-70 percent dry matter). Extrapolated annual fish yields are usually less than 1 tonne/ha in extensive systems. Examples of extensive IAA are traditional rice/fish culture in China.

Semi-intensive systems depend on fertilization and/or on the addition of supplementary feed to complement high-protein natural food for cultured aquatic animals. Natural food is a source of minerals and vitamins and intentional fertilization aims to produce it in situ. Natural food provided in semi-intensive IAA systems is increased by organic fertilization with livestock or green manure (vegetation). There is also a residual fertilizer effect from uneaten fish feed and fish excretory products and faeces.

Traditional supplementary feeds are locally available plants and agricultural by-products, often with a low protein content that nutritionally complement high-protein natural food. The most common are rice bran, wheat bran, broken rice, and waste vegetables; volunteer (wild) or cultivated terrestrial vegetation e.g., grass and weeds; wild or cultivated aquatic macrophytes e.g. duckweed, water spinach and pond weed; agro-industrial by-products e.g. grain brans, broken rice and oil cakes; and also food processing wastes such as waste noodles and confectionary produce. Supplementary feed is traditionally fed as single ingredients, unprocessed and uncooked in pond culture in China and Southeast Asia although feeding practices in more recently developed aquaculture may involve mixed ingredients offered to fish in perforated sacs in some countries such as Bangladesh and India. Extrapolated annual fish yields range from 1-5 tonnes/ha for low-quality fertilizers and feeds, to 5-10 tonnes/ha for high-quality fertilizers (feedlot livestock manure).

Most IAA systems are semi-intensive e.g. rice/fish; crop/fish; livestock/fish. Those that use only on-farm inputs may be called direct IAA in contrast to those that use off-farm or local sources of vegetation, manures and agricultural by-products as nutritional inputs that are indirect IAA. Thus, some form of transportation is involved as inputs and production are not directly linked spatially. IAA are integrated with agriculture and animal husbandry because they provided the only sources of nutritional inputs for farmed aquatic organisms in the past, before the relatively recent manufacture of chemical fertilizers and formulated feed usually in pelleted form.

Intensive IAA systems are characterized by artificial feed input, often in the form of industrial manufactured, nutritionally complete pellets to primarily cultured aquatic animals. An example is the intensive culture of aquatic animals in earthen ponds integrated with production of a few secondary aquaculture species and aquatic plant/crop production in separate ponds in a recirculating system. In such a system, removal and reuse of nutrients from effluents of the intensive culture of the primary species are the major purpose of other farming activities/components. Other examples include aquaponics, intensive cage culture in earthen ponds, and some emerging systems such as in-pond raceway aquaculture, container-based aquaculture integrated with earthen ponds etc.

Table 1: System classification of IAA in Asia based on the production of the primary aquaculture component

Aquaculture facilities	Intensity of the primary aquaculture component		
	Extensive	Semi-intensive	Intensive
Open-water-based	Culture-based fisheries	Culture-based fisheries	
Trench/ditch-based	Fisheries in rice field	Integrated farming of rice and aquatic animals	
Pond-based		Livestock/fish integration Crop/fish integration Crop/aquaculture rotation	Earthen-pond-based integrated recirculating systems Crop/aquaculture rotation
Tank/raceway-based			Aquaponics Container-based integrated recirculating system In-pond raceway aquaculture system
Cage-based			Cage-in-pond integrated system Cage culture in agriculture irrigation system

4. IAA practices

Rice/fish culture

In a rice-fish culture system, a large area of rice field and a big volume of water provide essential living space and natural food for fish, which in turn, benefit rice production by suspending nutrients in soil into water column, reducing/eliminating weeds, controlling insects, loosening soil, and directly fertilizing rice field by fish excreta.

System description

There are mainly two ways: co-culture of fish and rice where fish and rice are concurrently raised together and fish-rice rotation by alternating fish and rice crops. Rice/fish co-culture is more popular. It however requires good coordination and management of field activities such as application of the pesticides, chemical fertilizers, irrigation and land drying process.

A trench or ditch is usually dug in the rice field with excavated soil used to strengthen and raise the height of the dike to hold more water for fish and prevent fish from escaping. The trenches or ditches are usually 50-60 cm deep, occupying anywhere from <1 to 10 percent of total rice field. A larger area of trenches may result in lower rice yield. A 1.0-1.5 m deep fish sump or pond may be constructed in the middle of the rice field. The trench provides deeper and cooler water in hot weather for fish and a refuge when the field is drained for weeding, pesticide application and harvesting rice. Water sources are screened to prevent loss of fish or entry of wild species. Traditional rice/fish culture is mostly extensive, with fish consuming natural food that develops in the rice field.

Commonly cultured fish are herbivorous/omnivorous species such as common carp (*Cyprinus carpio*), Chinese carps, Indian major carps, silver barb (*Barbonymus gonionotus*) and Nile tilapia (*Oreochromis niloticus*). Polyculture of multiple species of fish proves to be more effective in utilization of water space and nutritional niches. Extrapolated annual yields range from 100-250 kg/ha and to 1 tonne/ha or higher with supplementary feed if the trench is greater than 10 percent of the total area of the field. Rice yields are reported to increase by about 15 percent when fish are stocked, probably because farmers manage the water better. Fingerlings were traditionally nursed in rice fields in Indonesia. A rice-fish

system with large areas of trenches and fish sumps, and stocked with many fish e.g. one fish/m^2 needs intensive care, routine management and well-planned field activities.

Country Overviews

Bangladesh

Rice/fish culture was promoted as a technique for integrated pest management, as farmers who stocked fish in their rice fields reduced or eliminated the use of pesticides, but the extent of sustained adoption by farmers appeared to be limited (Nandeesha, 2004; Nabi, 2008).

Culture of high-value river prawn (*Macrobrachium rosenbergii*) has been developed recently in trenched rice fields with an abundant water supply in southwest Bangladesh. Post-larvae are nursed in trenches in rice fields and then are raised concurrently with rice as rains flood the field (Nandeesha, 2003; Ahmed *et al.*, 2013).

The feasibility of nursing common carp and Nile tilapia (*Oreochromis niloticus*) fry in irrigated rice fields in Northwest Bangladesh has been demonstrated and the practice has spread without further project support (Barman and Little, 2006; Haque *et al.*, 2010).

China

Culture of a red coloured variety of common carp in stream-fed terraced rice fields in mountainous Qingtian County, Zhejiang Province has a documented history of 1200 years (Edwards, 2006; Lu and Li, 2006; Hu *et al.*, 2016; Ren *et al.*, 2018). Fish production is low but the fish have a high market value, because of their special taste with local households and restaurants involved in the tourist industry (FAO, 2016). The system has been listed by FAO, UNDP and GEF as a "globally important indigenous agriculture heritage system". More widespread dissemination of the system appears unlikely because of its special situation as a localized tourist site.

Culture of high-value crustaceans has been developed recently in trenched rice fields. River prawns (*Macrobrachium nipponensis* and *M. rosenbergii*), Chinese mitten-handed crab (*Eriocheir sinensis*), and the red swamp crayfish (*Procambarus clarkii*) are also grown concurrently with rice in trenched rice fields (Fang, 2003; Miao, 2010). Rice field aquaculture is now reported to occur on a massive scale in China with over 1.5 million ha and fish production from paddy field over one million tonnes.

In 2017, China established a national standard (SCT 1135) on "Technical Specifications for Integrated Farming of Rice and Aquaculture Animals" which came into effect in January 2018 to standardize and regulate rice-fish culture. In the Part I: General Principles, it is stated that:

a) Rice yield: not lower than 7 500 kg per ha in low lying plains and not lower than average paddy yield in hilly areas;
b) Area ratio of ditches/fish refugee to paddy field: not over 10 percent;
c) Net income improvement: In comparison with rice cultivation alone in the same conditions, the net income in terms of per unit farming area is improved by 50 percent;
d) Reduction of use of fertilizers: In comparison with rice cultivation alone in the same conditions, use of fertilizers is reduced by 30 percent;
e) Reduction of use of agriculture chemicals: In comparison with rice cultivation alone in the same conditions, use of agriculture chemicals such as pesticides etc. is reduced by 30 percent;
f) Use of medicines for fish: no antibiotics and anti-parasitic medicines are allowed.

India

Rice/fish is being promoted for indigenous communities in northeast India (Sharma *et al.*, 2017).

Indonesia

Rice fields used to be a major source of fingerlings in Java, Indonesia but the practice of rice field nursing had declined significantly in Cianjur, a major nursing area. (Edwards, 2009a). It was reported that a nursery pond converted from a rice field would produce double the number of fingerlings. More

recently it has been reported that the Government of Indonesia has launched a "one million-hectare rice-fish programme" (FAO, 2015). Furthermore, a tilapia farming company, Regal Springs, paid local farmers to raise tilapia fingerlings in their rice fields for stocking in company cages installed in reservoirs (Seaman, 2014).

Viet Nam

Rice/fish culture in the mountains of Northern Viet Nam is a traditional practice (Le *et al.*, 1995) but it also occurs throughout the country today. Some farmers in the Mekong River Delta in southern Viet Nam culture low-value fish such as common carp, kissing gourami (*Helostoma temmincki*), rohu (*Labeo rohita*), silver carp (*Hypophthalmichthys molitrix*) and Nile tilapia concurrently with rice. Culture of high-value giant river prawn has developed recently in well watered trenched rice fields in southern Viet Nam; post-larvae are raised concurrently with rice and then in rotation after rice harvest as rains flood the field (Nguyen *et al.*, 2006).

Constraints

Although rice/fish farming has been promoted widely, the degree of sustainable adoption has been rather limited (Nandeesha, 2004; Nabi, 2008). Capture and culture of fish in rice fields have both diminished over recent decades.

The practice is constrained by intensification of rice culture: high yielding varieties of rice that require water level lower than 20 cm and have a shorter growing period than traditional rice varieties make it difficult for fish to attain marketable size. Increased use of pesticides is another risk factor affecting health of both fish and human consumers. Further constraints are theft of fish as rice fields are often considered as a common property resource and are difficult to guard due to their large size and location often distant from the farmer's dwelling. The culture of aquatic animals in rice fields is mostly not attractive to farmers in terms of return to labour. It requires considerable time and labour to modify rice fields for fish culture by digging trenches and raising the height of the surrounding dikes; and to maintain adequate water for the fish in the dry season as well as to prevent loss of the fish through flooding in the rainy season. Furthermore, rice/fish integration is likely to become even less prevalent with new rice technology promoting less water use in view of the diminishing availability of water (Uphoff, 2007).

The majority of fish ponds in Asia have been constructed from rice fields (Edwards, 2015). Some countries today have policies restricting rice field conversion because of concerns about the national food staple, rice, e.g. China. Rice-based aquaculture is considered as a low-cost and low-risk entry point for farmers to carry out aquaculture without jeopardizing the sustainability of rice production in China but some farmers have been reported to still abandon rice farming and convert their fields to ponds. Other countries are allowing farmers in some areas to diversify agricultural production as rice usually does not provide an adequate income e.g. Viet Nam. Thousands of hectares subject to flooding and able to produce only one rice crop annually have recently been converted to fish ponds in the Red River Delta, Viet Nam.

Future prospects

While there is a relatively low economic return on producing small fish in rice/fish systems, such fish may also provide an important source of animal protein, healthy fats, vitamins and minerals for poor farming households (Halwart, 2006). Consequently, there have been considerable efforts to promote rice/fish integration during recent decades, which should be continuously extended to small-scale farms wherever possible. It is an effective way to improve small-scale farming productivity with its flexible farming intensity, ready adoptability, and lower resource demand to entry.

There have been recent developments of intensification and diversification of rice-fish culture. Extensive operation has been evolving into more intensive culture characterized by better field layout and construction, more seed and feed inputs, and improved fish production. The systems have also diversified from a combination of rice and fish only to more complex integrated systems incorporating

the culture of other aquatic species, usually of high market value into rice fields in areas with an abundant water supply in Bangladesh, China and Viet Nam.

Pond-based IAA

Pond-based IAA systems (livestock/fish and/or crop/fish) have pond aquaculture as the major system components which either receive wastes and sub-products from other farming activities, for example, livestock production, to fertilize fish ponds for fish production, and/or recycle aquaculture pond nutrients and water back to support crop production.

Pond-based IAA systems probably originated in China, empirically developed through trial-and-error by farmers over centuries, and later spread to other countries in South East Asia. Similar traditional IAA systems that occurred in China probably spread more than a century ago to two other densely populated areas of Southeast Asian countries: West Java, Indonesia and the Red River Delta, Northern Viet Nam. IAA in other countries of South East Asia and South Asia, and regions of Indonesia and Central and Southern Viet Nam, probably developed less than a century ago.

There has been recent development to integrate crops and intensive culture of aquatic animals in earthen pond based recirculating systems. The system usually focus on intensive aquaculture with crop production as one of the measures to treat aquaculture effluents.

System description

(1) Livestock-fish integration

The most common example of IAA is the feedlot livestock/fish integrated farming that depends largely on manufactured formulated feed for the livestock: pig/fish, chicken/fish, duck/fish, and dairy cattle/fish integration (Little and Edwards, 1999, 2003). As the system is driven by off-farm formulated feed for the livestock, livestock production is intensive. Most of the food nutrients pass through the animal to provide high quality manure. The fertilized pond has high natural food production because of the nutrient-rich manure and it may also receive spilled livestock feed which further contributes to high fish production. Fish yields may be as high as 8-10 tonnes/ha/yr without any additional nutritional inputs.

Fish species in such system are mostly herbivores, omnivores and detritus feeders, such as carps and tilapia, which can use natural food produced by fertilization efficiently and are relatively tolerant to adverse pond environment and water quality such as Clarias catfish and Pangasius.

Feedlot livestock/fish is typical of suburban areas with access to agro-industrial products/by-products. Feedlot livestock/fish in rural areas is often associated with rice mills as the miller usually retains the rice bran which enables livestock to be raised in an intensive way.

A balance between livestock production and fish culture is crucial for a typical integrated livestock/fish farming system. Overloading wastes from livestock feedlots or poultry houses into fish ponds could result in water quality deterioration.

(2) Crop-fish integration

Fish ponds provide a source of water to irrigate crops, so cultivation of plants such as vegetables and fruit trees on pond dikes is widespread, mostly for human consumption. Plants, in particular old or damaged leaves, can be fed to herbivorous fish or used as green manure.

Purposefully growing green forage for fish is also practiced such as in grass/fish systems where grass produced from the dike crowns or slopes are either used for feeds or for compost making. The common grass varieties for this purpose in China are rye grass (*Lolium perenne*), Sudan grass (*Sorghum sudanense*), elephant grass (*Pennisetum purpureum*), *Astragalus sinicus,* Comfrey (*Symphytum peregrinum*), hybrid penisetum (*Pennisetum americanum* x *P. purpureum*), *Artemisia apiacea* and even green cabbages.

There is also practice to grow fish and crop/grass in rotation, i.e, plants (grass or other crops), for example, Barnyard grass (*Echinochloa crusgalli*) and ryegrass, are cultivated on pond bottoms upon the completion of the fish cycle. The plants improve pond soil conditions through absorbing excessive nutrients in pond sediments and can be used as feeds for fish in other ponds. The grass is submerged when reaching 30-50 cm high and decomposed as a green fertilizer to enrich pond water with natural food before fish are stocked for aquaculture cycle

(3) Earthen-pond-based recirculating integrated systems

Earthen-pond-based recirculating systems were probably developed initially for intensive shrimp culture to tackle the issues of excessive nutrient discharge from shrimp ponds. In such an integrated system, wastewater from shrimp ponds flows through sediment ponds, fish culture ponds (usually filter feeders are stocked such as tilapia, mullet, milkfish etc.), seaweed and shellfish ponds before recirculating back to shrimp ponds for reuse. The system was considered a better alternative to shrimp monoculture with improved nutrient utilization efficiency, and minimal environmental impacts. It has been successfully practiced at commercial scale for marine shrimp culture (Lin and Diana, 1995). Systems have been further developed for treatment and reuse of wastewater from intensive giant freshwater prawn ponds (Yuan and Yang, 2005), using filter feeding fish such as tilapia in combination with the cultivation of water mimosa (*Neptunia oleracea*). The advantage of such a system is its relative isolation from the surrounding environment, causing less pollution and less chance of introducing external pathogens and pollutants into culture ponds. Wastewater from intensive aquaculture ponds can stimulate the growth of plankton to support growth of filter-feeding fish and aquatic plants further absorb nutrients in water.

In China, a system has been developed to integrate pond fish culture with rice cultivation. The water discharged from aquaculture ponds enters an organic rice field and passes through the water distribution channels and catchment area in rice fields to purify. The water in rice field and the catchment can be recirculated back and reused in the aquaculture ponds. The system improves the overall profit by 20 percent, reduces the aquaculture water discharge by at least 60 percent and the pollutant discharge by at least 50 percent.

Country overviews

Bangladesh

Traditional polyculture of Indian major carps in Bangladesh was extensive but semi-intensive fish culture has been introduced through projects in the past three decades (ADB, 2005). Farmers attain extrapolated annual fish yields of 3-5 tonnes/ha in well-managed ponds, using on-farm and locally purchased manures, brans and oil cakes (ADB, 2005). Important introductions of exotic fish to the traditional polyculture of indigenous Indian major carps are grass carp, fed with on-farm vegetation such as grass, banana leaves and duckweed, and filter-feeding silver carp which grows rapidly in green water ponds and comprises a major part of the harvest.

Pond dikes are commonly used to raise fruit and vegetables (Ahmed, 2007; Edwards, 2007; Jahan *et al.*, 2015).

According to Hernandez *et al.* (2018), there has been a “quiet revolution” in the country’s aquaculture value chain, with a gradual shift from little use of any type of feed, to the use of on-farm feed resources such as cow manure and rice bran (direct integration), then to the purchase of the latter (indirect integration), and finally to the purchase of formulated pelleted feed without any integration. Poultry are sometimes raised on or near the pond.

China

Integrated farming has a long history in China where traditional family-level integrated farms were widespread in the Yangtze and Pearl River basins before the development of communes and collective agriculture in the 1950’s. There is a voluminous literature on IAA in China (NACA, 1989; Mathias, Charles and Hu, 1994; Symoens and Micha, 1994).

The traditional Chinese system of carp polyculture has several on-farm linkages. Fertilizers included human manure or night soil, livestock manure, mainly pig, vegetation or green manure for crops and pond, as well as pond mud for crops. Supplementary feed for fish was provided by using wild grass from the farm and its vicinity; and wastes from vegetables grown for humans and pigs. Mulberry used to be grown for leaves to feed silkworms and silkworm pupae were a traditional high-protein fish feed. Night soil and pig manure were used to fertilize rice, vegetables and fish pond in decreasing importance; feed requirements of pigs were met before feeding fish. Pond mud was used to fertilize terrestrial crops grown on pond dikes. Indeed, ponds fertilized with green manure and fed grass as green fodder for grass carp (*Ctenopharyngodon idella)* develop thick deposits of organic-rich sediments. Few on-farm resources were directly used for fish pond, due to intense competition from crops and pigs on resource-poor, small-scale farms. The main input to the pond was wild grass of low nutrient value, so extrapolated annual fish yields were low, probably only 1-2 tonnes/ha.

The most complex IAA were developed in China during the era of communes and they reached their peak of complexity in the 1980s with intensification through direct and indirect integration. Improved grasses such as elephant and rye grass were cultivated on pond dikes to feed grass carp. Nutrient flows were also greatly increased through manure from larger numbers of integrated livestock and transport of urban night soil as crop and pond fertilizers, harvest of wild aquatic feed organisms such aquatic macrophytes and snails from nearby lakes and use of wheat and rice bran, soybean and rapeseed cakes as well as chemical fertilizers and pelleted feed.

Carp production in China surged following the introduction of a market-driven economy in the mid-1980s because it was more profitable than terrestrial farming but production exceeded market demand with a decline in aquaculture profitability (Ye, 2002). Large-scale integrated farms became less integrated following privatization, with a reduction in the number of subsystems. Crops were eliminated except for grass used to feed the relatively high-value grass carp broodstock. Small-scale livestock integrated with aquaculture has been replaced by more efficient and profitable large-scale, industrial livestock farms; pond fertilization during grow-out has declined with increasing intensification, so less manure is required as the ponds already have excess nutrients from the residual fertilizer effects of feed (Miao and Liang, 2007; Miao and Yuan, 2007). The centuries-old integrated mulberry dike/pond system also disappeared from the Pearl River Delta, along with an increase in intensive monoculture of high-value fish, giant river prawn and soft shell turtle from the late 1980s (Yee, 1999).

There has also been a rapid increase in the use of commercial feed with more than 10 000 aqua-feed mills today in China (Zhang *et al.*, 2013). In the major Chinese carp farming areas, more than 95 percent of the farmers use manufactured feeds although some still used home-made feeds made from rice bran, soybean cake and wheat bran. However, some livestock/fish farms also do remain in China, particularly some small-scale duck/fish integration in Southern China.

India

The State of Andhra Pradesh is called the ‘fish bowl’ of India because it produces about 0.8 million tonnes of Indian major carps, mostly rohu and catla. Production is mainly an indirect IAA based on local off-farm by-products such as feedlot chicken manure as well as inorganic fertilizers, and brans and oil cakes as supplementary feeds (Ramakrishna, 2007; Edwards, 2008; Abraham *et al.*, 2010). Carp farmers are reluctant and cautious in using commercial pelleted feed as they remain to be convinced of the superior production and economic efficiency of pellets over traditional mash feed.

In a comparative study of farming practice in the two leading fish producing states of Andhra Pradesh and West Bengal a majority of the farmers in Andhra Pradesh were large-scale whereas in West Bengal farms were mostly small-scale integrated with duck rearing and horticulture (Abraham *et al.*, 2010).

Indonesia

A wide range of traditional integrated systems occur in West Java, Indonesia, both at small and large-scale (Edwards, 2009a). Feedlot livestock/fish integration (poultry/fish and small-scale goat/fish) is widespread. Giant gourami (*Osphronemus goramy*) is fed elephant ear plant (*Alocasia macrorrhizos*) leaves and water spinach (*Ipomoea aquatica*).

Myanmar

Rather curiously compared to other Asian countries, pond fertilization has not been a widespread practice in Burmese aquaculture (Belton *et al.*, 2015, 2017). It has been estimated that about 80 percent of Burmese aquaculture production is indirect integration based on off-farm rice bran and peanut cake, the remainder using pelleted feed. Feedlot livestock/fish integration has been present for several years on a small-scale but poultry/fish has expanded recently on indirect integrated, large-scale farms.

Philippines

There is limited IAA in the country with the most common freshwater fish, tilapia, being mostly pellet-fed (ADB, 2005).

Thailand

Feedlot livestock/fish farms are widespread: pig/fish, duck/fish, broiler chicken/fish and egg-laying chicken/fish. In Central Thailand where feedlot livestock/fish integration is common, most farmers began as livestock farmers and dug the pond initially for collecting soil to raise the land on which the livestock quarters can be constructed to minimize the risk of flooding. Recently, there has been a decline in feedlot/livestock IAA. Much of the tilapia, the major freshwater species farmed in the country today, is raised in ponds with indirect IAA, using feedlot chicken manure as fertilizer and rice bran as supplementary feed. There is also some small-scale integration of the herbivorous silver barb (*Barbonymus gonionotus*) with soft plants such as water spinach in rural areas.

Livestock are increasingly raised in monoculture, without integration with fish, in biosecure industrial scale farms. Following the outbreak of highly pathogenic avian influenza (HPA1), commonly known as bird flu, concerns about biosecurity to minimize risk of animal and human disease reduced the integration of broiler poultry with pond aquaculture. Fish farmers were not allowed to purchase day old chicks to integrate with fish. The Thai government allowed the continued integration of egg-laying poultry with fish but the chicken houses had to be screened from contact with possible virus carrying wild birds.

Viet Nam

Traditional IAA occurs in the country and especially in the River Delta where it has a long history. The Red River delta in Northern Viet Nam, one of the most densely populated areas in the world with over 1000 people per km^2, has a traditional small-scale integrated farming system known locally as VAC in which a polyculture of carps is raised in household-level ponds in association with livestock and crops (Luu *et al.*, 2002). VAC is an acronym for the Vietnamese words for garden (vuon), pond (ao) and livestock quarters (chuong). There are diverse linkages between VAC sub-systems, which vary with agro-ecological zone.

Livestock quarters for pigs and poultry are constructed adjacent to, or near, the pond so that washings and urine may be flushed or drained into the pond. Most households keep one to several pigs, and small herds of scavenging chickens or ducks, which may be caged at night. There may be a garden and/or an orchard. Annual and perennial crops are grown to provide year-round food for the household as well as to produce for market. Vegetables include cabbage, onion, sweet potato, tomato and water spinach. Fruit includes banana, litchi, longan, orange, papaya and peach. Pond water is used to irrigate crops. Leaves of vegetables are used to feed herbivorous fish or as green manure for the pond. Grass and other wild vegetation and chopped banana trunks are also used to feed herbivorous grass carp. Pond silt is removed annually to fertilize fruit trees and/or to provide a nutrient-rich layer of soil to cultivate vegetables. Extrapolated fish yields are 3-4 tonnes/ha in the 700-1 000 m^2 ponds.

As the traditional VAC system has fairly low yields, farmers now practice improved VAC with diversification of fish species such as Nile tilapia and use of pelleted feed to supplement the traditional pond inputs. However, pelleted feed is mainly used to fatten fish towards the end of grow-out culture, as it would not be profitable to use it throughout the growth period. Wide dikes created by pond excavation above the usual flood line are covered with vegetables and fruit trees. Some farmers grow high-value ornamental plants on pond dikes for sale.

The importance of VAC has long been recognized for household food security and increasingly as a source of income, as the rice-based economy is diversifying. Viet Nam has a policy of agricultural diversification because rice farming does not provide an adequate household income for small-scale farmers and the government now allows conversion of poor quality land, such as low-lying rice fields subject to flooding on which agriculture was not profitable, into fish ponds.

More recently feedlot livestock have become commonly raised, especially meat ducks, on small fenced areas of the pond and on the dikes.

Dike cropping of vegetables is also widespread in the Mekong delta (Nhan *et al.*, 2007). Giant gourami is raised in the Mekong Delta, integrated with crop production as feed for the herbivorous fish.

Constraints

(1) Issues in adoption of livestock-fish integration by small-scale farmers

Most livestock/fish integration depends on manufactured formulated feed for the livestock so it is an intensive practice for livestock although ponds are fertilized with manure. The practice is in decline in most countries as livestock farms are increasingly run as separate, highly specialized enterprises. Chicken manure is now often only available from large industrial-scale farms in Thailand, with indirect integration with aquaculture (Thongrod, 2007). Some livestock/fish farms remain in China, particularly the small-scale duck/fish integration and the practice has recently expanded in Myanmar and Viet Nam.

The limited fish production of IAA with limited on-farm resources is attractive only to the poorest households in remote areas, with limited access to alternative income generations. Attempts to introduce feedlot livestock to increase small-scale farm fish production have usually been unsuccessful, mostly due to marketing issues including competition with large-scale farms.

IAA has developed to varying degrees in recent decades in many countries, especially in South and Southeast Asia. Livestock such as pigs and poultry usually scavenge for their food on small-scale farms so it is difficult and labour intensive to collect manure for aquaculture. If they are confined or housed to permit manure collection then they have to be fed with feed manually collected or purchased. Large ruminants e.g. buffalo and cattle are penned/corralled at night near the house to prevent theft so it is possible to collect manure. However, scavenging ruminant manure is a poor fertilizer. It may also be possible to collect some manure of scavenging poultry when they are confined at night and given supplementary feed. Small-scale ponds may be fertilized with livestock manure but there are constraints to reuse the manure in ponds: labour is intensive to collect and apply if the livestock are not located adjacent to or over the pond, alternative use for crops, and pond may be used for domestic water supply. There may also be insufficient in quantity as most farms are resource-poor and there are often alternative/competitive uses as crop fertilizers or as fuel in the Indian sub-continent.

(2) Bird flu in poultry/fish integrated systems

Concerns about biosecurity to minimize the risk of animal and human disease have recently limited the integration of poultry with pond aquaculture. There is no evidence that poultry/fish integration has ever been involved in any outbreak of highly pathogenic avian influenza (HPA1), commonly known as bird flu. However, contract farming companies in Central Thailand stopped providing day-old chicks to broiler farmers operating open systems, including those integrated with fish ponds, after the 2003/2004 bird flu outbreak (Edwards and Mohan, 2007). Broiler farming is exclusively done on a contract basis with large companies providing day-old chicks and feed, and buying back birds at harvest, mostly for export. Only layer farms have been able to continue integration with fish in Central Thailand provided they follow the government regulation to screen the poultry house from wild birds and eggs are sold on the local market.

(3) Issues with crop-fish integration

Crop-fish integration is labour and land intensive i.e. the ratio of land:fish pond ranges from 1-2:1. It is also labour intensive to collect wild vegetation. The food conversion ratio of vegetation is high meaning that the feed conversion efficiency is low as plants are mostly made of water with only about 20 percent

dry matter. There may also be anti-nutritional chemicals in plants. Pond mud may be removed once the pond becomes shallow to fertilize dike crops but this is also labour intensive and seldom carried out, especially in the humid tropics.

(4) Issues concerning earthen-pond-based recirculating systems

This type of system is superior to intensive monoculture in terms of ecological efficiency and environmental friendliness. However, more land is needed to build secondary fish ponds and/or plant growing areas, which entails a much lower economic return than monoculture per unit area of land. This is the major constraint that hampers adoption of the IAA system.

Future prospects

(1) Poverty alleviation

Although there has been a decline in medium to large-scale IAA with the intensification of aquaculture and the increasing involvement of entrepreneurs to benefit from the profitability of aquaculture, there remains a role for IAA to help alleviate poverty for small-scale farming households. Recent studies have indicated that poor households received many benefits from fish production in Bangladesh (ADB, 2005; Little *et al.*, 2007; Pant *et al.*, 2014), Nepal (Farquhar *et al.*, 2019); Pant *et al.*, 2014), Philippines (ADB, 2005) and Thailand (ADB, 2005).

(2) Increase of productivity and profitability of small-scale farms

In many developing countries, the majority of farms are small-scale, dominant in numbers and arguably in farming area. Increase of productivity in small-scale farms is important and a solution to many of the issues we are facing today such as poverty and food security. It is however a major challenge to increase the productivity and profitability of small-scale farms. As a generalization, the profile of a typical Asian farm is: small farm area; crop dominated, usually rice; and livestock, 1-2 draught animals and a few scavenging pigs and/or poultry. Most small-scale farms have a poor on-farm resource base and therefore limited inputs and limited outputs (fish production), with most agriculture/aquaculture products being consumed by the household for subsistence (Edwards 2009b). In most of the tropics, fish yields of small-scale farms are usually low due to: limited indigenous technical knowledge, stocking of small fingerlings which may be predated by carnivorous fish, limited nutritional inputs so that surviving fish may not grow, and fish ponds constructed in infertile soils which may remain turbid due to suspended clay. When the water eventually clears and light penetrates to the pond bottom, the pond may become a ‘weed filled hole’ i.e., become infested with emergent aquatic macrophytes, with little to no space for fish and subsequent abandonment by the farmers. Small-scale farmers on nutrient-poor farms who aim to develop aquaculture as a major occupation need to import nutrients from off-farm to intensify production. This invariably leads to specialization with a reduction of farm subsystems or enterprises and on-farm integration.

Aquaculture intensification is essential in most cases to meet basic needs and to satisfy growing aspirations for a better life because of the declining size of farms. It is usually necessary to increase the input of off-farm nutrients, as there are limits to the export of nutrients from the farm through fish products. There must be a significant increase in nutrients to permit a significant increase in production (Edwards 1998). Semi-intensive aquaculture based on indirect integration with inputs sourced locally from off-farm (fertilizer, usually poultry manure; and supplementary feed, usually rice bran and oil cakes) would lead to considerable increased fish production and it has a huge potential for expansion as exemplified by recent experiences in South Asia (Bangladesh and India) and Southeast Asia, particularly Thailand.

(3) Earthen-pond-based integrated recirculating systems as system alternatives to intensive monoculture

Earthen-pond-based integrated recirculating systems could potentially be solutions for biological treatment of effluents and improvement of overall nutrient utilization of conventional intensive monoculture. It is not cost-effective (probably in most cases) to treat relatively dilute pond effluents by

conventional sewage treatment technology (Boyd *et al.*, 2007; Cripps and Kelly, 1996) and this kind of recirculating systems are especially relevant. Biological floating vegetation beds may also be introduced into the system to improve water treatment efficiency

Tank/Raceway-based IAA

System description

The aquaculture of primary species are carried out in tanks, modified shipping containers, or raceways and are integrated with other farming activities such as vegetable/fruit production in hydroponic systems, or pond culture of secondary aquaculture species and/or crop production.

(1) Aquaponics

Aquaponics, the integration of aquaculture with hydroponics (the cultivation of vegetables without soil) has been run on a pilot scale since the mid-1970s. The best known is a commercial-scale system run as a prototype at the University of the Virgin Islands (UVI) (Rakocy and Bailey, 2003; Rakocy *et al.*, 2006). Tilapia are reared in tanks, fed with pelleted feed and the effluents are used to fertilize vegetables such as basil, lettuce and okra kept on floating sheets of polystyrene in hydroponic tanks. The system occupies 500 m^2 of land and can produce 4.2-4.8 tonnes of tilapia and 5 tonnes of basil, 2.9 tonnes of okra or 1 400 cases (24-30 heads per case) of leaf lettuce annually. The immediate potential is for premium markets in which consumers are willing to pay a higher price for high-quality fish and vegetables, so there are limited climatic and market niches. It is unlikely that aquaponics will ever contribute significantly to global fish production because it is technically sophisticated with high capital and operating costs and requires skilled technical personnel for management. It also has high energy inputs with high greenhouse gas (GHG) emissions per unit of production.

There has been a recent explosion of Research and Development in aquaponics. Farms based on the UVI design have been constructed and perform well at temperate sites in Australia, Canada and the United States of America and in the tropics in India, Indonesia, Mexico and Thailand (J.E. Rakocy, personal communication).

(2) Container-based IAA

Container-based IAA has been developed recently in China. It integrates intensive fish culture in modified ship-containers and earthen pond culture of fish and aquatic plants. A standard container has a water holding capacity of 23-25 m^3, where fish can be stocked at the density of about 2000 - 5 000 pieces per container depending on species and harvestable size. Fish are fed with commercial pellets, sufficient aeration and water quality is monitored in real time. Water from the container flows through a solid separation compartment before entering earthen ponds where filter feeding fish such as carps or tilapia are grown, water can further pass through vegetation area for further nutrient removal before recirculating back to the fish culture container. The ratio of containers to earthen pond ranges from one container to 500 - 1 000 m^2. Solid waste collected is usually used as a fertilizer for growing vegetables. Species cultured on a trial basis include tilapia, snakehead, large-mouth bass etc. for both advanced nursing and grow-out purpose. Fish production in the containers ranges from one to three tonnes per container.

(3) In-pond raceway aquaculture system (IPRS)

Developed at the Auburn University with the investment from the U.S. soybean checkoff program, the In-Pond Raceway System (IPRS) creates a healthier environment with a riverine flow for fish and shrimp in pond raceways while greatly reducing the environmental impact. The system protects water quality by removing waste and recycling it for other uses, such as biodiesel and fertilizer. The pond water can be reused, leading to significant conservation of limited water resources. The technology is being rapidly adopted in China and throughout Southeast Asia. [20]

[20] For more information: www.soyaqua.org/technology/in-pond-raceway-system

Raceways usually occupy 1.5-2 percent of the total area and species cultured in IPRS in China include grass carp, black carp, common carp, crucian carp, largemouth bass, channel catfish, tilapia etc. The production in raceways can be as high as 80-150 kg/m^3, and the survival rate of fish can reach 95 percent.

Omnivorous fish are stocked in the pond and it should be feasible to integrate crop production into the pond such as growing vegetables, or to incorporate the concept of constructed wetland.

Constraints

A tank/raceway-based system needs relatively high capital outlay to set-up and run. In addition, the technologies are relatively complex and there are intensive requirements for managing processes. Small-scale farmers may have difficulties to start up and operate.

Future prospects

In a tank/raceway based system the primary cultured aquatic animals are confined in a relatively small space/culture unit with high stocking density to maintain a high level of aquaculture production while more land area can be used for water treatment, growing secondary aquaculture species and/or crop production. Small culture units for the primary species provide convenience for intensive management and integration of technologies such as smart control of farming process and automation. Tanks/containers/raceways can also be easily transported to different locations and are relatively flexible to fit into site conditions. For conventional intensive culture without proper effluent treatment, tank/raceway based systems are feasible alternatives that are more ecologically and environmentally friendly.

Aquaponics can be flexible in terms of scale, physical set-up, mobility, choices for fish and crops. An aquaponics system has considerably efficient use of water and nutrients, which is greatly relevant to aquaculture and vegetable production in places where freshwater is too scarce to support conventional aquaculture. Aquaponics also serves as a unique household food production activity in urban areas where land is expensive and space is limited.

Cage-based IAA

(1) Cage/crop integration

Small-scale cage farming occurs in Northern Viet Nam with grass and maize leaves used to raise grass carp. The system was probably introduced from Southern China where it was also reported. Grass and maize may be purposefully grown for this, but supply of industrial feed has become essential for production efficiency.

(2) Cage-in-pond integration

In the integrated cage-cum-pond culture system, high-valued fish species are fed with artificial diets in cages, and filter-feeding fish species are stocked to utilize natural foods derived from cage wastes. This integrated system has been developed and practiced using combinations of catfish-tilapia (Lin 1990, Lin and Diana 1995) and tilapia-tilapia (Yi el al. 1996, Yi 1997, Yi and Lin 2000 and 2001) at the Asian Institute of Technology (AIT), Thailand, carp-stinging catfish (Wahab *et al.*, 2005) and climbing perch - carps (Asaduzzaman *et al.*, 2006) at the Bangladesh Agricultural University (BAU), Bangladesh.

The system has been extended in Bangladesh, Cambodia, China, Thailand and Viet Nam with various system configurations. Aquatic plants are occasionally used in the semi-intensive ponds for nutrient management in effluents.

(3) Cage culture in agriculture irrigation systems

There is also considerable potential to expand cage culture in under-utilized reservoirs, lakes and rivers although fluctuating water levels in reservoirs used for irrigation and hydropower generation can adversely affect aquaculture due to drawdowns. The culture of fish in cages in irrigation canals also requires a coordination between the water authorities that manage the system and fish farmers. There was a recent massive caged fish kill due to a water shortage in an irrigation canal in Thailand in 2012, after the irrigation authority drew down a reservoir to increase the storage capacity in the coming monsoon season to reduce the chance of floods; the authorities had been instructed by the government to lower the level of water in the reservoir before the monsoon season to avoid having to suddenly release large volumes of water when the reservoir filled up, one of the causes of the massive flooding that had occurred in the country in 2011. Cage aquaculture in irrigation canals is prohibited in some countries because of concerns that it may reduce water flow and increase sedimentation in the canal (Dugan *et al.*, 2007).

Agricultural water storage reservoirs are dual purpose water bodies as they are also stocked with fish in Israel (Hepher, 1985; Sarig, 1984) and more recently in Egypt where fish farms are prohibited from using water in irrigation canals (van der Heijden *et al.*, 2013).

There used to be massive operation of cage culture in lakes, reservoirs, rivers, water canals in China, which is now under strict scrutiny and regulations, and in most locations where cage culture was prosperous in the past, it is now prohibited in an effort to curb the environmental pollution, protect and restore natural ecosystems.

Integration of aquaculture and irrigation (open-water-based IAA)

More efficient use of water is a critical challenge in agriculture and aquaculture. This could be attained by integration of aquaculture with natural and constructed water bodies, many of which are used for irrigation. The productivity of water may be increased through the integration of aquaculture in irrigation systems (integrated irrigated aquaculture, IIA), essentially a non-consumptive activity with fish grown in the water on its way to or from agriculture (FAO, 2006). There are major reviews of the integration of aquaculture into small as well as large-scale engineered irrigation systems (Haylor, 1994; Murray *et al.*, 2002).

(1) Culture-based fisheries

Community or culture-based fisheries (CBF), usually conducted extensively in small water bodies, is an "underutilized opportunity in aquaculture development" (De Silva, 2003). CBF is a form of extensive aquaculture, ideally conducted in small water bodies that are incapable of sustaining a fishery of any scale through natural recruitment processes, but that adopts a stock and recapture strategy, suitably developed, and managed communally. CBF is a low-cost, environmentally friendly activity usually with seed stock being the only external input that engages rural communities. It requires limited technical expertise and or associated legislative changes. CBF aims at being an effective user of water resources for the secondary purpose of food fish production without negating and or negatively impacting on the primary use of water resources frequently is for downstream rice cultivation, and home garden cultivation. CBF often benefits rural communities, who tend to be relatively more impoverished compared to the urban counterparts, by bringing about additional income and also providing access to food fish, thus enhancing the nutrition of these communities. CBF is an easily adoptable strategy that could contribute significantly to increase food fish production in developing countries with inland waters.

Production of more fish from existing waters with minimal external feed inputs provides an important means to supplement conventional aquaculture practices. Aquaculture-based fisheries enhancements have been successfully implemented in more than 27 countries with an estimated production of 2 million tonnes of fisheries products (Bostock *et al.*, 2010).

Culture based fisheries involve community consultation and resource appraisal, research into water bodies for CBF feasibility, decision on stocking density and strategies, stock management and harvest, and benefit sharing among community members.

CBF is believed to have a great potential to increase fisheries production as it has been estimated that there are 67 million ha of small water bodies in Asia, constructed mainly for irrigation (De Silva, 2003). The promotion of CBF is likely to deliver more immediate yield increases than investment in technology as it is technically simpler than conventional aquaculture although there are usually complex technical, social and institutional issues regarding biodiversity, access to water bodies, social equity arrangements, and competition of water use to be addressed (De Silva *et al.*, 2006).

(2) Use of nutrients from aquaculture effluents to produce aquatic plants

In low-intensity pond culture effluent discharge is minimal, with little to no adverse environmental impact as significant amounts of wastes are treated by the pond ecosystem during the culture cycle (Bergheim and Asgard, 1996; Boyd *et al.*, 2007). But an increasing amount of waste is now discharged directly to the external environment, as a result of intensification of aquaculture production trend. It is not cost-effective to treat relatively dilute pond effluents by conventional sewage treatment technology (Boyd *et al.*, 2007; Cripps and Kelly, 1996). Pond effluent treatment options are to use effluents to irrigate crops, to treat effluents in constructed wetlands or settling basins, or to reduce or eliminate water exchange (Tucker *et al.*, 2008). It is land-intensive to treat effluents using constructed wetlands, settling basins or sedimentation ponds, as well as to fertilize semi-intensive fish ponds. Reuse of intensive fish pond effluents to fertilize adjacent terrestrial crops has been reported but is not widespread, in part because of limited opportunities for fish ponds to be located adjacent to terrestrial crops which could be fertilized.

A promising technology is to integrate aquatic macrophytes with aquaculture to take up nutrients from eutrophic water, either in fish ponds or in water bodies to which nutrient-rich pond effluents have been discharged. The role of fish in food security is well known but the considerable role that aquatic plants such as water spinach (*Ipomoea aquatica*) and water mimosa (*Neptunia oleracea*) play in food security is less well appreciated (Edwards, 2009b). Water spinach is inexpensive, provides high-quality protein, minerals and vitamins, and is easy to digest; all parts of the plant, the stem, leaves and especially the young apex, can be consumed.

Considerable quantities of edible aquatic plants are cultivated in Asia but their production and value are not recorded in the annual FAO statistics for aquaculture production, despite creating income and employment for a significant number of especially peri-urban households, and in many cases recycling and treating urban wastewater while producing a green and nutritious foodstuff consumed on a daily basis by millions of people (PAPUSSA, 2002). This is presumably because freshwater aquatic macrophytes “fall between two stools”, being neglected by agronomists as they are aquatic and not terrestrial plant crops and by aquaculturists, a zoologically-dominated profession.

Water spinach in Phnom Penh, Cambodia, is mostly grown in floating beds secured by stakes by poor communities on the surface of a lake close to where the main city sewage is discharged untreated into the lake, accounting for nearly half of the total sales of fresh vegetables in the city. Although poor households benefit from farming aquatic plants, aquatic vegetable growers are often affected by wastewater related skin conditions from daily contact with wastewater in the lake although research has indicated that well- cooked aquatic vegetables do not pose a health risk to consumers. As the low-lying natural water bodies around the city where aquatic plants are farmed are threatened by an expanding city and increasing numbers of factories and industries around the lake, the future livelihood of the people who live around and depend on the lake is uncertain.

Over 80 percent of the total production of water spinach in Thailand, estimated at almost 60 000 tonnes, is produced in the central plains around Bangkok. Most is produced in former rice fields with inorganic fertilizers, although a lot is still produced in eutrophic canals.

A manual for the cultivation of the four most commonly cultivated aquatic plants in and around four South East Asian cities (water spinach; water mimosa, *Neptunia oleracea*; water dropwort, *Oenanthe stolonifera*; and water cress, *Rorippa nasturtium-aquaticum*) has been published (PAPUSSA, 2002).

Water spinach has also been reported to have a good purifying effect when it covers 10 percent of a tilapia pond area in an integrated system combining intensive aquaculture with semi-intensive fish farming and a constructed wetland (Laszlo Varadi, personal communication). Beside the high water purifying efficiency, another advantage is the low running and maintenance costs. However, there are also disadvantages, such as the purifying efficiency that varies with the weather, the land requirement that is high, as is the investment cost.

5. Research and capacity building needs

Decades of research since the early 1950's in different countries and geographic locations has elucidated the scientific basis and ecological principles of IAA, and developed a number of successful farming models. However, social-economic contexts and resource settings are changing and IAA practices need to evolve to keep up with the changes.

Research and development of IAA need to address issues at both ends of the aquaculture development spectrum - to increase productivity and profitability of small-scale resource-poor farms and to improve sustainability of conventional intensive aquaculture.

Research on rural development contexts for IAA adoption: There is no doubt that IAA is one of the most effective approaches to improve efficiency of small-scale farming in resource poor rural communities and that it should be promoted. It is unlikely that there would be any significant scientific or technical obstacles in this regards and the effectiveness of extension and adoption of IAA is much dependent upon proper social economic intervention. Therefore research on social dynamics, economic conditions and resource settings of rural communities where poverty still prevails warrants a priority. This is a prerequisite for extension of any farming technologies, including IAA to small-scale farmers. Careful evaluation and modification of IAA models are needed to contextualize them and fit them into local conditions.

Research on IAA systems to improve aquaculture sustainability should include studies:

(1) To evaluate and document newly emerging IAA systems on their ecological efficiency, economic viability and adoptability in different geographic locations with different socio-economic and resource settings. Indigenous knowledge and farmers' innovations should be fully respected and studied;

(2) To test and develop new IAA systems using agroecological principles and applying efficient engineering approaches as system alternatives to current prevailing unsustainable practices of intensive aquaculture.

Research on integrated cluster/community-based farming with agro-ecological approaches and building of "agro-ecological communities/villages": A farming community with common shared resources such as irrigation systems, water supplies and drainage, public wetland etc. is treated as an agro-ecosystem, within which resource use, farming activities, and probably family livelihoods are optimized using agroecological approaches.

Promotion of IAA through training and education has been a constant effort by various international, regional and national organizations such as FAO, the Network of Aquaculture Centres in Asia (NACA), the Freshwater Fisheries Research Institute, Wuxi, China (FFRC), and the AIT in the past three decades. Thousands of professionals have been trained on IAA and they have been playing key roles in IAA research, extension and practices. Many training and extension programs on IAA have been carried out at national and local level. Integrated aquaculture is also a key subject and important part of curricula in aquaculture-related tertiary and vocational education all over the Asia. However it remains a major

concern that many small-scale farmers don't have readily access to technical know-hows. Capacity building for farmers and technical assistance require continuing effort.

6. Recommendations

(1) International communities, national governments, and development agencies should continue to encourage and promote IAA development for poverty alleviation, rural nutrition and food security through policy support, capacity building and strategic investment on research and development.

(2) For most resource-poor small-scale farms, adoption of indirect IAA by importing locally available off-farm inputs such as fertilizers (mostly in forms of manures) and supplementary feed such as rice bran, broken rice, oil cakes, agro-by-products is a feasible and may be an effective start to improve farm productivity.

(3) Rice-fish integration remains the extension priority in rice growing areas with relatively abundant water resource. Intensification and diversification are encouraged, wherever resources allow, to increase fish production and profitability.

(4) Conventional pellet-fed aquaculture needs to adapt to more ecologically efficient and environmentally friendly farming methods by applying the agroecological approaches of using less land/water for intensive fish production but more land/water for nutrient reuse and water treatment. The alternative systems include tank/raceway-based IAA, earthen-pond-based recirculating systems, cage-in-pond systems etc. Cost effectiveness however should be taken into consideration in the system shift.

(5) Some IAA systems may be improved to produce chemical free or organic products, e.g. rice/fish culture, aquaponics, integration of fish ponds and organic rice field etc.

(6) Aquaponics of various types are the rationale choices for fish and vegetable production in places where water is not enough to support conventional aquaculture. It may also be promoted as a food production activity in urban areas.

(7) National governments are encouraged to set up policy frameworks to facilitate culture-based fisheries development and adopt CBF as a strategy to increase fisheries production for rural communities, contributing to food security, environmental protection and resource conservation.

(8) Cage culture in irrigation may be promoted but with careful assessment of the carrying capacities of water bodies.

(9) International collaboration is needed in research, development, information sharing and human capacity building. Organizations like FAO, NACA and some leading national institutes are recommended to play the vital roles in networking, coordination and cooperation.

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THE SONGHAI RURAL GROWTH INITIATIVE: AN AGROECOLOGICAL AND SUSTAINABLE DEVELOPMENT ALTERNATIVE IN AFRICA

Fr Godfrey Nzamujo o.p.

Developing an agroecological literacy and systemic worldview and the corresponding authentic technologies and practices to build sustainable agricultural farming systems to leapfrog productivity.

1. The transition to integrated development systems

Why the systems approach?

For a long time we have taken the species, subspecies or some other biological blocks as separate units of development. But now, modern sciences among other sources, are providing us with fundamentally different and refreshing information on the frameworks and organizational patterns of our planet. It has become quite clear now that the unit of development and sustainability is not any of these entities. Though autonomous, they are not independent units and cannot survive alone. In other words, they are not units of survival and cannot constitute separate sustainable units.

What survives and what is sustainable is the organism or biological unit-in-its-environment. Any organism that works or is forced to work only in terms of its own survival will invariably destroy its environment and, as we are learning from bitter experience, will thus destroy itself.

From the systems point of view therefore, the unit of development or survival is not the entity (humans, animal, fish or crop) at all, but rather a pattern of organization, developed and adopted by any of these entities in its interaction with its environment. We believe that is it time to abandon the linear and mechanistic world view that shaped the present day agricultural and food systems and embrace a systemic worldview.

A close look at the major crises facing the world today (food insecurity/poverty, unemployment, environmental degradation, etc.), reveals that they are all connected and in fact inseparable - suggesting that our present crisis is fundamentally a systemic problem that requires a systemic, holistic and broad based approach.

Unfortunately most of the solutions we have seen so far seem to be piecemeal and symptomatic therapies that hardly work. This is because, we have been trying to solve systemic problems in a piecemeal manner. In the best cases, these solutions are simply band aid endeavors. In most cases however, they end up creating more problems. The dominant and conventional aquaculture system today is a good example of this crisis. But once a systems view has been embraced by our agriculturists, scientists, engineers, political and corporate leaders, we will see the emergence of radically different kinds of sustainable practices and enterprises.

The Songhai Initiative

Songhai believes that Africans in this 21st century have hit a point in history that calls for dynamics and orientations that are deeper and broader than previous attempts. Today's challenges require a radical shift not just in our vision of the world or our mentality and how we think, but in every sphere of our lives - from the way we see ourselves and relate to each other; from our relationship with the environment to our intellectual, scientific, technical and business orientations; from our production systems to the ways we exchange and consume our goods and services.

The Songhai program is built on the premix that agriculture, by its very nature is a systemic process and if it is done as it should be, could constitutes a radical and sustainable pathway to holistic solutions to our present day challenges. Some of the principles at play in this new paradigm are:

- synergy

- symbiosis
- complementarity
- collaboration
- supplementarity

We believe that the only sustainable pathway is how to harness these principles to invent and develop new and appropriate technological and developmental trajectories (Figure 1).

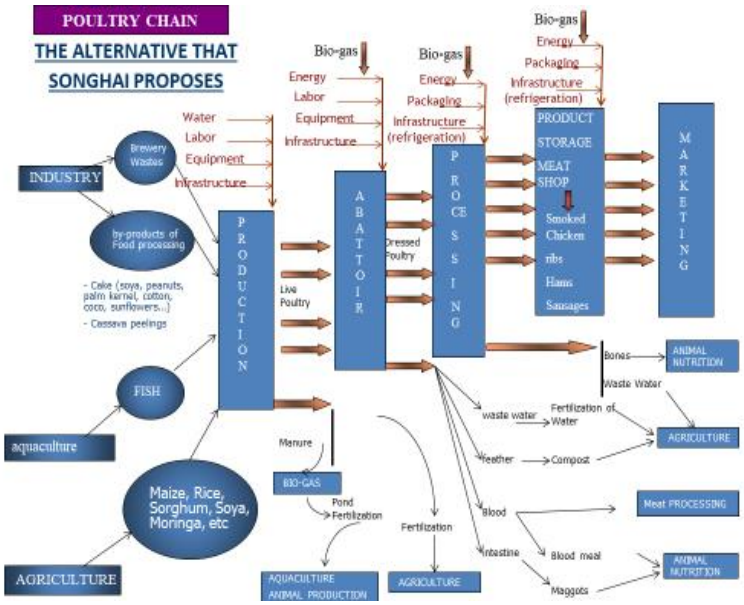


Figure 1: A system view of agriculture at Songhai.

We believe that from seeing our planet from this world view, we will be in a better position to design and re-engineer our way out of these crises. This new paradigm has to be appropriated and deployed if we are really committed to creating designing and inventing organizations, industries, economic activities that would solve our present day problems.

The Songhai initiative is basically the harnessing of the principles of the systemic world view to build agro-ecological, sustainable and broad-based development programs in Africa. It is an integrated development system that organically create dynamic linkages and synergies within agriculture (livestock, fish and crops) and between agriculture, industry and services.

Biomimicry

This approach is far from the conventional agriculture which is primarily a bio-chemical interventionist approach. We start by first learning and understanding the biological process of nature and then our agricultural practices and technologies will be essentially alignment of our designs and actions to these processes to enhance productivity. This is biomimicry and it is the only way that our incredible environmental and biological capitals can be sustainably deployed and harnessed. The resultant efficiency is mainly because this system enables different life cycles or metabolic networks involved to operate in a systemic, synergetic and efficient manner. We call it "*Dancing with Nature*"

2. An agroecological perspective of aquaculture at Songhai

Songhai

Songhai as an innovative institution has five components to deliver its mission.

- It is an agroecological literacy and cultural reorientation center where the new and emerging world view, new ideas and the corresponding organisational and social values are developed and inculcated in the youths and future farmers.
- It is a technology park, where new techniques aligned with the new worldview are developed and contextualized.
- It is an industrial park and production centre, where techniques and ideas are turned into enterprises and into different types of production activities in an integrated manner.
- It is an incubation/training/human resource development centre- an effective incubation space where new competences are developed. Here, the trainees are equipped with the new vision and culture (systemic world view- component 1), new techniques and methods developed and deployed at the centres (Technology parks component2) and new practices/farming systems (Component 3) to enable them to become more productive and efficient. By participating in production activities, the trainees, facilitated by mentors who are practitioners themselves, develop organizational and managerial competences to enable them to become functional individuals and entrepreneurs.
- The large number of youths (especially former and potential migrants) seeking for enrolment at the various Songhai centers is not only a sign that this initiative is making agriculture attractive to the youths, but that it is also helping to reverse the massive rural exodus and illegal and hearth breaking immigration crisis that is taking place in Africa today; and
- It is a service centre. After training, the job is far from over. Trainees need to be leveraged with services such as marketing, input procurement, hospitality services, networking, financial/loan and advisory services to enable them to stand on their own and create synergy and cooperation among themselves.

The Songhai Integrated system of production

In the Songhai Integrated system of production, the aquaculture program is seen as one of the key metabolic networks in harnessing the incredible environmental capitals (matter, diverse genetic resources and energy) in the African water bodies (Figures 2 and 3).

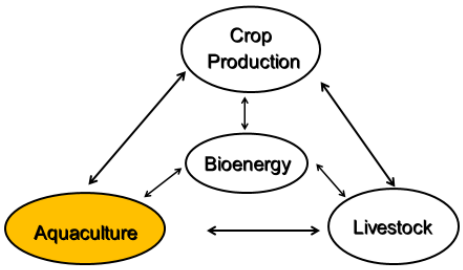


Figure 2: Integrated production system in Songhai

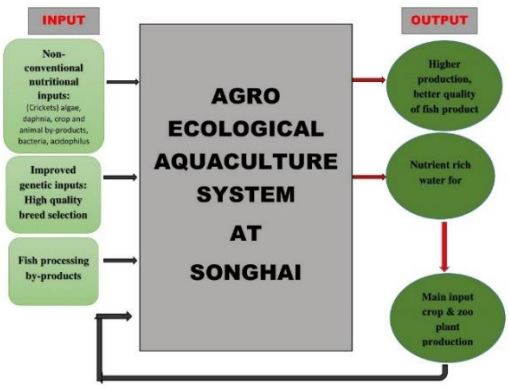


Figure 3: Inputs and outputs of the agroecological aquaculture system at Songhai.

The objective is not only to grow food (fish products) but also to enhance the overall productive capacity of the environment and strives to tackle the triple challenge of poverty/food insecurity, unemployment and environmental degradation in a holistic and systemic way.

Regenerative and sustainable aquaculture technologies constitute a central part of Songhai's drive to develop authentic technologies that bring into play the natural forces of synergy and amplification in nature that have been ignored by conventional methods. This method creates a probiotic environment that empowers the regenerative agents of nature to optimize the productivity of the whole system by creating dynamic linkages between different trophic levels (from micro-organisms that recycles nutrients, through intermediate levels like algae, daphnia, etc. to the fish population). The overall effect is the creation of a so-called "reverse entropy" (syntropy) and the "super enabling" conditions and environments like enzymatic actions, appropriate pH conditions, optimal oxygen levels etc.

"Producing more and better with less"

Essentially this process strives to harness the regenerative forces/elements in nature to develop an agriculture that is not only multidimensional and multifunctional, but also enhances benevolent cycles and pathways as it:

a) Produces food in sufficient quantities and with qualities that promote healthy living, healthy aging, and disease prevention;
b) Enhances the environment (soil life, food web, soil structure, etc.);
c) Provides the framework for a new settlement model- Agro-hoods or Green Rural Cities;
d) Builds sustainability and biodiversity;
e) Provides raw materials for agro-industry;
f) Provides feed stock for renewable energy;
g) Creates employment, particularly for youths and women.

The merits of a development strategy based on this type of agriculture are not only safe, affordable, high yield, high quality and sustainable, it also addresses employment and environmental problems in both rural and urban areas and builds a strong base for an inclusive and broad-based economy.

A major value proposition in this endeavor is that as it breaks the vicious cycle of poverty, it counters the "scarcity syndrome" in the developing countries that underpins socio-economic conflicts by developing a natural and integrated farming system that is based on low cost inputs.

3. Illustrations of agroecological aquaculture at Songhai

The species

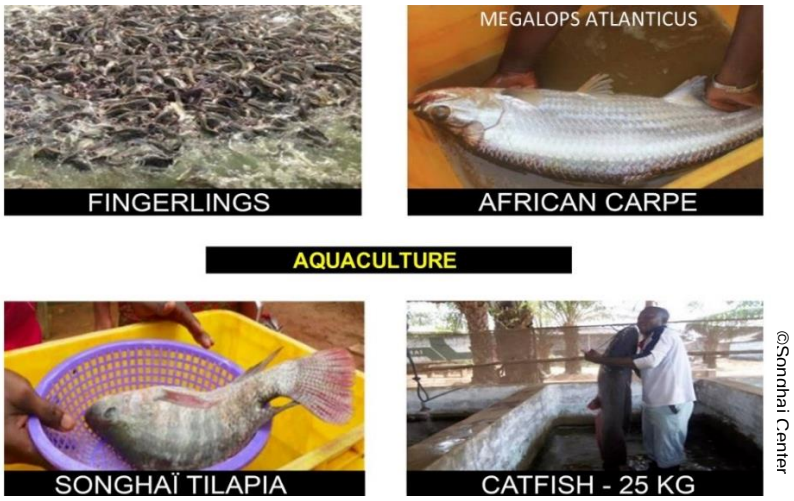


Figure 4: **The species farmed at Songhai.**

Figure 5: Breeders of common and African carps.

Figure 6: African carp Megalops atlanticus, a new promising species for aquaculture.

The growing-out facility

Figure 7: Ponds and concrete tanks used for aquaculture.

©Sonnhai Center

Figure 8: Other facilities.

INTEGRATED AQUACULTURE - AGRICULTURE AND AGROECOLOGY IN AQUACULTURE: VIEWS FROM EUROPE

Joël Aubin and Jérôme Hussenot

1. Introduction

The global food system is now facing a growing human demand and needs to deliver a sustainable and steady supply of food to guarantee food security and nutrition for all people, while also limiting climate change and sustaining biodiversity and ecosystem services (Foresight, 2011). The role of aquaculture in the resilience of the planet can however be discussed in light of diversity of its products, its environmental impacts and reliance on feed ingredients (Troell *et al.*, 2014). Therefore, as claimed for agriculture, it is necessary to revise the design of aquaculture systems to increase production in quantity and quality while preserving the environment and, from a sustainability point of view, by considering economic robustness, development of high-quality jobs and building of new relationships among producers, consumers, and production systems.

In the European Union, average per capita fish consumption reached 25.1 kg per year in 2015, and the value of seafood imports in 2016 was EUR[21] 24.4 billion (EUMOFA, 2017). Aquatic production is therefore an important challenge for European countries, although aquaculture is paradoxically characterized by its lack of significant development (except for salmon), despite the interest it has always aroused. Freshwater pond systems have existed for centuries. They were built for religious purposes in the Middle Age and still dominate large areas of landscape. Nonetheless, pond systems based on extensive polyculture are regularly replaced by more intensive systems. Abandoning pond causes changes in associated ecosystems, which are being covered by woody vegetation. Modern aquaculture developed in the 1960s, based on fish monoculture and supply of formulated feed. Advances in research allowed the reproduction of many species and the elaboration of efficient feed, even for the small larvae of marine fish. This control of life stages led to improvements in fish rearing and genetics. Freshwater pond species were replaced on the market by salmonids (e.g. Atlantic salmon, rainbow trout) and carnivorous marine fish (e.g. seabass, gilthead seabream, turbot, meagre, sole).

The overall rearing performance of farmed fish, especially their ability to convert feed to body weight, are better than those of traditional livestock (Fry *et al.*, 2018). Nonetheless, fish biology limits N-protein retention to 15-35 percent, depending on the species and rearing practices. Thus, at best, 65 percent of the nitrogen provided to a fish raised in monoculture is lost as nitrogen compounds. Similar percentage can also be observed for phosphorus. Therefore, the trend toward fish monoculture implies not only an increase in management and control of the species but also an increase in nutrient losses. In livestock systems, most animal waste is reused in crop systems and contributes to feed production and maintenance of soil organic matter. Increased nutrient losses are only observed with excessive animal concentrations (e.g. feedlots) or huge number of farms in a given region (FAO, 2006).

In "modern" European aquaculture, recycling of nutrients within a production system or in connected agriculture systems disappeared. Thus, this kind of production system suffers from a double penalty: (1) the overall recovery of inputs remains low, meaning that farmers must pay for large amounts of inputs that are ultimately lost, and (2) the nutrient losses induce extra costs for water treatment, which has to be borne by farmers (water treatment devices, practices such as sea-cage rotation), society (environmental monitoring, water purification) and ecosystems (carrying capacity, environmental impacts).

As a consequence, aquaculture in Europe is not perceived positively. Critics of aquaculture highlight its impacts: pollution from fish waste, accumulation of organic matter in water bodies, spread of

[21] EUR 1 = USD 1.1.

diseases and parasites, use of medicines in the environment, escapees of domesticated species, degradation of coastal landscapes and fragile ecosystems, use of fish meal and oil in fish feeds, etc.

The European Union regulations are also restrictive. By setting water quality objectives, the regulations limit the size of existing farms and the creation of new farms. Moreover, European Union countries apply the same European Union directives differently, creating market distortions between neighboring countries. As a result, annual aquaculture production (including fish, crustaceans, mollusks and algae) in the European Union has plateaued at 3 million tonnes for a decade (FAO, 2016).

The fish farming sector is now considering two main strategies. One is to move cages further out at sea, where carrying capacity no longer seems to be a constraint, but which requires larger cages and infrastructure investments. The other is to design onshore Recirculating Aquaculture Systems (RAS) or Zero Exchange Systems to limit interactions with natural ecosystems and better manage waste, but this requires technological investments and more energy to operate (Blancheton *et al.*, 2009; Martins *et al.*, 2010).

2. Escaping the deadlock

Conceptual frameworks

Different ways of thinking, adopted by fish farmers, emerged and influenced the perception of aquaculture systems in Europe. Sustainable development implies moving beyond technology-only approaches, towards recognizing connections with surrounding activities and the natural environment by introducing the idea of long-term impacts (Lazard *et al.*, 2014). Nonetheless, the implementation and monitoring of the effectiveness of this approach remain a key question. Following the "ecological aquaculture" approach appeared to be a good solution as ecological aquaculture "not only brings the technical aspects of ecosystems design and ecological principles to aquaculture but also incorporates... social ecology, planning for human community development, and concerns for the wider social, economic, and environmental contexts of aquaculture" (Costa-Pierce, 2010). Ecological aquaculture greatly inspired the ecosystem-based approach to aquaculture (EAA), described and promoted by FAO (Soto *et al.*, 2008; FAO, 2010). EAA is not considered a new paradigm; it is more an attempt to construct a common framework. One key point is not to consider the aquaculture systems as a separate activity but as a part of a larger system that includes and influences the landscape. Therefore, integrating aquaculture with other human activities, mainly agriculture (but also tourism, other economic activities…), is an essential factor to understand its influence on the sustainable development of a region.

This approach is also parallel to the raising awareness of the limits of intensive practices in agriculture and the need to develop agroecological practices. The term "agroecology" may refer to a practice, a science (Dalgaard *et al.*, 2003) or a movement (Wezel *et al.*, 2009). Agroecology emerged as a science in the 1930s but was popularized decades later by Altieri (1995). Later, Altieri (2002) developed five principles specifically dedicated to small-scale farming systems: (1) recycle biomass and balance nutrient flows; (2) achieve and maintain soil conditions (e.g. organic matter, soil biotic activity) that favor plant growth; (3) minimize losses of solar energy, air, water and nutrients (e.g. microclimate management, water harvesting, soil cover); (4) increase species and genetic diversity in time and space and (5) increase beneficial biological interactions that promote key ecological processes and services. These principles are based on two main concepts: (1) recycling nutrients and energy within agroecosystems increases their efficiency (i.e. increases productivity, decreases losses and pollutant emissions) and (2) maintaining diversity (mainly biodiversity) increases resilience, stability and robustness of agroecosystems. An agroecosystem is a modified ecosystem, managed by humans to extract resources through agriculture. This concept is complex due to interactions between

socio-economic and ecological processes (Conway, 1987; Garbach *et al.*, 2014). Currently, FAO embodies all these characteristics into 10 elements of agroecology.[22]

Introducing more ecology into aquaculture is therefore a goal, as shown by the concept of ecological intensification of aquaculture (Aubin *et al.*, 2019). This approach also embodies the concept of ecosystem services (MEA, 2005), which can be defined as services that ecosystems provide to humans. When ecosystem services are considered in agriculture, agroecosystems become not only sources of food but also sources of regulation and cultural services (Haines-Young and Potschin, 2013). Ecosystem services can be transposed directly to the aqua-ecosystems associated with aquaculture systems (Figure 1).

Integration practices

Having intensive fish monoculture as a starting point in Europe makes changing practices difficult. Ecological intensification defines three sequential levels of aquaculture integration: (1) focus on inlet and outlet control, (2) reconsider the targets of the aquaculture system and (3) include ecosystem services when changing system's objectives. The first level consists mainly of feed-related choices: depending less on fish meal and oil from industrial fisheries and using associated strategies (alternate by-product sources, new ingredients, more recycled ingredients). In pond systems, using natural feed is also a strategy, with possible integration with agriculture by recycling livestock waste as an input. This traditional practice is still followed in some European freshwater polyculture ponds.

Controlling aquaculture waste is a classic problem. Since aquaculture emissions into water-bodies are a major concern, developing water treatment methods is an initial step for onshore aquaculture systems. By this rationale, adding a water treatment device creates an extra cost for the aquaculture system. Recirculating Aquaculture Systems are derived from this approach. In the best cases, RAS can be integrated with agriculture by exporting and reusing sludge (from suspended solids) as a source of organic matter for land-based agriculture.

More advanced water treatment methods may require specific changes to the production system and imply changing the production target and organization. In the Middle Age, aquaculture was integrated with agriculture when crops were grown in the bottom of freshwater pond, during a pond-drying year. This practice, still followed in parts of Europe, provides good yields of spring crops (e.g. maize, wheat, barley, oats, buckwheat), due to the nutrient-rich pond sludge, and increases fish yields in subsequent production cycles, possibly due to organic matter mineralization (Wezel *et al.*, 2013).

[22] More information can be found at http://www.fao.org/agroecology/home/en/ (consulted August 2019)

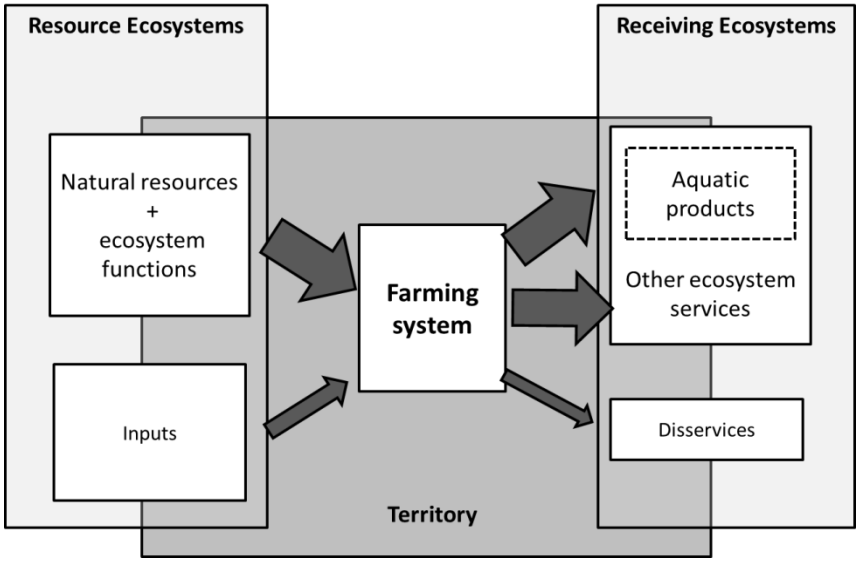


Figure 1: Aqua-ecosystem components involved in ecological intensification (Aubin *et al.*, 2019). A farming system is located in a territory connected to resource ecosystems which provide resources, inputs and functions to the farming system, and to receiving ecosystems where products are delivered as well as services and disservices (perceived as negative consequences).

Aquaponics, the combination of aquaculture (usually RAS) and hydroponics, represents a new type of integrated aquaculture. Supported by the development of urban aquaculture, many small aquaponic projects are emerging in Europe. In aquaponics, dissolved nutrients provided by fish are reused as fertilizer in hydroponics. Different fish species have been tested (e.g. rainbow trout, common carp, ornamental fish, pike, perch) depending on the period of the year and production objectives, and many plant species have also been tested (e.g. lettuce, strawberries, tomatoes, aromatic plants). Aquaponics appears to be expanding in Europe but has yet to become economically viable there, unlike in the United States of America (Love *et al.*, 2015). Moreover, the true ability of aquaponics to purify water is regularly debated (Wongkiew *et al.*, 2017).

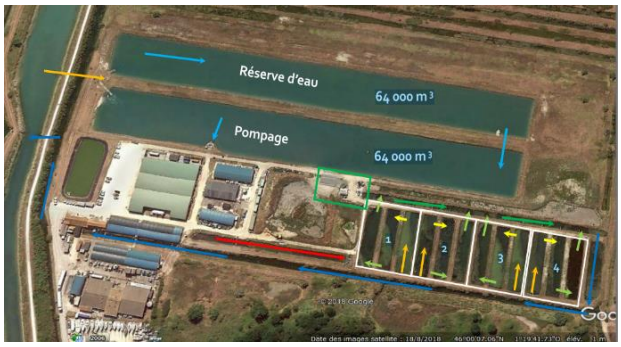
Co-producing food or other products by recycling aquaculture waste is the key idea behind the concept of Integrated Multi-Trophic Aquaculture - IMTA (Neori *et al.*, 2004; Troell *et al.*, 2009; Barrington *et al.*, 2009; Chopin, 2013). IMTA is based on combining complementary species with trophic habits and living in different compartments of the ecosystem. Inorganic and organic wastes from fed aquaculture species (e.g. finfish) are respectively assimilated by autotrophic (e.g. phytoplankton, macroalgae, plants) and heterotrophic species (e.g. oysters, mussels, sea cucumbers) that are co-cultured with the fed aquaculture species. Thus, the generic concept of IMTA covers a large set of practices based on the complementarity of productive compartments and is applied to many groups of species inhabiting different ecological niches (Figure 2). Different types of integrated rearing systems have been developed in temperate and tropical areas, such as the association of Atlantic salmon (*Salmo salar*), macroalgae (*Saccharina latissima*) and mussels (*Mytilus edulis*) in Canada (Barrington *et al.*, 2009) or a macroalgae-scallop, urchin-gilthead seabream, or seabream-mullets associations in Israel (Shpigel *et al.*, 2016; Neori *et al.*, 2017). IMTA can also be designed by using aquatic macrophytes to purify water and provide an alternate source of food for fish. Improvement of water quality by macrophytes has been well studied and tested under field conditions (Hasan and Chakrabarti, 2009). In saline aquaculture, halophytic macrophytes are also used in constructed wetland systems to treat effluents (De Lange *et al.*, 2013) or produce biofuels (Sharma *et al.*, 2016)

Inset A: European IMTA system: IMTA FISH / SEAWEEDS

Commercial companies
FRANCE (FMD), Portugal (ALGA+)

Main species	Seabream (*Sparus aurata*)	Ulva [Ao-nori] (*Ulva rigida*)
Rearing technique	intensive or semi-intensive [Pt]	IMTA in earthen ponds [Fr] IMTA in open raceways [Pt]
Rearing period	all the year, 12/12	March to Nov. [Fr]; 12/12 [Pt]
Ulva production in IMTA for 2018	and production potential into brackets [metric tons]	France (FMD): 11 [700] Portugal (ALGA+): 45 [180]
Product quality	seabream, meagre juveniles [Fr] organic seabass, seabream [Pt]	food grade [Fr] organic label [Pt]

ulva (sea salad)



France, Oléron Island: FMD

On the right the algae ponds,
on the left the fish hatchery-nursery

Portugal, Ria de Aveiro: ALGA+

In the foreground the seaweed raceways,
In the distance the earthen fish ponds
open raceway ponds in Portugal

References:

Roblin (2019).

Abreu (2019).

(Credit for the pictures: Jérôme Hussenot)

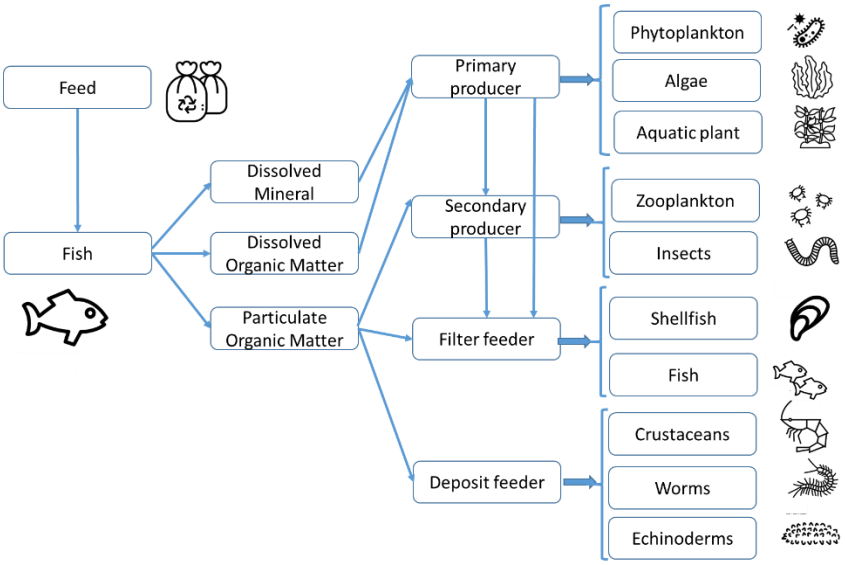


Figure 2: Representation of Integrated Multitrophic Aquaculture used in the IMTA-Effect Eranet-CO FASP project (Aubin *et al.*, 2017).

In Europe, IMTA began in the 1990s, mainly by treating fish waste with microalgae (Hussenot *et al.*, 1998, Hussenot, 2003; Lefebvre *et al.*, 2004). The idea was then further developed as a way to reuse macroalgae produced for nutritional or industrial purposes (Santos, 2006). It was also adapted to the production of halophytes *Salicornia* in constructed wetlands, in Israel, Wales and Portugal (Webb *et al.*, 2012; Shpigel *et al.*, 2013). More complex systems have since been developed to reuse plants produced with wastewater to feed other species like microalgae for oysters (Lefebvre *et al.*, 2001; Li *et al.*, 2019). These experiments have yielded interesting results but require a precise management of the ecosystem compartments as well as the management of some limiting factors such as silicates for diatom microalgae growth.

In Europe, IMTA has developed in three ways. The original approach, combining fish in traditional sea cages with macroalgae and bivalves, exists but remains uncommon (Hughes *et al.*, 2016). The second approach combines several onshore monoculture systems in series (finfish, algae, mollusks or detritivorous organisms); it is better suited to RAS and requires extensive knowledge and technology. Fish and macroalgae (Inset A), fish and halophytes (Inset B) are the first land-based systems in series developed in Europe in commercial fish farms. The third approach puts all species in the same freshwater or coastal pond; it requires little technology, but the species interactions still need to be analyzed and managed. One example in Europe is the polyculture shrimp-oyster developed in France from more than twenty years (Inset C). Another one, experimented in Portugal is to mix fish, oysters and macroalgae in earthen ponds (Cunha *et al.*, 2019; table 1). It shows the advantages of mixing these species.

Intermediate systems can also be imagined. For example, ragworms (*Nereis virens*) were produced intensively in Netherlands to feed sole juveniles (*Solea solea*) in the same pond, and microalgae were produced using effluent water to feed bivalves, each species being in a separate pond (Ruizeveld de Winter, 2014).

Table 1: Comparison of rearing performances of fish polyculture: Meagre (*Argyrosomus regius*), white seabream (*Diplodus sargus*), and flathead mullet (*Mugil cephalus*), supplemented with oyster (*Crassostrea gigas*) and/or macroalgae (*Ulva* spp.). SGR: Specific growth rate; FCR: feed conversion ratio. Adapted from Cunha *et al. (*2019)

		Fish, oyster, phytoplankton, seaweed	Fish, oyster, phytoplankton	Fish, phytoplankton, seaweed
Meagre	Harvested Biomass (kg)	865	861	603
	SGR (percent per day)	0,43	0,44	0,29
White seabream	Harvested Biomass (kg)	160	135	145
	SGR (percent per day)	0,53	0,46	0,5
Flathead mullet	Harvested Biomass (kg)	120	90	109
	SGR (percent per day)	0,24	0,12	0,21
Total fish	Harvested Biomass (kg)	1115	1087	857
	FCR	1,59	1,65	2,46

3. Constraints

IMTA remains in its infancy in Europe, in part due to a variety of constraints (Kleitou *et al.*, 2018). Starting from well-managed fish monoculture systems, the addition of ecological compartments to produce additional species using fish waste requires investments of time, knowledge and infrastructure that must be compensated by an increased income from the additional species. How to earn this additional income is not always clear, however, since the market of the new species may be small. Moreover, the use of additional resources, even with the objective of environmental improvement, does not necessarily lead to overall environmental benefits (Mendoza Beltran *et al.*, 2018).

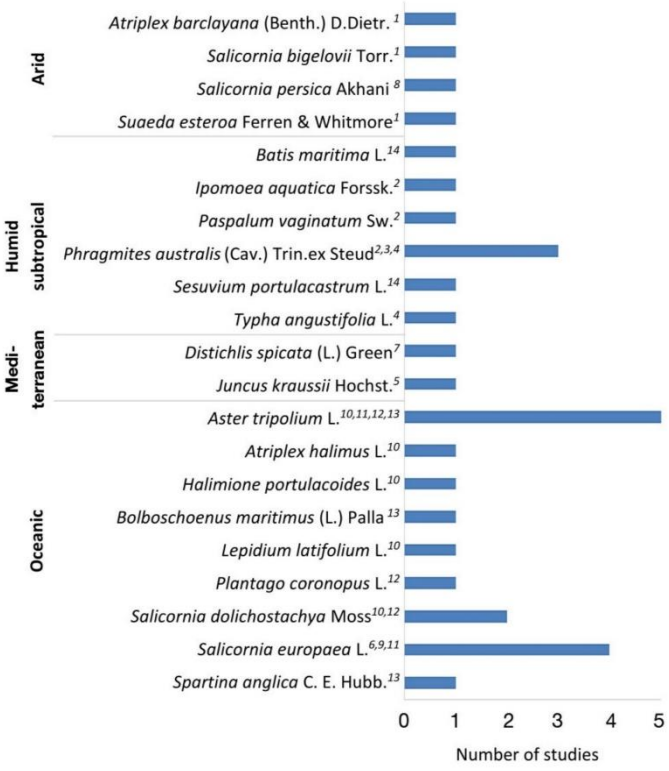
The European Union regulations also limit IMTA, in particular because of the prohibition to feed animal waste or by-products to domestic animals. Consequently, the legal status of detritivorous species (e.g. sea cucumbers) and filter feeders (e.g. mussels, oysters) reared in IMTA for human consumption remains unclear. Regulations adapted to IMTA are needed to ensure that it continues to develop. There are also questions about consumer perception, especially of filter feeders produced by IMTA (Alexander *et al.*, 2016). Focused communication and quality control must be organized to ensure access to markets.

Inset B: European IMTA system: IMTA FISH / HALOPHYTES

Pilot or experimental stages
UNITED KINGDOM, PORTUGAL

Main Species	Marine Fish	samphire (*Salicornia europea*), sea aster (*Aster tripolium*), sea purslane (*Halimione portulacoïdes*), ...
Rearing technique	intensive or semi-intensive	Constructed wetlands or hydroponics
Rearing period	all the year	March to Nov. [UK] ; 12/12 [Pt]

Number of studies per halophyte species where phytoremediation was tested and growth performances evaluated upon irrigation with saline aquaculture wastewater. Source: Custódio *et al.* (2017).



Constructed wetland developed in the Seafare project

Samphire *(Salicornia europaea*)

Sea purslane *(Halimione portulacoides*)

Sea aster (*Aster tripolium*)

References:

Webb *et al.* (2012).

Marques *et al.* (2017).

(Credit for the pictures: Jérôme Hussenot)

4. Perspectives

Combining multiple species into the same production system is a real opportunity for aquaculture; however, the perspective must change from waste treatment to a genuine multi-species integration. Moreover, species interactions are not only trophic; integrated aquaculture must also consider other types of interactions that influence the performance of systems, such as aquatic animal health improvement with decreased occurrence of diseases and parasites, or the improvement of animal behavior and welfare. Knowledge about these topics exists but is scattered; it must be strengthened to become truly useful.

As supported by agroecology, the sustainable use of natural environment factors as production factors must also increase. Natural primary production and invertebrates that develop naturally in and around aquaculture systems must be considered as supplemental food resources. Knowledge on microorganisms, a large part of the biodiversity and productivity of natural ecosystems, and key to their functioning, must also be strengthened.

In general, interaction with biodiversity is a major aspect for the sustainability of open and semi-open aquaculture systems. Aqua-ecosystems may be considered to restrict natural biodiversity, but they also support and stimulate it (FAO, 2018). One interesting perspective for future research is how to use agroecological practices to improve interactions between aquaculture and surrounding biodiversity. This role of biodiversity support is usually related to the ecosystem services provided by the aqua-ecosystem.

While species interactions and the supply of different products for different markets makes integrated aquaculture more robust, associated economic models must be built and strengthened. Developing viable commercial-scale systems in Europe remains a challenge.

5. Conclusion

In Europe, traditional integrated aquaculture-agriculture has been slowly replaced by intensive monoculture. Pond aquaculture still exists in some landscapes, in which nutrients from livestock waste sustain primary production and pond sludge is used to grow crops. They are, however, all semi-extensive systems with low yields. Ancient polyculture systems are now being reinvestigated to help design new systems. In particular, IMTA combining fish, primary producers and secondary producers recycling organic matter are based on the same principles. Due to production limitations and regulations, applying integrated aquaculture in Europe remains complex. Nonetheless, it has the potential to be productive, resilient and robust, providing high-quality and environmentally friendly products, which society expects from aquaculture systems.

6. Acknowledgement

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Inset C: European IMTA system: POLYCULTURE SHRIMP/OYSTER

Commercial level
FRANCE (Atlantic coast)

Species	Kuruma shrimp (*Marsupenaeus japonicus*)	Pacific oyster (*Crassostrea gigas*)
Rearing technique	Marine pond extensive	Marine pond extensive / semi extensive
Initial density	1-5 i/m²	2-5 i/m²
Rearing period	May to October (3-5 months)	June to December (4-6 months)
Total production (IMTA and monoculture, 2018)	~ 50 MT	187 MT
Number of producers (IMTA and monoculture, 2018)	30	112
Selling price by producers	40-50 €/kg	10-20 €/kg
Product quality	«Crevette impériale» (Label BIO)	«Pousse en claires» (Label Rouge)

Production area « Charente-Maritime »

Kuruma shrimp (*Marsupenaeus japonicus*)

Pacific oyster (*Crassostrea gigas*)

(Credit for the pictures: Jérôme Hussenot)

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MALAGASY RICE-FISH FARMING

Jean-Michel Mortillaro and Lionel Dabbadie

1. Introduction

Some integrated aquaculture and agriculture systems (IAA) such as Chinese rice-fish farming are possibly as old as 2000 to 8000 years (MacKay, 1995; Edwards, 2019) and overtime, other integrated systems also emerged in both marine and freshwater environments, in temperate or tropical countries. Eventhough some gradually fell into disuse to make room for intensification and monoculture, IAA systems are nowadays rediscovered for their benefits that contribute to many of the sustainable development goals. Indeed, IAA systems are designed to decrease the farmers' dependence on external inputs, and to increase the whole system efficiency by optimizing the use of nutrients, energy and water. IAA systems also permit to diversify farm production and to generate a more resilient source of income, less dependent on mono-product marketing. Finally, they also generate and use different types of ecosystem services. In rural areas with low input availability and incomes, IAA systems bring the opportunity for farmers to extensively produce fish when intensive aquaculture is not within their technical reach. This is particularly the case in Madagascar where integrated rice-fish farming has been promoted by FAO since 1985 and by the non-governmental organization APDRA since 2006 (Dabbadie and Mikolasek, 2017).

Madagascar is an island country, located off the southeast coast of Africa. Frequently ranked among the poorest and most vulnerable nations, it faces several critical challenges (The World Bank, 2019). Food security and nutrition is one of them. Indeed, whereas rice is locally the main staple and main crop, the national production is insufficient to meet the demand, despite a mean yield of 2.5 t/ha and an estimated production area of 1.2 million hectares (Andriamparany, 2010). Malnutrition is another recurring issue in Madagascar, especially for children, as low household incomes limit access to a diversified diet (Razafiarisoa *et al.*, 2009). For example, fish consumption is reported to be as low as 1.3 kg/capita/year according to official statistics (Rakotomalala *et al.*, 2017), whereas the global average is now higher than 20 kg/capita/year (FAO, 2018).

To cope with these issues, the integrated production of fish with rice in paddies appeared as a promising technology, as it allows to harvest a double crop from the same field, and to benefit from synergies between them. Integrated rice-fish farming increases diet diversity, food security and nutrition, improves farmers' income and, overall, improves livelihoods in the rural areas through diversification and intensification of crop productions (Tsuruta *et al.*, 2011). However, given the low availability and accessibility of production inputs to farmers, rice-fish farming in Madagascar needs to focus on improving the productivity of both rice and fish by minimizing inefficiencies and effectively recycling wastes or by-products.

2. Ecological basis of rice-fish farming

Irrigated rice fields are ecosystems favorable to the growth and production of aquatic organisms. They can even play a major role in feeding and nutrition of local communities as a source of self-recruiting species. Flooded rice fields are composed of several trophic compartments, the main ones being rice, water and sediment (Figure1). But insects, snails and weed are also commonly encountered in flooded rice fields as a result of the abundance of natural food and nutrients. They are often considered pests for rice, resulting in the intensive use of pesticides in modern rice crops. But self-recruiting species or stocked fish for aquaculture purpose, freshwater prawns or crabs also give value to these organisms by consuming them and recycling the nutrients they contain.

On the other side, the use of pesticides, fortunately limited in IAA, can affect the survival of most organisms encountered in the rice fields and on the overall trophic foodweb. Fish, crabs and prawns

rely directly and indirectly on phytoplankton and zooplankton produced in the water column. Sediments also host a multitude of invertebrates such as freshwater mussels, bacteria, biofilms and many other macro- and micro-organisms, all contributing to the trophic functioning of the flooded rice fields. Lastly, frogs, tadpoles, birds, snakes and rats are also not uncommon as they are looking for shelter or forage on the food resources of the rice fields.

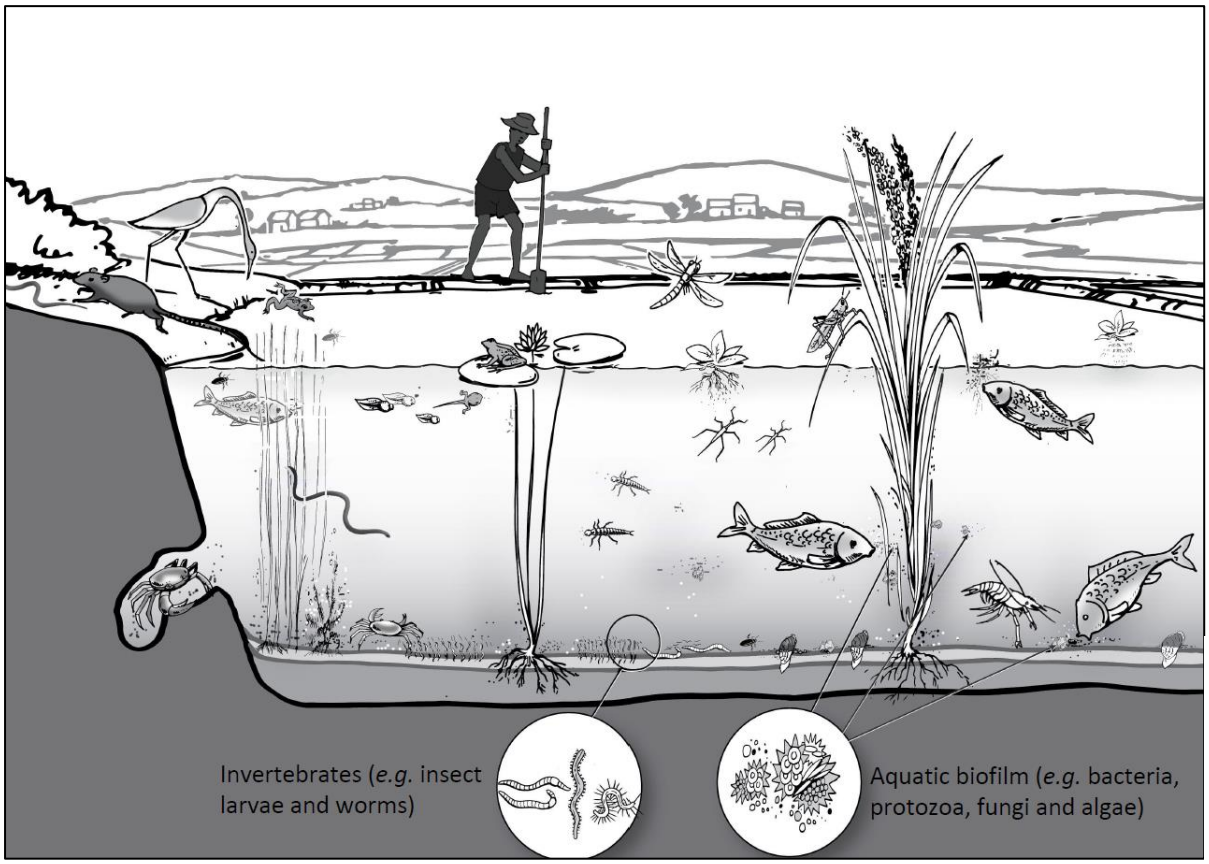

Figure 1: Schematic representation of the food web in a flooded rice field.

If wild fish, mostly consisting of various species of tilapias, have been traditionally harvested in Madagascar rice fields, technologies introduced since the middle of the 1980s were aiming at intensifying the rural fish production by promoting improved rice-fish farming practices and stocking common carp fry (*Cyprinus carpio*) in the irrigated rice fields. Besides the interest of this fast-growing species for its adaptation to the water temperature of Madagascar highlands (14 to 26°C), common carp also feeds through bioturbation on the bottom, which has been demonstrated to increase the oxygen supply to a greater depth in fishpond soil, thereby improving its quality (Ritvo *et al.*, 2004). Furthermore, common carp have been considered as ecosystem engineers affecting the water transparency and community composition (phytoplankton, zooplankton, macroinvertebrates and submerged macrophytes; Matsuzaki *et al.*, 2007). Matsuzaki *et al.* (2007) also demonstrated the effect of common carp on nutrient dynamics through excretion as a primary mechanism. Nutrient excretion by common carp should occur, as stated previously, while foraging on macro-invertebrates and weeds thus fighting against rice pests. Also, common carp can limit the growth of phytoplankton and submerged macrophytes (weeds) that compete with rice for nutrients, by affecting water transparency. Therefore, common carp are particularly adapted to the IAA context of rice-fish farming in Madagascar.

3. Malagasy rice-fish farming study case

Rice-fish farming has been carried out traditionally in the irrigated rice plots of Madagascar highlands (Kutty, 1987), which consist of four major ecosystems:

- Swamps, where rice is cultivated by farmers without modification of the landscape.
- Rainfed hillsides, where poor water management may lead to flood and drought (Fujisaka, 1990).
- Floodplain rice, where rice plots are characterized by more than 10 consecutive days of medium to deep flooding (50 cm flood to more than 300 cm) during the production cycle (Greenland, 1997) and where the water supply depends on rain and river flow.
- Irrigated leveled rice terraces, where fields are bunded with water control systems.

Fish can be found in all these ecosystems except in the rainfed hillsides. Nonetheless, floodplain rice and swamps are not appropriate for fish farming considering the risk of fish escapees during flood episodes. Eventhough the harvest of wild fish trapped in paddy fields during rice culture is widely practiced, intensifying the production through improved rice-fish technologies and stocking of farmed fish, faces several technical and social problems:

- One is the fear of fish theft, often associated or even confused with mortality through predation on fry (e.g. by birds, aquatic insects, snakes).
- Another one is the poor rearing or fish handling/transport conditions due to the lack of technical knowledge.
- The water management is also frequently questioned. This is particularly the case for the plots with raised bunds built to increase the water level for fish and that use new technologies that promote periodic drainage and drying to fight weeds and oxygenate soils.
- The use of refuge channels dug inside the plots to shelter fish in case of heat or drought, is also often seen as problematic because it leads to a loss of cultivable surface for rice. However, the loss of area is assumed to be offset by the increased rice yields observed with IAA, according to the FAO technical manual for dissemination of rice-fish culture (Kutty, 1987).

The technologies allowing an improved water management through raised bunds and refuge channels were therefore evaluated and compared to traditional practices in rural areas. The objectives of the case study were to characterize the agronomic performance in traditional (rice + self-recruiting species) and integrated systems (rice+carps). This was achieved by measuring the weight of commercial and self-recruiting species, as well as the yield of rice at harvest.

Farm experiments were conducted twice during a dry (2016-2017) and a wet (2017-2018) campaign. During the dry campaign, the first experiment consisted of six rice plots of 467 to 863 m^2 (total of 3 882 m^2) randomly distributed in two treatments: traditional (rice + self-recruiting species; n=3) and integrated systems (rice+carps; n=3). The rice plots were located near the village of Tsiafahy, Antananarivo (-19.06, 47.61; Figure 2) and investigated during a 100 days cycle, beginning on the 11 January 2017 with fish stoking in integrated systems plots. Eight additional plots located in the village of Fihaonana, Antananarivo (-18.66, 47.17; Figure 2) were added during the wet season. These rice plots measuring 270 to 655 m^2 (total of 3 552 m^2) were receiving two treatments: integrated (rice+carps; n=3) and fed systems (rice+carps+feed; n= 5). Feed provided to the fish in the last treatment consisted of food remains, cow dung and termitary collected locally.

The second experiment started on the 04 December 2017 in Fihaonana and on the 28 January 2018 in Tsiafahy, and lasted for 98 and 89 days, respectively. Fish in each rice field were sorted by size and weighed at stocking and harvesting. Survival rate was calculated. Rice yields were also evaluated through three replicates, with a surface of 0.25 m^2, sampled randomly in each plot.

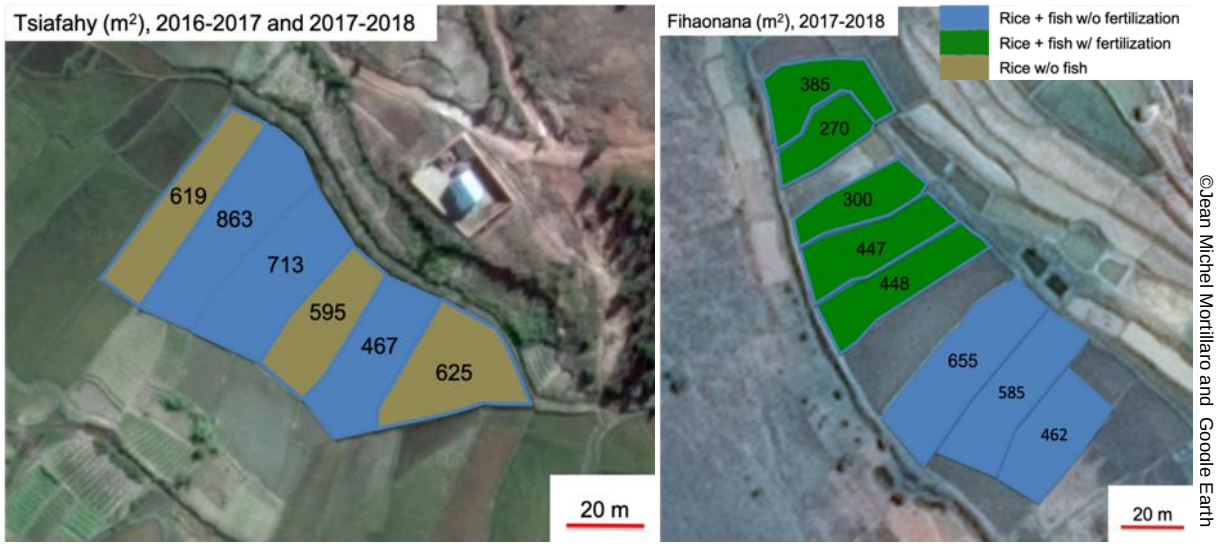

Figure 2: Experimental setup of the rice-fish farming (left: Tsiafahy; right: Fihaonana)

The efficiency of rice-fish farming and the benefits brought by fish were demonstrated from these on farm trials (Mortillaro *et al.*, 2018, Raminoharisoa *et al.*, 2018). Indeed, despite a refuge channel covering about 10 percent of the rice plot surface (Kutty, 1987), the rice production increase reached 19 percent after a dry, unfavorable, season (2016-2017) and up to 31 percent after a wet, favorable, season (2017-2018; Figure 3), thus largely compensating for the 10 percent surface loss. However, in Fihaonana, the fish feeding had no significant impact on rice, despite a seemingly high rice yield (Figure 3).

New insights on the integration of aquaculture with agriculture came up from the use of crop residues and raw materials from the agroecosystem. From a 30 farms survey, no correlation between the amount of zebu manure and rice productivity was recorded (Raminoharisoa *et al.*, 2018). Such findings highlight the diversity of practices (e.g. Intensive Rice System-SRI, traditional rice culture and off-season rice systems), soils quality and agro-environmental conditions, where standardization of inputs and techniques do not provide the expected results.

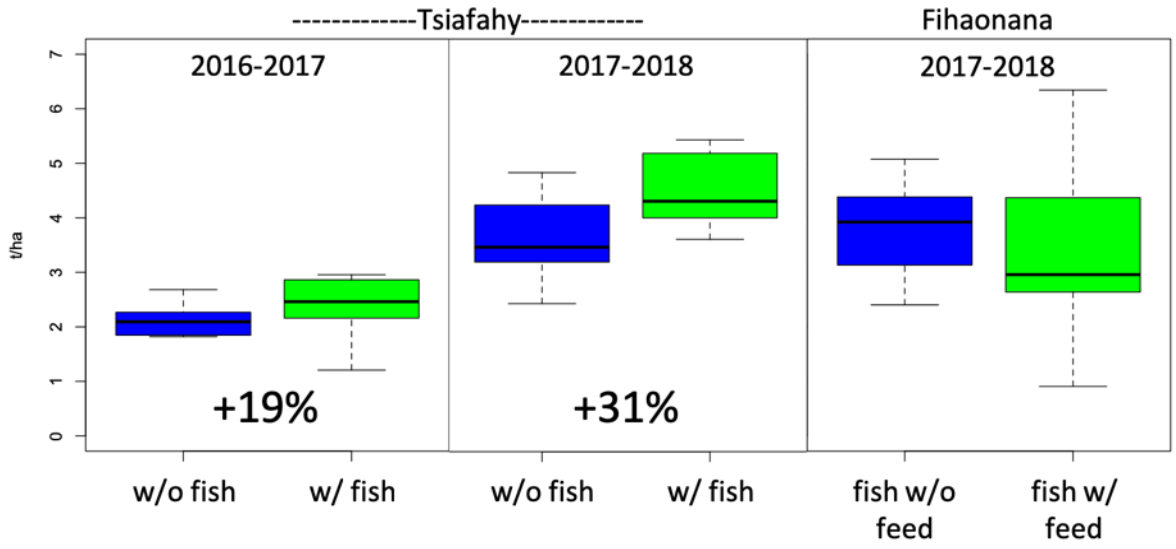

Figure 3: Rice yields from Tsiafahy (2016-2017 and 2017-2018; left) and Fihaonana (2017-2018; right).

Fish reared in extensive condition are generally not fed and it is also common that no fertilizing input is applied. Therefore, fish rely on their natural feed in the rice field, especially the insects that can be harmful for rice as well as algae and weeds that compete with rice for nutrients (Moreau, 1972). In extensive conditions, fish production remains small (39 to 59 kg/ha/cycle; Table 1) and no difference was recorded in fish weight and yield from Tsiafahy experiments (Figure 4, Table 1). However, feeding fish with qualitative inputs of termitary, cow dung and food remains, has significantly improved fish weight and yield, reaching 97 kg/ha/cycle (Figure 4, Table 1).

Survival is also quite low, with a maximum of 40 percent in Fihaonana fed plots (Table 1). Similar results in fish weight, yields and survival in Tsiafahy suggest that fish carrying capacity of rice plots was reached in such extensive conditions. It can be suggested that stocking density in such depleted systems was too high, leading to low survival, but it is also locally acknowledged that the size of stocked fish and the stocking/transport practices could be improved to increase fish survival.

Table 1: Fish productivity of integrated rice fish farming in Tsiafahy (2016-2017 and 2017-2018) and Fihaonana (2017-2018; without or with feed)

Site	Campaign	Cycle (days)	Fish yield (kg/ha)	Survival (%)
Tsiafahy	2016-2017	100	39	38
	2017-2018	89	48	39
Fihaonana w/o feed	2017-2018	98	59	32
Fihaonana w/ feed	2017-2018	98	97	40

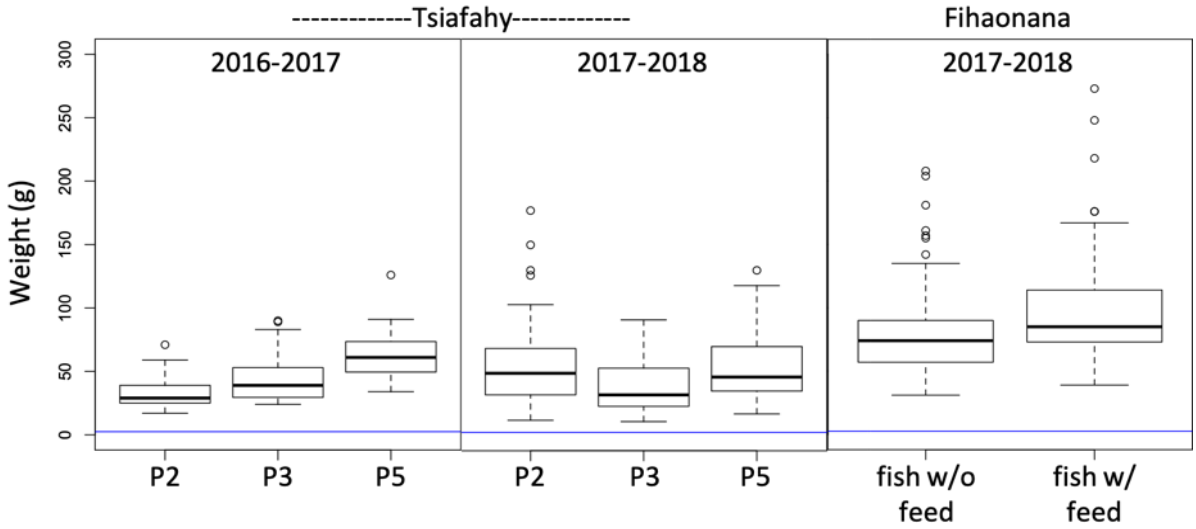

Figure 4: Fish weight (g) from Tsiafahy (2016-2017 and 2017-2018; left) and Fihaonana (2017-2018; right); P2, P3 and P5 refers to the three rice plots stocked with fish (Figure 2). Blue line refers to stocking weight which was of 2.5 g on average.

Although small yields were recorded in these experiments, intensification with fertilizers and feeds can improve yields up to 500 kg/ha/cycle (avg. 100 days). In that context, trophic characterization of rice-fish systems will be needed to improve the knowledge on ecosystem dynamics as well as on fish and rice yields determinants, by considering the whole diversity of situations encountered in the Malagasy highlands: rice culture practices, climate, environment, soils, feed and/or fish quality.

Finally, although traditional rice-fish farming has been practised in Madagascar for more than a century, the low adoption rate of improved technologies will need to be better understood through socio-economical surveys. In such extensive systems, the fish density should be adapted and kept to a minimum for the model to remain economically viable (less than 1 fish / 4 m^2).

For an average 400 m^2 rice plot, raising bunds and digging a fish refuge channel cost EUR 16, while the price of a 2 cm-long common carp fry is EUR 0.05 per unit (EUR 6.25 at a 1 fish / 4 m^2 density), leading to an initial investment of approximately EUR 22 for 400 m^2 (Randrianetsy, personal communication, 2019). Considering that the average monthly income for a 5 people household is EUR 21 (Andrianantoandro, 2015), and that the daily income for an average farmer is EUR 1, the initial investment to start rice-fish farming is greater than one month of labor. Moreover, because of the climate seasonality in the highlands, this investment is needed at the beginning of the lean season.

Furthermore, fry is often difficult to access for farmers, given the remoteness of rice plots and the poor road infrastructure. Aquaculture development projects have therefore focused part of their activities on giving farmers autonomy in fry production by promoting and supporting small-scale hatcheries (APDRA, 2016). This proved quite successful as many small-scale hatcheries can now be observed in the different regions were projects had interventions, but fry production remains low with an average of 2 000-3 000 individuals from a single female. The development of rice-fish and overall aquaculture production in Madagascar, is therefore limited by the access and high cost of fry as well as the limited availability inputs such as the high-quality feeds and fertilizers.

Further development of rice-fish farming and aquaculture in Madagascar will have to focus on reducing costs for farmers to encourage adoption and facilitate risk taking. Many pathways are available to achieve these goals, in particular the improvement of the breeding techniques to increase the survival and quality of early stage fry (use of feed for breeders and fry, improve breeding ponds, avoid predators etc.). New approaches will also have to focus on the integration of rice-fish farming within the agroecosystem and on the evaluation of the organic resources allocation trade-offs.

Optimization of rice-fish farming practices will also need to consider polyculture systems by combining fish species that have supplementary feeding habits and making use of organic inputs. Finally, ecological slope continuum within rainfed hillsides and irrigated leveled rice will have to be characterized, given the similarity of the ecological processes (bioturbation, soil dynamics, pest control) between both and opportunities to recycle nutrients between one and the other one through runoff.

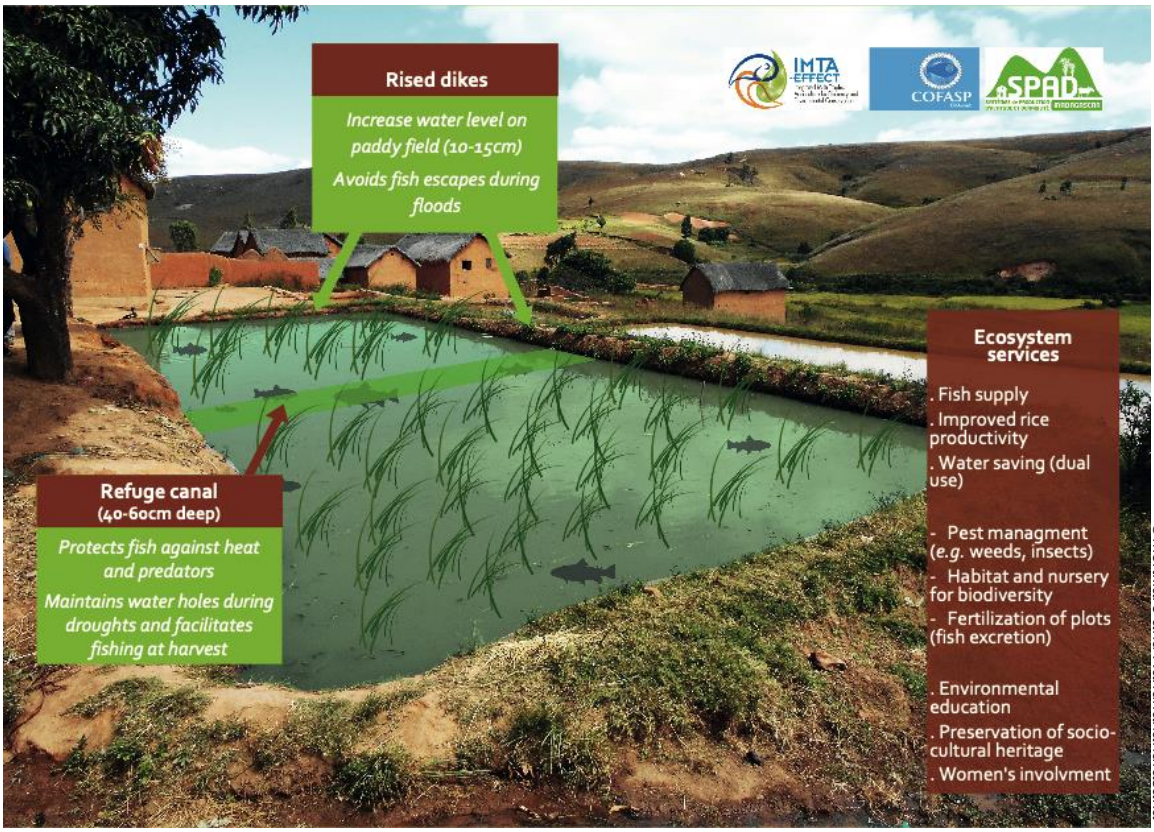

Figure 5: Rice fish farming popularization leaflet

4. Conclusion

Altogether, rice-fish farming promoted through participatory research with farmers can help to diversify farm production and increase the local supply of fish and other aquatic products. This will in turn enhance food security and nutrition, in accordance with the cultural heritage of Madagascar. Rice fish farming improve also farmers' income, but the high investment cost and need to have access to appropriate land areas may lead to the exclusion to some stakeholders, especially the middle-to-lower classes, in particular in peri-urban areas were land availability is a critical issue (Dabbadie and Andria-Mananjara, 2016; Fertin, 2018). Moreover, gender inequities among rural communities with regards to land ownership and access to capacity building remains an issue (Randrianandrasana and Randrianetsy, 2019). This is particularly visible in the fish farming development projects where women beneficiaries represent only for 13 percent of the total, although 80 percent of women are involved in the decision-making at the household level (Vololoharimanana, 2018). Improving tilapia farming in these areas, given the lower investment production cost compared to common carp may help to protect and improve livelihoods, equity and social well-being (Fertin, 2018). However, the building cost of rice-fish plots still represents more than 70 percent of the budget and further prospect will need to reduce it. Increasing the efficiency of the system by improving the knowledge on the trophic dynamics of this aquatic ecosystem and promoting ecosystem services (Figure 5).

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BIOMIMICRY IN AQUACULTURE – CONNECTING SCIENCE AND PRACTICE

Krishna R. Salin

1. Introduction

In response to both the local and international demand for food fish, profit-driven commercial aquaculture rapidly expanded throughout Southeast Asia from the late 1970s, fueled by the seed availability from newly-developed, science-based hatchery technologies. Since the government involvement in the initial era of aquaculture development was minimal, the credits for expansion of the industry should go to the innovative entrepreneurs who pioneered new aquaculture practices. However, the undisciplined growth of commercial aquaculture had its consequences as it impacted the natural environment negatively. The sector itself suffered from several bacterial and viral diseases which slowed down its growth. Resource limitations such as land, water, and other essential inputs in the 21st century are gradually declining the growth of the industry further when it is most needed to supply fish to meet the demand of a growing human population. Given this situation, the emergence of sustainable aquaculture technologies assumes great importance, particularly in Asia which produces almost 90 percent of the global aquaculture production.

2. The effluent challenge

The major challenge posed by intensive aquaculture is the accumulation of organic debris that are often discharged into the surrounding water resources leading to largescale pollution and eutrophication. The effluents from intensive aquaculture with high stocking densities typically contain dissolved and suspended solids, and nutrients including nitrogen and phosphorus that play a major role in eutrophication (Salin and Gabriel, 2018). Proper treatment of aquaculture effluents, particularly from the coastal shrimp farms, has always been a challenge. Intensive culture systems that involve high stocking and feeding rates face problems as a result of bad water quality, often leaving the cultured species under stress and vulnerable to diseases. There has been a heavy dependence on the use of chemicals and antibiotics to counter the threats from diseases owing to bad water quality (Ozbay *et al.*, 2014). In the early years of development, the shrimp farm effluents were pumped out after harvest by forceful jets of water that have caused considerable damage leading to eutrophication of water bodies. Modern practices involve microbial applications in farms to aid in digesting organic matter as this has many advantages.

3. Biomimicry

Biomimicry is the imitation of natural systems to emulate new models that are beneficial to humankind and the ecosystem. The application of biomimicry in aquaculture had emerged as a concept in Thailand when farmers innovated in their pursuit to seek solutions for the increasing challenges in intensive shrimp farming. Biomimicry in aquaculture, often termed aquamimicry, has become popular by collective farmer efforts and has evolved mostly based on extensive farm trials rather than based on a systematic scientific trial. Thus, this appears to be a ‘practical’ technology that is tested in the farmer fields.

The concept of biomimicry - the science that studies nature’s models and then imitates nature to design eco-friendly production systems - has been inspired by planners, designers, and producers. Benyus (2002) identified nine principles underlying nature-mimicking designs. According to her, the nature (1) runs on sunlight, (2) uses only the energy it needs, (3) fits form to function, (4) recycles everything, (5) rewards cooperation, (6) banks on diversity, (7) demands local expertise, (8) curbs excesses from within, and (9) taps the power of limits. She recommended that if people design their industry and build

environment according to these principles, they would be living within the limits of carrying capacity of nature and will achieve the Sustainable Development Goals.

Mimicking nature in the aquaculture production process means the development of open and complex aquaculture systems consisting of a large number of subsystems with several feedback loops. These feedback loops consist of phytoplankton, zooplankton, bacteria, micro-grazers, fish, feeds and the abiotic environment. The subsystems interact in a nonlinear way to produce synergistic effects by reducing metabolic products such as NH_3, improving feed efficiency and immune system of fish and shrimp. However, such an aquaculture system functions far away from equilibrium and needs constant inputs (energy) and human attention to manage it without collapses.

4. Aquamimicry – A new farming model

The protocols emerged as part of aquamimicry technique are primarily based on the application of microbial inputs to promote digestion of pond soil organic matter thereby assisting in the production of rich soups of microinvertebrates, dominated by copepods. These form part of the natural starter diet for the shrimp postlarvae stocked in the pond. Primarily, as a system that mimics nature, aquamimicry does not use many inputs for pond preparation as is being done in the case of a conventional intensive shrimp farming protocol currently in practice.

As a concept, aquamimicry absorbs many principles from the biofloc technology that has enabled highly intensive production by the manipulation of bacterial diversity in a closed, zero water exchange aquaculture system. Biofloc often follows a complex production protocol that relies on the dynamics of some of the naturally occurring heterotrophic bacteria to regulate water quality and to promote the conversion of organic biomass into the useful protein that can be assimilated by the shrimp or fish cultured (Avnimelech, 2014; Taw, 2014). The stability of the Biofloc system depends on the maintenance of carbon-nitrogen ratios appropriate to the cultured animal and the environment.

The aquamimicry concept, however is based on the application of probiotic bacteria dominated by *Bacillus* spp., and aided by their synergistic action with graded and fermented rice bran as prebiotic supplements to enhance the action of probiotic bacteria, leading to a favourable ‘synbiotic’ environment in which the shrimp grow faster and healthier (Romano 2017). This synergistic action aids to develop consistent blooms of zooplankton dominated by copepods, mostly mimicking the natural estuarine environment in which the shrimp postlarvae thrive to complete a significant phase of their natural lifecycle.

Farm design

The aquamimicry protocol encompasses a unique recirculating pond design that includes a rectangular/square shaped grow-out (production) pond attached to a pond water treatment system (Figures 1 and 2). The latter includes a main sedimentation pond (anoxic pond) and a series of clarifying pond areas with baffle wall partitions.

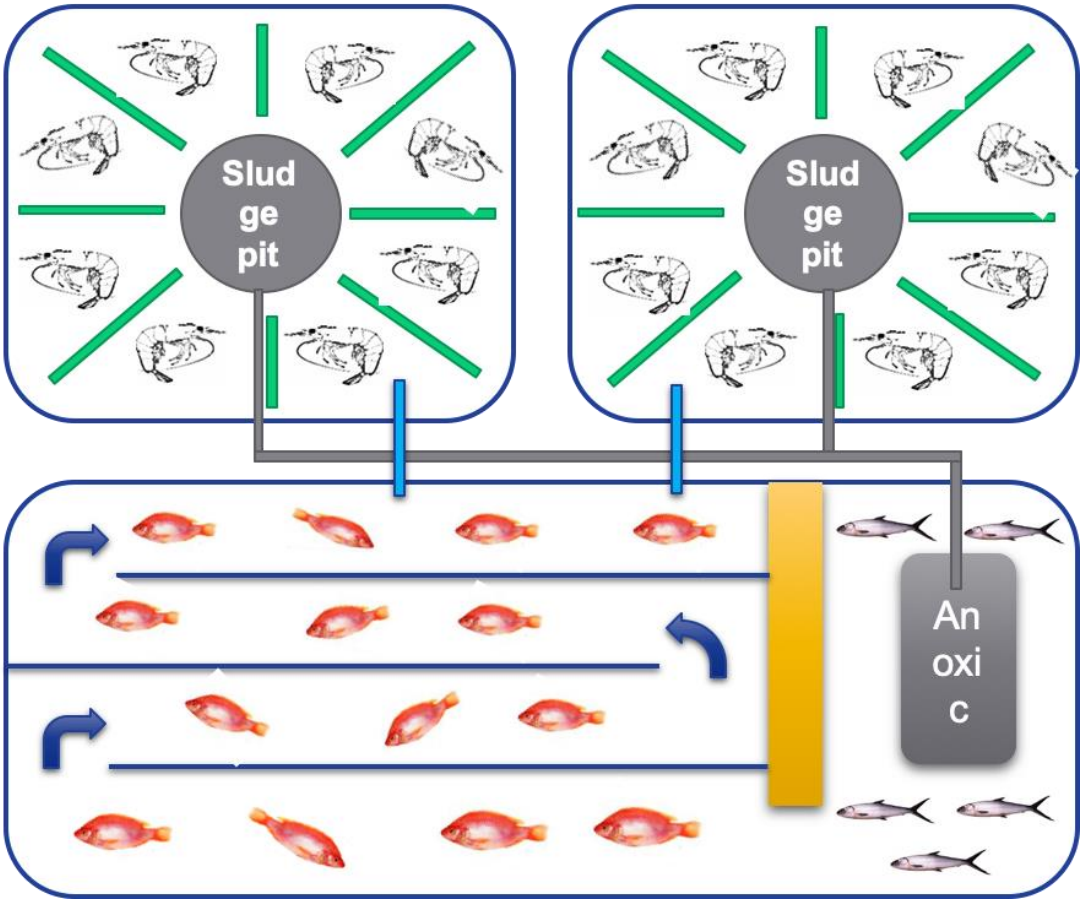

Figure 1: The aquamimicry farming model. The green spirals indicate aerator placement; grey lines indicate sludge pumping, and blue lines/arrows are baffle partitions/water movement.

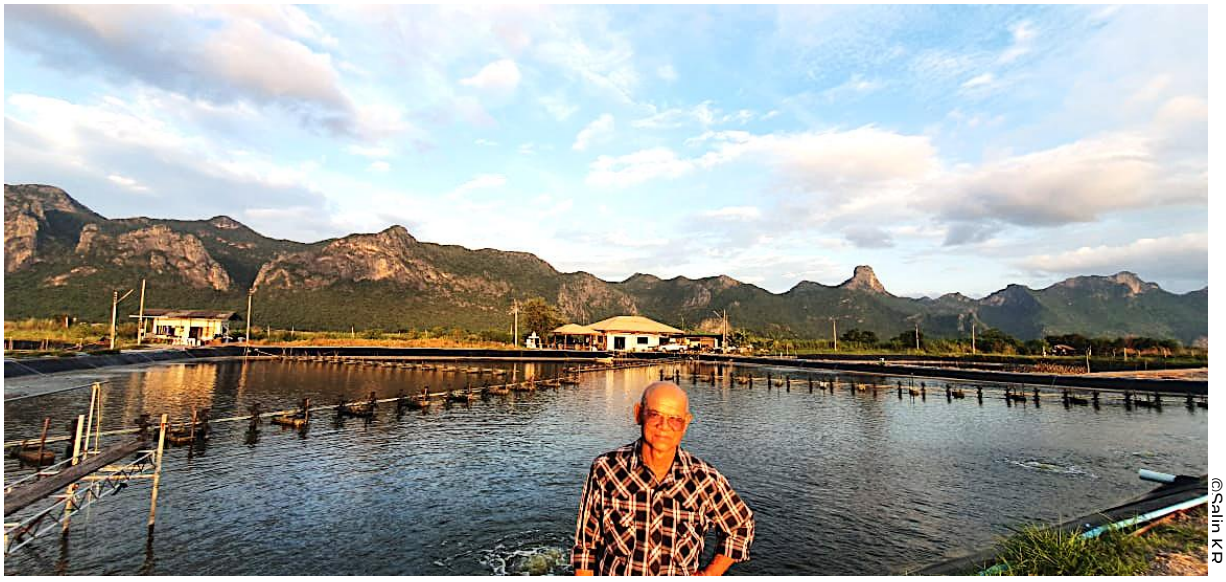

Figure 2: Mr Daecha Bunluedej, President of the Farmers' Cooperative at Sam Rayod in Prachuapkirikhan Province of Thailand, at his aquamimicry model farm.

The treatment system takes just about the same area as that of the grow-out pond. There is no water exchange in the grow-out pond as the solid sediments pumped from the center of the grow-out pond

passes through the anoxic pond and the sedimentation system where the water is clarified with the help of live fish, molluscs, and seaweeds before the water is returned to the grow-out pond by gravity flow. This system has been found to maintain stable water quality in the grow-out pond while preventing a major share of the foul water from entering the natural water bodies surrounding the farm.

A noticeable feature of pond construction includes the preparation of a central sludge pit from where the solid sediments are pumped out during culture, with the frequency varying from several times daily to a few times in a week based on the level of water turbidity. Typical sizes of the production ponds range from 0.5-1.0 ha in area. Smaller ponds of 0.5 ha (71 x 71 m) are preferable because of their better efficiency in placing aerators to circulate water towards the central sump and lower energy consumption (Figure 3). The depth of the ponds range from 1.2-2.0 m, while in deeper ponds the shrimp stocking density can be increased to 100-150 PL/m3. In smaller ponds, four long-arm aerators are adequate to provide high dissolved oxygen and optimum circulation of water. Simultaneous operation of all the aerators is often necessary only at the time of sludge pumping for adequate circulation.

Figure 3: (A) The aquamimicry pond under preparation. (B) The pond under operation.

Central sludge sump

The central sump with a diameter of 10-12 m and 2 m depth is dug precisely at the center of the pond (Figure 4). The pond bottom gradually slopes (3-5 percent) towards this sump. Inside of the sump slopes steeply towards a central pit (60-80 cm diameter) from where the solid sediments are pumped using a

sludge pump though a PVC pipe of 4 inches diameter that leads to the anoxic pond placed adjacent to the production pond. The pond dikes and the central sump are lined by HDPE geomembrane that facilitates dike consolidation and smooth surface for pumping the sludge.

Figure 4: (A) The digging of a central pit. (B) The lined central sump with piping ready.

The water treatment system

The treatment system is of 0.3-0.5 ha in area, and consists of the sedimentation pond (anoxic pond), which is a rectangular pond of 2 m depth, but with a deeper area of 4 m depth at the center that receives the sludge pumped directly from production pond (Figures 5 and 6). Fish such as red tilapia hybrid, catfish or milkfish are stocked in this pond at a density of 1 fish/m^2. No aerators are placed in this pond, and the denitrification process releasing gaseous N_2 appears to occur in this pond which is aided by the addition of fermented rice bran as carbon source. The presence of fish also appears to help in regulating the water quality.

Clarifying ponds

The water from the anoxic pond then passes into the clarifying ponds with a few compartments separated by baffle walls (made of HDPE liner material). Live horse mussels (*Arcuatula arcuatula*), and seaweeds are planted in these compartments, which help to effectively reduce the suspended solids before the water circulates back to production pond. Tilapia are stocked at 1-2 fish/m^2 while for mussel culture, 200 ropes of 4 m long/ha or stakes are placed as substrates (Figure 6). Liquid fermented rice bran (LFRB) is added at 1 ppm to the treatment ponds, and often about two aerators are placed to facilitate water movement and to develop zooplankton, avoiding microalgae production. Every time the sludge is pumped from production pond to the treatment pond, water also flows back into the production pond by gravity at a rate of approximately 20 m^3/hour.

Pumping is involved only at one stage of the production flow, for pumping sludge into the anoxic pond, while the rest of the water flow follows gravity. Therefore, the water treatment system does not consume a significant amount of energy in this system.

Figure 5: The sedimentation pond with a deeper central area.

Figure 6: (A) sludge from grow-out pond pumped to the sedimentation tank. (B) Stakes used to grow mussels in the pond for water treatment (C) Mussel growth on the substratum.

Aquamimicry farming protocols

The farming protocols associated with the aquamimicry technique have been developed by trial and error basis as a farmer innovation in Thailand, and are based on the principle of developing live food in ponds just the same way as it exists in the natural feeding grounds of shrimp. This involves the use of microbially digested particles of rice bran and/or soybean meal in a fermentation medium aided by probiotics. The fermented meal is fed to pond water to create an appropriate medium for microinvertebrates to flourish in the pond environment. Graded rice bran and soybean grits are sieved to about 500 µm size and fermented using a commercial bacterial formulation before applying to the ponds. The detailed procedures and inputs are described in the following sections.

Pond preparation

Standard protocols for pond preparation can be followed in the case of aquamimicry, except the use of any inorganic chemical for the elimination of invertebrates or other pests from the pond. It is good to have pond soil with less than 3 percent of organic carbon, as higher stocking densities would not be suitable in soils with high carbon content. Initially, tea seed cake (20 ppm) is applied to eliminate small fish from the ponds. The pond is then filled up to the level of 80-100 cm with clean seawater filtered through 200-300 µm mesh. Specific preparations of microbes are available that can stabilize the pH based on the initial soil pH value.

To develop abundant blooms of copepods, liquid fermented rice bran (LFRB) is to be applied to the pond at 400-500 kg/ha (40-50 ppm). Fermentation of rice bran is done after grinding good quality rice bran and then sieving it through 500 µm mesh before mixing with probiotic bacteria. It is crucial to remove big particles from rice bran, because the accumulation of these particles may cause the development of black biofilm at the pond bottom. To one kilogramme of sieved rice bran 5-10 litres of water is added. If freshwater is used, 1-3 percent of salt is added. A probiotic bacterial preparation is added to this mixture at 1-2 g per 50-100 litres of water and 10 kg of rice bran for fermentation. The pH is adjusted to about 7.0 by adding powdered calcium carbonate. The fermentation process takes about 24 hours under constant aeration (Figure 7). If there are more coarse particles, then the fermented bran should be sieved before application.

Figure 7: (A) Mixing the ingredients for fermentation. (B) Fermented rice bran ready for application. (C) Sieving the fermented rice bran to remove coarse particles.

The LFRB is applied to the pond at 30-50 kg/ha (3-5 ppm) daily or until the Secchi disc turbidity reaches 30-50 cm. LFRB is applied near the aerators so that it quickly disperses throughout the pond. Dissolved oxygen should be maintained above 5 ppm, and the pH between 7.5 and 8.0. Rich blooms of copepods develop within 10 to 15 days. Imhoff cone readings of 5 to 20 ml/l are often observed during this period (Figure 8). Two aerators are adequate to be operating at this time to maintain mild circulation. Along with copepods, there are also other micro-invertebrates such as blood worms and sandworms that develop in the pond and provide excellent nutrition to the shrimp immediately after stocking. During the initial days, it may be necessary to carry out a chain-dragging operation at the pond bottom to prevent the formation of biofilm and toxic gas formation at the soil-water interface.

Figure 8: (A) Copepods as observed in an Imhoff cone. (B) The boat for chain dragging.

Stocking of shrimp postlarvae

The aquamimicry protocol helps to avoid a nursery phase as the postlarval (PL) shrimp can feed on natural food soon after stocking in the production pond that significantly enhances their initial growth. The optimum size of shrimp PL for stocking is when they are 6 to 8 days old (PL-6 to PL-8), as larger sizes often face higher mortalities during transportation. The post-larvae are subject to a stress test in freshwater before stocking. Stocking densities vary from 20-140 PL/m^2, but densities around 100 PL/m^2 is optimum. Chain-dragging can be done very gently (covering not more than 25 percent of the pond area per day) during the first 15 days of the stocking to release the sludge towards the central sump. Probiotic bacteria for faster digestion of organic matter are also added at this time.

Pond management

The pond management protocols involve feeding the postlarvae, maintenance of water quality, and management of biosolids (sludge).

Feeding

The postlarvae begin feeding the copepod blooms immediately after stocking. After 5-7 days of stocking, fermented soybean meal (FSy) can also be included in the menu if there is no commercial pellet feed provided to shrimp. Fermented soybean meal is prepared by fermenting 1 kg soy in 1 litre of water, with the addition of 1-3 percent salt in the case of freshwater. Full fat soy grits, defatted soy, or dehulled soy with protein content ranging from 45-50 percent are used for fermentation. Probiotic bacteria preparation at 1-2 g in 10 litres of water with 10 kg of soy product is used for fermentation. The pH is adjusted to nearly 7.0 by addition of calcium carbonate. The mixture is placed in a warm place away from sunlight, and the fermentation process takes about 12 hours when it is ready for feeding.

The FSy is applied at 1-3 kg of sieved soybean meal for every 100 000 PL/day using feeding trays. When the shrimp grow to about 1 g size, the FSy is given as in Table 1, about 2-4 times daily, in feeding trays (4 trays per ha). The feeding rates are adjusted based on the shrimp's consumption in the trays.

Table 1: Feeding rate for shrimp using fermented soymeal

Feeding rate (percent)	Shrimp body weight (g)
4-5	1-5
3-4	5-10
2-3	10-20
2-1	20-30

The efficacy of feeding LFRB and FSy alone without any pelleted feed is highly variable, obviously because of the apparent lack of some of the essential amino acids and other nutrients in the fermented product compared to the formulated feed. Because of this, farmers often follow the aquamimicry protocol using LFRB to maintain water quality and mix both FSy and a commercial pellet feed in varying proportions for optimum shrimp growth and farm production. The absence of a nursery phase with the PL stocked directly in the production pond, and a significant reduction in the use of pellet feed are the other advantages of adopting the aquamimicry protocol.

Maintenance of water quality

Maintaining a stable pH in the pond without substantial diurnal fluctuations is key to the success of farming. The aquamimicry system remarkably contributes to a stable pH and regulates the nitrogen spikes thereby offering a rearing environment that is conducive for shrimps. The water is relatively more turbid compared to the conventional farming methods as contributed by the enhanced levels of biocolloids. The turbidity is regulated to be below 30 cm as Secchi disc reading. Turbidity is maintained by the application of LFRB (1-5 ppm, daily), the dose divided into morning and afternoon rations.

The accumulation of biocolloids in water is one of the major contributors to turbidity in culture pond. Biocolloids might include bacteria, viruses, proteins, DNA, spores, algae, protozoa and other microorganisms that exist in the aqueous phase (Juergen and Michael, 2001) and are of significant interest to the development of a natural ecosystem within the pond under an aquamimicry protocol. Biocolloids in an aquamimicry pond (Figure 9) formed by microalgae, bacteria, copepods, rice bran, and other microorganisms are a source of natural food, maintains water quality by controlling nitrogen spike and stabilizing pH, and appear to prevent microalgae bloom and pathogenic bacteria in the pond. However, excessive biocolloids can do more harm than good as it will lead to rapid depletion of dissolved oxygen in the water, stressing shrimp. Therefore, it is essential to maintain the level of biocolloids to less than 5 ml/l of Imhoff cone reading by periodically removing the biosolids (sludge) from the central sump, and also by application of specific probiotics that can accelerate the digestion of organic matter.

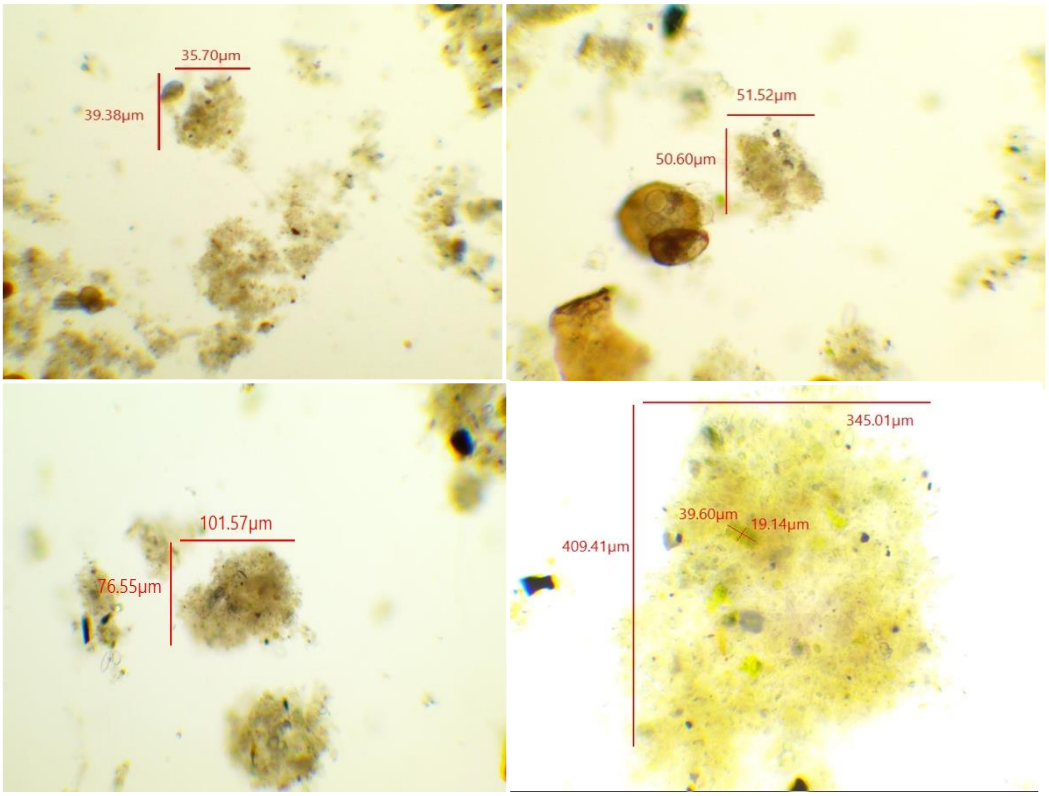

Figure 9: Photomicrograph of biocolloids observed in an experimental aquamimicry system at AIT, Thailand.The particle sizes are indicated.

The dissolved oxygen is maintained in pond water between 5 and 8 ppm, and at no time allowed to exceed 10 ppm to prevent phytoplankton blooms (by adjusting the operation of aerators). The fluctuation of pH should not be more than 0.2 in a day. Since no water is exchanged, the only addition of water to the pond during the culture period is to replenish the evaporation loss, which would be approximately 0.2 cm/day. It is also necessary to add minerals such as calcium, magnesium, and potassium because copepods and shrimp need regular mineral supplements for optimum growth and development.

Management of sludge

Sludge is the collection of solids consisting of uneaten feed, feces, biocolloids, and all other organic material that accumulate in the pond. Pumping of sludge begins after 2-4 hours of feeding when water circulation created by aerators sweeps the solids into the central sump, which are then pumped out to the treatment pond. A net cage is placed around the central pit to avoid any shrimps entering the area. Commercial probiotics are also added with full aeration at night time to reduce the build-up of sludge.

The regular application of probiotics helps to regulate water quality as well as to maintain the quality of the soil even after harvest. At least half of the rearing water can be reused for the next crop. The accumulated sludge in the treatment pond is removed after one year and used for composting.

5. Production and economics

Aquamimicry protocols were initially developed for low-intensity farming situations with stocking densities as low as 20 PL/m^2. However, higher intensities have now been tested and found to be highly successful. The production details and economics of a successful crop using aquamimicry farm at the Prachuabkirikhan Province of Thailand is given in Table 2. The PLs stocked in a 0.4 ha pond at a density of 225 PLs/m^2 and reared for 67 days grew to an average body weight of 12.2 g at harvest with a survival

rate of 91 percent and average daily growth of 0.18 g. The total production was equivalent to 25 tonnes/ha. The FCR was 1.08:1 and the feed cost was 57.5 percent of the total cost of operation. Seed, electricity, labour, mineral supplements, probiotics, and tea seed cake and rice bran were the other major costs, which consisted of 11.4 percent, 12.6 percent, 10.6 percent, 3.79 percent, 2.27 percent, and 1.77 percent of the total cost of production, respectively. This result shows the potential of aquamimicry to grow shrimp in such high-density farming conditions.

Table 2: Production and economics of a crop of shrimp produced in an intensive aquamimicry system in Thailand

Production			**Economics**				
			Item	**Quantity**	**Unit price**	**Amount (THB)**	**Percentage of total cost**
Crop period	14 Sep – 20 Nov 2015		Seed	900 000	THB 100 per 1000 PL	90 000	11.38 percent
DOC	67 days		Feed	10 829 kg	42 per kg	454 818	57.51 percent
Pond size	0.4 ha		Electricity			100 000	12.64 percent
Stocking	900 000 pcs		Labor and incentive			84 000	10.62 percent
Density	225 pcs/m2		Mineral supplements			30 000	3.79 percent
ABW at harvest	82 count		Probiotics			18 000	2.27 percent
Biomass	10 000 kg		Tea seed cake and rice bran			14 000	1.77 percent
Total feed	10 829 kg						
FCR	1.08 : 1		TOTAL	10 000 kg	79.08 per kg / USD 2.25 per kg	790 818	
ADG	0.182 g						
Survival rate	91.14 percent						

DOC is Days of culture; ABW is Average Body Weight; ADG is Average Daily Growth; THB 1=USD 0.03
Source: Mr. Veerasun Prayotamornkul, Thailand (personal communication)

6. Advantages of aquamimicry system

The principles of biomimicry in aquaculture are inspired by nature and its processes to benefit aquaculture systems in a way that modifies the current practices for a sustainable future. Although more scientific understanding of the processes are yet to be in place, the practical utility of this practice looks very promising, given the successes that have achieved in real-world farming situations. Consistent application rates of fermented rice bran have been found to enhance development of microdiets in pond water consisting of zooplankton dominated by copepods while preventing the excessive production of microalgae. This can provide an initial boost to the growth of shrimp postlarvae that enables avoidance of a separate nursery system. The zooplankton blooms that develop in the water column result in healthy juveniles that are able to ingest the pellet feed of fermented soybean meal more efficiently within two weeks of stocking. The graded rice bran particles might also serve as a substrate for heterotrophic bacteria dominating the soup of biocolloids in an aquamimicry system.

One of the major advantages of aquamimicry is that this technique could be used for rehabilitation of abandoned shrimp ponds that have been left unutilized for several years. The rapid development of intensive shrimp farming in Thailand in the 1990's had left significant environmental damage by the destruction of mangrove areas and other landforms for shrimp farming. Zakir and Lin (2001) had observed that almost 70 percent of ponds were abandoned after a few crops of shrimp farming and in

1996 there was about 20 800 ha of abandoned ponds with an economic loss of about USD 200 million. Aquamimicry protocols seem appropriate for bioremediation of abandoned pond soils that can enhance their productivity.

Given the scientific evidence available at present, aquamimicry protocols could successfully control water quality in the intensive production of shrimp. Use of probiotics stabilizes water quality and maintains a healthy ecosystem for clean and healthy shrimp without significant disease occurrences. The pond-recirculating system using fish, molluscs, and seaweed serves as a unique means of recycling used water in an intensive production system. The protocols in aquamimicry are a lot simpler than a typical biofloc production system that may require the operator to be more technically proficient. In a broad sense, the aquamimicry offers a naturally biosecure system with stable water quality, thanks to the abundant natural microdiet that ensures fast growth rate and high survival to produce healthy shrimp, intensively.

The concept of functional feeds in aquaculture is relatively new. Such foods that facilitate growth by providing essential nutrients and by preventing or reducing the risk of several diseases have been extensively studied in the case of humans. With the limited understanding of the aquamimicry system, there is currently no evidence to assume that the symbiotic action of probiotic bacteria and other prebiotic inputs to provide any functional complements in water to favor shrimp growth and better water quality. More research is required to elucidate the mechanisms of action of the supplements in a shrimp production system that modulates water quality and a favorable living place for shrimps.

7. Future outlook

Often farming technologies are evolved in researchers' laboratory and subsequently tested in the real farming situations to gauge their success. A technology that fails in the field never makes any impact. However, aquamimicry has emerged from the farmers' field as a successful technology that helped to obtain consistent production from some of the abandoned shrimp farms of Thailand. Protocols have emerged from a few enterprising farmers in Thailand based on a trial and error basis. The system requires extensive farming areas as the water treatment system takes almost the same area as that of the production pond. Perhaps, this may change in future as the techniques are further refined and a better water treatment protocol is developed. Currently the protocols are under scientific scrutiny to understand their mechanisms of action and to investigate the scope for further refining the techniques for shrimp, and other suitable farming systems. The prospects of this technology to improve the water quality consistently in intensive shrimp farms appear very promising, while the extent of its benefits to enhance the efficiency of current feeding practices in intensive shrimp farming have yet to be fully explored. Further, more aquaculture species and systems have to be evaluated for their suitability to the aquamimicry technology, and that is expected to provide a simple and cost-effective solution for intensive aquaculture, globally.

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AQUAPONICS IN THE SULTANATE OF OMAN

Wenresti Gallardo

1. Introduction

According to the World Resources Institute (2015), fourteen of the world's 33 most water-stressed countries are in the Near East and North Africa (NENA) region. These include Bahrain, Kuwait, Qatar, the United Arab Emirates, Palestine, Israel, Saudi Arabia, Oman, Iran (Islamic Republic of) and Lebanon. In the Sultanate of Oman, due to the limited supply of freshwater, the development of freshwater aquaculture is also constrained. Therefore, there is a need to develop a culture system (i.e. recirculating) that conserves water and has no adverse effect on the environment. Aquaponics has the potential to produce both fish and vegetables in an environment-friendly and economically efficient way.

Aquaponics is the integration of recirculating aquaculture and hydroponics in one production system (Somerville *et al.*, 2014). Non-integrated aquaculture requires both the removal of excess nutrients from the water and an input of clean water. On the other hand, hydroponics requires a regular provision of expensive packaged nutrients, and routine flushing of the system. Both of these are not completely efficient, and both require outside input and maintenance at frequent intervals. Among the benefits or advantages of aquaponics are: 1) efficient use of water as it is recirculated in the system, 2) little or no discharge of aquaculture wastewater, thus, the environment is protected, and 3) no pesticide use, thus, products are safe for human consumption.

The Sultanate of Oman is promoting the development of aquaponics as it is expected to boost aquaculture output. The Ministry of Agriculture and Fisheries Wealth is supporting some agriculture and aquaculture farmers to go into aquaponics. In addition to the Ministry, some organizations even outside the country are supporting initiatives to develop aquaponic farming in Oman. Furthermore, some individuals are setting up aquaponic projects as a hobby and as entrepreneurial ventures. The Sultan Qaboos University is conducting scientific research to generate scientific knowledge that will contribute to the development of aquaponics in the country.

This paper presents the research and development activities on aquaponics at Sultan Qaboos University and a description of some aquaponic farms in Oman.

2. Aquaponics research and development at Sultan Qaboos University Oman

Aquaponics research at Sultan Qaboos University was first reported by Goddard *et al.* (2010) who produced red hybrid tilapia and tomatoes in an aquaponic system using nutrient film technique at the Rumais Agricultural Research Centre of the Ministry of Agriculture and Fisheries Wealth. The research was extended with funding support from the Agricultural and Fisheries Development Fund of the Ministry of Agriculture and Fisheries Wealth in 2014-2015. New varieties of salad crops and tilapia were successfully grown in a temperature-controlled greenhouse in this research centre.

After I joined Sultan Qaboos University in 2013, I conducted aquaponic experiments with some undergraduate students. With the aim of developing a simple and effective aquaponic system, we set up three culture systems: 1) non-recirculating system without plants, serving as the control, 2) non-recirculating system with plants grown on top, patterned after Liang and Chien (2013), and 3) recirculating system with fish grown in separate tanks connected to another set of tanks for growing plants. The research team tested three fish densities (10, 15 and 20 fishes per 100 l) and evaluated the growth and survival of tilapia and lettuce in recirculating and non-recirculating aquaponic systems. It also compared the growth and survival of fish grown in a non-recirculating non-aquaponic system (control). Furthermore, since it has been reported by Martins *et al.* (2011) that heavy metals are

accumulated in fish cultured in recirculating aquaculture systems (RAS), they also investigated the heavy metal accumulation in tilapia and lettuce in recirculating and non-recirculating systems. Results showed that recirculating aquaponic system resulted in the best growth and survival of fish and plants. As shown in igure 1, of the three fish densities tested, 20 fishes per 100 l tank resulted in the best growth (64 percent higher than non-recirculating system and 120 percent more than the non-aquaponic system). This can be attributed to the better water quality in recirculating aquaponic system, particularly the lower ammonia and nitrite levels.

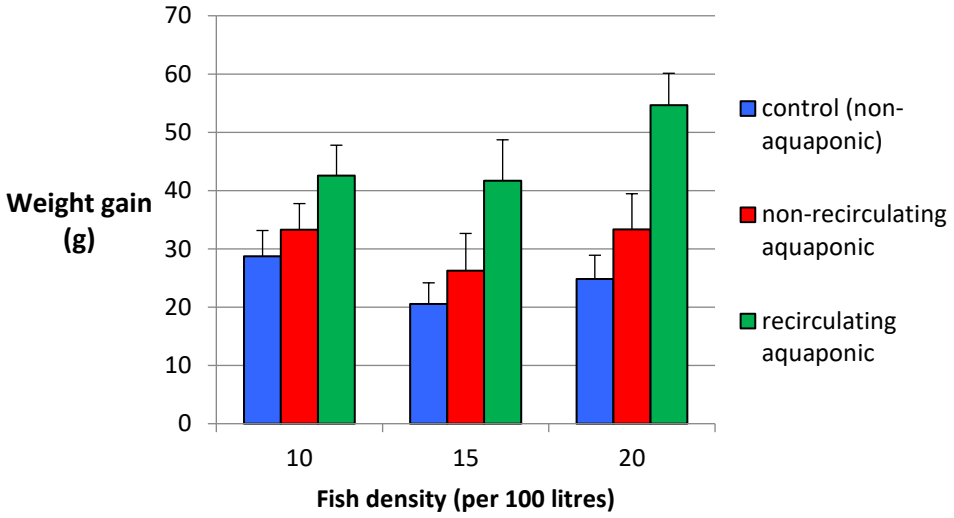

Figure 1: Weight gain of tilapia at three densities for three treatments: control, non-recirculating aquaponic and recirculating aquaponics.

Figure 2 shows that fish densities of 10 and 15 resulted in the best growth of lettuce (Al-Mahfudhi and Gallardo, 2015).

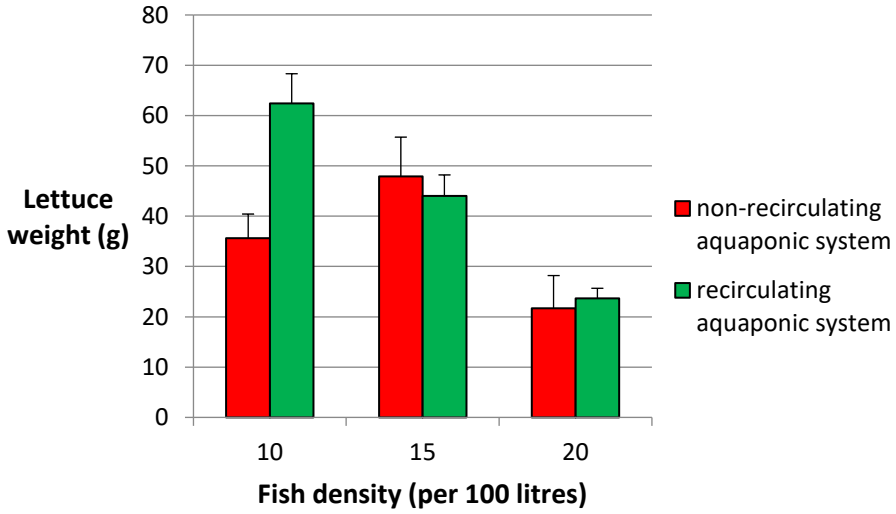

Figure 2: Lettuce weight at three fish stocking densities for three treatments: control, non-recirculating aquaponic and recirculating aquaponics.

Based on the results of the previous experiments, the following are some of the research questions that need to be answered to fully develop a simple and effective aquaponic system suitable for the climate in Oman.

- Considering that the highest density (20 fishes per 100 litres) in the previous experiment resulted in the best growth of fish, would higher densities sustain the best growth and survival of fish and plants? What would be the optimum fish density?
- What plant species would be suitable for aquaponics at different seasons in Oman?
- Aside from tilapia, what other freshwater fish species would be suitable for aquaponics, considering the market price? Would koi carp *Cyprinus carpio* be suitable for aquaponics in Oman?
- Since the previous experiment showed that heavy metals accumulated more in lettuce than in fish, what plant type (fruit-bearing or flowering, i.e. for human consumption or ornamental) would be more suitable for aquaponics? Which type takes up more nutrients and heavy metals?
- Which part (leaves, fruits or flowers) of the plants accumulates more heavy metals?

With some funding from The Research Council of Oman (TRC) through its Faculty-Mentored Undergraduate Research Award Program (FURAP), a follow up project was carried out in 2015 to address some of the above-listed research questions, particularly with the following objectives:

1. To determine the optimum density of fish to be grown in combination with fruit-bearing or flowering/ornamental plant, based on the growth and survival of fish and plants and water quality.
2. To determine what plant type (fruit-bearing or flowering) takes up more nutrients and heavy metals, and which part of the plant (leaves, fruits or flowers) accumulates more heavy metals.

The aquaponic system consisted of 16 rectangular tanks (80x40x40 cm) containing 100 l of tap water stocked with different densities of fish (20, 25 and 30 fish per tank). The fish were grown in combination with either lettuce and flowers or lettuce and beans (Figure 3). The fish were fed three times daily and measurements of their weight and length were taken every two weeks. Plants (lettuce, beans, and flowers) seedlings were planted on a styrofoam raft with holes for the roots to extract water and nutrients (fish waste and residual feeds) they need to grow.

Figure 3: Aquaponic experiments conducted Sultan Qaboos University.

The final weight of tilapia in all stocking densities (20, 25 and 30 fish per tank) was higher when grown in combination with lettuce and flowers than with beans and lettuce. Final weight of plants was highest among those grown in combination with fish at 20 fish per tank. Highest average weight of lettuce was at 20 fish per tank. Growth and survival of fish at different densities was not significantly different but 30 fish per tank is recommended based on economic consideration.

Another experiment tested several plant species (lettuce, cabbage, chili, eggplant, *Petunia* and mint) and results showed that mint grows and survives more than the other plants even in summer when temperature goes up to 40°C or sometimes higher (Figure 4).

Figure 4: Comparison of the performance of several plant species in aquaponic.

The next project in 2017 funded again by The Research Council of Oman through its Faculty-Mentored Undergraduate Research Award Program focused on culturing the commercially valuable Japanese koi carp together with suitable plant species in an aquaponic system. Tilapia is the most commonly used fish species in aquaponic systems because they can tolerate poor water quality but it has low commercial value in Oman. On the other hand, koi carp has very high commercial value (OMR 5 / USD 13 per juvenile, OMR 50 / USD 130 per breeder) and has potential for culture in an aquaponic system because it can also tolerate a wide range of environmental conditions. However, research on their growth, survival, optimal stock density in an aquaponic system should be carried out to determine its feasibility. Based on our literature search there is only one research paper on the culture of koi carp in an aquaponic system. Hussain *et al.* (2014) tested three stocking densities of 1.4, 2.1 and 2.8 kg/m^3 and reported that 1.4 kg/m^3 resulted in highest growth. However, it is possible that a lower density of 1.4 kg/m^3 may be the optimum. Therefore, our next research had the following specific objectives:

1. To determine the optimum density of koi carp in an aquaponic system (Figure 5);
2. To determine the suitable plant species that can be grown in combination with koi carp;
3. To determine the water quality and nutrient concentration in the water and plants grown in the aquaponic system.

Eighteen units of glass tanks (80x40x40 cm) containing 100 litres of tap water were set up in pairs. All tanks were identical allowing replication of experimental treatments. Nine of the 18 tanks were without plants the other 9 tanks were with plants. The fish tanks without plants were placed on a platform while the fish tanks with plants were placed on the floor. All tanks were connected with air stones to provide dissolved oxygen to the fish and plants. Each fish tank without plants was connected to a fish tanks with plants with a pipe or hose to allow water flow from the fish tank without plants to the fish tanks with plants by gravity. The fish tanks with plants had gravels on the bottom and a vertical layer of gravels in net bags on one end of the tank before the submersible pump to filter the water from solid and bring the filtered water back to the fish tank without plants. Each tank had a 3 cm thick Styrofoam covering the entire water surface. For fish tanks without plants there was a small opening for the feed to be given. For fish tanks with plants, each Styrofoam cover (polyethylene raft) had 13-15 evenly-spaced holes for the plants.

Two experiments were conducted in this project. In the first experiment, koi carp postlarvae with an average of initial weight of 0.3-0.5 g were stocked in each tank at 50, 100, 150 individuals per tank (0.1 m^3). The lower 9 tanks were planted with peppermint and *Petunia*. Both plants were cut (10 cm long) and wrapped around with cotton on the lower part and placed in a plastic seedling container with open bottom to allow the roots to go down into the water. In the second experiment, the upper 9 tanks were used to grow koi carps of the initial weight of around 6 g at a stocking density of 30 juvenile per tank. The lower 9 tanks were used to grow peppermint, eggplants and tomatoes. The same growing method was used as the first part.

Figure 5: Koi carp used in aquaponic experiments at Sultan Qaboos University.

Results show that koi carp stocked at 100 per tank had significantly better growth. Survival rate was highest at 50 per tank. Pepper mint growth was better in tanks with 50 fish per tank. *Petunia* had flowers in all treatments. Water quality parameters were within optimal range even at high fish stocking densities. Overall, stocking density of 50 fish per tank can be recommended based on survival data. In the second experiment, 30 koi carp juveniles were stocked in all tanks and the results showed that the best growth and survival of koi carp was in combination with peppermint.

Our initial experiments in non-greenhouse condition show that koi carp can grow well with mint in an aquaponic system. Our previous aquaponic experiments in non-greenhouse condition since 2014 using tilapia in combination with lettuce, tomatoes, chili pepper, eggplant, cabbage, mint and the ornamental flowering plant *Petunia* have shown that most of these plants grow well only in winter (Dec-Jan) in Oman while mint can grow well year-round, even in summer (Gallardo, 2017). However, mint has low market price in Oman.

Many high-value plant species that can grow well in an aquaponics system require a suitable temperature below 30°C but in Oman, the temperature is above 30°C most of the year, thus there is a need to use a temperature-controlled greenhouse. With funding from SQU Deanship of Research, we conducted aquaponic experiments in a greenhouse to test high-value species of plants (e.g. strawberry, lettuce, cabbage, cauliflower) that require cool and stable temperature. The following are the specific objectives of the experiments:

- To determine the best plant species that can be grown in floating versus media-based aquaponic system in a greenhouse;
- To compare the water quality and growth and survival of fish (tilapia versus koi carp) and plants grown in a floating versus media-based aquaponic system in a greenhouse;
- To evaluate the cost and benefit of an aquaponic system in a greenhouse.

Results are being analyzed and will be published later.

3. Aquaponic farms in Oman

With the support of FAO in Oman, Sultan Qaboos University is currently conducting a survey of aquaponic farms in Oman to document the technical and socio-economic aspects of the existing farms. The survey is part of a regional project within the framework of FAO Water Scarcity Regional Initiative (WSI) for the Near East and North Africa Region, titled “Use of non-conventional water in agriculture

in support to sustainable agri-aquaculture development in desert and arid lands in MENA". It is being implemented in three focus countries: Algeria, Egypt and Oman.

The research team from Sultan Qaboos University is composed of Wenresti Gallardo, Hussein Al-Masroori, Adil Al-Sulaimani and Ahmed Al-Souti and the collaborators from FAO-Oman are Nora Ourabah Haddad, Ghady Chedrawi and Hasna' bint Mohammed Al Harthyiah.

Based on initial findings of the survey, there are at least 14 aquaponic farms particularly in and around Muscat. The farms that have been visited are described below.

Al Arfan farms

Figure 6: Al-Arfan aquaponic farms.

Considered as Oman's largest aquaponic farm established by Muscat Horizons International, this state-of-the-art 600 m2 aquaponic pilot greenhouse facility is 50 km from Muscat, the capital of the Sultanate of Oman. It aims to promote and develop a commercial model that may be replicated in Oman for its farmers at an economical and operationally feasible scale.

The aquaponic system uses media beds and deep-water culture troughs to grow different species of plants such as lettuce, basil, kale, Swiss chard, tomatoes, etc. in combination with Omani-bred tilapia. The farm is already producing vegetables that are sold in major hotels and supermarkets in Muscat. More information on the farm are available at www.omanaquaponics.com/.

Al-Rayan farm

This farm owned by Mr. Ghassan Al-Bahrani was established in 2010 by growing cucumbers, pepper, lettuce and basil in greenhouses. He started with two greenhouses and currently has 26. In July 2017 Mr. Al-Bahrani utilized one greenhouse and started an aquaponic project with the support from the Ministry of Agriculture and Fisheries which provided 500 pcs of fish (tilapia), aquaponic equipment, feeds and organic fertilizer. Due to lack of freshwater, well water with a salinity of 30 ppt undergoes desalinization to reduce the salinity to 3-4 ppt. Plants grown in the aquaponic system are mostly lettuce/salads. Iron is added to the water since fish feeds lack iron which the plants need. A mixture of essential amino acids and seaweed extract is also added to increase nutrients in the water. The farm has an alarm system that sends a message in case of electricity shutdown that would cut off the aeration and endanger the survival of the fishes.

Figure 7: Al-Rayan aquaponic farm.

Al Lezegh farm

Al-Lezegh aquaponic farm was started in 2010 in collaboration with an organization based in the United Kingdom. This farm is unique because it uses the traditional irrigation system (aflaj) bringing water from the mountains to the agricultural lands. The benefits of using this water is that it does not contain any pollutants. Water from the aflaj is pumped to the aquaponic system which recirculates the water between fish and plant tanks. The cultured species in the aquaponic farm are tilapia and Greek basil.

Fish are cultured in fiberglass tanks (half ton capacity) in which they are provided with aeration and feeds. The water from the fish tank goes through a biofilter where the metabolic waste ammonia is converted to nitrite and then to nitrate which serves as nutrient for the plants. The water with nutrients is then pumped to the hydroponic system (plant tank). Water is recirculated as much as possible but when it is not anymore suitable, it is used as irrigation water for the plants grown on soil (agriculture).

Figure 8: Al-Lezegh aquaponic farm.

The farm gets more income from the sale of the plants (basil) than the fish (tilapia) which are both sold locally. Basil are harvested every 6 months while tilapia are harvested every 4 months at a price of OMR 2.5 (USD 6.5) per kg and OMR 1.5 (USD 3.9) per kg, respectively. There is a need to advertise and promote the products so that they can be sold in big hotels, restaurants, markets and shops.

MAFW Rumais Agricultural Research Centre

Figure 9: Ministry of Agriculture and Fisheries Wealth, mais Agricultural Research Centre.

This centre under the Ministry of Agriculture and Fisheries Wealth (MAFW) conducts research and workshops for farmers on the latest technology and field practice in agriculture. It has a research agreement with the farmers to provide them with greenhouse, water, seeds, electricity and technical expertise to grow plants.

The center has several greenhouses but one is for the aquaponic system which has an area of 1 m^2 that can grow about 9 kg of lettuce and 13.5 kg of tilapia. Agricultural fertilizer is not used as the nutrients for the plants come from the fish tanks. However, they are using commercially available iron fertilizer as a supplement as the fish feeds and wastes do not have enough iron which the plants need. Leaves of the plants become yellowish due to lack of iron.

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MALAGASY INTEGRATED AQUACULTURE-AGRICULTURE

Diana Edithe Andria-Mananjara, Philippe Martel, Modestine Raliniaina, Rija Andriamarolaza, Domoina Rakotomanana, Olivier Mikolasek, Jean Michel Mortillaro

1. Introduction

Aquaculture is one of the most relevant activities to fight poverty and hunger in Madagascar. The sector contributes to foreign revenues through exportation of seaweed and farmed shrimps, as well as to improve population incomes, food security and nutrition (FAO, 2008). Moreover, it has been identified as a promising sector for keeping pace of growing demand and overfishing pressure. Inland aquaculture, mostly finfish farming, is the dominant practice among small farmers but still, its production remains marginal compared to marine aquaculture and inland fisheries. In 2017, the Malagasy marine aquaculture produced 5 439 tonnes of shrimps and 17 407 tonnes of algae, and inland fisheries, 35 993 tonnes (FAO, 2019). In the meantime, freshwater finfish farming harvested only 5 390 tonnes (FAO, 2019). However, the potential of the sector is still largely untapped, with Madagascar having about 150 000 ha of lakes and lacustrine areas and 200 000 ha of irrigated paddy fields appropriate for fish farming, of which less than 20 percent are exploited (MRHP, 2015). One relevant way of increasing the national farming of freshwater fish, while benefiting from synergies, recycling and circular economy is to integrate fish farming into existing agricultural systems. Over the years, Madagascar farmers have championed this integrated aquaculture-agriculture by implementing several systems described in this article.

2. Rice-fish farming

The integration of aquaculture and agriculture is traditional and diverse in Madagascar but rice-fish farming is the most common and oldest practice. It consists in raising rice and fish together in the same irrigated field to obtain a fish crop in addition to the rice which remains the main production (Halwart and Gupta, 2004). Fish feed on the rice midge larvae, pest and other undesirable organisms for rice. Their excreta provides fertilization and their bioturbation behaviour increases the nutrient availability for plants such as nitrogen and phosphorus. Traditional rice-fish farming requires reasonable amounts of labour and inputs: farmers just trap wild fish entering water from irrigation canals, ditches and rice fields and let them grow until rice harvest or later. In some regions, another rice fish system was introduced, in which dykes are made high enough to retain a sufficient water depth for the fish. A canal is also dug in the field and used as fish refuge. Livestock manures can also be provided as a fertilizer benefiting both rice and fish.

Malagasy rice-fish farming is probably as old as rice cultivation itself and goes back to the royal era (Dabbadie and Mikolasek, 2017) but it is only after 1950, after common carp and tilapia were introduced in the country, that the use of improved practices started to be observed and spread (Lemasson, 1954, 1957). Unfortunately, in the absence of government's subsidies, the process stopped and declined until FAO started to implement various projects from 1985 (Oswald *et al.*, 2016). The FAO approach was based on the privatization of fry production as well as on the promotion of the common carp stocking into the rice paddies (Dabbadie and Mikolasek, 2017; Oswald *et al.*, 2016). Since 2006, this FAO method was taken over, improved and implemented in 7 regions of Madagascar by the NGO APDRA to support smallholders and promote culture of carp in rice fields. Improvements include the rice plot construction according to the rearing stage, the use of fertilisation and affordable supplementary feeding in production, and the support to small-farmers hatcheries network. Rice plot construction consists of building a spawning pond of 3*3 m inside the parcel (Figure 1) for fry production and increasing side dikes and digging a fish refuge channel (Figure 2) for growing fish (APDRA, 2018a).

Figure 1: Spawing pond within rice plot for hatcheries.

Figure 2: Rice fish farming using fish refuge channel.

According to the Ministry of Fishery and Fish Resources (MRHP), there are currently 21 000 rice-fish farmers in operation throughout the country (MRHP, 2015), producing mainly Common carp with rice. Wild species involuntarily introduced in rice fields such as tilapia or *Carassius* sp. can contribute to secondary production of rice plots by up to five percent of the total harvested fish weight, providing an interesting additional income for farmers (APDRA, 2018b).

The production cycle depends on the objective of the farmer (fry production or fish growing-out), as well as market access and water availability. Generally, fry production period extends from September (end of August for the earliest) to December. However, to meet the late demand of fry for some fish growers, particularly on February, March or after floods, some fry producers try to postpone their spawning period at the beginning of the year. In most cases, fish growing-out is conducted during the rice production period (from November to June), but it may also continue after the rice harvest to get bigger fish. Fish yields change across regions, with natural productivity of the paddy and depending on the technical operations used by farmers (e.g. fertilization or fish feeding). For instance, in the highland, the average common carp yield is 200 to 300 kg/ha/year(APDRA, 2018b; Dabbadie and Mikolasek, 2017). According to AMPIANA (2019) , one of fish project working in the highland of Madagascar,

the 2018 -2019 breeding campaign allowed a production of 1 150 000 fry with an average of 5 000 fry/hatchery.

Production data on integrated rice-fish production are still lacking but a study conducted in 2016-2018 showed that the stocking of carp in rice field enables the rice yield to increase by 19 percent to 31 percent if climate conditions are favourable (Mortillaro, Raminoharisoa and Randriamihanta, 2018).

Beside this traditional rice-fish farming system, another integrated practice has been experimented by APDRA with fish farmers on the east coast of Madagascar. Instead of stocking fish in rice fields, it consists in planting rice in fish ponds, as already practised in West Africa (Keita, 2019). During the 2015-2016 rice campaign, 82 percent of the fish farmers supported by APDRA harvested rice in their ponds, in addition to 765 kg fish/ha. According to APDRA (2017), the success of the system requires a good water management and good choice of rice variety.

3. Tanjona integrated crop-fish farming

Tanjona system is a new kind of integrated aquaculture system that emerged recently in the floodplains surrounding Antananarivo, the capital of Madagascar. The term Tanjona refers locally to a large dyke built in the middle of the floodplain (Figure 3), which serves as an emerged land plot that can be used for various crops during the rainy season, or for fruit orchards (in particular orange trees) throughout the year. Tanjona are not recent, as they were already mentioned in 1962 (Kiener, 1962). However, it is only recently, since 2000, that fish farming has been integrated in the system by connecting several dykes to each other, in order to delimit an enclosed water body inside, which can be used as a pond. While fish farmers were initially stocking wild fish in their ponds by trapping them during the flooding season, some progressively intensified their system by purchasing fry and feeding them.

Figure 3: Tanjona system in Fenoarivo, Madagascar.

A study conducted in Fenoarivo, a suburb locality where Tanjona systems are widespread, allowed to identify 27 integrated fish farmers (Mortillaro *et al.*, 2017). Two types of fish farming practices have been identified. The first type consists in practising fish farming in ponds and crops/orchards on dykes. With a production cycle of 6 to 12 months, the average fish yield is between 0.7 and 1.3 tonnes/ha.

The second type of Tanjona consists in an integrated rice-fish farming in the flooded part of the system combined with crops/orchards on dykes. The fish cycle is shorter (6 to 9 months) and the average fish yield observed in this system is between 0.3 and 1 tonne/ha.

Generally, fish are raised in polyculture and are fed on crops residues. Zebu waste is exclusively destined for fertilization of rice and vegetable fields, not for fish ponds. However, duck are sometimes introduced in the system after the crop harvest, to feed on plant residues and fertilize the water. The

Tanjona system provides essential financial resource for households, from 3 to 26 percent of additional income.

4. Livestock fish farming

By combining livestock such as cattle, pig or poultry with fish, animal excreta and waste food serve to stimulate water productivity, natural feed production and fish growth, as well as delivering other symbiotic benefits for both animals (Barash, Plavnik and Moav, 1982).

In Madagascar, integrated livestock-fish was first tested and carried out by FAO in the 1960s (Muir, 1981). Given its importance in Madagascar rural areas, it is common to see cattle used to provide manure to fertilize ponds or rice fields, even though it is not its sole purpose. It can also be used for labour and fish ponds construction. Some farmers also practice duck-fish farming to maximize the use and productivity of their water bodies, benefit from synergies and recycle nutrients. In 2016, 32 percent of the pond fish farmers supported by APDRA on the East coast of Madagascar had at least one livestock in their aquaculture system, and for 18 percent it was a poultry farm (chicken, duck, or goose) (APDRA, 2017).

On the other hand, some fish farmers with access to intensive farm wastes like pork or poultry manures have been able to significantly increase their fish production by transforming animal waste into other sources of animal protein for fish. One such example is a farmer using poultry litter to produce maggots serving as fish feed. With this method, it is possible to obtain 9 tonnes/ha of fish for a 15 months production cycle (Loharano Andriantafita, personal communication, 2017).

Unlike other countries, in Madagascar, the livestock farm is seldom located nearby or over the pond to facilitate the collection of manure and waste, because of the distance between the farmer's house and the fish ponds, which are often located in the lowlands. Organic fertilizers are also frequently used for other farm production than fish.

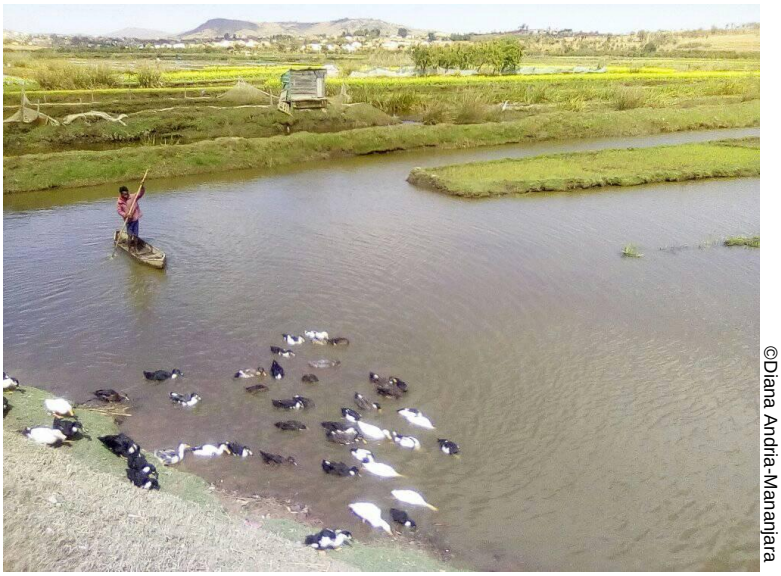

Figure 4: Duck-cum-fish farming in pond in Vatomandry, Madagascar.

5. Advantage of integrated aquaculture

The main benefit of integrated fish farming is the synergies between livestock, crops and fish. The first one is related to the nutrients transfer between them. Indeed, fertilizers from livestock are reused by fish and crops for their growth. Fish in turn fertilize water with their excrements and improve the availability of some nutrients like nitrogen and phosphorus through bioturbation (Mortillaro,

Raminoharisoa and Randriamihanta, 2018). Conversely, crop residues are used to feed directly or indirectly livestock and fish. Other benefits include the reduction in pest occurrence when fish eat crop pest. The main consequence of this recycling and synergies is the reduction of production costs for farmers.

Integrated aquaculture allow farmers to significantly improve their living conditions. Food is more readily accessible and available, and household incomes benefit from the sale of additional farm products. For example, fish farming contributes to 2 to 11 percent of the gross added value of rice fish farmer households (Randrianandrasana, 2017) and 3 to 26 percent of the gross added value of Tanjona farmer households (Mihaja Rakotoarinoro, personal communication, 2017). The additional income can improve family life, social activities, child wellbeing or education, or be used for investing in other activities or farm expansion.

6. Constraints of integrated aquaculture

In Madagascar, land availability is a major problem for many small-scale farmers. Indeed, integrated aquaculture requires access to favourable land. Favourable refers to water, its accessibility and the ability of the parcel to retain water for a long time without being exposed to natural hazard such as flood or drought. Unfortunately, the majority of these parcels belong to wealthy families. As a result, smallholders tend to use plots that are more vulnerable to climatic hazards (especially flood) and their land productivity is lowered.

Another issue is land ownership. In connection with their social status, the most common way for smallholders to have access to land is through renting or sharecropping. Five percent of the Malagasy rice fields are concerned by these methods (Burnod *et al.*, 2014), which is problematic as it may prevent farmers from investing into pond or rice-fish plots construction and/or expansion.

Another constraint relates to climate changes and hazards. In some cases, early or late beginning of the rainy season disturbs the cycle of production and creates a financial risk for farmers. In other cases, flood can result in fish escapees, crops destruction or dikes crumbling. For livestock, especially cattle, climate change can also induce a whole range of issues, especially with regards to new diseases.

Integration implies the diversification of activities, but it is not always easy for farmers to manage a new production that requires more investment in terms of finance, farm inputs and labour. With aquaculture, the main expense after construction is the fry purchase for stocking, which coincide with the lean season from September to January, when food shortage occur and school expenses are needed.

Last but not the least, theft is a constraint identified by many farmers, especially those producing fry as the loss of a common carp breeder is a big financial loss. Plots surveillance and monitoring is only possible if the house is not too far.

7. Prospects

Integrated Aquaculture-Agriculture has proven to be successful in many of the most advanced aquaculture countries such as in Asia (De Silva and Davy, 2010) thanks to its resilience. Although local studies have also shown its importance in Malagasy farms, its contribution is not yet fully perceived at the government and policymakers' level. Adoption and operationalization of development strategies that consider the economic and social benefits and constraints of integrated aquaculture, especially for small-scale farms and households, should be developed.

Current production yields are still quite low and very heterogeneous compared to other countries. This will require further research and support for the development of a more appropriate technical model for Madagascar, which takes into account the socio-agro-climatic constraints of the different regions.

Finally, a study of the evolution of integrated aquaculture-agriculture farming systems should be conducted in order to understand fish farming appropriation in the system, its impact on households, communities, farming systems and potential risks related to the system intensification.

8. Conclusion

The integration of aquaculture with agriculture and/or livestock is a very relevant activity for farmers in Madagascar, who generally have very limited inputs. Thanks to the synergetic effects of the integration, households can intensify and diversify their production in order to increase their incomes. But efforts should still be made for its mainstreaming at national level, by taking into account the socio-agro-economic disparities between regions.

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PISCIRIZICULTURE: THE GUINEAN FISH-RICE CULTURE

Sidiki Keita

1. Introduction

Guinea is a West African country covering 245 857 km^2, covering four main agro-ecological natural regions: Lower Guinea, Central Guinea, Upper Guinea and Guinea Forest Region. The climate is tropical, with a monsoon-type rainy season lasting from April to November, except in the Sahelian Upper Guinea where it is shorter, with greater daily temperature variations.

Guinea's topography varies from coastal plains to inland mountains that account for about 60 percent of the country. Several of the West Africa's major river systems, in particular the Niger, Senegal, and Gambia, originate from these highlands, making Guinea the "water tower" of West Africa. The country is drained by 1 161 rivers grouped into 23 watersheds, 14 of which are international. There are also many perennial and temporary natural water bodies, as well as artificially created reservoirs that can be used for fish production (Figure 1). Guinea's coastline is 300 kilometres long and has extensive mangrove swamps partially converted into rice-growing areas.

Guinea has a population of about 11 million people,[23] more than two thirds of which live in rural areas (69.4 percent). An estimated 74 percent of the country's population is younger than 35 years old. Fish is an important source of animal protein for Guinean populations, although its contribution to diets dropped sharply from 46 percent to 27 percent between 1993 and 2013 (Figure 2). Nevertheless, in rural areas where the population rely mainly on agricultural activities, it's a crucial commodity and represents nearly 85 percent of the total animal protein intake (MPAEM, 2017). The wild fish catches have been stagnating around 100 000 MT for the marine capture and 30 000 MT for inland fisheries in recent years (FAO, 2019a), as a result of overfishing and environmental degradation. The contribution of fish to people's diets, food and nutrition could thus decline even more in the future, owing to demographic growth.

[23] Last national population census in 2014: 10 523 261 inhabitants. The average annual growth of the population is calculated at 2.5 percent per year (2010-2015).

Figure 1: Guinean fish production potential and fish farming practices.

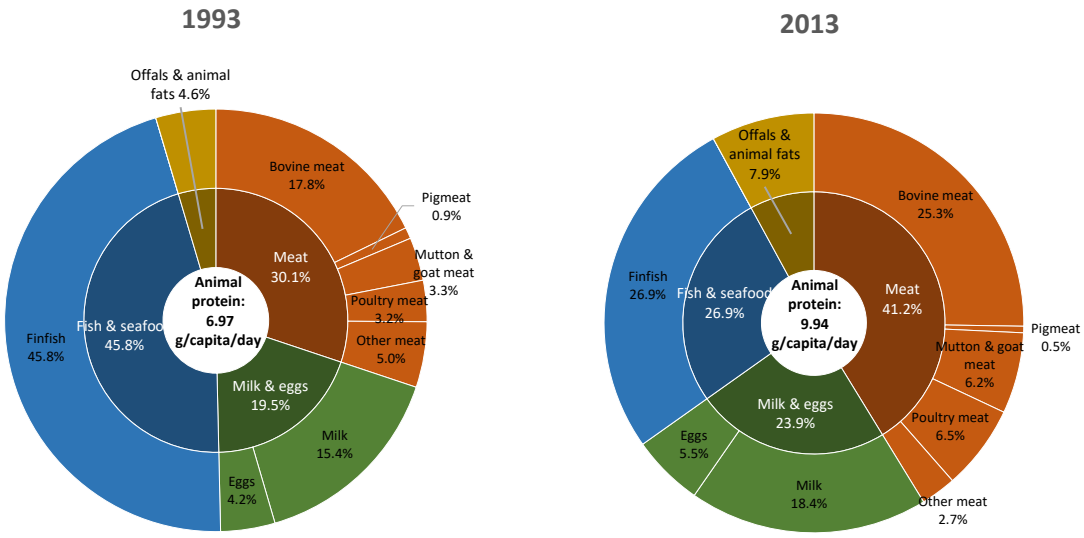

Figure 2: Composition of per capita protein intake from major animal products in Guinea, 2013 versus 1993 (WAPI, FAO 2019b).

To address this issue, the government of Guinea decided to invest in fish farming, to make it a sustainable alternative to meet the demand for fish, to diversify the rural income, to empower women and to create jobs for the youth. Strategic programs like the Accelerated Food Security, Nutrition and Sustainable Agriculture Development Program (PASANDAD) and the National Program for

Agricultural Investment, Food Security and Nutrition (PNIASAN) were created to attain the 2030 Agenda and the Sustainable Development Goals (SDGs).

2. Importance and current trends

A wide range of technical models for fish farming are feasible in Guinea, due to the diversity of the country' water resources: ponds, tanks, floating cages, pens etc. However, the most common and successful practice so far is an integrated system that combines the cultivation of rice and pond fish farming, called "pisciriziculture (fish-rice culture)". It consists in growing rice inside fish ponds and differs from raising fish inside irrigated paddy fields, commonly known as rice-fish culture or rizipisciculture.

Even though the two systems produce the same outputs (rice and fish), their technical models are different, as are the respective economic contributions of their crops. The analysis of some indices over 10 years of practical experience shows that this unique concept of fish farming developed in Guinea is a replicable technology, a profitable investment and a production system accessible to smallholders and family farmers as it improves income and strengthens food security and nutrition of their families.

A large number of projects have contributed to the emergence of this Guinean pisciriziculture concept, in particular those funded by the French Development Agency (AFD), and implemented by the French NGO APDRA Pisciculture Paysanne in partnership with the French Centre for International Cooperation on Agronomic Research for Development (Cirad). Experiences from fish farming interventions funded by other Technical and Funding Partners (TFP) such as the Food and Agriculture Organization of the United Nations (FAO), the French Research Institute for Development (IRD), the French NGO Veterinarians Without Borders (VSF), the Japan International Cooperation Agency (JICA) and the African Development Bank (AfDB) have also helped to boost and refine the system. Table 1 presents some of the projects implemented, their targets and achievements.

Table 1: Targets and effective fish production (metric tonnes) for completed, ongoing and upcoming projects (2016-2017 production cycle)[24]

N°	Project name	TFP	Fish production (t)			Comments	Next steps
			Target	Real	Deficit		
1	PDRPGF	AFD	350	283	67	Completed. Activities were delayed by Ebola.	Preparation of a new project
2	WAAPP	WB	500	101	399	Delayed start	Implementation
3	PGIR/ OMVS	WB	50	2	48	Ongoing	Speed-up implementation
4	SARITEM	AFD	20	0	20	Delayed start	Speed-up inception
5	PAFISAM	AFD	5	0	5	Ongoing	Implementation
6	PCHG	JICA	20	0	20	Under preparation	Under negotiation
7	PISCO-FAM	AFD	0	0	0	Awaiting signature	Start-up after signing
8	AGRI-FARM	IFAD	0	0	0	Under preparation	Start-up in 2018
9	PDAID	WB	0	0	0	Under preparation	Start-up in 2018
10	Others	-	2 453	106	2 347		
Total 2017			3 398	492	2 906		

Most of the interventions to promote fish culture are currently carried out in the Guinea Forest Region (Figures 3 and 4) by implementing an institutional vision promoted by the DNP and the sector's regional professional organization (FPRGF - Federation of fish-rice farmers in Guinea Forest Region).

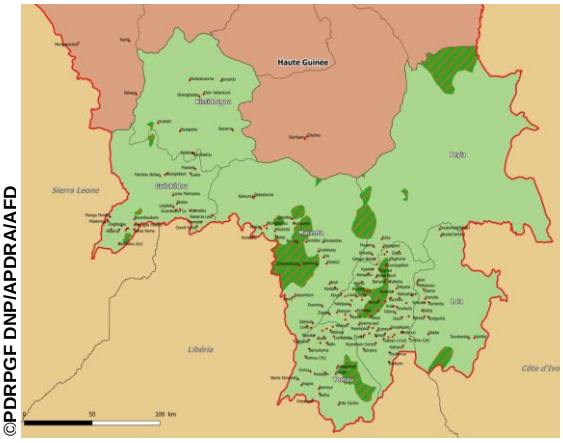

Figure 3: Location of the fish farming areas in Guinea Forest Region (dark green).

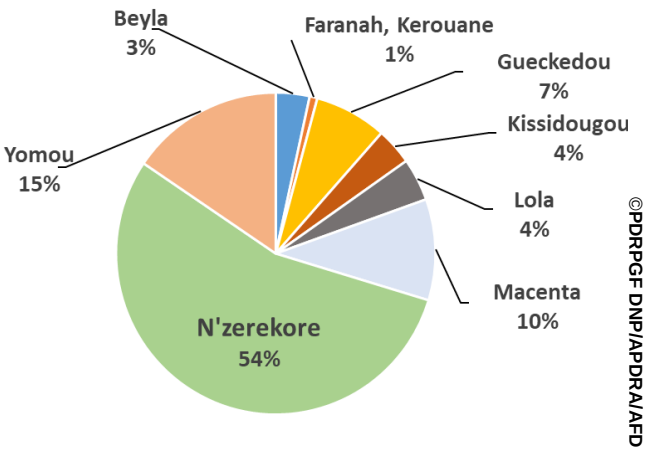

Figure 4: Location of the fish farmers of the Guinea Forest Region.

Table 2 present the expenditures of one of the main fish development project. Major support was needed for of production (56 percent of the expenses), farm infrastructure (22 percent) and technical assistance

[24] The 2018 challenge for rural fish farming investment through Public-Private Partnership schemes can be calculated at 4.178 T (production deficit for 2017 of 2.906 T + increase of production target for 2018 of 1.272 T).

(21 percent). Given the present state of development of the sector, the budget assigned to marketing and fish processing is still minor (less than 1 percent), but this should change in the future when the latter will become more and more important as a result of an increased production (Table 2).

Table 2: Expenditures of a fish farming project (currency: EUR)[25]

Budget lines	2017	2018	2019	2020	Total
Technical assistance, action research, training	2 000 000	1 250 000	700 000	450 000	4 400 000
Pond construction, building of technical facilities	1 198 942	1 294 410	1 089 000	1 114 000	4 696 352
Fish production (breeding, stocking, management, training)	3 053 562	2 953 440	2 933 440	2 933 440	11 873 882
Fish marketing	1 402	1 926	2 648	2 888	8 864
Fish processing	28 034	38 528	52 965	57 750	177 277
Total	6 283 957	5 540 322	4 780 072	4 560 098	21 156 375

In Guinea, the total number of registered fish farmers is 2 372, of which nearly 85 percent are assisted by different TFP intervention projects. The commercial agro-ecological fish farming "piscirizículture" system has rapidly expanded in the Guinea Forest Region (Figure 5), highlighting that it is filling a gap and answering a need in rural areas. The current annual production of fish-rice farming in Guinea is estimated at 660 tonnes of fish and 856 tonnes of paddy rice. Recent average production figures of the AFD funded PDRPGF project, reaching almost 1 tonne of fish and 2.5 tonnes of paddy rice per hectare of barrage pond, show the relevance of the model of which the productivity could still be increased through action-research and valorisation of endogenous innovations.

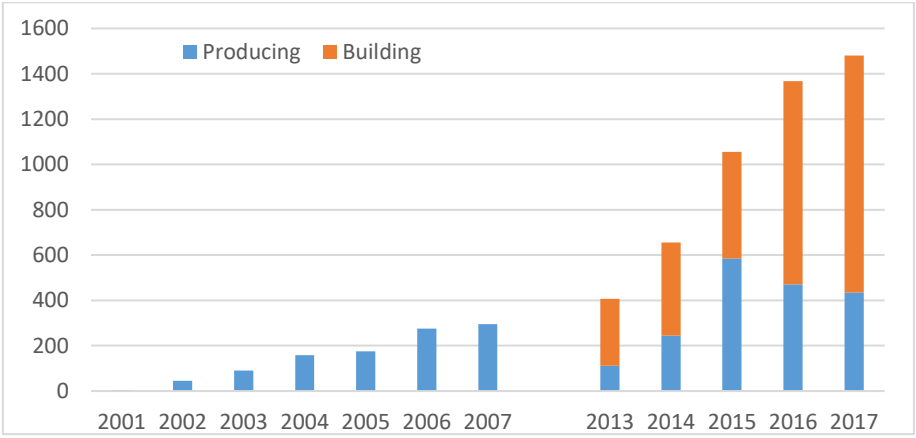

Figure 5: Number of fish farmers supported by PPGF[26] and PDRPGF[27] projects. Farmers already producing are highlighted in blue whereas those in orange are in the process of building their production facilities (no disaggregated data available before 2013).

The selected approach of beneficiaries was highly participatory, involving the fish farmers at all stages. Young unemployed graduates received training to allow them to create their own specialized private

[25] EUR 1 = USD 1.1-1.2
[26] PPGF: Fish Culture Project in Guinea Forest Region financed by AFD (1999-2008).
[27] PDRPGF: Fish-Rice Culture Development Project in Guinea Forest Region financed by AFD/EU (2012-2017).

sector services and provide technical assistance to the producers. They were thereafter contracted by several development projects.

More recently, in response to the fast growing demand for technical support, the intervention approach has been updated to cope with the upscaling challenge (Figure 6). It is now focused on the technical accountability of selected experienced producers who provide advice and assistance to new fish farmers, and of specialized private service providers. This allows for a quick expansion and upscaling of the development of pisciriziculture in the region.

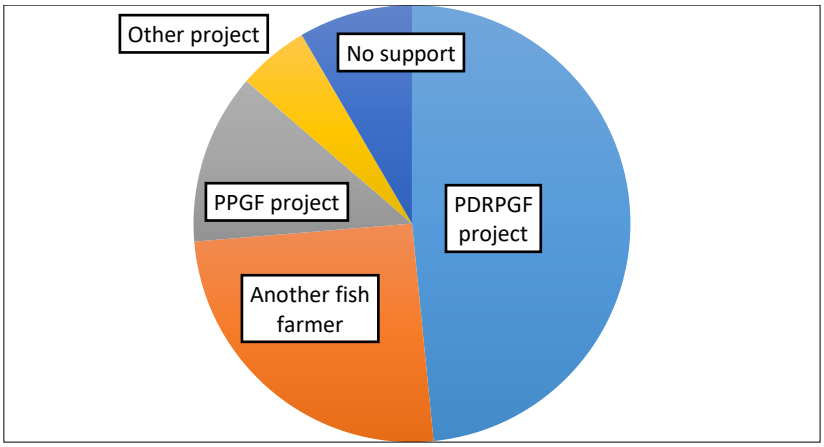

Figure 6: Sources of technical support provided to fish farmers.

In terms of production, tilapia accounts for 65 percent of the harvest in weight (Oreochromis niloticus but also some Tilapia zillii incidentally introduced from the wild). Other farmed species include Heterotis niloticus (23 percent of harvest) and catfish (10 percent of harvest). Other species account for less than 2 percent of the harvested volume. They consist mainly in fry predator fish Hemichromis fasciatus (that is generally kept by the farmer for restocking) and miscellaneous other wild species (Figure 7).

Figure 7: Main farmed fish species: *Heterobranchus isopterus* (top), *Hemichromis fasciatus* (middle, left), *Oreochromis niloticus* (middle, right), *Heterotis niloticus* (bottom).

Sixty-five percent of the harvest is sold on farm or at nearby local markets. Depending on the location, fish species and size, the average selling price varies between EUR 1.5 to 5 per kilogram (Table 3). The remaining 35 percent serves mainly for family consumption and/or gifts.

Table 3: Fish selling prices per species and size in Guinea Forest Region

Species	Individual weight (g)	Price per kilogramme (EUR[28])	
		Farm gate	Urban market
Oreochromis niloticus	150	1.4	1.7
	180-200	1.5	2.0
	200-350	2.5	3.2
Heterotis niloticus	600	4.0	5.0
	2 000 (breeder)	6.0	7.0
	3 000 (breeder)	6.0	8.0
Heterobranchus isopterus	800-2 000	3.0	5.0

3. Technical steps

Although there is no prescriptive technical guidelines, the fish-rice farmers tend to follow similar production patterns (Figure 8), which are:

- Preliminary steps (first year only): Infrastructure set-up - topographic survey, marking out of the ponds and ponds/facilities (monk, inlet, outlet etc.) building;
- Sowing of rice nursery;
- Water immersion until plant material is decomposed;
- Lowering of the pond's water level until submersion is limited to the monk area: as a result, 80 percent of the pond surface is drained;
- Transplanting rice seedlings from rice nursery to pond in July/August;
- Gradual filling of the pond: This should start at the earliest 7 days after transplanting of rice seedlings;
- Progressive stocking of the pond with different fish species at recommended stocking rates;
- Managing of the fish growing-out through regular sampling and partial harvests; Removal of fingerlings reproduced in the pond and invasive species like Tilapia zillii (until October);
- Rice harvest in November/December;
- Fish harvest in November/December/January;
- Restarting a second growing out cycle in January/February using off-season rice or doing a fish growing-out without rice;
- Second harvest in May/June/July.

[28] EUR 1 = USD 1.1-1.2

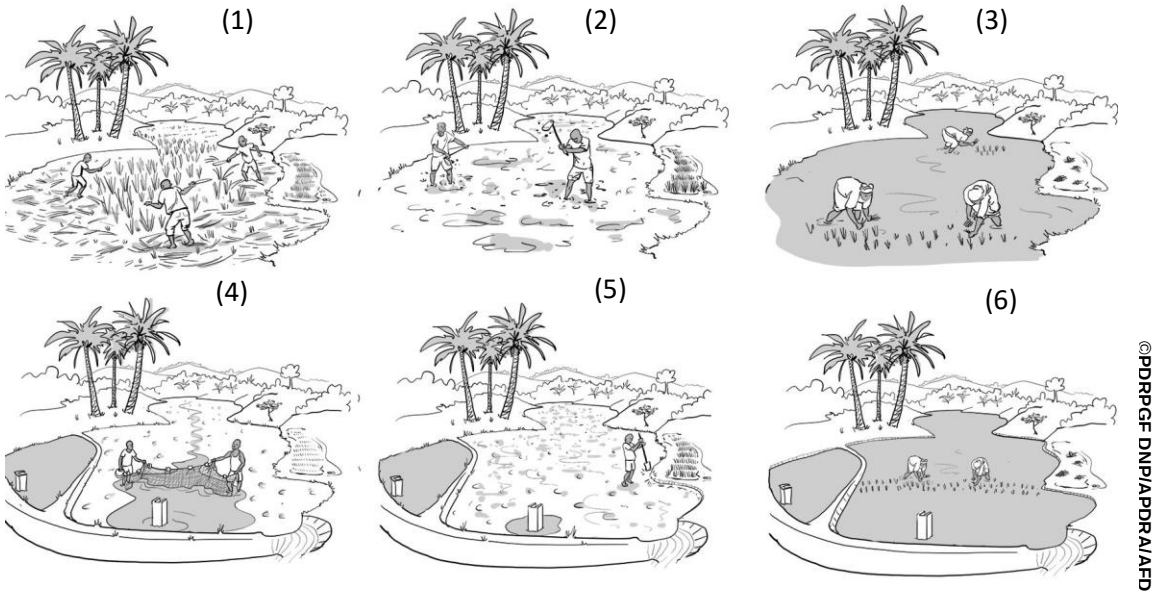

Figure 8: Main steps of the traditional rice culture vs. fish-rice culture. (1) Traditional valley with rice but without pond (2) Preliminary land clearing (3) Tillage and rice transplanting (4) Fish harvest in the same valley after dam-pond building (5) Pond cleaning and servicing (6) Rice transplanting (Credit: PDRPGF DNP/APDRA/AFD).

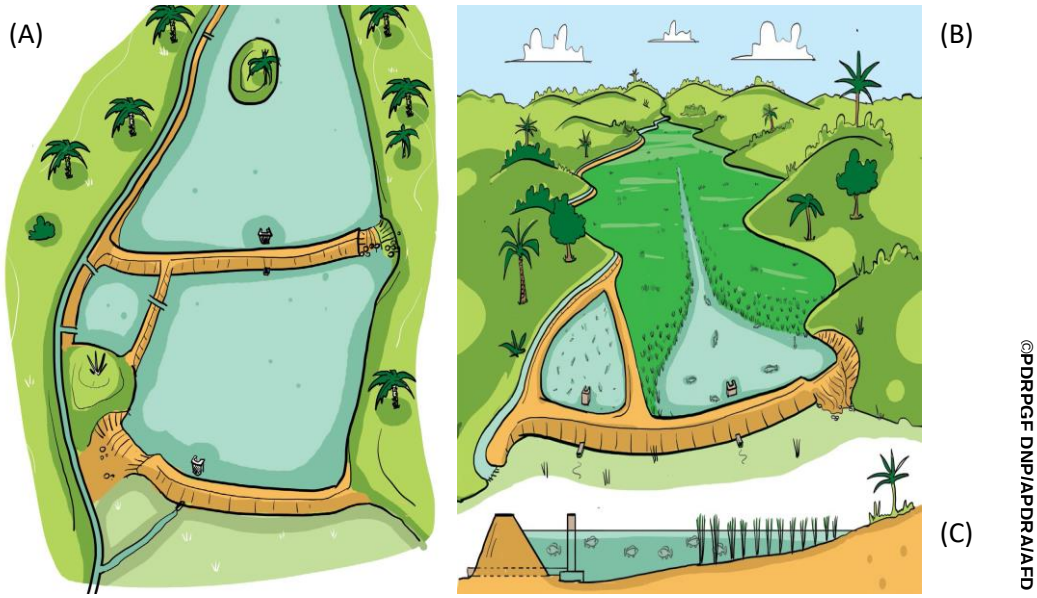

Figure 9: The different features of a dam-pond (A) Top view showing two growing-out ponds in series, one small multi-purpose pond, one bypass channel, several water inlets and outlets (monk) and two overflow outlets (B) Perspective view showing the same as well as rice planting pattern in stocked ponds (C) Side view showing the dyke, the monk, the water outlet and the rice planting pattern in the pond (Credit: PDRPGF DNP/APDRA/AFD).

4. Technical elements

Dam-ponds

Dam-ponds (Figures 8 and 9) are the most common fish production facility encountered in the Guinea Forest Region. The main reason is that they are well adapted to the local topography and to the investment capacity of the farmers in terms of labour and financial resources. All farmers are also guaranteed to receive a long-term technical support by the project.

The dam-ponds are made by building a dyke across a small valley stream (Figures 9 and 10). The set-up of the production facilities is gradual and generally carried out by mutual aid groups of individual fish farmers, hence reducing the construction costs which represent a value ranging from EUR [29]2 000 to 5 000. Construction time varies from 1 to 3 years and the recovery time of the investment is generally between 3 and 5 years.

Water generally originates from a spring or a seepage area. The extent of the submerged surface depends on the height of the dyke retaining the water and on the topography of the location. The size of the dam-ponds is thus highly variable. The average surface in the Guinea Forest Region is 3 000 square-meters, with the largest ones of about 1 ha.

Ponds can be designed to be either "open" or "closed". "Closed" dam-ponds are more expensive to construct because they need a supplementary embankment upstream and a bypass channel to deviate unduly descending water, but they are more productive than "open" systems in which there is a continuous flow of water, where the water is poorer in natural feed for the fish, and where water fertilization is not as effective as it is in "closed" ponds.

The monk and the spillway are the main operating elements of the system. Dam-ponds can be seen as a mean for enhancing muddy/sandy bottomlands which are considered agricultural marginal land because they are not really suited for rice culture or other agricultural purposes. It is recommended that in addition to grow-out ponds, farmers construct one or more small "service ponds" (multi-purpose pond) for fingerling production and/or fish stocking purposes (Figure 12).

Figure 10: Digging of a core trench to prevent water seepage underneath the main pond dike.

Farmed species

Four species are commonly raised together in a polyculture system: the Nile tilapia *Oreochromis niloticus*, the heterotis *Heterotis niloticus*, the catfish *Heterobranchus isopterus* and the predator fish *Hemichromis fasciatus* which is used as a police-fish to avoid excessive and unintended tilapia fry proliferation (Figures 7 and 11). Polyculture is preferred to monoculture by most farmers because their goal is to maximize fish production by making a better use of the various trophic sources available in the ponds.

[29] EUR 1 = USD 1.1-1.2

Recommended stocking densities are adjusted in function of the natural productivity of the pond environment and the ability of the fish farmer to provide additional inputs as feeds or fertilizers. The indicative values are one male *O. niloticus* fingerling per 10 m^2, one *H. niloticus* per 100 m^2, one *H. isopterus* per 100 m^2 and one *H. fasciatus* per every ten *O. niloticus* fingerlings.

O. niloticus is the main crop species and although mixed-sex farming is common, more experienced farmers switch to all-male farming, as males grow faster than females. Male 15-30 g *O. niloticus* fingerlings are obtained by manual sexing after a first growing-out cycle of fry in the multi-purpose ponds.

For rice cultivation in dam-ponds, a long stem and long cycle local variety of rice such as CK90 is recommended.

O. niloticus *H. niloticus* *H. isopterus* *H. fasciatus*

Figure 11: Commonly farmed species in Guinea Forest Region.

Water fertilizers and fish feeds

Guinean fish-rice farming is agroecological and based on the principles of synergies, recycling and circular economy. The duration of the production cycles vary from 6 to 9 months and depends on the availability of nutrients in the pond water, on the stocking density of the farmed fish and on the desired marketing sizes at harvest. For growing-out, agricultural, animal or household by-products are used. Inorganic and fertilizers maybe be available in the region but they are too expensive because they are not produced locally and the transportation costs are high. Similarly, no commercial fish feeds is imported in Guinea, so these are not accessible to the farmers. Sometimes and when available, rice bran is used as a water fertilizer and/or fish feed but the recent development of poultry and pig farming in rural areas makes it a highly demanded and always more expensive commodity. Palm kernel cake is a largely available by-product of the local palm oil industry and some farmers use it in their ponds. The quantities of by-products used are not monitored so their efficiency and impact on the growth of fish is not well known. Some research and development activities on this subject are currently ongoing.

Some fish farmers have also opted to fertilize their ponds by using animal wastes or associating fish with pig farming (Figure 12). The water fertility and the presence of natural feeds such as plankton, invertebrates etc., is evaluated through direct measurements using Secchi disk or visual observations (water colour).

Figure 12: Valley converted from poor bare land to dam-ponds, showing multi-purpose ponds with fish-rice-pig association.

5. Production and consumption

The Guinean government aims to increase the average fish consumption in the country. At the national level, the last objective was to increase the annual per capita fish availability from 11 kg in 2005 to 17 kg/capita/year in 2015.

A case study conducted in Gbötöye, a Guinea Forest town where fish-rice farming is well established, showed a dramatic increase in the average fish consumption, from 4 kg/capita/year in 1995 to 14 kg/capita/year in 2015 (Table 4).

Table 4: Increase in local fish consumption through commercial small-scale aquaculture

Designation	Year				
	1995	2000	2005	2010	2015
Number of fish farming development projects in Gbötöye	0	1	1	1	1
Number of fish farmers in Gbötöye	1	3	7	24	38
Average annual production in the region (kg/ha/year)	80	90	700	800	900
Average annual production in Gbötöye (kg/ha/year)	400	400	672	1 000	1 150*
Average national consumption (kg/capita/year)	10	12	11	11	11
Average consumption in Conakry (kg/capita/year)	23	25	22	22	22
Average consumption in Gbötöye (kg/capita/year)	4	5	9	12	14

*Some experienced farmers produce 2 to 3 tonnes per hectare per year.

6. Constraints

Some constraints to the development of fish farming in Guinea have been identified. These include:

- The low public budget allocated to upscale fish farming and develop it in the other regions, in contrast with the increasing demand and huge natural potential.
- The absence of national human/ institutional capacity to respond to requests for intensification and diversification of current production techniques due to a lack of specialized expertise.

- The lack of funds and fish farming facilities for applied research targeted at local production techniques.
- The restricted capacity for intensification of the existing production systems put in place, due to the unavailability of feed.
- The divergence between the traditional school curricula and adequate knowledge needs for the Guinean context.
- The limited offer of training courses on fish farming in the four national vocational schools dispensing agricultural training (ENAE) and at the Fisheries and Aquaculture Department of the scientific institute of higher education in Dalaba (ISSMV).

7. Perspectives

The future needs and perspectives for the development of fish farming in Guinea are:

- The achievement of the production target of 7 000 tonnes by 2020, as set in the PNDES.
- The extension of fish farming to new areas in the four national regions of Guinea by diversifying current farming techniques in reply to needs and local conditions.
- The continuation of the technical assistance to national government.
- The mobilization of additional funds.
- The formulation of feasibility studies and pilot actions.
- The monitoring and capitalization of innovations as well as the dissemination of achievements.
- The participation in knowledge exchange meetings, aquaculture networks and specific training courses.
- The further training of young executives from national technical services.
- The development of fish farming as a strategy for adapting to climate change by making productive use of different natural and artificial water bodies.

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INTEGRATED ANIMAL-FISH FARMING IN SOUTHERN BRAZIL: PRACTICES, CHALLENGES, OPPORTUNITIES AND DIFFICULTIES

Manoel Xavier Pedroza Filho and Cesar William Albuquerque de Sousa

1. Introduction and principles

1.1. Origin

The development of integrated animal-fish farming in southern Brazil is directly related to the increase in demand for farmed fish during the 80's. This change in consumer's preference was driven by several factors, among which the increase in wild fish price, the growing health concerns and the expansion of *pesque-pagues* ("fish and pay" in Brazilian Portuguese), which became particularly popular as a recreational activity and source of fresh fish.

The pesque-pagues consist of fish farm facilities where customers can catch themselves the fish in the pond with a fishing rod and either pay and take away or consume in the local restaurant (Figure 1). In addition to the fish, the pesque-pagues offer many other recreational activities such as playground, soccer field, and artisanal brewery.

Figure 1: *Pesque-pagues* in Santa Catarina, Brazil.

As the demand for farmed fish continued to increase during the 90's, the small-scale producers, who are predominant in the southern states, started to implement more professional fish farming structures. The introduction of sex-reversed tilapia and the implementation of fish processing plants were fundamental innovations following which the Santa Catarina state's extension agency, EPAGRI, along with other local organisms, began significant activities of technology transfer and fish farming development, including the construction of five thousands small (2 000 m^2) earthen ponds (Cavalett, 2004).

According to the Brazilian Institute of Geography and Statistics (IBGE), Santa Catarina population is 7 million inhabitants, about 16 percent of which live in rural areas. The state is characterized by the presence of very small farms, considering the Brazilian standards, with 90 percent of them smaller than 50 ha. The average fish farms have 2 hectares of water and they rely on family labor (EPAGRI, 2017). The rural area's population is composed mainly by descendants of Europeans (e.g. Italians, Germans and Portugueses), who immigrated in the nineteenth century.

Main agricultural products are pork and poultry, corn, soybean, wheat and beans, which are managed by agro-industries integrated with small farmers (Cavalett *et al.*, 2004). In these small farms, the integration of production generally occurs by using corn as the main component for pig diet and recycling manure to fertilize corn, wheat and soybean.

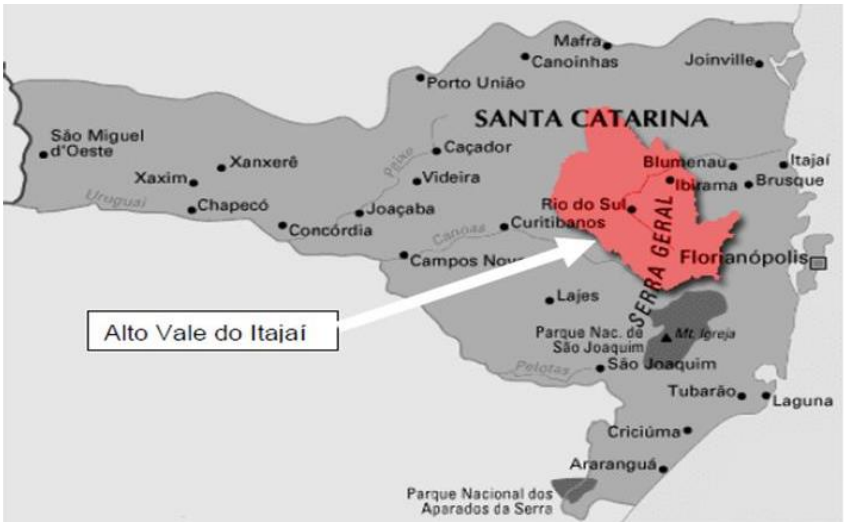

Figure 2: Localization of the Upper Itajaí Valley, in Santa Catarina state.

Santa Catarina is a traditional pig producer and most of the production is located in the West (3 million swine heads in the 90's). In this context, the integration with fish farming emerged as a logical complementary activity allowing to increase pig´s income, by optimizing its wastes and obtaining economies of scales in terms of land use and work force (Perin, 2010). The integrated pig-fish farming became particularly popular in the Upper Itajaí Valley (Figure 2) and estimates indicate that the technical model developed there is practiced by at least 13.000 farms (Tomazelli JR *et al.*, 2007).[30]

1.2. Concepts

The integrated pig-fish farming developed in Santa Catarina consists in a polyculture based on the Chinese model coupled with pig manure utilization (Table 1). The main species stocked are common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*), combined with herbivorous carp (*Ctenopharyngodon idella*) which feeds on aquatic plants, silver carp (*Hypophthalmichthys molitrix*) which feeds on phytoplankton, and other species like catfish Jundiá (*Rhamdia quelens*).

The association of these species aims to rationally take advantage of the various natural trophic niches in the water resulting from the addition of pig manure and pig feed losses falling directly into the pond, as pigs are reared in wooden structures over or beside of the water surface (Wezel, 2017).

As such, the fishpond acts as a treatment system for the animal waste, by recycling its trophic potential. Recycling manure improves the environmental quality of the entire farm, and increases the food availability (Tamassia, 2011). The nutrients present in the waste material (mainly phosphorus and nitrogen) act as catalysts in a complex aquatic metabolism composed of three main stages: production, consumption and decomposition (Casaca and Tomazelli Jr., 2001; Kumaresan *et al.*, 2009). The

[30] MAVIPI model, for the Brazilian acronym of "Integrated Fish Farming Model in the Upper Itajaí Valley"

interrelation of organisms in the ecosystem is called the food or web chain, which represents the flow of energy and matter between living beings in the environment, under the precepts of thermodynamics (Perin, 2010 *apud* Esteves, 1998).

Figure 3: Structures used on integrated pig-fish farming in Santa Catarina state.

The system associates species with different eating habits and the selected species are classified into three categories. Primary species represents the largest quantity in the polyculture, mainly by the market value or availability of food in the pond. The secondary species are used in intermediate amounts, playing the role of "filtering", by removing the excess of plankton in the pond. The complementary species enter into the polyculture in small quantities, taking advantage of natural feed not used by other species, or their debris (Perin, 2010).

The choice of the species also takes into account the specificities of the local markets. The economic viability of the system depends on the acceptability of the fish produced, as well as its value addition. Only species authorized by the environmental legislation should be considered. Table 1 shows the main species used in the integrated pig-fish farming in Santa Catarina, according to their feeding habits and category.

Table 1: Main species used in the integrated pig-fish farming in Santa Catarina. Source: Tomazelli *et al.* (2005)

Species	Feeding habits	Category
Common carp (*Cyprinus carpio*)	Omnivore, Benthos	Primary or secondary
Silver carp (*Hypophthalmichthys molitrix*)	Phytoplankton	Secondary
Big head carp (*Aristichthys nobilis*)	Zooplankton	Secondary
Herbivorous carp (*Ctenopharyngodon idella*)	Macroplankton	Complementary
Nile tilapia (*Oreochromis niloticus*)	Omnivore, Plankton	Primary or secondary
Pacu (*Piaractus mesopotamicus*)	Omnivore, Fruits	Complementary
Cascudo (*Hypostomus affinis*)	Perifitoplankton	Complementary
American catfish (*Ictalurus punctatus*)	Omnivore	Complementary
African catfish (*Clarias gariepinus*)	Omnivore, Nectar	Complementary
Jundiá catfish (*Rhamdia quelens*)	Omnivore	Complementary

Two integrated systems

The integrated pig-fish farming in Santa Catarina is composed by two main models: the traditional model and the MAVIPI model, but some intermediate variations based on these two systems can also be found in Santa Catarina. The main differences between them is the use of feed, mechanical aeration, control in the number of pigs and water management (Table 2).

Table 2: Main differences between traditional integrated pig-fish farming and MAVIPI Model in Santa Catarina. Source: Authors

Characteristics	Traditional	MAVIPI
Type of pond	Small reservoirs for multiple water uses, without water in and outflow management	Specific ponds for fish farming , with control of water in and outflow management
Control of water quality	Low	High
Control of the pigs manure quantity in the pond	No	Yes
Species	Main carps	Tilapia, carps and catfishes
Aeration	No	Yes
Use of complementary commercial feed	No	Yes (only in the final phase, after the fourth month)

The traditional system

In the traditional integration model, the carps are the primary species and the system does not use commercial feed. Thus, the only food available is the planktonic organisms in the pond, which may be in the water (phytoplankton and zooplankton) or on the bottom (benthos). In this system it is fundamental to know the natural productivity of the ponds in order to increase their production through the use of organic and inorganic fertilizers. Organic and inorganic fertilizer (chemical fertilizer) acts as catalysts in the development of these organisms and as the ponds receive fertilizer inputs, the natural productivity increases proportionally (Tamassia, 2011).

According to Perin (2010) and Tomazelli *et al.* (2005) the main species and their proportion in the traditional system are: Common carp (40 percent), Silver carp (12percent), Big head carp (8 percent), Herbivorous carp (4 percent), Nile tilapia (20 percent), Cascudo (4 percent), American catfish (4 percent), African catfish (4 percent), and Jundiá catfish (4 percent).

This system has a lower productivity and a longer cultivation time, but also the lowest production cost. For this reason the farmers who may encounter difficulties to pay the expenses of fish farming based on the use of commercial feed, such as amateurs or recreational fish farmers for example, tend to favor it (EPAGRI, 2017).

However, most of ponds used in the traditional system were initially built to serve as water reserves, by diverting watercourses and, consequently, they are generally located near the rivers. In 2012, the new Brazilian Forest Code determined a 30-m-wide protection zone along watercourses that are at least 10 m wide. As a result, most of these fish farms found themselves in violation of environmental regulations, putting their future at risk, as the farms are typically small and their areas favorable to fish farming practice are not widely available (Aubin *et al.*, 2014).

The MAVIPI model

The traditional integrated pig-fish farming system expanded significantly in the 90's but its rapid expansion also resulted in some issues with environmental Non-Governmental Organizations (NGO). A complain was raised to the public prosecutor office in 1996, accusing fish farming of being responsible for the proliferation of the "*borrachudo*" black fly (*Simulium pertinax*), and for the increased water pollution in the Upper Itajaí Valley (Figure 3). The fact that most of the local fish hatcheries were also located in permanent preservation areas (APPs) was also denounced (Souza, 2007).

Then, in response to these environmental issues and to increase the productivity of the integrated pig-fish system, the producers and EPAGRI jointly worked to develop the MAVIPI Model (Wezel, 2017).

In the MAVIPI model tilapia is the primary species and the feed is provided by natural organisms during the initial phase (first 3 to 4 months) and by supplementary commercial feed at the end of the production

cycle. The duration of the cycle and the productivity are lower than with the monoculture system exclusively based on commercial feed, also practiced in the state, but the cost of production is approximately 25 to 30 percent lower (EPAGRI, 2017).

The MAVIPI model incorporates several innovations that provide significant improvements in terms of productivity, production management and water quality, compared to the traditional integrated system. It is based on six main characteristics (Tamassia, 2011):

1. Polyculture characteristics: tilapia (70 to 75 percent), common carp (10 to 15 percent), silver carp (7 percent), big head carp (6 percent) and others (2 percent). This combination allows for an efficient recycling and facilitates the control of effluent emissions.
2. Supplementary feeding with commercial feed: the supplementary use of commercial feed starts when biometrics monitoring show that the fish growth rate is decreasing. In standard conditions, this only applies in the final steps of the production cycle.
3. Integration with pigs: the nutrients from the swine manure and feed losses allow the production of natural feed, which replace the commercial feed during most of the growing-out. There are two classes of benefits: the economic one, because it uses cheaper nutrients compared to the nutrients supplied by the commercial feeds. Second, by recycling nutrients, the waste release into natural water bodies is reduced.
4. Complete control of water inflow and outflow in the ponds: This is one of the basic conditions for controlling environmental impacts and enabling the intensification of ecosystem services, as it allows controlling the water quality of the ponds and quantifying the nutrients emissions to the environment.
5. Mechanical aeration: it makes possible to keep the water column homogeneous during the day, when the primary production is maximum. This also allows to maintain the dissolved oxygen levels in the night and during cloudy days.
6. Controlled harvest: it consist in harvesting fish without decreasing the water level in the ponds, thus enabling an important reduction in the environmental impacts associated with MAVIPI model. This is only possible when ponds are properly constructed (not in marsh areas, no trunks in the background, regular shape, etc.) and the necessary structure is available. As it requires high investment, the practice of the partial exhaustion of the water is currently used.

In the MAVIPI model, the pig confinement units are located directly over the pond, on the smaller side and opposite to the drainage system. This allows the distribution of manure throughout the day without human labor. Because the manure is supplied in its fresh form, it quickly dissolves and with the use of aerators, its distribution is homogeneous throughout the pond (Tamassia, 2011).

1.3. Importance of the integrated pig-fish farming

One of the main goals of the integrated pig-fish farming is the reduction of the production costs and the realization of scope economies by sharing resources and manpower. According to Casaca and Tomazelli Jr. (2001), the use of swine manure for the fertilization of the ponds can reduce the cost of production of fish farming by up to 70 percent.

In addition to the economic advantages for the fish farming, there are also some benefits for swine production. In particular, the feed conversion ratio for pigs is reduced because of the improved wellbeing of the animals resulting from a greater thermal stability in the cold nights and dawns, a decrease in ammonia levels in the air and an unlimited availability of water for the swine to cool in the hottest days (Tamassia, 2011).

These benefits allow farmers working in the integrated pig-fish systems to reach best economic results compared to pigs produced on conventional farms. Another positive factor is the possibility to minimize one of the biggest environmental problems of swine farming in Brazil by recycling pig manure and avoid pollution (Tamassia, 2011).

2. Technical and economic performance

As shown in table 3, the MAVIPI system presents a higher productivity performance than the traditional integration system. The main differences concern the shorter duration of the production cycle and the annual yield.

Table 3: Technical indicators of the three fish farming systems in Santa Catarina

Indicators	Traditional integration	MAVIPI	Monoculture fish farming of tilapia (only commercial feed)
Average fish farming yield (Tonne/ha/year)	5	13	22
Feed conversion factor	-	0.6	1.6
Duration of the production cycle (Months)	14	10	7
Average cost of production (BRL/Kg)	1.75	2.60	3.70

Source: Project Campo Futuro/Embrapa/CNA (2017); Silva (2015); Hilton Jr. (2004), EPAGRI, 2017. *Exchange rate, BRL 1 = USD 0.26

However, in terms of production costs for the primary specie (tilapia) the MAVIPI model is about 32 percent less effective than the traditional integration, but 30 percent lower when compared to the monoculture production of tilapia using exclusively commercial feed. The use of commercial feed is one of the most important determinants in the MAVIPI performance, but this impacts directly the production costs.

The current fish market in Santa Catarina and Brazil is demanding higher volumes, as most of the production is being oriented to supermarkets. This market has high requirements in terms of volume, regularity or quality, and most of the fish is commercialized by fish processing plants. These processors also require high volumes and consequently supply from individual producers working in small-scale basis is not viable, considering logistics aspects. Therefore, this scenario benefits more intensive systems than the traditional integration model (Flores and Pedroza, 2014).

The stocking density of the main fish species varies according to the number of pigs per hectare, to the species chosen and also to the natural productivity of the pond, resulting in an amount of 3 000 to 6 000 fishes/ha. In the MAVIPI model the recommended number of pig is 60 pig (weighing each between 25 and 100 kg) per hectare of water, which results in a natural productivity (without commercial feed) of 2 000 kg/ha for the primary specie (Tamassia, 2011; Tomazelli Jr. *et al.*, 2005)

Wohlfarth and Schroeder (1979) affirm that manuring up to a maximum of 175 kg of dry matter per hectare and per day results in a production of 32 kg of fish/ha/day for a period of 125 days. According to Tamassia (2011) these data corresponding to a fish production of about 4 000 kg/ha, which represents the maximum biomass supported by natural productivity using organic fertilization.

The total pond productivity relies on management practices, water quality, and species that will complement the polyculture. The production cycle duration varies according to the choice of the main species: six months for tilapia and one year for common carp. On the other hand, the choice of complementary species is a function of feeding habits and of their development capacity in pond (Tamassia, 2011).

3. Main constraints

According to Kubitza (2006), the main factors limiting the expansion of the integrated pig-fish farming systems in southern Brazil are:

- Limitations on pig waste recycling: Despite offering an alternative for recycling pig manures, the integrated pig-fish farming cannot be considered as the solution for disposing of waste generated by large or intensive pig farms.
- Low financial income: the reduced production cost or higher profit per kilo do not results always in higher profitability, as it is determined by the combination of productivity per area (production cycles x biomass per cycle) and profit margin per kilogram of fish sold (sales value less cost of production). At this point, the integrated systems can present a lower financial income compared to the more intensive systems, because it presents a low yield per area (see table 3).
- Consumer perception and cultural restrictions in new markets: despite being well accepted in the local market, the fish from integrated systems can also face resistance of consumers in the other regions of Brazil. Indeed, consumers are more conscious about the origin and production systems concerning all animal protein, including farmed fish. In this context, the way the integrated fish is produced can raise issues by consumers concerning sanitary risks. Although there is scientific evidence to support the quality of the product and the safety for consumption (Pilarski *et al.* 2004; Coelho *et al.* 1990; Rosa *et al.* 1990), it is hard to convince the Brazilian consumers to buy fish that have been produced in ponds fertilized with pig manure.

4. Current trends and future prospects

Despite offering an ecological and low cost technology to produce fish, the number of producers practicing integrated pig-fish systems in southern Brazil has been stagnating or even reducing in recent years. Official statistics do not consider these types of data but several experts mention a decline, whereas the more intensive systems were growing in popularity and according to Aubin (2014), many producers working with integrated systems in Santa Catarina have returned to non-integrated polyculture/pig production systems.

The current trend towards the intensification of the Brazilian aquaculture and the concentration capital lead by large companies and cooperatives has transformed the sector which is becoming more competitive (Pedroza and Routledge, 2016). Therefore, ecological aquaculture systems face huge challenges to assure a sustainable position in the market. Differentiation from the conventional farmed fish and compliance to the environmental rules is crucial to ensure the development of these systems.

Some of the challenges faced by integrated pig-fish farmers in Brazil are similar to those of the small-scale fish farmers in Brazilian aquaculture nowadays. Some of the reasons behind this situation concern the lack of organization, which results in limitations like the low production volume, the high cost of inputs, the low standard of quality and the lack of fish processing. At this point, organization is a determinant factor in order to assure competitiveness of these categories of producers.

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AN OVERVIEW ON AQUACULTURE IN DESERT AND ARID LANDS

Valerio Crespi

1. Introduction

The global population growth and increase in food demand is driving the rapid expansion and intensification of cultivated lands. An estimated 13 percent of the world population, 313 million, live in arid zones with 92 million residing in hyper-arid deserts (UNCCD, 2007). Deserts cover more than one fifth of the Earth's land. They are found on every continent and they can represent new unexploited areas for development. Arid lands are characterized by high temperature variations (between day and night); low precipitations; high solar radiation and evaporation; limited surface and subsurface water; abundant inexpensive land; and large aquifers of fresh and brackish water available.
Although water is a renewable resource, the rate of water use and demand growth for agricultural and non-agricultural (industrial, municipal and domestic consumption) uses is increasingly threatening to outpace the rate of water renewal. The global use of freshwater doubled between 1964 and 2014 as a result of population growth, urbanisation, industrialisation as well as increased production and consumption. Climate change-induced water stress is also increasingly becoming a threat for countries having great extension of arid lands particularly, the Near East and North Africa where agriculture is a significant sector in rural areas of the region.
The idea of desert aquaculture was formulated in the early sixties showing that it was possible to use fresh, salty or brackish waters to farm fish successfully. The high mineral content of waters found in the deserts, along with the high temperatures and solar radiation support high primary productivity forming an appropriate and favorable food-base environment for the fish.
Desert and arid lands can nowadays be better exploited for food production through the use of modern and responsible aquaculture practices including by applying agroecology principles, thus reducing water use while increasingly supporting the food safety and environmental protection and conservation.
In the last two decades, the integration of aquaculture with agriculture has become more popular in areas where water is limited. These integrated farming systems can produce a source of cheap quality protein and fresh vegetable products, with reduced water use especially for the small-scale farm households in rural areas. Desert aquaculture can also provide social benefits, assuring an improved public health and food security for rural communities, reducing migration of rural population towards cities and/or abroad.

2. Water sources

In arid lands the main sources of water are represented by dams, ponds, irrigation canals, salt/brackish water lakes, ground water (aquifers), temporary rivers and rain fed reservoirs. Ground water in arid lands is often only partially used, although this water is abundant and of high quality. Among the issues to be considered are drilling costs to access water or the fact that water often comes out from the wells at very high temperatures and cooling practices have to be adopted to secure suitable temperature for cultured species.

Other sources of water such as rivers, lakes and rain fed reservoirs are often available only seasonally, depending on the distribution of annual precipitations. Therefore, the integration of aquaculture with agriculture practices is becoming increasingly attractive for farmers living in areas where water is a limited resource. In fact such systems can reduce water requirement for the simultaneous production of quality protein and fresh vegetable products.

3. Main aquaculture farming systems

Developing aquaculture in arid climate conditions, forces the adoption of production strategies focused on good water management, which includes water savings and recycling practices. In rural and arid areas where traditional small-scale agriculture activities are practiced, small-scale fish farming can be carried out using the irrigation ponds which farmers use for watering their agricultural crops. Medium and large-scale agri-aqua systems based on irrigation reservoirs used to store groundwater or rainwater during the wet season have also started to become common to farm fish in integrated farming systems.

On a more intensive scale closed recirculation aquaculture systems that incorporate water filtration systems, biological filters, protein skimmers and oxygen injection systems, etc., have been successfully established in many localities around the world particularly in regions where fish is in high demand and markets are ready to pay premium prices. These systems may support up to 50 kg of fish/m^3 of water. Aquaponic systems, integrating recirculating aquaculture with hydroponic vegetable production, are becoming increasingly popular as small household units as well as larger commercial operations. Large-scale recirculating systems, in which water from outdoor fish ponds, raceways and tanks, is passed into sediment ponds to remove the solids. The water is then passed to an adjacent water reservoir, and good quality water is then returned from the reservoir to the fish rearing systems (Kolkovsky *et al.*, 2011). Floating cages are also commonly found in dams or disused mines, allowing the growth of fish in low or non-exploited artificial water bodies.

4. Suitable species

A large variety of organisms can be cultured in arid conditions and they typically do not differ from species that are cultured under different and more favourable environmental conditions. Their farming is possible as long as the culture environment provided conforms to the physiological requirements of the farmed animal. However, those species that have a wide tolerance to a number of environmental parameters (e.g. temperature, salinity) are preferred. Fast growing species are also preferred candidates.

Currently, the most suitable fish species for water-limited aquaculture systems include the tilapias (*Oreochromis* spp.) and their hybrids, barramundi or the Asian seabass (*Lates calcarifer*), a number of carp species, mullets (*Mugil cephalus* and *Liza ramada*) and several catfish species (*Clarias gariepinus* and *Bagrus* spp.).

In Egypt, among other countries, good results have been achieved with the rearing of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) in brackish waters. With regard to shrimp, the Indian white prawn (*Penaeus indicus*) and whiteleg prawn (*Penaeus vannamei*) represent successful examples respectively of marine and freshwater aquaculture (e.g. in Saudi Arabia and Algeria).

5. Examples of aquaculture in arid lands

Algeria is an example of success story, where the government has provided support to the private and public sector for the development of aquaculture, particularly in the arid regions located in the southern part of the country. It has been estimated that more than a thousand irrigation ponds are associated to 300 farmers practicing fish farming integrated with agriculture. They represent nearly 50 percent of the 626 farmers practicing fish farming throughout the national territory.

Aquaculture stakeholders range from small-scale farmers owning 1-2 ha small plot with one earthen pond mainly used for irrigation, to medium-large-scale farmers with farms covering a surface of 10 to 20 ha with several ponds.

In recent years, ten aquaculture projects were set up in the Algerian desert. These facilities have an annual total production capacity of approximately 1 700 tonnes of fish (tilapia, catfish) per year. Many

small-scale integrated agri-aquaculture farms established in southern Algeria and that were supported by the government with the technical assistance of FAO, also successfully achieved the production of Nile tilapia, including for the production of seed in hapas or farm-made feed using available agriculture products, for harvesting and reusing fertilized water for irrigation, giving them a certain degree of autonomy.

A good example of success is the fish farm "Biofloc group" located in the municipality of Hassi Ben Abdellah in the district of Ouargla (800 km south of Alger). The farm was established in 2015 through the collaboration with the Korea International Cooperation Agency (KOICA, the Republic of Korea). The farm built on 10 hectares of sandy land has a production capacity of 10 tonnes of whiteleg shrimp (*Penaeus vannamei*) per production cycle. Underground water is always, and all the year round, available in wells and it is treated with filters using RAS technology. Almost 95 percent of water is recycled with limited water wasting.

Egypt is another example, as it has increased the quantity of fish produced in integrated agri-aquaculture (IAA) farms from 700 tonnes in 2010 to 2 200 tonnes in 2017. In recent years, the number of integrated farms has also increased. About 100 commercial farms have been set up in different desert regions of Egypt, mainly based in ten governorates within the broader Nile delta, near the Nile valley and Sinai Peninsula. Although eight fish species are produced, the main one is Nile tilapia (Oreochromis niloticus), which accounts for 90 percent of desert-based aquaculture production. Water for desert farms comes from underground saline water, desalination plants and agricultural drainage, with a salinity between 0.5 to 26 g/litre, and a temperature from 22 to 26°C.

In Egypt there are two good example of success: the first one is El-Keram, an IAA system in the Egyptian desert. Water is first used for the fish production (hatchery and grow-out), then the waste water and fish wastes are used to grow plants, including alfalfa to feed sheep. Sheep dropping is used to generate biogas (heating for hatchery, staff houses and cooking). The system operates with a 67 percent reduction of water use. The second example is Wadi Tal Village Farm in South Sinai, Egypt. The approximately 13 000 hectares farm is organized in a cooperative supported by 120 Bedouin families. Desert land has been reclaimed to produce several crops, including date palms, figs, olives, pomegranate, guava, clover, vegetables and fish produced under greenhouses.

Israel is another pioneer country in desert aquaculture. In the Negev desert (southern Israel), incredible amounts of saline underground and geothermal water allowed the establishment of super-intensive fish farms that operate successfully. Hybrid-tilapias are being cultured with average annual production yields of 20-27 kg/m^3. In the United States of America around 40 aquaculture farms located in desert regions in six states, currently produce about 1 percent of the total annual national fish production equivalent to about 4 000 tonnes.

6. Pictures of aquaculture in arid land

Figure 1: Hybrid of red tilapia (*Oreochromis mossambicus* × *O. niloticus*) farmed in an aquaponic systems, Oman.

Figure 2: Irrigation pond used to farm Nile tilapia (Oreochromis niloticus) in the district of Ouargla, Algeria.

Figure 3: Harvesting Nile tilapia (Oreochromis niloticus) in an irrigation pond in the district of Ouargla, Algeria.

Figure 4: Agricultural crop grown using water fertilized by farmed Nile tilapia in the irrigation pond.

Figure 5: Example of a closed aquaculture recirculation system in Oman.

Figure 6: Example of aquaponics system (salad grown in soilless media) in Oman.

Figure 7: Example of aquaponics system (salad grown in soilless media) in Oman.

Figure 8: Aquaponics farm (basil grown in soilless media) in Oman.

Figure 9: Floating cages in a disused mine in the south of Namibia.

Figure 10: Irrigation pond used to farm Nile tilapia, Egypt.

Figure 11: Lined earthen pond for fish farming, district of Ouargla, Algeria.

Figure 12: Irrigation pond used to farm Nile tilapia (*Oreochromis niloticus*) in the district of Ouargla, Algeria.

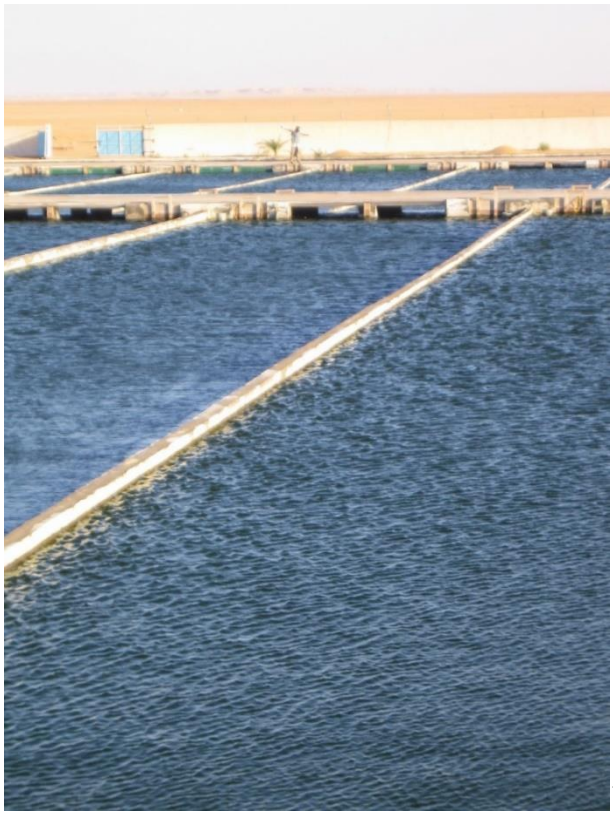

Figure 13: Large-scale closed aquaculture recirculation system in the district of Ouargla, Algeria.

7. Conclusions

The main goal of aquaculture in the desert is to utilize productively and efficiently the limited water resources for fully integrated aquaculture-agriculture food production systems. This is very much in line with the main agroecology principles.

Desert aquaculture appears to give water resources an economical value rather than induce a competition in water consumption between aquaculture and agriculture (Suloma *et al.*, 2006). This system indeed allows the production of different crops (fish, agriculture and livestock) by using the same quantity of water.

There is a growing interest by farmers living in many arid regions in starting aquaculture activities as a parallel activity or fully integrated business along their agriculture activities. It represents also a real opportunity to encourage migrants to the cities, especially youth and women from rural areas, to return to their hometowns and start integrated aquaculture-agriculture businesses.

However, the limited technical competences, the low availability of inputs (typically feed and fish fingerlings) and the lack of adequate incentives from governments represent three important obstacles to the development of the sector.

Current and future developments of inland aquaculture in desert and arid lands will rely greatly on the appropriate use of subsurface waters, by using farming practices which ensure the smart use of this resource. The constant growth of the human population and the continuous exploitation of land and water resources particularly in arid environments will require the application of new strategies and incentives, as well as capacity development to ensure the adequate production of food (animal protein and vegetables) by populations living in these remote and isolated areas.

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PRACTICES AND RESOURCE USE EFFICIENCY OF EGYPTIAN FARMS APPLYING AQUACULTURE - AGRICULTURE INTEGRATION

Harrison Charo-Karisa and Ahmed Nasr Allah

1. Introduction

Rapid sustained growth of the Egyptian aquaculture has made it a global leading sector, now producing approximately 1.2 million MT of fish worthy over USD 2 billion in revenue per year, and providing 65 percent of Egypt's fish supply. At a production of 989 606 MT in 2016, Egypt became third largest producer of tilapia in the world. Despite these impressive figures, growth in production of fish cannot keep pace with demand and reports of malnutrition among the rural and urban poor are common. Environmental and water scarcity concerns are emotive in Egypt since the country depends mainly on waters of River Nile whose fixed water allocation is 55.5 Billion Cubic Meters (BCM). Egypt is currently a water scarce country with renewable water resources of only 650-m3 capita^{-1} /year. Furthermore, with mounting pressure from the large population and high growth rate, production of low-cost food while minimizing environmental impacts are a major priority of the Egyptian Government.

The Ministry of Water Resources and Irrigation (MWRI) and Ministry of Agriculture and Land Reclamation (MALR) are responsible for optimum utilization of the available water resources. A major focus of the MWRI is an equitable allocation of water resources between various users. Highest priority allocation goes to potable water, industrial and agriculture. Unfortunately, over the years, MWRI did not accord aquaculture priority allocation while MALR's focusses on maintenance of food security, and recognizes aquaculture key alongside other agricultural activities. Due to the conflicting priorities between the two ministries, aquaculture is restricted to lands that are not suitable for agriculture and only with agricultural drainage water.

Integrated Agriculture Aquaculture Systems (IAAS) could offer solution to this policy challenge. IAAS are defined as the concurrent or sequential linkage between two or more agricultural activities including aquaculture as part of the components (Little and Edwards 2003). The integration of aquaculture and agriculture enables the efficient generation of synergies between different farm components and the use of an output from one component in an integrated farming system as an input for another component. This system reduces wastes and further utilised them as useful inputs for production of other desired products within the farm such as the use of animal manure and crop residues as fertilizers and feed, respectively, in fishponds (Prein 2002).

WorldFish and its partners have undertaken to understand IAAS in Egypt to inform policy changes towards aquaculture. To determine resource use efficiency and suggest optimization pathways for the different integrated aquaculture agriculture systems practised in Egypt, a series of experiments were conducted at WorldFish Abbassa station (30.544227; 31.736793) to collect biological and economic data of the systems. Results of the experiments are presented.

2. Methodology

First, an experiment was conducted to describe and quantify sediment and nutrient accumulation in semi-intensive tilapia ponds and estimate potential for use in land based agriculture. Sixteen 200 m2 earthen ponds with treatments including chicken manure versus pelleted feed and two stocking densities (1 or 2 fish m^{-2}). *Oreochromis niloticus* fingerlings weighing 20-25g were stocked and harvested after 4.5 months. Monthly core pond sediments were collected from the top of ceramic tiles installed horizontally at 5 cm depth before pond filling. Fertilizer potential of the pond sediment was estimated based on the quantified sediment and nutrient accumulation.

In the second experiment, two integration units were developed at two sites in WordFish Abbassa research facility. The units consisted of three 200 m2 fish ponds; two crop plots each 525 m2; and a 3 HP solar powered water pump. The unit was designed to allow canal water through the fish ponds before use for crop irrigation.

Pond stocking and fish feeding

Fish ponds were stocked at the start of growing season in May with Abbassa tilapia (*Oreochromis niloticus*) with an average initial weight of 1.1 g (site 1) and 30 g (site 2) and stocking rate of 2 and 2.5 fish m^{-2} in site 1 and 2 respectively. The ponds were fertilized with 3 kg chicken manure $week^{-1}$ for first 8 weeks (site 1) and first 24 weeks (site 2) to enhance growth of natural food. In the next 8 weeks, ponds received additional rice bran at rate of 1 percent of fish body weight and last 4 weeks at 2 percent body weight (site 1). For site 2, fish were fed 30 percent crude protein floating fish feed at rate of 1 percent of fish body weight to the end of trial. Fish were harvested 28 weeks after stocking.

Weekly water samples were collected (9.30 am) at inlet and effluent, and analysed for physico-chemical parameters: pH, total ammonia nitrogen (TAN), and nitrate-nitrogen. To compensate for evaporation and seepage or water discharged to irrigated crop, and improve dissolved oxygen, 20 percent of the pond water was recycled using solar pump.

Growth was monitored monthly and at harvest, fish were graded: premium >500, super 330-500 g, Grade One 200-330 g, Grade Two 125-200g and farm-gate prices were used for evaluation.

Hybrid maize from Agriculture Research Centre, ARC, Egypt was cultivated in two plots in the two different sites at Abbassa. Grains were planted at a density of 47 600 plants/ha in August (site 1) and June (site 2) and harvested in November and October respectively. Crop plots were divided into three treatments in each site:

- T1 – Traditional crop system, crop irrigated using canal water and complete fertilization as commercial maize grower;
- T2 – Irrigated with fish pond effluent throughout the growth period;
- T3 – Irrigated with fish pond effluent + 50 commercial fertilization rate.

Calcium superphosphate (15.5 percent P_2O_5) was applied at 467 kg/ha during land preparation and Nitrogenous fertilizer in form of urea (33.5 percent N) applied at 490 kg/ha in two equal portions before the first and second irrigation. Amount of water applied was estimated as a function of the number of pumping hours and pump capacity.

3. Results and discussion

Aquaculture systems that optimize water use efficiency are an important prerequisite for successful tilapia farming in arid lands. In Egypt, demand for aquaculture systems that can boost growth while ensuring efficient water and nutrient utilization and better environmental sustainability is increasing. Water-efficient strategies may vary depending on ecological conditions of different parts of the country. In Egypt, these strategies include integrating production systems with crops and livestock, and the exploitation of brackish or saline non-potable water or which is not suitable for agriculture; and use of the productive pond water and pond mud as a crop fertilizer. These systems enable optimization of production and can be easily scaled-up and adapted to small-scale fish farming situations.

Production Practices in Egypt

Integrated systems in Egypt may include application of organic fertilizers from chicken, and livestock onto the ponds and of the water from ponds into the farm (Figure 1). The water drained from the tanks or ponds may be utilized for horticulture principally targeting fruit trees, vegetables, tomatoes, cucumber, potatoes, yellow corn, flowers, alfalfa as well as barley and wheat (e.g. Figure 2). Water discharged from catfish ponds irrigates Hejaz clover, which is in turn used to feed cows and sheep (Sadek 2011; Nasr-Allah *et al.*, 2012).

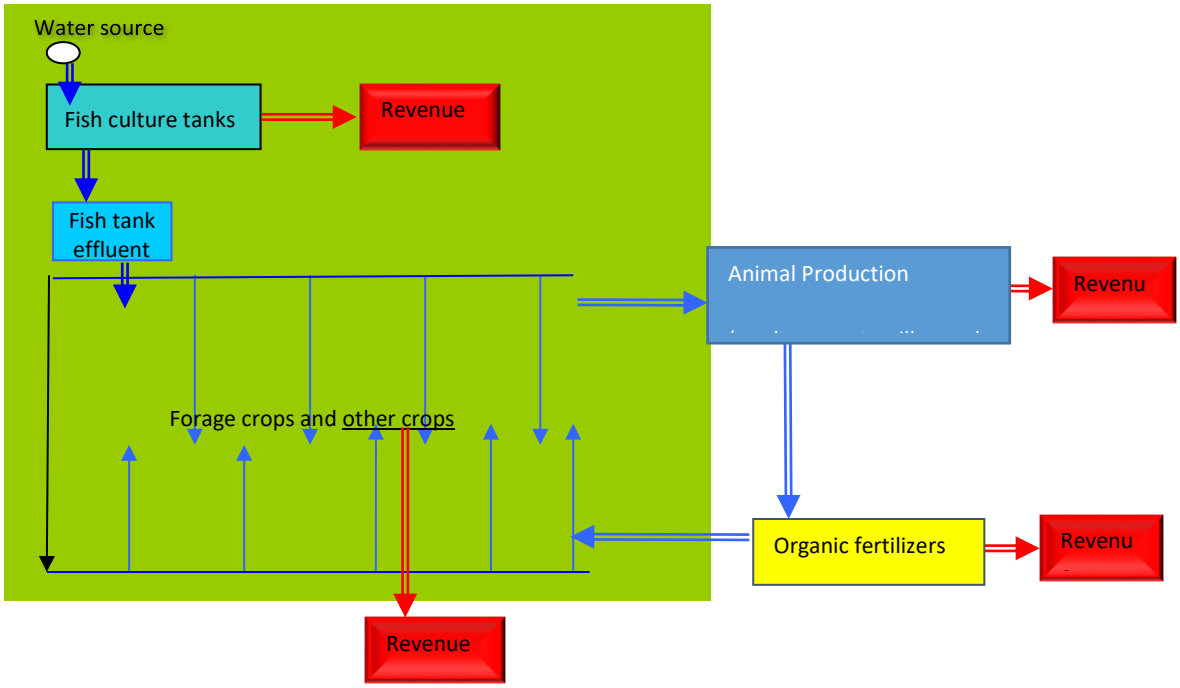

Figure 1: Schematic presentation of water use and output in integrated farms in Egypt (modified from Nasr-Allah *et al.* 2012).

Desert agriculture has been on the increase in Egypt since the 1990s due to support by the Government. Due to increased electricity and fuel prices, the costs of pumping of water from boreholes has become prohibitive and the farmers are embracing the use of solar power which substantially lowers pumping costs. Animal manures are used for production of energy in form of biogas and as organic fertilizers for clover and other crops. To cut costs further and get extra production, farmers store water in open reservoirs and use them for fish production before irrigating the crops (Figure 3). These farms use water flows and mechanical aerators to produce between 10-30 kg tilapia/m^3.

Figure 2: Polyethylene lined fish pond integrated with drought tolerant crops in Menia governorate (Upper Egypt).

Figure 3: Water reservoir used for fish culture and irrigated horticulture farm (background) in east of Suez Canal (Ismailia Governorate).

Results indicate that sediments depth increased significantly across all the treatments (by about 3 cm per pond) but bulk densities (upper 5 cm sediment layer) decreased (0.1- 0.3 g cm^{-3}) with no effect of input type or stocking density for both sediment and bulk densities (Table 1). A large and wide ranging proportion (39-95 percent) of the nutrients used in fish ponds including fertilizers, manures and supplemental fish feed are trapped in pond sediments away from the intended fish (Wahab and Stirling, 1991; Funge-Smith and Briggs, 1994). Our studies indicate that influent water and direct organic inputs contributed to sediment accumulation (Table 1). Sediment accumulation quantities ranged from 1-3.1 (Minimum) and 1.5-3.46 tonnes/pond/cycle (Maximum) translating to a maximum of 173 tonnes/ha/cycle. Typically, a deposition of about 200 tonnes/ha is reported for earthen ponds (Avnimelech and Ritvo, 2003) indicating that the results were within range. The contribution from organic sources (manure, uneaten feed, fecal matter and plankton depositions) ranged from 76.3-137.8 kg across the different treatments. Influent water did not contribute much to the deposition (about 10 percent of total accumulation).

Table 1: Multi-comparison test (Tukey test) of sediment accumulation means by treatment (± stdev)

Parameters	Treatments							
	CM1		CM2		P1		P2	
Accumulated sediment layer (cm)	3.0		2.8		2.9		3.2	
	Min	Max	Min	Max	Min	Max	Min	Max
Quantity of accumulated sediment over culture period (tonnes/pond/cycle)	3.1	3.46	-0.78	1.5	2.8	3.3	1.67	2.8
Sediment sources								
Influent water (kg/pond culture $period^{-1}$)	0.19 ± 0.01		0.21 ± 0.07		0.20 ± 0.02		0.17 ± 0.03	
Estimated sedimentation from organic sources (kg)	137.79		129.21		62.9			
Percent of accumulated sediment accounted by influent water and organic sources	4.4	4.0	-	8.6	2.5	1.9	4.6	2.7

CM1= Chicken manure at 50 kg dm/ha/day and stocking density 1 fish m^{-2}; CM2= Chicken manure at 50 kg dm/ha/day and stocking density of 2 fish m^{-2}, P1= 25% protein pellets at 3% body weight (BW) /day and 1 fish m^{-2}; P2= 25% protein pellets at 3% BW /day and 2 fish m^{-2}; All treatment means not significant (modified from Muendo, 2006)

Table 2: Quantity of nutrients in the sediment and concentration at harvest

Parameters	Treatments			
	CM1	CM2	P1	P2
Accumulated sediment (tonnes/pond/cycle)	3.28	0.36	3.05	2.24
Nitrogen				
Concentration at harvest (g/kg)	1.9	1.9	1.8	0.88
Quantity in accumulated sediment (tonnes/ha)	312	71.5	259.5	174
Organic carbon				
Concentration at harvest (g/kg)	14.5	12.5	11.7	12.7
Quantity in accumulated sediment (tonnes/ha)	2.4	0.45	1.75	1.45
Available phosphorous				
Concentration at harvest (g/kg)	0.0063	0.0038	0.0033	0.0035
Quantity in accumulated sediment (tonnes/ha)	1.035	0.14	0.5	0.39
Potassium				
Concentration at harvest (g/kg)	0.072	0.077	0.074	0.073
Quantity in accumulated sediment (tonnes/ha)	118.5	29	113	81.5

Modified from Muendo, 2006: CM1= Chicken manure at 50 kg dry matter/ha/day; and stocking density 1 fish/m^2; CM2= Chicken manure at 50 kg dry matter/ha/day; and stock density of 2 fish/m^2, P1= 25% protein pellets at 3% Body Weight/day and 1 fish/m^2; P2= 25% protein pellets at 3% Body Weight/day and 2 fish/m^2.

Table 2 shows the amount of different nutrients in the sediments. This study indicated that based on the Egyptian recommendations for maize cultivation of 286 kg/ha nitrogen, 200 phosphorus and 85 potassium, the sediment accumulation quantities of between 100-300kg nitrogen, 1.8-5 tonnes organic matter, 0.2-1.1 kg available phosphorus and 50-125 kg exchangeable potassium/ha per growing season is enough to sustain the crop if phosphorus is augmented by 1 percent.

Table 3: Water quality parameters for water inlet and outlet

Source	Parameters				
	Temperature	pH	DO (mg/l)	NH4 (mg/l)	NO3 (mg/l)
Site 1					
Inlet	24.9	8.24	5.83	0.12	0.28
Pond	26.6	8.17	5.46	0.42	0.21
Outlet	24.7	7.81	4.43	0.16	0.21
Site 2					
Inlet	28.7	7.6	6.0	0.11	-
Pond	28.6	7.7	6.2	0.12	-
Outlet	28.8	7.5	3.6	0.15	-

The results of the field trial cultivation of maize using fishpond effluents and the fish growth curve (Figure 4) indicate that the fish were able to grow well on the integrated system. Because, influent water contributed about 0.17-0.21 kg of sediment/pond, the trials used an initial fertilization of the field with urea and calcium superphosphate during land preparation. Charo-Karisa *et al.* (2006) undertook selective breeding of Nile tilapia in ponds receiving only 50 kg/ha /day chicken manure with impressive response to selection of about 35 percent in three generations.

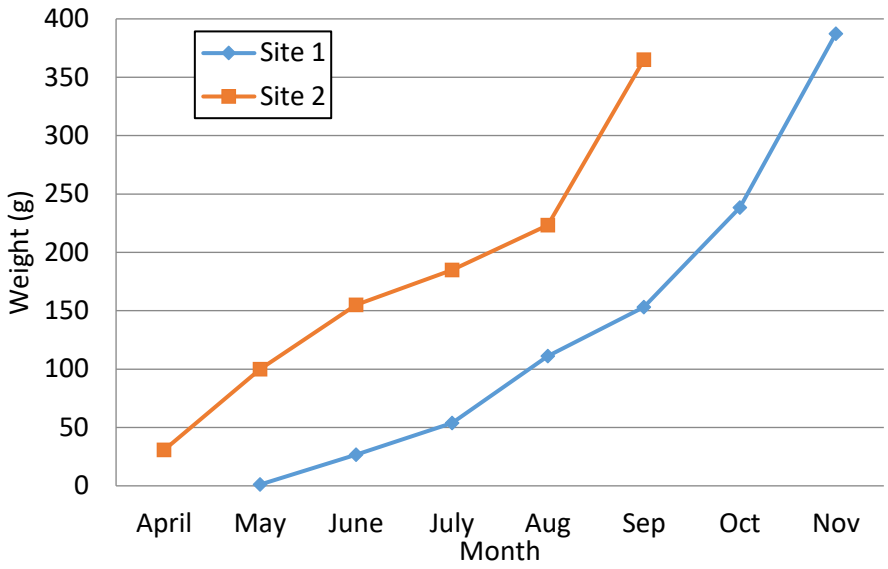

Figure 4: Fish growth curve over the growth period in site 1 and 2.

The result of water quality analysis for one production season (Table 3) indicate that the level of nitrogen in effluent water increased compared to the source water (canal water). The pond water effluent when used to irrigate maize crop plots plus fifty percent commercial fertilization rate produced a maize crop higher or equal in yield to the traditional fertilization regime (Table 4).

Table 4: Maize growth parameters and yield per different treatments

Trait	Traditional culture (Canal water + 100 percent fertilization)	Fish pond water + 0 fertilization	Fish pond water + 50 percent fertilization
Plant Length	158 ± 5.7	158 ± 1.5	161 ± 1.1
Plant Weight	0.6 ± 0.05	0.5 ± 0.02	0.7 ± 0.1
Crop weight (kg)	0.34 ± 0.02	0.3 ± 0.03	0.35 ± 0.01
Production (kg/fed)	137 ± 8.2	126 ± 7	142 ± 5.9

According to Thompson *et al.* (1995), studies indicate that for every kilogram of market size production of rainbow trout (*Salmo gairdneri*), 0.1 kg nitrogen, 0.023 phosphorus and 0.75 of carbon became released to the water. The studies with Nile tilapia tend to agree with this finding indicating that these can be used to fertilize crops. Taken together with the revenue realized from the sale of the maize and the fish (Table 5) it is clear that an integrated agriculture aquaculture farm realizes much higher economic efficiency than each of the components separately. Although these results are preliminary, it is instrumental that the ponds receiving chicken manure and bran did better, in terms of total revenue and water use efficiency, than those receiving commercial fish feed. Fish feed is the most expensive component in fish farming operations and can take up to 70 percent of the total costs. As a result, farmers have been known to utilize a mixture of better quality commercial (but often expensive) and cottage or on-farm made feed (often low-cost but of inferior quality). Integrating fishponds with crop production unlocks the nutrients from the sediments leading to better nutrient use efficiency. This paper indicates that there is scope for optimization of IAA systems to further lower costs of production and increase overall water use and economic efficiency in Egyptian farms.

Table 5: Water use efficiency table

Parameter	Site 1	Site 2
Water use in m^3		
Pond filling (3*200)	600	600
Compensate water lose (0.5 cm/day)	600	600
Water discharge to maize	405	720
Total water use m^3	1 005	1 320
Yield		
Fish yield in kg	407	350
Maize yield	750	850
Revenue		
Maize Revenue EGP	2 775	3 175
Fish revenue	9 138	7 523
Fertilizers saving	560	460
Total Gross Revenue (EGP)	12 473	11 158
Return on unit of water used (EGP/m^3)	12.4	8.5

4. Acknowledgements

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STRENGTHENING INTEGRATED AQUATIC PLANT AND ANIMAL FARMING IN THE RICE FIELDS OF THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

Chanthaboun Sirimanotham and Nick Innes-Taylor

1. Introduction

The Lao People's Democratic Republic has rich aquatic biodiversity and rice fields are a sanctuary for a diverse set of aquatic organisms (Figure 1). These aquatic animals and plants are vital to the food and nutrition security of Lao people, especially those living in rural and remote areas. They provide poor communities with critical animal protein and micronutrients, important in the development of young children and pregnant women.

Figure 1: Rice fields are a sanctuary for a diverse set of aquatic organisms.

Many small-scale family farmers have tried to intensify aquatic animal production in their rice field environments, but in practice, this is difficult to achieve. Most poor communities cannot increase their production of fish and other aquatic animals (e.g. crabs and snails), above that of traditional systems which mainly augment the natural recruitment of aquatic animals found in nearly all Lao rice field environments. While it is technically possible to increase this natural production, interventions typically promoted by rural development projects, require farmers to make substantial modifications to their rice fields. These often include digging long trenches, undertaking predator control and guarding against theft. While technically sound, following such advice implies significant investments in family time and money, and is not feasible for most small-scale farmers. The risks associated with digging-up rice paddies for example, are generally too high for families constantly challenged by food and nutrition insecurities.

2. Common misunderstandings

The lack of appropriate advice currently available to small-scale farmers in the Lao People's Democratic Republic, mainly stems from two important misunderstandings. Firstly, despite numerous technical studies conducted over the last 10 years, most policy makers and local development workers do not appreciate the value and importance of these resources to food and nutrition security. The key findings of these studies have not been fully understood and effectively communicated with local-level stakeholders and consequently, they are often overlooked in the design of poverty reduction programs.

Figure 2: Small hand-dug ponds improve nutrition.

Secondly, there is a misunderstanding among policy makers and development workers about how small-scale farmers want to approach the intensification of their rice-fish systems. Farmers require recommendations which are low-risk and work to gradual modify their existing farming systems, rather than replacing them with new ones. Small-scale farmers also want to augment the diverse natural productivity of their rice fields rather than replacing it with the intensive culture of one or two species. These desires are often at odds with extension advice provided by development agencies, which tend to offer complete "packages" of technical recommendations that require significant and rapid changes in farming practices. The recommendations are also often relatively generic (one size fits all), which means they do not readily integrate into the local agro-ecology and usually exclude local biodiversity from small-scale farming systems.

3. Working to develop solutions

Since 2013 the Lao Department of Livestock and Fisheries (DLF) has been working with FAO to address these misunderstandings and devise more effective approaches towards supporting small-scale family farmers to develop their rice-fish systems. Under FAO's Regional Rice Initiative, DLF and FAO have collaborated with farming communities and local agricultural extension staff in five provinces of the country. These include provinces in the mountainous valleys of the North (Xieng Khouang, Oudomxay and Luang Namtha provinces), and provinces in the Mekong river floodplains of the South (Savannakhet and Salavan provinces). Each province has different agroecologies in and around their rice farming environments and significant differences in institutional arrangements for the provision of agricultural extension services.

DLF's collaboration with FAO has developed a better understanding of the importance of aquatic animals in the rice field environments of these five provinces. Focusing on small-scale family farmers and local-level government extension workers, it has bridged the information gap on the value and importance of aquatic animals in rice field environments. With this understanding, it has been possible to gain the support of local policy makers, and extension workers have been able to establish a series of farmer-managed Promotion Trials across the five provinces (2015-2018). The trials have supported poor communities to develop their own strategies for a gradual intensification of rice-fish culture that are integrated into local agroecologies and work to conserve local aquatic biodiversity.

Another important component of DLF and FAO support to local extension officers, was assisting them to develop their own processes of Trial establishment and farmer support. Processes such as these, are often prescribed by central level government agencies and international Development Partners, but due to differences in institutional arrangements and local capacity, such prescribed (top-down) approaches, often lead to inefficient and ineffective implementation. They can also be highly demoralizing for local

staff and stifle innovations for organizational development. Providing extension officers with the opportunity to develop their own types of Trials, that leveraged local capacities and expertise, provided a strong motivational force for change and produced highly effective processes of Promotion Trial establishment, monitoring and support.

4. Bridging the information gap

DLF's first step towards improving integrated rice-fish culture, was to address local understanding about the value and importance of aquatic animals and plants in rice field environments. While detailed and extensive studies of this issue have already been conducted at national level, the conclusions have been poorly communicated at local levels (provincial, district and community levels).

To bridge this communication gap, DLF and FAO supported local extension workers to undertake small surveys of aquatic animal and plant consumption in collaboration with farming communities. Conducting these small studies helped extension staff developed community dialogue on this issue and build political momentum for changes in local agricultural extension policy.

Figure 3: Rice fields are providing many food, including aquatic plants, eels, fish, insects or molluscs.

In 2013 DLF supported provincial and district officers from five provinces to work with farmers to collect and analyse household consumption data on aquatic resources harvested from rice field environments. These local staff mobilized farmers and engaged local policy makers in Xieng Khouang, Oudomxay, Luang Namtha, Savannakhet, and Champasak provinces. Farmers were invited and helped to collect their own consumption data using specially designed Farmer Record Books. With this support, farming families made systematic records of the name and quantity of aquatic animals and plants they harvested from rice fields over a 10-day period. The farmers then shared their findings with local policy makers. Data were collected in both dry and wet seasons.

The consumption data were highly variable between different families, but the analysis of results surprised everyone, and clearly demonstrated the economic importance of these resources. Some families in Savannakhet province consumed nearly 3 Kg per day of aquatic animals and plants harvested from their rice field. Data also showed that other aquatic animals such as frogs, snails, crabs and insects, are just as important to their food security as fish.

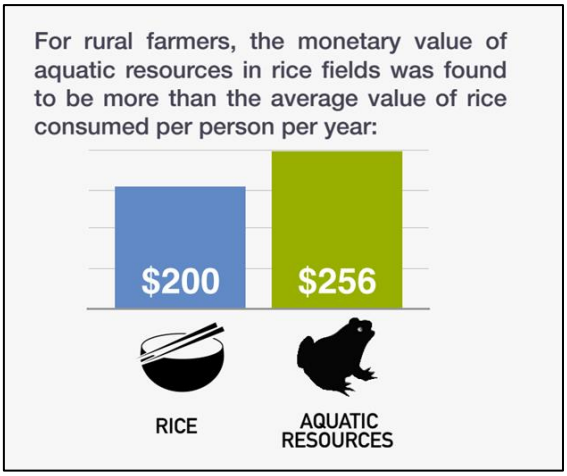


Figure 4: Monetary value of aquatic resources in rice fields (USD).

In Xieng Khouang, 10 farming families recorded consuming 10 different species of fish, 6 different species of Other Aquatic Animals (OAA - frogs, eels, snails, crabs etc.), 7 different types of aquatic plants and 6 types of aquatic forest products (in areas of natural forest next to their rice fields).

During the dry season, the harvest of aquatic animals and plants is less than the wet season, but these resources clearly make an important contribution to family food and nutrition security throughout the year.

When compared with the average value of rice consumed by farming families in the Lao People's Democratic Republic, the value of rice-field aquatic animals and plants to rural families is higher. While this information was new to many farmers and local policy makers, it supports earlier national studies as well as a general sense of concern over a perceived decline in these resources. In a context were many rural households continue to face serious challenges to their food and nutrition security, farmers requests for “practical solutions” to this decline, are increasingly relevant.

5. Farmers developing practical solutions

The next step in DLF’s approach towards developing rice-fish culture was to expand local government partnerships with farming communities. In 2015 the Department initiated a series of Promotion Trials in which individual farming families tested and developed new rice-fish farming strategies. By 2018, over 200 families had participated in these trials (across five provinces), which as well as developing practical farming recommendations, has also generated locally produced communication materials (posters, booklets etc), and the operational procedures government agencies need to scale-up promotion of rice-fish culture to other areas.

Assistance to farming families participating in these Trials was provided by local government agricultural extension officers, operating within the existing institutional framework of agricultural extension services (no artificial project structures were established). DLF and FAO supported these officers to develop new ways in which they interact with poor communities and develop their roles as facilitators of farmer experimentation. They were encouraged to challenge traditional perceptions of their role in community development, where they are often seen as passive conduits for technical “packages” of new farming practices. As well as providing technical advice to farmers, government extension workers were supported to work with communities to identify good practices, communicate local innovation, facilitate community meetings, document lessons learned and produce locally appropriate communication materials (e.g. posters for village schools). The use of social media was also promoted by DLF to encourage extension workers in different provinces to exchange knowledge and experiences.

Farmers managed the Promotion Trials themselves, with support from mainly district-level government agricultural extension staff. Technical advice was provided by DLF and staff from the Lao Aquatic Resources Research Centre (LARReC), as well as provincial-level technical support staff. Farmers kept records of their fish production, and regular discussions were organized between farmers and extension workers to review progress of the Trials and discuss new innovations.

6. Plastic-lined earth pond

One of the integrated aquaculture-agriculture strategies developed by farmers during the Promotion Trials, requires the construction of a small plastic-lined earth pond which they can easily manage and use to intensify parts of their rice-fish culture system. The pond is small enough to be dug by hand, but not big enough to grow substantial quantities of fish. It allows farmers to conveniently nurse seed fish to reduce predation but relies on fish being "fattened" in rice fields. The pond also provides farmers with a facility to maintain a small stock of fish during the dry season. This is used as a source of food during a time when nutritious food is most scarce and to maintain broodstock for the following season's supply of seed fish.

Figure 5: This farmer is using water from her small plastic-lined pond to water vegetables. Small seed fish are nursed in the pond before being released into rice fields later in the growing season.

Many farmers have integrated these small ponds into family vegetable production plots, often located on the margins of rice fields (Figure 5). Waste vegetables are fed to the fish before being released into the rice fields, and small amounts of manure from free-range chickens are used to fertilize the water.

By introducing farmers to existing simple low-cost integrated agriculture-aquaculture practices, and then locally supporting them to test and adapt these practices, participating families have been able to produce a year-round supply of nutritious food.

7. Fish seed production

Trial recommendations also include techniques to produce fish seed (fish fingerlings for stocking into ponds and rice fields), and many farmers have started to sell the seed locally to neighbouring farmers. This helps promote aquaculture in the wider community and at the same time, addresses a key constraint to aquaculture in rural areas - the limited availability of fish seed.

8. Estimates of aquatic animal production and impact

Based on detailed monitoring data collected during 2017, 140 farming families participating in the Promotion Trials produced an additional 22.7 tonnes of fish (and other aquatic animals), mainly for family consumption. This represents an average production of 27 kg/person/year with a value of approximately USD 79 000 (local price of fish is approximately USD 3.5 /kg). A level of fish production close to government targets for increasing the average national fish consumption to 28 kg/person/year by 2020.

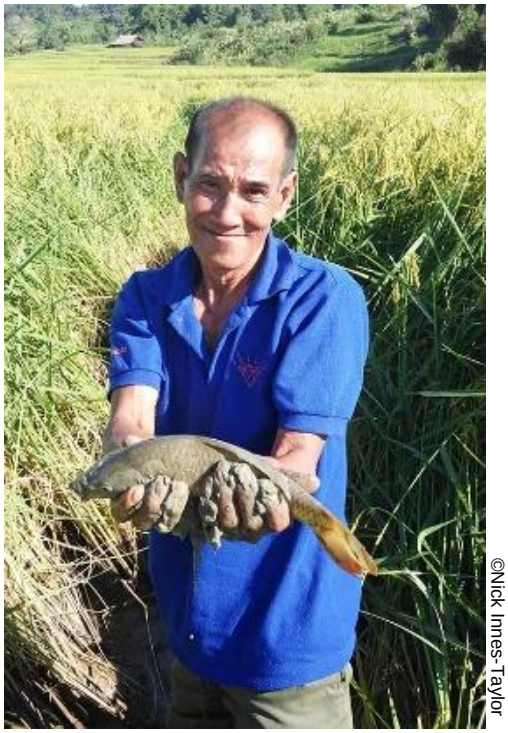


Figure 6: Integrated rice-fish farming.

This additional supply of nutritious food from existing rice field environments makes an important contribution to national food and nutrition security. It represents an important source of protein and key nutrients for poor communities that include high levels of calcium and oils essential for the absorption of some vitamins. Pregnant women and young children especially benefit from an increased supply of such food, as it is not only inexpensive and highly nutritious, but can also be produced near the family house. This greatly reduces the foraging burden of women and teenage girls, who are largely responsible for collecting wild foods (including aquatic animals), among poor communities.

Promoting small-sale fish seed production also helps to ensure Trial benefits can be sustained in the longer term, but also provides some families with significant additional income. During 2017, 30 families participating in the Trials produced 102 000 seed fish with a total commercial value of USD 6 220 (approximately USD 200 per household).

9. Building local capacity

The DLF/FAO partnership described in this paper, aimed to build the capacity of government agricultural extension services to provide practical support to the large number of farmers in the Lao People's Democratic Republic who want to intensify their rice-fish production but have limited resources. Through the Promotion Trial process, DLF generated “entry-level” advice for these farmers who generally have little or no experience of aquaculture. The recommendations, developed by farmers themselves, are low-risk, based on existing technology and use locally available feeds and materials.

They have been developed using existing expertise (at both national and local levels) and promote the integration of aquaculture into established rice farming practices. They also consider family labour constraints and aim to utilize on-farm resources more efficiently.

Figure 7: Farmers and local development officers discuss trial recommendations at a workshop organized to share and exchange information and experiences between provinces.

A cornerstone of DLF's Promotion Trial approach is the localized development of recommendations for farming system improvements. For sustained and wide-scale adoption by farmers, recommendations must be practical, specific to the local situation and developed in a process of dialog between farmers, extension workers and technical experts. During the 2017/2018 growing season, platforms for this type of dialogue were created in five provinces and expertise developed at national level to facilitate and support this local dialogue rather than lead it. The Department's approach emphasises the importance of local stakeholders having the opportunity to learn together and building local ownership of project management.

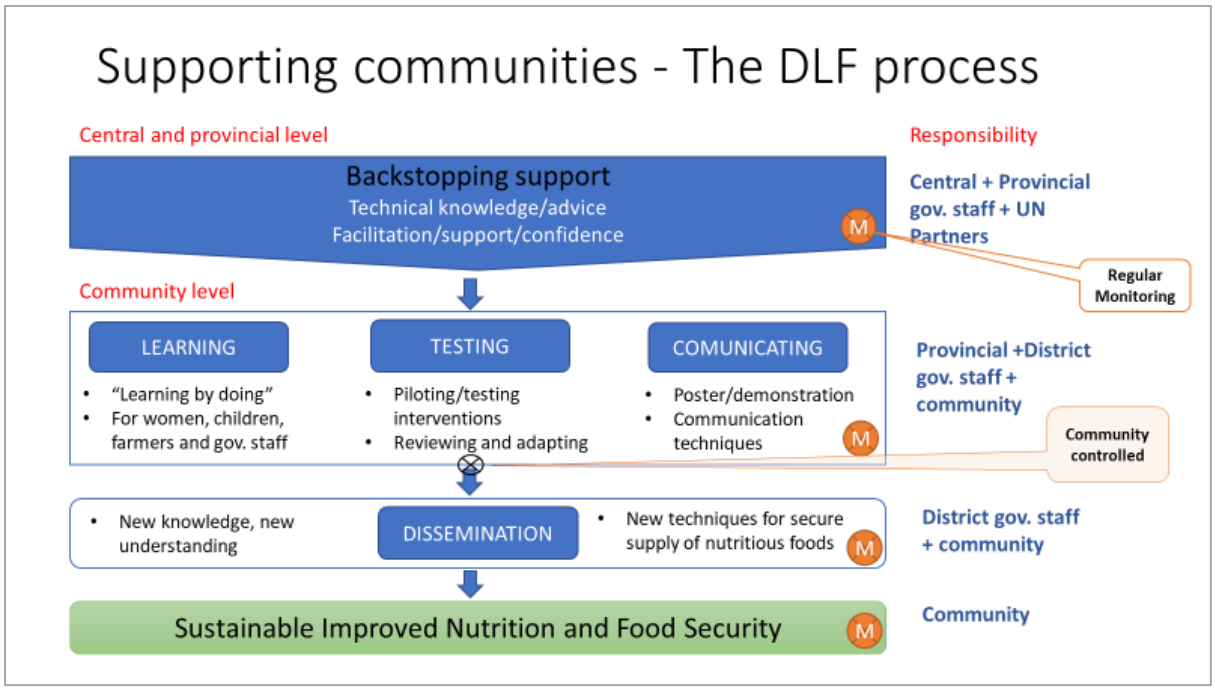


Figure 8: The DLF process for supporting communities.

Developing the skills and expertise of stakeholders to manage and support this dialogue and create a supportive environment for local learning and training, was therefore an important part of DLF capacity

building to support the Promotion Trials. Activities included schemes for the creation of officially recognized Farmer Trainers, training agricultural extension staff in convening/moderation skills and developing local-level understanding of how better integration of farming enterprises can boost productivity and conserve the natural environment.

At least 30 government staff working at provincial and district levels in five provinces, have benefited from these types of capacity building activities. With FAO support, DLF developed new approaches to staff training to build this capacity, which places a greater emphasis on "Peer-to-Peer" learning techniques and takes advantage of new communication opportunities available through social media. Local government staff in the five provinces say they now have more "confidence" to engage with poor communities and welcome the new approaches to capacity building which focus on their workplace and increase professional exchange with their peers.

10. Effectiveness of international support

Based on estimates from monitoring data collected during 2017, farming families participating in Promotion Trials generated additional fish for family consumption and fish seed worth approximately USD 85 200. During 2018, the monetary value of Trial production is confidently expected to increase to at least USD 100 000. This represents a total contribution to the local economy of approximately USD 185 000 over two years.

Figure 9: Food Aid provided to a village school in Savannakhet by World Food Programme (WFP).

While these figures are approximate, they can be used to illustrate the effectiveness of the FAO/DLF partnership. Over the same two-year period, the FAO local contribution was approximately USD 124 000, which indicates that FAO's investment in developing DLF's institutional capacity has been effective. Within two years, it has produced tangible benefits to the food and nutrition security of poor communities in five provinces worth at least 150 percent of the total investment. These benefits are also likely to further increase, as the FAO intervention was designed to be sustained both in terms of the changes farmers have made to their farming systems and in terms of the developments in government staff capacity.

A comparison with alternative strategies to improve food and nutrition security in the Lao People's Democratic Republic is also useful. For example, many poor rural communities are supported by food donations from the World Food Program (e.g. as support to school lunch programs), and WFP average

expenditure per beneficiary has gradually increased over the last few years to nearly USD 40 in the Asia-Pacific region (World Food Assistance 2017 - Taking Stock and Looking Ahead). If WFP were to provide this type of assistance to 200 families over two years, it would cost approximately USD 88 000. While the FAO contribution is initially greater, the longer-term benefits of strengthening DLF's institutional capacity and establishing more resilient and efficient farming systems among poor communities, makes this investment a more effective strategy.

RACEWAY-IN-POND AQUACULTURE SYSTEM

Liu Xingguo, Xu Hao, Gu Zhaojun, Wang Xiaodong

Abstract

A combined ecological engineering facility composed of aquaculture ponds linked to an ecological ditch, an ecological pond, and a subsurface flow constructed wetland was designed and tested as a Raceway-in-Pond Aquaculture System (RPAS). The mean removal rates of ammonia nitrogen (NH^4-N), total nitrogen (TN), total phosphorus (TP), potassium permanganate index (CODMn), and chlorophyll a (Chl-a) by the ecological depurating facilities were 44.2, 47.6, 63.4, 61.5, and 83.0 percent, respectively. These were significantly lower than in the control pond ($p < 0.05$). Compared with traditional pond aquaculture, the RPAS increases the fish production from 0.75 to 0.82 (mean value) kg/m^3, and reduces the feed coefficient ratio by 8.2 percent. By improving the water quality and providing a good culture environment, the RPAS contributes to improve the culture efficiency.

1 Introduction

In China, the freshwater ponds cover 2 668.835 km^2, and produce 22.11 million tonnes, accounting for almost 74.7 percent of the total freshwater aquaculture products (China Fisheries Year Book, 2019). However, most of China aquaculture ponds were built during the 1960s and 1970s and many problems have arisen since, among which the extensive production, the inefficient use of water resources or the pollution, which seriously impede any further development of pond aquaculture (Xu, Liu, Wu, 2009). In Hangjiahu district, Zhejiang province, the production of 1 kg of freshwater fish is reported to consume 4 to 6.5 m^3 of water, and the annual emissions of permanganate index (COD_{Mn}), total nitrogen (TN) and total phosphorus (TP) were 199 kg 101 kg, 5.0 kg per 1 hm^2 aquaculture pond. The cumulative impacts of pond aquaculture have thus become an important issue in China (Zhou and Wen, 2004; Huang *et al.*, 2007).

Ecologically-engineered aquaculture systems are an environmentally friendly and healthy alternative. Indeed, by using ecological engineering to design and construct pond aquaculture systems, it is possible to regulate the water quality and control the pollution. This paper describes the first freshwater recirculating aquaculture pond system designed in China, which consists of three purification units (ecological ditch, ecological pond and composite artificial wetland) and culture ponds. A running test was conducted over a 210 days rearing period, in order (1) to investigate the purification effects of the different ecologically-engineered facilities on the water discharged by aquaculture and (2) to provide a reference for constructing ecologically-engineered pond aquaculture system in support to the freshwater fish farming in China. The primary results are presented in this article.

2 Material and methods

2.1 The Raceway-in-Ponds Aquaculture Systems (RPAS)

2.1.1 Design equations

The ecologically-engineered pond facilities and recirculating aquaculture system were designed by following the relevant standards and results from related studies. The following equations were used:

Sub-surface Flow Constructed Wetland (SFCW) - Eq. (1):

SFCW volume: $V = Q_{av} t / \varepsilon$ (1)

where Q_{av} is the average flow (m^3/d), t is the hydraulic retention time (d), V is wetland volume (m^3), and ε is SFCW porosity (dimensionless) (HJ, 2011).

Ecological ditch and ecological pond - Eq. (2):

area: $A=QS_0 t/N_a$ (2)

where Q is the sewage flow (m^3/d), S_0 is influent BOD_5 (g/m^3), t is the water dwelling time (d), and N_a is area load (g/(m^2·d)) (HICEA, 1994).

The RPAS was constructed by using three traditional static ponds (P1, P2 and P3) and 200 m of drainage ditch at Punan aquafarm (31°57′01″N, 120°08′52″E), Songjiang district, Shanghai, China. Considering the results from previous trials, the daily volume of water recycled was set to be 10 percent (Liu and He, 1992). The regulating reservoir was used to construct an ecological pond and the subsurface flow wetland. According to Eq. (1) and characteristics of COD_{Mn} in the pond water discharge, t was determined to be 0.4 d, with ε = 0.50 (gravel of average diameter of 50 mm), and Q_{av} = 1500 m^3/d, V was 1200 m^3. The depth of the SFCW was 0.7 m, and the surface was 1500 m^2. According to Eq. (2) and the concentrations of BOD_5 (g/m^3) in pond water discharge, it was determined that N_a was 40 g/(m^2·d), Q was 1500 m^3/d, t was 1.5 d, and the eco-pond area (a) was 2750 m^2.

2.1.2 System construction

The RPAS covers 2 hectares and consists of three culture ponds (15000 m^2) and three purification units that include an ecological ditch (500 m^2), an ecological pond (2500 m^2) and a 1500 m^2 sub-surface flow constructed wetland (SFCW). The three culture ponds are connected in series, and drainage channels are located on both sides of the ponds, with the ecological pond (eco-pond) and SFCW at one end. The ecological ditch (eco-ditch) is also connected with the external river so that water replenishment can be performed. The components of the system have different elevation levels. The ponds and eco-ditch have the same elevation, but the eco-pond is higher by 30 cm than eco-ditch and by 35 cm than SFCW. There is a water pump at the end of eco-ditch to fill the ecological pond so that when water is added, it flows by gravity into the SFCW, before entering a re-aeration pond, and the culture pond 1, 2 and 3. The water also can flow into eco-ditch from the bottom of pond 3, thus forming the recirculating system (Figure 1).

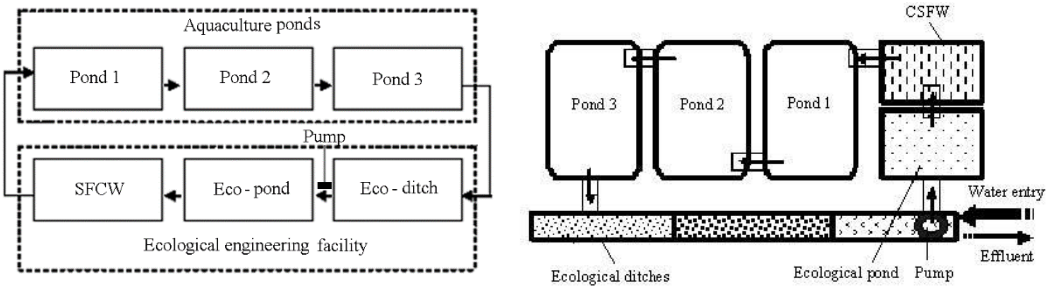


Figure 1: Layout of the RAPS.

2.2 Experiment

The experiment was conducted during 210 days, from 15 March 2014 to 14 November 2014. A static pond near the RPAS was selected as a control (Figure 2). The control pond without recirculation corresponded to the stagnant water conditions, representative of traditional aquaculture ponds. In the culture ponds (P1, P2 and P3) and control, fish were stocked in polyculture, associating grass carp (*Ctenopharyngodon idellus*) (45 percent of the total weight), blunt-snout bream (*Megalobrama amblycephala*) (40 percent of the total weight), as well as silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*) and crucian carp (*Carassius cuvieri*) altogether accounting for 15 percent of the total weight. The initial stocking density was 0.15 kg/m^3 in each pond. During the experiment, fish were fed 10000 kg of feed, with the same quantity in each pond. The pump water flow was 120 m^3h^{-1}, the daily circulated volume was 2800 m^3/day, and the actual daily exchange rate of the pond water was 9.6 percent.

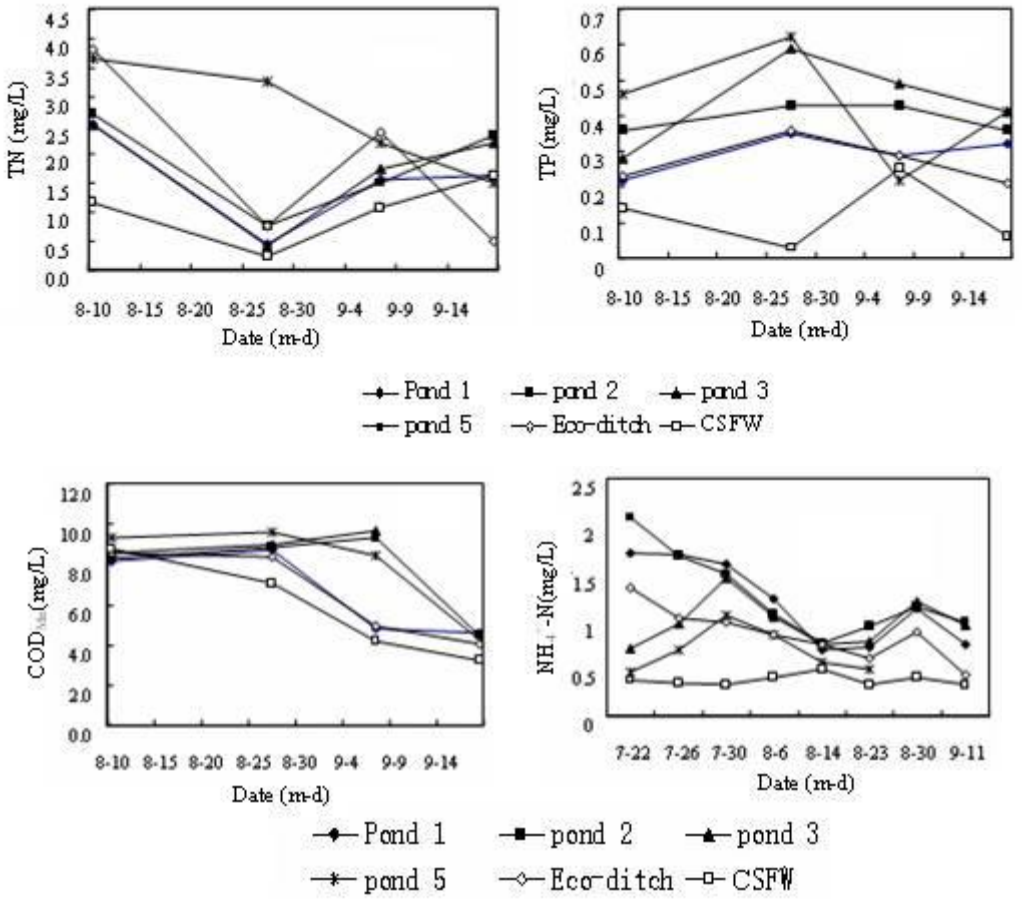
a b c

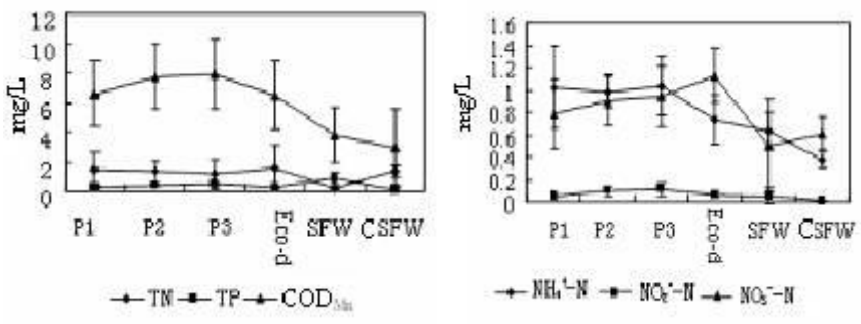
Figure 2: Components of the Raceway-in-Pond Aquaculture System: a) ecological ditch, b) ecological pond and SFCW c) overview of the RPAS.

3 Results

3.1 Water quality in RPAS

With the exception of COD_{Mn} for which concentration gradually reduced overtime in the different RPAS units (p<0.05), the quantity of TN, NH_4^+-N and TP remained stable throughout the progress of the growing-out (p>0.05). In contrast, COD_{Mn}, TN and NH_4^+-N in the control pond kept on increasing during the same period. The NH_4^+-N concentration increased from 0.68 mg/l in March to 1.45 mg/l in October, a 2.13 folds increase. At the end of the experiment, the concentrations of COD_{Mn}, TN and NH_4^+-N were all significantly higher in control than in the RPAS (p<0.05, Figure 3)).





Fig, 3: Water quality and purification efficiency.

3.2 Fish production

The fish production parameters in the RPAS and control are presented in Table 1. At the end of the experiment, the mean yield in RPAS was 0.82 kg/m^3 and the mean feed conversion ratio (FCR) was 1.22. In the control pond, the fish yield was 0.75 kg/m^3 and the FCR 1.33. The fish production in the RPAS was thus 8.5 percent higher than in the traditional pond, and the FCR was 8.2 percent lower. Meanwhile, there was also difference in fish yield and FCR between the three culture ponds. The production was obviously higher in P1 than in P2 and P3 (Table 1).

Table 1: Production of the RPAS

	Initial weight kg	Stocking density kg/m^3	Harvest weight kg	Yield kg/m^3	Feed weight kg	Feed coefficient
Pond 1	1 500	0.2	8 406	0.84	10 000	1.19
Pond 2	1 500	0.2	8 320	0.83	10 000	1.20
Pond 3	1 500	0.2	7 874	0.79	10 000	1.27
Control pond	1 500	0.2	7 515	0.75	10 000	1.33

3.3 Water-savings and emission-reduction

In China, traditional aquaculture ponds exchange water 3 to 5 times a year, but only 1 or 2 times a year in RPAS system. Moreover, the discharged water is depurated by the ecological pond. Table 2 compares the water consumption and pollution emission by RPAS and traditional static pond aquaculture systems. RPAS saves 63.6 percent of water, compared to the traditional system, and reduces the emission of TN, TP and COD_{Mn} by 87.8 percent, 91.7 percent and 78.1 percent, respectively. (Table 2)

Table 2: Water consumption and pollution comparison of ecological engineering and the traditional pond aquaculture

Item	Water losses m^3/kg		TN emissions g/kg fish	TP emissions g/kg fish	COD_{Mn} emissions g/kg fish
	Evaporation	Water exchanges and drainage			
Traditional pond aquaculture	0.18	5.25	15.9	2.64	49.5
Ecological engineering pond aquaculture	0.18	1.95	1.95	0.22	10.9
Average reduction ratio percent		63.6	87.8	91.7	78.1

Note: Total nitrogen emissions (emissions of per unit of production) = emissions of total nitrogen × water discharge of per unit product. Total phosphorus and COD_{Mn} emissions calculated with the total nitrogen emissions.

4 Results and discussions

Although the nutrient concentrations in the control pond increased during the growing-out period, they remained stable (TN, TP and NH_4^+-N) or even decreased (COD_{Mn}) in the RPAS system. The purification units, consisting of the eco-ditch, eco-pond and SFCW thus proved to be effective (Figure 2). These units are a natural treatment system based on a biological symbiosis between macrophytes (*Phragmites* sp., *Acorus* sp., etc.), microorganisms (bacteria, fungi, algae), and their interactions with the soil and water chemistry (Schulz, Gelbrecht and Rennert, 2003). On the other side, the water quality in the culture ponds decreased with the water flow. This is probably the consequence of fact that the first pond (P1) was continuously replenished with clean water (i.e. the final effluent after the purification units) (Zhang *et al.*, 2011). However, monthly variations were also observed, as a result of seasonal oscillations, including physicochemical and biological variations within the purification units, influent fluctuation, and climate changes.

The fish production efficiency highlights the purification effects by the RPAS, which provides better environmental conditions to fish during the rearing period, contributes to an accelerated growth and minimizes the FCR, thus improving the overall culture efficiency (Zhang *et al.*, 2011).

The present study also revealed that RPAS saved 63.6 percent of water, compared to the traditional pond, and reduced the emission of TN, TP and COD_{Mn} by 87.8 percent, 91.7 percent and 78.1 percent, respectively. Constructing ecological engineering facilities might be an effective way to control aquaculture pollution.

However, some researchers believe that ecological engineering facilities such as this constructed wetland are too space-consuming (Sindilariu, Wolter and Reiter, 2008). Therefore, in order to maximize the beneficial effects of the engineering facilities, it will be necessary to assess the most reasonable surface ratio between the purification units and the aquaculture pond.

5. Acknowledgments

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INCREASING CARP AND SMALL INDIGENOUS SPECIES PRODUCTION IN SEMI-INTENSIVE PONDS THROUGH ENHANCING PERIPHYTON GROWTH

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Abstract

Carp is the major group of fish grown in South Asia. However, productivity of carp is still low. From 2014 to 2017 on-station and on-farm trials were conducted in Nepal to evaluate production of carp (Silver carp *Hypophthalmichthys molitrix*, Bighead carp *Aristichthys nobilis*, Grass carp *Ctenopharyngodon idella*, Common carp *Cyprinus carpio*, Rohu *Labeo rohita* and Mrigal *Cirrhinus mrigala*) and small indigenous fish species (SIS) such as *Dedhuwa Esomus danricus* and *Pothi Puntius sophore*. Profit in a periphyton enhanced system and performances of various substrates (split bamboo, whole bamboo, banana midrib, plastic bottle) were also tested. Results showed that the yield of carp, FCR and profit were better in periphyton enhanced ponds. An on-station trial using split bamboo as a substrate with 50 percent feeding revealed that the net yield of carp was 55 percent higher in carp-SIS ponds with periphyton enhancement (5.45 ± 0.45 t/ha/yr) compared to without periphyton ponds (3.51 ± 0.42t/ha/yr). Reduced feed input and periphyton enhancement resulted in increased profit in carp-SIS ponds with periphyton enhancement by 109 percent over ponds without periphyton enhancement. No such differences were found in field trials except in FCR. All experimental substrates split bamboo, whole bamboo, banana midrib and plastic bottle were equal in terms of carp and SIS production and profit from carp. However, banana midrib was not durable and decayed faster requiring replacements 3-4 times during the experimentation period. Thus reduced feeding with split bamboo as a periphyton substrate has been found to be effective for small-scale farmers.

1. Introduction

Carp polyculture is practiced throughout South Asia, however, yields from these systems are less than optimum (Jha *et al.*, 2018). In Nepal, carp polyculture is the major aquaculture system used, contributing about 87.5 percent of total fish production (Kunwar and Adhikari, 2016). Carp are grown semi-intensively using fertilizers and supplementary feed where the feed cost is up to 70 percent of total operational cost (Yadav and Rai, 2014). For small-scale farmers it is hard to bear the feed cost. Providing an alternative means to reduce the feed cost has thus become essential for economic viability of the system to small-scale farmers. In most pond production systems, only a small proportion of nutrient input (30 percent) is converted into harvestable matter while the rest is lost into sediments, effluent water and atmosphere (Acosta Nassar *et al.*, 1994; Beveridge *et al.*, 1994; Olah *et al.*, 1994). Improving the conversion of nutrients into harvestable matters by enhancing the natural food production may be a suitable solution to the problem of higher cost, as well as loss of nutrient inputs. Enhancing the growth of periphyton in pond production systems has been proved to be a suitable method to increase the natural food production (Azim *et al.*, 2001a; Rai *et al.*, 2008; Jha *et al.*, 2018).

Many fish in wild, as well as in culture, rely on periphyton for its food. Indian major carp (Wahab *et al.*, 1999; Ramesh *et al.*, 1999; Rai *et al.*, 2010), tilapia (Hem and Avit, 1994; Dabbadie, 1996; Shrestha and Knud-Hansen, 1994; Milstein *et al.*, 2009; Jiwyam, 2013), common carp (Rai and Yi, 2012) as well prawn (Udin *et al.*, 2007) prefer periphyton as natural food. Significant research in periphyton based aquaculture was carried out using different substrates such as bamboo poles, PVC pipes, sugarcane bagasse, jute stick, plastic sheet, bamboo side branches, rice straw, coconut coir and coconut shell in Bangladesh, India and Nepal (Azim *et al.*, 2001a; Azim *et al.*, 2001b; Azim *et al.*, 2002; Keshavnath *et al.*, 2001a, Rai *et al.*, 2008; Shirin *et al.*, 2013; Santhiya *et al.*, 2017; Jha *et al.*, 2018). Among these substrates, bamboo and coconut coir was better (Keshavnath *et al.*, 2001; Azim *et al.*, 2002; Van Dam *et al.*, 2002, Santhiya *et al.*, 2017).

Carp-SIS polyculture is not new to Nepal. Farmers have been harvesting varieties of SIS from household ponds for a long time. The technology received more attention starting in 2009, when formal studies began in Terai, Nepal with technical support from Bangladesh. It added nutrition sensitivity to the aquaculture due to micro-nutrient rich nature of SIS (Roos *et al.*, 2006, Rai *et al.*, 2014). In Nepal, three recent consecutive studies have been done to evaluate the production of carp and SIS and the profitability in periphyton enhanced systems. Technology and results of carp polyculture and carp-SIS polyculture in periphyton enhanced systems tested on the research station and in farmers' pond have been summarized in this paper chronologically.

2. Effect of substrates on carp production

Periphyton is considered an appropriate natural food for fish (Hepher, 1988). The nutritive value of periphyton is high (ash 15-19 percent, protein 23-26 percent, energy 19-20 kJ/g) (Azim et al., 2002). It is estimated that potential fish production from a periphyton enhanced pond is around 5 t/ha/y (Azim et al., 2001b; Van Dam et al., 2002). However, in practice fish production obtained from the system is less than this figure. A preliminary trial was carried out in farmers' ponds to assess effect of split bamboo substrate on carp polyculture. The trial was done at Sukranagar Village Development Committee in Chitwan District for 240 days from 20 April to 28 December 2014. The experiment included two treatments: T1 (Carp) and T2 (Carp+bamboo substrate) and four replicates. Fingerlings of Silver carp (20 percent), Bighead carp (5 percent), Grass carp (30 percent), Common carp (15 percent), Rohu (20 percent) and Mrigal (10 percent) were stocked at a rate of 20 000 fish/ha whereas two SIS, Dedhuwa and Pothi were stocked at a rate of 50 000 fish/ha in 1:1 ratio. Prior to stocking, split bamboo mats (Figure 1) were attached in substrate ponds to enhance periphyton growth covering 2 percent of pond surface area. Carp were fed with dough of rice bran and mustard oil cake (1:1) at the rate of 3 percent BW/day and Grass carp with grass and banana leaves at 50 percent BW/day. Water quality parameters such as temperature, Secchi disk visibility, DO and pH were monitored biweekly.

Figure 1: Split bamboo mat used as a substrate in the on-farm trial.

Although a periphyton feeder like Rohu and Common carp, Catla was not included in the experiment but was replaced Bighead carp. Growth rate and net yield of Rohu (0.8 ± 0.0 g/fish/day and 0.9 ± 0.0 t/ha/yr) and Common carp (2.1 ± 0.1 g/fish/day and 0.8 ± 0.1 t/ha/yr) was higher in periphyton enhanced ponds because both species benefitted from periphyton (Rai *et al.*, 2012) and supplementary feed. Despite higher yield of Rohu and Common carp in periphyton enhanced ponds, net yield of carp did not differ between carp ponds with and without periphyton enhancement (Table 1). Full feeding (3 percent BW) was used in the experiment which might have supplied sufficient nutrients for growth of carp and thus carp may not have used periphyton. Therefore, periphyton enhancement at full feeding of 3 percent BW did not reduce the feed input and gross margin remained unaffected (Table 2). Periphyton

enhancement at full feeding was not found effective probably due to sufficient supplementary feed in the system but the periphyton technology could be effective in carp polyculture with reduced feeding.

Table 1: Yield and FCR in carp and carp + substrate treatments (mean ± SE)

Yield (t/ha/yr)	Treatment	
	Carp	Carp + Substrate
GFY of carp only (t/ha/yr)	5.40 ± 0.06[a]	5.69 ± 0.21[a]
NFY of carp only (t/ha/yr)	4.04 ± 0.06[a]	4.31 ± 0.13[a]
Feed conversion ratio (FCR)	3.34 ± 0.07[a]	3.23 ± 0.02[a]

Similar superscripts for values in a row indicate no significant difference among the values.

Table 2: Gross margin (NRP/100 m^2/240 days) analysis in carp and carp + substrate treatments (mean ± SE)

	Treatment	
	Carp	Carp + Substrate
Feed	3 008 ± 38[a]	3 045 ± 59[a]
Total variable cost	4 205 ± 38[b]	4 367 ± 59[a]
Return	7 771 ± 85[a]	8 181 ± 169[a]
Gross margin	3 565 ± 109[a]	3 814 ± 120[a]

Similar superscripts for values in a row indicate no significant difference among the values.
Note: Exchange rate used was USD 1 = NRP 101.4 during fish harvesting.

3. Production of periphyton to enhance yield in polyculture ponds with carp and small indigenous species

Carp polyculture is the major aquaculture system in Nepal. Pond production largely goes to the market. Intentional inclusion of SIS into carp polyculture helps these systems contribute to household consumption and nutrition. The intake of nutrient-rich SIS intended to improve the health and nutrition of women and children because vitamin A, calcium, zinc, and iron are found to be much higher in the eyes, head, organs, and viscera of SIS (Roos *et al.*, 2007). Adding periphyton substrates to these ponds should increase fish production and nutrition. An experiment was conducted at Agriculture and Forestry University (AFU), Chitwan, Nepal to develop a cost effective means to increase fish production. The experimental period was 210 days from 24 August 2014 to 28 March 2015. The experiment included four treatments, T_1 (Carp+100 percent feeding), T_2 (Carp+SIS+100 percent feeding), T_3 (Carp+SIS+50 percent feeding+Bamboo substrate) and T_4 (Carp+SIS+Bamboo substrate) each with three replications. Silver carp (20 percent), Bighead carp (5 percent), Grass carp (20 percent), Common carp (20 percent), Rohu (25 percent) and Mrigal (10 percent) were stocked at a density of 15 000 fish/ha whereas two SIS, Dedhuwa and Pothi were stocked at a ratio of 1:1 and at a density of 50 000 fish/ha. Carp excluding Grass carp were fed daily with freshly made dough of mustard oil cake and rice bran (1:1) at the rate of 2 percent BW whereas Grass carp was fed daily with grass at 50 percent BW. Floats and sinkers were tied to two ends of top and base of split bamboo mats (Figure 2) to suspend them in the water column in each substrate pond. Substrate covered 1 percent surface area of a substrate pond.

Figure 2: Split bamboo mat used as a substrate with floats and sinkers tied to the top ends and bottom ends in the experiment. Vertically suspended split bamboo mat in the experimental pond.

On station trial revealed that carp are benefitted by periphyton enhancement. Yield of carp and combined fish yield were best in ponds with reduced feeding (1 percent BW) and periphyton enhancement (Table 3). SIS production was higher in T_2 with SIS and carp at 100 percent feeding (2 percent BW) than in T_3 or T_4. FCR was best (1.02) in T_3 compared to the other two feeding treatments. Lower FCR in substrate ponds indicated periphyton could decrease feed supply to carp. However, in terms of profit, the reduced feeding treatment (T_3) and no feeding treatment (T_4) performed best (Table 4). Some of these results were probably affected by the grow-out schedule, including three months (mid November to mid February) of winter conditions when growth in all treatments was reduced and feed consumption was also changed. Most likely, full feeding would have been the second most profitable and productive system if the trials were conducted only during warm temperatures. Nevertheless, carp-SIS polyculture with reduced-feeding including periphyton-enhancement seemed most productive and profitable.

Table 3: Yields of carp and SIS in different treatments (mean ± SE)

	Treatment			
	T_1	T_2	T_3	T_4
NFY of carp only (t/ha/yr)	4.36 ± 0.47^{ab}	3.51 ± 0.42^{b}	5.45 ± 0.45^{a}	4.15 ± 0.40^{ab}
NFY of SIS only (t/ha/yr)	-	0.21 ± 0.07^{a}	0.05 ± 0.02^{b}	0.05 ± 0.02^{b}
Combined NFY (t/ha/yr)	4.36 ± 0.47^{ab}	3.72 ± 0.36^{b}	5.52 ± 0.43^{a}	4.20 ± 0.41^{ab}
Feed conversion ratio (FCR)	2.44 ± 0.30^{a}	2.44 ± 0.21^{a}	1.02 ± 0.06^{b}	-

Similar superscripts for values in a row indicate no significant difference among the values.

T_1 – Carp+100 percent feeding, T_2 – Carp+SIS+100 percent feeding, T_3 – Carp+SIS+50 percent feeding + bamboo substrate, T_4 – Carp + SIS + bamboo substrate

Table 4: Gross margin (NRs/100 m^2/210 days) analysis of different treatments (mean ± SE)

	Treatment			
	T_1	T_2	T_3	T_4
Cost				
Feed	$1\,627 \pm 166^{a}$	$1\,382 \pm 7^{a}$	871 ± 47^{b}	-
Total variable cost	$3\,248 \pm 166^{a}$	$3\,056 \pm 10^{a}$	$2\,796.8 \pm 46.7^{b}$	$1\,851 \pm 3.2^{c}$
Return				
Carp	$6\,440 \pm 6\,80^{ab}$	$5\,200 \pm 613^{b}$	$8\,031 \pm 631^{a}$	$6\,136 \pm 574^{ab}$
SIS	-	509 ± 101^{a}	324 ± 45^{a}	383 ± 29^{ab}
Gross return	$6\,440 \pm 680^{ab}$	$5\,710 \pm 525^{b}$	$8\,355 \pm 613^{a}$	$6\,519 \pm 563^{ab}$
Gross margin	$3\,193 \pm 622^{bc}$	$2\,654 \pm 520^{c}$	$5\,558 \pm 588^{a}$	$4\,618 \pm 566^{ab}$

Similar superscripts for values in a row indicate no significant difference among the values.

T_1 – Carp+100 percent feeding, T_2 – Carp+SIS+100 percent feeding,
T_3 – Carp+SIS+50 percent feeding+periphyton enhancement, T_4- Carp+SIS+periphyton enhancement

Note: Exchange rate used was USD 1 = NRP 99.6 during fish harvesting.

4. Potential substrates for periphyton enhancement in carp-SIS polyculture

Substrate is one of the key factors in determining fish production in a periphyton enhanced aquaculture system. The substrate type determines quantity and quality of periphyton. Periphyton biomass was found greater in natural substrates due probably to hydrophilic nature of the materials or leaching of nutrients from the substrates (Van Dam *et al.*, 2002). In addition to growing periphyton, substrate also drives away predators and poachers. In previous experiments, split bamboo mats were used as a periphyton substrate. Although yields were better in split bamboo ponds, farmers faced difficulty in partial harvesting of both carp and SIS. Substrates interfered in the netting of fish, although on the positive side, they may also have provided hiding places for fish to avoid predation by birds. Thus, an experiment was carried out to assess alternative substrates for periphyton enhancement in farmer's ponds in Nawalparasi district. Prior to the experiment, a workshop was organized to learn farmers' choices and perspectives on types of substrate.

Based on farmers' suggestions, four locally available substrates split bamboo, whole bamboo, banana midrib and plastic bottle (Figure 3) were tested for periphyton enhancement in farmers' ponds at Seri and Nandapur in Nawalparasi district for 7 months from 12 April to 10 November 2017. Six carp species as in previous experiments Silver carp (20 percent), Bighead carp (5 percent), Grass carp (20 percent), Common carp (20 percent), Rohu (25 percent) and Mrigal (10 percent) were stocked at 15 000 fish/hectare whereas SIS (Dedhuwa and Pothi) were stocked at unrecorded densities. Eggs and juveniles of SIS were simply allowed to enter the ponds along canal water through water inlet. Considering best results obtained with reduced feeding in previous experiments, the feeding rate was fixed at 1.5 percent BW/day for carp in this experiment while feeding rate of Grass carp was kept same of 50 percent BW/day.

a b c

Figure 3: Banana mid rib (a), whole bamboo (b), plastic bottles (c) used as substrates in the on-farm trial.

The yields of carp and SIS and gross margin in each treatment ponds are given in Tables 5 and 6, respectively. Yields of carp and SIS, and gross margin were the same in all ponds indicating that fish were not benefitting from substrates and periphyton enhancement as in a previous trial in farmers' ponds. In on-farm trials farmers do the pond management, and level of management varies farmer to farmer to affect the results. Among substrates used split bamboo, whole bamboo and plastic bottles were more durable than banana midrib. Banana midrib decayed fast within 2-3 months and was replaced 3-4 times during experimental period. So, care should be taken while using banana midribs because excessive loading might cause oxygen deficiency to fish. Lower DO in the rice straw treatment ponds due to increased biological oxygen demand was also reported by Rai *et al.* (2008). Although banana is

easily available in the farm and has multiple uses, replacement effort is important. The substrate should be checked regularly and decayed midribs should be removed quickly. Feed conversion ratio was less than 1.9 in all periphyton enhanced ponds, indicating periphyton enhancement has potential for reducing supplemental feed input. FCR was better in split bamboo ponds than in control ponds which might be due to utilization of periphyton by carp. Probably split bamboo mat provided greater surface area for periphyton colonization. Most likely differences in the surface area of each substrate type, the exposure to sunlight, and the attraction of algae to the substrate surface made each substrate type a unique environment for the production of periphyton and thus resulted in a difference in fish production.

Table 5: Yields of carp and SIS in different treatments (mean ± SE)

	Treatments				
	T1	T2	T3	T4	T5
NFY of carp only (t/ha/yr)	3.63 ± 0.49a	3.87 ± 2.78a	4.05 ± 0.74a	4.28 ± 0.97a	4.34 ± 3.75a
NFY of SIS only (t/ha/yr)	0.07 ± 0.47a	0.07 ± 2.78a	0.1 ± 0.02a	0.1 ± 0.97a	0.08 ± 3.75a
Combined NFY (t/ha/yr)	3.59 ± 0.49a	3.82 ± 0.28a	4.03 ± 0.74a	4.27 ± 0.10a	4.30 ± 0.37a
Feed conversion ratio (FCR)	2.0 ± 0.0b	1.5 ± 0.1a	1.7 ± 0.2ab	1.8 ± 0.1ab	1.9 ± 0.2ab

Similar superscripts for values in a row indicate no significant difference among the values.
T_1 – Without substrate, T_2 –Split bamboo, T_3 – Whole bamboo, T_4 – Banana midrib, T_5 - Plastic bottle

Table 6: Gross margin (NRs/100 m^2 pond/21 days) analysis for different treatments (mean ± SE)

	T_1	T_2	T_3	T_4	T_5
Cost					
Feed	1 368 ± 192 [a]	1 066 ± 75[a]	1 306 ± 288[a]	1 452 ± 117[a]	1 489 ± 25[a]
Total variable cost	2 422 ± 193[a]	2 124 ± 74[a]	2 362 ± 287[a]	2 509 ± 115[a]	2 460 ± 111[a]
Return					
Carp	6 258 ± 846[a]	6 678 ± 461[a]	6 993 ± 1 281[a]	7 386 ± 206[a]	7 485 ± 636[a]
SIS	83 ± 0[a]	75 ± 17[a]	109 ± 26[a]	115 ± 27[a]	87 ± 13[a]
Gross return	6 342 ± 846[a]	6 753 ± 473[a]	7 102 ± 1 283[a]	7 501 ± 180[a]	7 572 ± 643[a]
Gross margin	3 920 ± 655[a]	4 630 ± 440[a]	4 741 ± 1 062[a]	4 992 ± 164[a]	5 111 ± 749[a]

Similar superscripts for values in a row indicate no significant difference among the values.
Note: Exchange rate used was USD 1 = NRP 103.6 during fish harvesting.

5. Conclusion

Carp polyculture is the most popular aquaculture practice in South Asia (Miah *et al.*, 1997), due mainly to the higher production in polyculture compared to monoculture semi-intensive ponds and higher market demands for Indian major carps (Wahab *et al.*, 1995). Periphyton enhanced carp polyculture is mostly practiced by small-scale farmers in Nepal where farmers add substrate in 6-7 species stocked carp ponds to avoid poaching rather than for its food value, because poaching is a common problem. Based on results of three trials it seems that periphyton enhancement system using split bamboo mat with reduced feeding rate at 1-1.5 percent BW/day could be a better option for carp polyculture and carp-SIS polyculture. Quickly decaying substrate may be as good as other natural substrates in terms of periphyton colonization but their decomposition might affect water quality adversely. Although technology is aimed to benefit small-scale farmers its application to commercial farmers should be sought.

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CURRENT PRACTICES OF INTEGRATED MANGROVE-SHRIMP FARMING IN VIET NAM

Phan Thanh Lam

Abstract

Integrated mangrove-shrimp farming systems combine sylviculture with the production of shrimps (seeds of wild species and of *Penaeus monodon*), crab and/or fish. It could be a good alternative to prevent mangrove loss and promote forest conservation measures. This study describes the current integrated mangrove-shrimp farming practices, provides an assessment of the gaps between existing farming practices and selected food standard criteria, and gives some insight on the sustainability of farms' operation. A survey of one hundred farms was conducted by RIA2 in 2017. The findings show that many integrated mangrove-shrimp farms implement a low risk and sustainable production, compatible with many organic certification requirements: no feeding, low stocking density, no use of banned chemical or drug, wild-seed source, positive community relations, valid property rights, and biodiversity protection. However, several other criteria are not yet fully met, especially with regard to effluent management, farms registration, management of mortality, labour arrangements, farm hygiene, and record-keeping requirements. To cope with the increasing food safety, quality and sustainability requirements, current farms have to improve in these areas. Moreover, most current shrimp farms are small-scale farms, and their specificities must be considered in the future development of the aquaculture sector. The possible solutions for this inclusion of smaller farms in the value chain could be horizontal coordination and vertical coordination.

Key words: integrated mangrove-shrimp; farming practices; small-scale farms

1. Introduction

Shrimp farming takes place in coastal areas by using a great diversity of farming system (Vu and Phan 2008; Nguyen and Dang 2009; Nguyen *et al.*, 2009; Tran *et al.*, 2013). It plays an important role in Vietnamese aquaculture, not only by contributing to significant export earnings but also by creating jobs and increasing the income of local people (Cannon and Johnson, 2013; CBI, 2012; Nguyen *et al.*, 2009; De Silva and Nguyen, 2011; Tran *et al.*, 2013). Small-farms owned and managed by families still dominate in the Mekong River Delta (Phan *et al.*, 2009; Tran *et al.*, 2013) but aquaculture farms, especially small ones are considered highly vulnerable in the value chain (Siar and Sajise, 2009; Tran *et al.*, 2013; Washington and Ababouch, 2011a). Small-farms must be included in the future development of the sector, because they account for more than 200 000 operators (Phan *et al.*, 2011; SFP, 2013; Tran *et al.*, 2013).

In Viet Nam, aquaculture is the main occupation of many small-scale coastal shrimp farmers, who have very few other opportunities to diversify their livelihoods (Le, 2009; Nhuong *et al.*, 2003; Tran *et al.*, 2013). Including them in the future development of the value chain can be achieved through horizontal or vertical coordination (Khiem *et al.*, 2010; Khoi, 2011; De Silva and Nguyen, 2011; Umesh *et al.*, 2009). Hence, policymakers need to find suitable measures to support them in the planning processes (Dey and Ahmed, 2005; De Silva and Nguyen, 2011). An overview of the difference in farming practices among farm categories can provide valuable information to policy makers, thus supporting policies and developing strategies suited to specific farm categories.

On the other hand, market trends for certified seafood products are increasing as customers pay more attention to the quality of products (Corsin *et al.*, 2007; Reilly 2007; Yamprayoon and Sukhumparnich 2010). So far, certification has mainly been the realm of large aquaculture farms operated by seafood processors (Belton *et al.*, 2011; Bush *et al.*, 2010; Trifković, 2013). Some large-farms have achieved certification such as the Aquaculture Stewardship Council (ASC), the Best Aquaculture Practices of the

Global Aquaculture Alliance (GAA-BAP) or the Good Agricultural Practices of the GlobalG.A.P. association of producers and retailers (Fisheries Directorate, 2013; Lam and Truong, 2010; SFP, 2013; Vu *et al.*, 2013).

However, achieving certification may be a challenging task for small-farms, due to their limited capacity (Belton and Little, 2011; Bush and Belton, 2012; Haugen, Bremer and Kaiser, 2013; Khiem *et al.*, 2010; Pham *et al.*, 2011; Trifković, 2013; Umesh *et al.*, 2009). Moreover, the economic cost of certification can be another restriction as the profitability of certified production may not be higher than that of uncertified production because of the more costly investments and difficulties to implement standards (Dey and Ahmed, 2005; Haugen, Bremer and Kaiser, 2013; Khiem *et al.*, 2010; Oosterveer, 2006; Tran *et al.*, 2013).

As a result, it seems that assessment of the sustainability of shrimp farming as only been carried out through certification programmes, but it must encompass all categories of farms to see how they can comply with the standards too and to identify the constraints to success. The sustainable development of an industry is affected by many value chain actors (Grunert *et al.*, 2005; Tran *et al.*, 2013; Vo, Bush and Le, 2009). Growing-out farms are the primary producers of the value chain. Understanding better their operation thus provides the basis for policy-making and development of more appropriate strategies in support to the development of the whole value chain.

This paper describes and assesses the current integrated mangrove-shrimp farming practices. It also provides an analysis of the gaps between current farming practices and selected food standard criteria. Finally, it gives some insight into factors related to sustainability of the farms operation.

2. Methodology

Site selection: data was collected from shrimp farms in the Mekong River Delta (MKD). The survey sites (at district level) were selected by using a purposive sampling method, after analysing the distribution of shrimp farms by culture area and type of production. The criteria used were 1) the concentration of certain shrimp systems (i.e. type of shrimp system in a given district); 2) the importance of the shrimp culture area (i.e. total shrimp pond surface (ha) per district); and 3) the historical development of shrimp farming systems.

Shrimp farms selection: At each selected site, a collaboration with local officers allowed to check the lists of shrimp producers and to classify the farms. After that, a randomized stratified sampling was applied to select a sub-set of farms in each district to be interviewed. The total sample size was 100 mixed mangrove-shrimp farms, of which 30 were surveyed by the "Sustaining Ethical Aquaculture Trade" (SEAT) project in 2011 and 70 by RIA2 in 2017.

Shrimp farm data collection: Structured-questionnaires were developed, and the questionnaire was standardized through pilot interviews. The standardized questionnaire was used to collect data from integrated farms. Enumerators were trained on interviewing skills, data recording and methods for minimizing errors during the investigation process. Selected interviewees were owners, managers or technicians who participated or managed farm operations; sometimes interviewees were a group of people working in the same large-scale farms. The interviewees had to know reasonably well the operation of their farm. The information was recorded and checked on the same day. Information gaps were supplemented by telephone. The information collected in the study provided data from the last production cycle.

Data analysis and interpretation: Data analysis was performed to answer research questions and databases were exported to relevant statistical software packages such as SPSS 21 (SPSS Inc., Illinois, United States of America) and MS Excel 2007 for statistical analysis. Descriptive analysis was used to estimate the frequency of responses, mean and standard deviation.

3. Results

3.1. General information

General development trends: In the 1970s, extensive shrimp culture based on wild seed started in the mangrove-forest areas, along the coastal zones of the MKD (Nhuong *et al.*, 2002, 2003). The total shrimp farmed area reached 70 000 hectares by the beginning of 1970s (Nhuong *et al.*, 2002). From 1975 to 1990, shrimp culture remained extensive and supplied the domestic market. This is the time when destruction of mangrove-forest for constructing shrimp ponds took place (Nhuong *et al.*, 2003; Phan and Populus, 2007); around 75 000 ha of mangrove forest were lost to exploit fuels and develop agriculture and shrimp culture. A step change occurred around 1987 (Nhuong *et al.*, 2003), when international trade spurred expansion of shrimp aquaculture (Tran *et al.*, 2013). The development of shrimp farming was also driven by the introduction of artificial hatchery production, the gradual improvement in culture technology for grow-out farming, and the broader Government economic reform, the *Doimoi* policy (Nhuong *et al.*, 2002; Nhuong, 2011; Tran *et al.*, 2013). Hatchery development occurred mainly in Central Viet Nam where Nha Trang University introduced the technology to local hatcheries for its spread to the private sector. By the middle of the 1990s, shrimp farming faced serious epidemic diseases in the MKD, and the industry came to a halt. After that, shrimp disease declined as a result of effective improvement in the seed quality and management practices but it still caused significant economic damages to farmers (Nhuong *et al.*, 2003).

Since 2000, the shrimp industry has developed rapidly, following the Decree 09/2000/NQ-CP allowing farmers to convert saltpans and low producing, saline rice fields into shrimp ponds. The shrimp farmed area increased from 171 820 ha in 1999 to 422 060 ha in 2001, reaching 601 850 ha in 2013. According to MOFI (2006), the total conversion of agricultural land to shrimp culture was around 310 000 ha during the period 1999 to 2005, 42 percent of which came from low-yielding rice land conversion. Since 2005, shrimp farming has continued to grow but mainly through improved-extensive and semi-intensive culture systems instead of the traditional extensive system. However, performances are still limited, particularly in terms of farm infrastructure and access to good quality seed. Moreover, large shrimp mortalities still occur and cause losses to shrimp farmers, particularly in the more intensive systems (DoAH, 2012; Nguyen *et al.*, 2009; VIFEP, 2009).

Ca Mau province now has the largest farming area, accounting for 45 percent of the MKD shrimp farming areas, and the main shrimp systems are the mixed mangrove-shrimp, the rice-shrimp rotation system and the improved-extensive system (Table 1). Soc Trang, Bac Lieu and Ben Tre provinces are also important shrimp farming areas, where the main systems are semi-intensive. The other provinces have a less important shrimp farming area, and the main systems are the improved-extensive and the semi-intensive. Ca Mau, Bac Lieu and Soc Trang provinces altogether contributed 68 percent of the total MKD shrimp production in 2013 (Fisheries Directorate, 2014).

Table 1: Major indicators of shrimp farm-systems classification

Indicator	BTS					WLS
	Intensive model	Semi-intensive	Improved-Extensive	Mixed mangrove-shrimp	Rice-shrimp rotation	Semi-intensive
1. Seed sources	Artificial	Artificial	Natural /Artificial	Natural /Artificial	Artificial	Artificial
- Density	≥20pcs/m^2	≥10pcs/m^2	≥1pcs/m^2	≥0.5pcs/m^2	≥3pcs/m^2	≥45pcs/m^2
- Bio-security	PCR test	PCR test	No	No	PCR test	PCR test
2. Feeding regime	Pellet feed	Pellet feed	Natural	Natural	Pellet feed	Pellet feed
- eFCR	≥1.3	≥1.0	0	0	≥1.0	≥1.0
3. Shrimp yield	≥4 tonnes/ha	≥1tonnes/ha	≥0.2tonnes/ha	≥0.2tonnes/ha	≥0.5tonnes/ha	≥5tonnes/ha

- Survival rate	≤95 percent	≤95percent	≤50 percent	≤50 percent	≤90 percent	≤95 percent
4. Water exchange	Top-up	Top-up	Tidal cycle	Tidal cycle	Top-up	Top-up
- Aeration use	Yes	No/Yes	No	No	No	Yes
5. Management	Company[a]/ Salaried manager	Household/ Salaried manager	Household	Household	Household	Household/ Salaried manager

[a]Farm is fully owned and operated by Aquaculture Ltd. company or Seafood processor; BTS: black tiger shrimp; WLS: white-legged shrimp. Source: Phan *et al.* (2011)

Mangrove destruction and integrated mangrove-shrimp farming: Mangrove forests provide a wide range of ecosystems services, including biodiversity, nutrients cycling and carbon storage, climate change mitigation, coastal protection, nursery ground for fish and shrimps, fuel, tourism and a source of income and food security for local communities (Laure 2017). The largest mangrove area of Viet Nam is located in the southern region of Ca Mau, but its area decreased from 400 000 ha in the 1960s to 73 000 hectares in 1990 under different drivers (Figure 1): the use of herbicides during the Indochina war, the conversion to agriculture (for rice plantations from 1975 to 1979), and to aquaculture (shrimp ponds from 1995 to 2008) as well as the urban development in recent years (Minh *et al.*, 2001, Nguyen *et al.*, 2011; Van *et al.*, 2015; Richards and Friess, 2015). Coastal resources are now threatened by the rapid and unregulated growth of the fishery sector, coastal agriculture, marine transportation and ports, oil and gas exploitation, tourism development, high population density and the daily migration to coastal cities of 1000 people (MFF Viet Nam, 2015). This also puts the provision of ecosystems services provided by mangrove forests at risk and negatively impacts the livelihoods and food security of coastal communities.

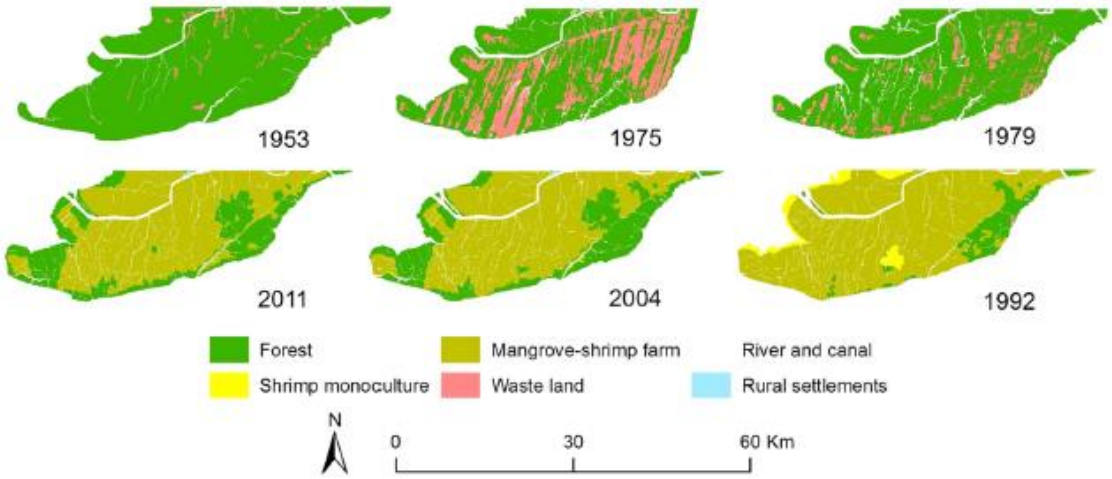

Figure 1. Land cover maps of the Ca Mau for the years 1953, 1975, 1979, 1992, 2004, 2011 (Source: Van *et al.*, 2015).

Blue carbon is the carbon stored and sequestered in coastal ecosystems such as mangrove, sea-grass and tidal marsh. The blue carbon is stored in the living biomass and the non-living biomass like dead wood pool, above and below ground (about 80 percent in the soils). At the global scale, shrimp farming had devastating effects on mangrove forests, by emitting tremendous quantities of blue carbon while also threatening ecosystem goods and services. The conversion of mangrove to shrimp pond farming is not a light hand process. It generates high greenhouse gases (GHG) emissions from land use change (carbon loss from mangrove deforestation and pond excavation), and from GHG activities linked to the farming system. These include use of feed if any, agricultural inputs for pond management, nitrous oxide (N_2O) emissions from fish/shrimp fed farming system and methane (CH_4) emissions for aquaculture developed in freshwater and brackish water.

Preventing mangrove loss and adopting conservation measures could help reduce blue carbon emissions. Integrated mangrove-shrimp farming systems combine sylviculture with shrimps (both wild seeds and artificial seeds of *Penaeus monodon*), crab and/or fish farming. It could be an alternative solution to reverse blue carbon emissions into sequestration if forest is well managed. In Viet Nam, these systems are regulated by the provincial governments to maintain a mangrove-to-water surface ratio of at least 60 percent and are characterized by no or low feed, no or low fertilization, passive water exchange and low production (Decision 186/2006/QD-TTg, 178/2001/QĐ-TTg; Jonell and Henricksson, 2014). Three different kinds of integrated mangrove-shrimp pond systems can be distinguished (Bosma *et al.*, 2014): (1) the integrated farming with canals between platforms planted with mangroves (Figure 2a); (2) the associated farming with large areas of water intermixed with large mangrove area (Figure 2b), and (3) the separated farming with a dyke separating ponds from forest (Figure 2c, d).

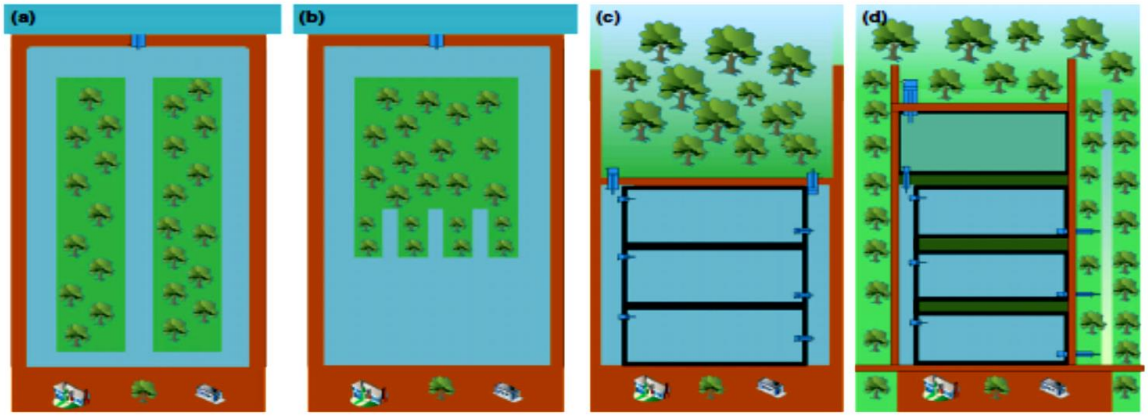

Figure 2. Forms of integrated mangrove-shrimp farm (Source: Bosma *et al.*, 2016).

3.2. Current shrimp farming practices

3.2.1. Shrimp farms characteristics

a) Shrimp farms characteristics

Farm history: Most farms were established more than 20 years before the study (20.7 ± 6.01 years), and they are owned by independent families (87 percent of total surveyed farms).

Pond infrastructures: The farms do not have reservoirs or sediment ponds, as all ponds are used for growing-out shrimp. The water is sourced directly from the river but the exchange is not fully controlled, leading to an increased risk of disease.

The integrated mangrove-shrimp farms are characterized by a low stocking density. No feed is used so that the shrimp rely on natural feed in ponds. The pond size is larger than in the non-integrated shrimp farms (4.37 ± 2.89 ha per farm), but considering that part of the surface is covered with mangrove (51 percent on average), the actual surface available for shrimp is similar to non-integrated systems. Generally, water depth is over 1 m (1.12 ± 0.23 m), and most ponds are earthen as very few have a polyethylene sheet covering. As a result, some ponds have a low structural quality, with unstable dykes and water leakages. Moreover, predators like crabs, snails, or wild fish cannot not be controlled although they may act as a pathogen vectors for from one pond to another.

b) Status of labour in farms

The average age of respondents ranged between 40-60 years old (47.6 ± 11.7) with over 20 years of experience (20.4 ± 7.42 years). As a result, their technical husbandry skills to manage the shrimp ponds is relatively good. The farm management is frequently based on family labour (>80 percent of surveyed farms), but all farms also hire part-time workers under verbal agreements for sludge removal and pond

preparation. This shows the significant employment impact on local communities, both in terms of permanent and seasonal jobs.

3.2.2. Technical aspects

a) Pond preparation and stocking

Only 30 percent of the farms carry out water preparation such as water storage and treatment before stocking, but most of them remove sediment after each crop. Shrimp post-larvae (PL) are purchased from private hatcheries, but most farms do not know the broodstock source. They also do not care about a polymerase chain reaction (PCR) test for post-larvae before buying and stocking (87 percent). Shrimp mortality rates (>95 percent at harvest time) are higher in the integrated mangrove-shrimp farming due to the inconsistent seed quality, which is an important factor affecting production efficiency. Shrimp PLs are stocked directly into the ponds in 80 percent of the surveyed farms, with only 20 percent using nursing ponds first. The stocking density is lower, with intermittent restocking and harvest (20.3 ± 12.4 PL/m^2/year, 6-7 restocking/year at a density of 3.58 ± 2.51 PL/m^2 per stocking).

b) Feed and water management

The integrated mangrove-shrimp system does not use external feed for shrimp.

As the farms are often located in coastal areas and estuaries, the water comes mainly from the river-mouth, coastal canals, with a few farms getting their water from primary and secondary canals. The integrated mangrove-shrimp ponds are filled with untreated water and 2-3 days later, stocked with PL.

Eighty-four percent of the surveyed farms use a "partial drainage and water replacement" method, to cope with the fluctuation of the environmental conditions and disease outbreaks risks. The water exchange is based on the tidal regime, so it is usually carried out fortnightly or monthly. Water filling also bring additional wild seeds and natural feeds into the ponds. The farms with large ponds can only carry out partial water exchange, around 20-40 percent of the total volume (26.3 ± 7.11 percent of total water volume).

c) Effluent management

Drainage is carried out by gravity. Wastewater is not treated and is released directly into the surrounding rivers and canals that are also used to fill the ponds. As many ponds cannot be fully drained, especially the large ones, wastewater is partially reused at the beginning of a new production cycle. Sludge is removed from the ponds and dropped over the dykes after each harvest. Although the unfed mangrove-shrimp systems produce much lower volumes of sludge, the water exchanges lead to the accumulation of significant quantities that need to be removed annually. However, the storage capacity of the dykes is limited and some sludge has to be released into the rivers.

d) Shrimp disease management

Most farms have experienced shrimp mortality during their production cycles. The main cause is shrimp disease (>70 percent of survey farms), followed by extreme weather events and seed quality. At the time of the survey, the most common shrimp diseases were the *White Spot Syndrome Virus (WSSV)*, followed by the *Yellow Head Virus (YHV)* and *Vibrosis*.

A low water quality such as a high Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD) is certainly an aggravating factor of shrimp disease occurrence (Anh *et al.*, 2010; Oanh and Phuong, 2012) but the rapid spread of mortalities is mostly the result of the discharge of untreated wastewater and sludge, especially during outbreaks. Hence, the pathogens from infected ponds are likely to spread to other ponds (Anh *et al.*, 2010; Oanh and Phuong, 2012) as Hoa *et al.*, (2011) found that WSSV can be transmitted horizontally through water, via carrier organisms and/or by cannibalism of infected shrimp. The transmission from neighbouring ponds (at current crop or from previous crop) was the main route for WSSV transmission in the semi-intensive shrimp farming system. A clear

separation between the canals used for water supply and drainage would be needed, but this is not yet the case in the MKD (Anh *et al.*, 2010a).

3.2.3. Economic aspects

a) Harvesting management

The integrated mangrove-shrimp farms harvest shrimp after three months and then carry out monthly stocking and harvesting. The survival rate is low (Table 2) and the system produces less than 250 kg shrimp/ha/year, with an average size of 20-30 pieces per kg. Once harvested, shrimp are sold to the collectors or wholesalers but since the integrated mangrove-shrimp farms are frequently located in remote areas, it is more common that collectors come to the farm.

Table 2: Shrimp farming: Harvesting and marketing in two provinces of the MKD

Items	Bạc Lieu (N=35)	Ca Mau (N=35)	All (N=70)
Number of stocking (times/year)	5.36 ± 1.27	5.4 ± 1.17	5.38 ± 1.21
Duration between stocking (months)	2.06 ± 0.81	1.32 ± 0.53	1.69 ± 0.78
Stocking density (PL/ha/year)	16.8 ± 9.51	24.0 ± 14.0	20.3 ± 12.4
Survival rate at harvest (percent)	3.93 ± 3.49	2.24 ± 2.18	3.09 ± 3.01
Aquaculture production (kg/ha/year)	487 ± 269	616 ± 506	550 ± 405
Black tiger shrimp (percent)	36 percent	38 percent	37 percent
Wild shrimp (percent)	12 percent	20 percent	17 percent
Crab (percent)	27 percent	14 percent	20 percent
Fish (percent)	25 percent	27 percent	26 percent
Share of shrimp sold to collectors / wholesalers (percent)	69 percent / 31 percent	83 percent / 17 percent	76 percent / 24 percent

b) Economic efficiency

The integrated production generates a lower shrimp yield and economic performance per hectare than intensive shrimp farming system, but the size of shrimp is bigger and thus they deserve a better market price. Moreover, wild shrimp, wild fish and crabs provide an additional income from the ponds and since the stocking density is low, no artificial feeding is used and less chemical are employed, the integrated system could classify for some premium markets such as the organic production certifiable by organisations like *Naturland*.

Shrimp and crab seed are the highest costs in the system, with USD 852/ha/year, accounting for 41 percent of the total costs. Labour comes next with USD 750/ha/year or 36 percent of total costs, although they are often family labour. Gross return from black tiger shrimp production was USD 2 523/ha/year, accounting for 57 percent of total income (Table 3), and the net return was USD 1 170/ha/year.

Table 3: Cost-benefit analysis for the integrated mangrove-shrimp farm model (*Source: IPSARD, 2016)*

Items (per 1ha)	1 000 VND	USD
Outflows:	70 685	3 213
Costs for fix asset (harvest sluice, boat, others facilities)	41 000	1 864
Costs for mangrove shrimp production		
Black tiger shrimp seed	14 250	648
Crab seed	4 500	204
Mangrove plantation	1 500	68.2
Mangrove protection and management	120	5.45
Removing mud	7 500	341
Lime, chemical for treatment	475	21.5
Trap, harvest net	1 340	60.9
Family labour	16 500	750
Inflows:	96 430	4 383
Black tiger shrimp	55 500	2 523
Crab	12 800	582
Fish and others	5 200	236
Wood	21 860	994
Others (carbon, existent value)	1 070	48.6
Net return:	25 745	1 170

3.2.4. Shrimp farm certification and sustainability issues

a) Main certification issues of shrimp farms

As trends in shrimp consumption increase, the requirements for product quality and food safety also become more stringent. A comparison between the integrated mangrove-shrimp farming in the MKD and the practices requested by shrimp systems, such as the Best Aquaculture Practices of the Global Aquaculture Alliance (GAA-BAP), the Good Agricultural Practices of the GlobalG.A.P. association of producers and retailers, the Aquaculture Stewardship Council (ASC) or Naturland shows that many farms are already compliant with criteria like the non use of external feed, low stocking density ($\leq$15 PL/m^2), no banned chemical/drug use, good relationships with community, respect of property rights or biodiversity protection.

However, there are also several criteria that farms cannot meet, especially for effluent management (most farms release their wastewater without any treatment and they don't have sediment basins), shrimp mortality management (lack of proper methods), labour arrangements (verbal contracts), farm hygiene, and recordkeeping requirements.

To meet standard criteria, the current farms need to improve their practices and for this, they need to get support from the local officers on technical aspects (training courses) and management issues such as trade name registration, land ownership certification or property right. Unlike the intensive farms that have greater financial and physical assets, the integrated mangrove-shrimp farms have limited resources, making certification a more difficult target for them. Moreover, several criteria are particularly difficult for the small individual farms. This includes the requirement on labour, farming infrastructure, storage and disposal of supplies, effluent management, microbial sanitation, shrimp disease control, and traceability requirements. In addition, the technical and financial constraints resulting from recordkeeping, adjustment of farms (e.g. remove the on-farm toilet, no animal and livestock on-farms) and certification fee constitute a major difficulty for them.

b) Main constraints to sustainable development

The shrimp farmers surveyed perceive three important factors that are likely to affect the long-term development of shrimp farming (Table 4).

Seed quality is the first one. At present, shrimp mortality is high during the growing-out, >95 percent, and the main perceived cause is the seed quality. Moreover, due to their biological characteristics, shrimp are sensitive to environmental changes, so that water quality and extreme weather variability are aggravating factors.

Water quality is another key issue. It has fluctuated in recent years and tended to decline. Many farms pointed out that the use of chemicals has increased over the last five years, and that the bad water quality may also be resulting from nutrient discharge by other industries.

Over 70 percent of shrimp farms surveyed mentioned they had faced shrimp disease problems, and most of them had to use therapeutic methods during the production cycle. Shrimp health management has become increasingly complex with new diseases in recent years.

3.3. Recommendations for improving shrimp farming practices

The integrated mangrove shrimp farming is a relevant model, adapted to natural conditions and farmers' constraints that produces good quality shrimp, and could be a relevant model for organic certification. It is regulated by the provincial government to maintain a mangrove-to-water surface ratio of at least 60 percent and is characterized by a large culture area, a low stocking density, a limited-to-no use of chemical or feeds, a limited-to-no use of fertilization, passive water exchange and low yield (Decisions 186/2006/ QĐ-TTg and 178/2001/QĐ-TTg). The current mangrove-to-water surface ratio is 51:49 percent but the development plan calls for mangrove to reach 60 percent in the future, hence, the need to intensify the farming to maintain the aquaculture production (shrimp, crab, wild shrimp and fish production. From our study, three important technical factors emerged for this (Table 5):

- The shrimp yield is higher when the PLs are stocked in nursing ponds before their release into the growing-out ponds. Thus, we suggest that farmers should buy good quality seed and apply nursing techniques in order to reduce the shrimp mortality.
- The shrimp yield is higher when the shrimp PLs are stocked at a suitable stocking density, 10-15 PLs/m^2/year. With this stocking density, the shrimp grow well in the absence of external feeding and it also complies with the criteria for organic certification.
- The shrimp yield is higher when probiotics are applied into shrimp ponds to improve water quality and create a natural food base for shrimp growth. The declining natural food base observed in recent years requires probiotics addition to be restored (Johnston *et al.*, 2000; Nguyen *et al.*, 2009).

Table 4: Major factors impeding the sustainable development of shrimp farming

Constraints	Current farming practices	Solutions and outcomes	How does it related to sustainability?
Shrimp disease	- Shrimp disease (>70 percent). - Main disease: WSSV, YHV.	- *Solutions:* Update and improve technical skills; use of good seed; new technology for production. - *Expected outcomes:* Successful harvest (less mortality and high yields); lower cost from using less of chemicals and drugs.	- *Why it is important:* Indicates a better farm management, effective health management protocols. - *How it relates to sustainability indicator (SIs):* Effective environmental and health management, a higher biodiversity promotes sustainability, contributes to the protection of natural capital and to enhance economic performance.
Water quality	- Farms do not have sediment ponds. - Water quality is not monitored regularly. - Wastewater released without treatment.	- *Solutions:* Update and improve technical skills; Upgrading of farm infrastructure; new technology for production - *Expected outcomes:* No or low incidence of challenges to the farm from government; less negative effects to public environment; lower disease incidence and lower seed mortalities.	- *Why it is important:* It indicates environmentally responsible and friendly farming; also a proxy indicator of better sector governance (i.e. zoning, planning) - *How it relates to SIs:* Environmentally friendly farming; good sector management (zoning, planning); fewer social risks (less risk from food safety issues) and environmental risk (from pollution or contamination of the environment); improves yields.
Seed quality	- High shrimp mortality in the extensive farms (>95 percent), SD is <15 PL/m^2.	- *Solutions:* Use of good seed; update and improve technical skills. - *Expected outcomes:* Less disease incidence; less mortality; and higher yields.	- *Why it is important:* Indication of good risk management practices. - *How it related to SIs:* Farmers' widespread use encourages seed producers to adopt seed certification standards. This improves overall productivity and sustainability of farming.

Table 5: Average shrimp yield associated with different practices

Items	Shrimp yield (kg/ha/year)
Nursing applied?	
No	191
Yes	216
Probiotics applied?	
No	187
Yes	214
Stocking density (PL/m^2/year)	
<10	139
10-15	212
>15	203

4. Discussion

4.1. Farming practices: challenges to reach food standards

Consumers are increasingly concerned about the environmental and social impacts of food production in developing countries (Belton and Bush, 2014; Brunori *et al.*, 2011; Bush, 2008; Bush and Oosterveer, 2007; Corsin, Funge-Smith and Jesper, 2007; Jespersen *et al.*, 2014; Oosterveer, 2006). They are also interested in the process through which a product travels and it's process-oriented quality (Brunori *et al.*, 2011; Corsin, Funge-Smith and Jesper, 2007; Reilly, 2007; Yamprayoon and Sukhumparnich, 2010; Young, Goulding and Stirrat, 2011).

Food certification has been identified as a way of demonstrating the sustainability of aquaculture production (Bush *et al.*, 2010; Bush and Oosterveer, 2007, 2012; Kelling, 2012; Mohan, 2013; Young, Goulding and Stirrat, 2011). Farmed shrimp is a target species for the Vietnamese seafood export, and it has moved towards meeting various food standards to maintain access to its access to markets.

Private governance standards have now become the norm as farmers have to comply with food quality and safety standards to gain or maintain their position in export markets (Bush *et al.*, 2010). The focus of new regulations covers all operations from farm-to-fork and the primary responsibility for marketing safe food lies with producers and processors (Reilly 2007). The general principles of food hygiene also extend to all operations, including the primary production of food (Reilly, 2007; Washington and Ababouch, 2011; Tran *et al.*, 2013), to such extend that some authors now view it as a trade barrier (Reilly, 2007; De Silva and Nguyen, 2011; Tran *et al.*, 2013).

Seafood producing countries should overcome challenges by continuously improving the whole production chain (Bush, Khiem and Chau, 2010; Bush and Belton, 2012; Reilly, 2007). The main constraint for farmers is that they frequently lack access to proper knowledge and awareness on requirements, and they also lack expertise and training on compliance with standards requirements on technical requirements, implementation and monitoring capacity (Jespersen *et al.*, 2014; Kelling, Kruijssen and Li, 2010; Mohan, 2013; Ponte *et al.*, 2014). Washington and Ababouch (2011) suggested that farms should follow the national standards, as it would make it easier for them to then meet the additional criteria requested by the private standards and certification (Nietes-Satapornvanit, 2014). Farm-level certification contributes to sustainable seafood trading, but it is still beset with significant limits such as measuring the impacts of the external environment on the farms (Allsopp, Johnston and Santillo, 2008; Bush *et al.*, 2013; Bush and Belton, 2012; Han and Immink, 2013).

Moreover, although food standards pay more attention to the primary production at the farm level, fraud in the value chain is often not associated with farmers but rather intermediaries such as secondary processors where illegal/poor practices occur such as lack of the knowledge on food hygiene and safety (Fisheries Directorate, 2012; VASEP, 2014; Vu *et al.*, 2013). Moreover, the certification schemes should be integrated with other governance mechanisms and public rulings, including local standards that are already in place, making use of the existing local expertise (Bush *et al.*, 2013).

4.2. Farm upgrading - the key barriers to upgrading

Shrimp has become a major product in the international seafood trade, and there is an increasing pressure from markets such as the European Union, the United States of America and Japan on food safety and sustainability of farmed seafood. This prompted a value chain upgrading to reduce environmental, social and economic risks (Jespersen *et al.*, 2014; Khiem *et al.*, 2010; Pham *et al.*, 2011; Ponte *et al.*, 2014).

Ponte *et al.*, (2014) presented upgrading strategies for the seafood farm-level in Asia. These included the improvement of the process, the improvement of the product, the improvement of the volume and the improvement of the variety. At farm level, the barriers include the lack of explicit economic incentives (e.g. improved market access or increased price), the limited access to capital to invest in improved management practices, and the lack of appropriate skills for smallholders. Another one relates

to the economic risks associated with market volatility and quality regulation (Bush and Belton, 2012; Ponte *et al.*, 2014).

To implement upgrading strategies, the shrimp sector needs finance to invest, but shrimp farmers are currently facing financial constraints (lack of operational finance) and constraints on access to credit (limited access to credit, or lack of access to credit for production inputs). The costs associated with upgrading include the certification fees (USD 4 500-6 000), the annual fees (USD 1 000-2 000) (Haugen, Bremer and Kaiser, 2013; Nguyen, 2012), the cost for consultants providing technical support (USD 10 000-15 000), the cost for farm re-structuring and for water/effluent quality monitoring (Fisheries Directorate, 2014).

However, even though the producers bear high costs of investment, the farms certified by GAA-BAP achieved better production (Lam and Truong, 2010), while an 11 percent price premium (Lam and Truong, 2010). Nonetheless, these costs are high and tend to exclude the weakest farms, especially the small-producers, from the export supply chain (Belton, 2010; Belton *et al.*, 2011; Dey and Ahmed, 2005; Haugen, Bremer and Kaiser, 2013; Khiem *et al.*, 2010; Oosterveer, 2006; Pham *et al.*, 2011; Subasinghe, Soto and Jia, 2009).

5. Conclusions

Shrimp has dominated Viet Nam's seafood exports over the last decade (Fisheries Directorate, 2013; Tuan *et al.*, 2013) and the industry has shown a strong growth in export value, with annual growth rates of over 12 percent since 2001. The substitution of black tiger by white legged shrimp in some major producing countries has resulted in Viet Nam becoming the biggest producer of black tiger shrimp. Large areas are used for the farming of the species, usually at a lower level of intensity that provides Viet Nam with opportunities to differentiate its shrimp export.

With current emerging trends, it is likely that shrimp commodities will continue to head towards the sustainable production practices promoted by third party standards on food safety animal welfare, environmental integrity and social responsibility (MARD, 2014; De Silva and Nguyen, 2011; Tuan *et al.*, 2013). The integrated mangrove-shrimp farming system, with its low stocking density, no feeding and lower use of chemicals is a less risky and more sustainable model, which has a strong potential for the organic certification market (Naturland, 2012; Nguyen *et al.*, 2009; Vu *et al.*, 2013).

Moreover, most of these farms are small-scale, so that the promotion of this model would allow smallholders to be included in the future development of the aquaculture sector. However, for this to happen, the smaller-scale farms will have to be included in the value chain through horizontal coordination and vertical coordination (Khiem *et al.*, 2010; Khoi, 2011; De Silva and Nguyen, 2011; Umesh *et al.*, 2009).

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BRINE SHRIMP *ARTEMIA* PRODUCTION IN COASTAL SALT PONDS IN ASIA

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Abstract

The brine shrimp *Artemia* is a highly required, convenient and cost-effective live food in marine larviculture. *Artemia* cysts, originating from a limited number of inland salt lakes, are a commodity traded worldwide. Over the past decades, *Artemia* pond production in solar saltworks has emerged as an alternative to cope with possible cyst shortages and high market prices, and as a tool to fulfill local cyst demands associated to local aquaculture developments. This article provides an overview on *Artemia* pond production in a number of countries in the South, with emphasis on the production techniques.

1. Introduction

Aquaculture is thought to supplement the over-exploited fisheries in fulfilling the need of the growing human population for high quality animal protein. One of the problems faced by the hatchery stage of fish and crustaceans is the quantitative and qualitative supply of brine shrimp *Artemia*. *Artemia* are naturally spread worldwide in hypersaline lakes and in coastal saltponds where seawater is concentrated by evaporation until crystallization. Its freshly hatched nauplii are an essential live food for farmed marine crustacean and fish larvae, due to their availability and convenience as dry cysts that can be kept in a viable state on the shelf. *Artemia* cysts are the trade coin in the marine aquaculture business and are naturally harvested in a limited number of salt lakes. In a scenario of climate change and increasing harvesting pressure on these natural salt lakes, it is difficult to manage the dynamics of the *Artemia* population cycles and hence to predict cyst harvests over the mid- and long-term. New locations such as solar saltworks, suitable for *Artemia* biomass and cyst production, have been more or less successfully exploited in a number of countries in the south over the last decades. Although the bulk of *Artemia* cyst product still originates from the Great Salt Lake and other inland salt lakes (e.g. in China, Kazakhstan, the Russian Federation), the production of cysts in solar saltworks may make up for a considerable share of local markets.

Artemia naturally occur in medium to high salinity evaporation salt ponds (salinity ranging from 60 to 200 g /l), in solar saltworks, and are mainly found in ponds at intermediate salinity levels since the organism has no defence mechanisms against predators (which are generally dwindling or absent above 80-100 g /l). The presence of *Artemia* in sufficient numbers allows to improve the salt production quantitatively and qualitatively as it is not only needed for controlling algal blooms, but their corpses also eventually provide essential nutrients for the development of the red halophilic *Halobacterium* that help promote evaporation in the crystallization ponds. Reduced levels of dissolved organic matter and viscosity, as well as red coloration of saturated brine, thereby improve salt production qualitatively and quantitatively (Tackaert and Sorgeloos, 1993). Therefore, *Artemia* culture turns out as a profitable economic activity integrated with the salt production, provided salt producers are willing to adopt the technology and researchers support such endeavor with research and sustained dissemination activities.

Artemia pond production can be seen as a form of extractive aquaculture, in which low-cost products are turned into high-quality products, such as cysts and protein-rich biomass, for local use in marine shrimp and fish farm. In the development of *Artemia* pond production, issues such as the ability of the (often introduced) *Artemia* strain(s) to adapt to local climatological and biological conditions, and the socio-economic imperatives of the local aquaculture environment need to be considered. We thus hope that the information presented will help the emergence of new initiatives in areas in the South where often fisheries resources are over-exploited, and where initiatives to diversify aquaculture are currently underway.

2. Intensive management of *Artemia* cyst production in Viet Nam

Since the first initiatives in early 1980s, interest in the seasonal culture of *Artemia* in the Mekong Delta has steadily expanded and mainly aimed at cyst production. The Mekong delta is characterized by a tropical monsoon climate with an annual average air temperature of 26.1°C. In April-May, air temperatures frequently exceed 35°C. The dry season generally lasts from November/December to April/May. The pond system is described as static as there is no continuous flow of water from one pond to another. Brine shrimp are generally inoculated in January, at high densities (> 20 nauplii/l) in ponds with an appropriate salinity of 80-90 g/l. Within nearly 20 years after the first inoculation, the originally inoculated SFB-type *A. franciscana* has evolved into the so-called Vinh Chau (VC) strain with characteristics different from the original mother strain, especially increased temperature tolerance (Kappas *et al.*, 2004). Over the past few years the culture area had more or less stabilized to 200-400 ha. Cysts of the VC strain are considered of excellent quality for their small size, high hatching and nutritional qualities, especially the levels of highly unsaturated fatty acids (Nguyen Thi Ngoc Anh *et al.*, 2009, 2010). They are therefore sold at prices which may be twice the price of the Great Salt Lake type cysts or more.

Figure 1: Intensive *Artemia* cyst production in Vinh Chau-Bac Lieu, Mekong Delta, Viet Nam.

Ponds are intensively managed, targeting increasing yields and enhancing operational efficiency. Ponds are oriented, with the longest axis parallel to dominant winds for a better oxygen diffusion into the water column. As salt ponds are shallow, excavating (part of) the pond bottom and/or heightening the dikes to increase the water depth is often done to enlarge the production volume and to reduce temperature stress for *Artemia*. Predators and food competitors are kept out and/or removed from the *Artemia* ponds as much as possible by using a variety of tools. A fertilized pond with a lower salinity (which surface is about 30 percent of the total surface used for *Artemia* culture) is generally used to produce phytoplankton-rich green water that serves as feed for *Artemia*. Green water is pumped from this common fertilization pond(s) into the culture ponds, if needed after mixing it with brine to maintain sufficiently high salinity levels (Vu Do Quynh anh Nguyen, 1987; Baert *et al.*, 1997). Green water is often supplemented with chicken manure and cheap agricultural by-products (such as micronized rice bran and soy pellets) which may be consumed directly by the brine shrimp population or act as a substrate for the proliferation of bacteria (so called biofloc technology), which in their turn are consumed by *Artemia*. Frequent raking of the pond bottom is provided to avoid the excessive growth of macroalgae and re-suspends particles that have settled down and makes them accessible again for filtration uptake by *Artemia*. Two to three weeks after inoculation, *Artemia* starts reproducing, generally first ovoviviparously and later oviparously. High production of cysts usually occurs in February and March as water temperature stays below 35°C. Towards the end of the dry season the productivity decreases as a result of the high temperature, food limitation and senescence of the population, which may collapse prematurely in extreme cases. To boost production, ponds are sometimes re-inoculated towards the second half of the dry season for a new production run ("crop" or "cycle") but higher water levels are needed in order to avoid excessive water temperatures.

As outlined in detail by Nguyen and Sorgeloos (2015) this combined salt-cum-*Artemia* production in Viet Nam has become a very lucrative business with major socio-economic ramifications in the coastal areas of Vinh Chau – Bac Lieu in the Mekong Delta: over 500 families of salt farmers have improved their income by more than USD 5 000 per household and per dry season with the production and sales of brine shrimp (mostly cysts but also now adult brine shrimp biomass harvested towards the end of the dry season, through the first months of the rainy season). Although cyst harvests amount to about 50 tonnes in a dry season of 3 to 4 months, these meet less than 10 percent of the present demand for *Artemia* cysts by the Vietnamese aquaculture industry. Local availability of top-quality *Artemia* cysts has allowed Viet Nam to become the first in the world to develop commercial mud crab hatcheries (as umbrella *Artemia* can be used to replace rotifers at the start of feeding). As the profitability of seasonal solar salt production is under much pressure in many countries around the world integrated salt with brine shrimp production should be further explored: it can make this artisanal sector, often involving many thousands of households, again profitable (with brine shrimp *Artemia* as extra by-product and thanks to its filterfeeding activity producing a higher NaCl quality) and furthermore contribute to the expansion of local fish and shellfish farming activities as the *Artemia* ponds can be used in the rainy season for the ongrowing of mud skipper, mud crab, etc.

3. Intensive *Artemia* biomass production in Thailand

Artemia culture was introduced into Thailand in 1978 to produce cysts. Since then the status of Artemia culture has changed as a function of aquaculture demand, causing a shift of Artemia production from cysts to biomass. Nowadays the production in Thailand is entirely based on the use of the so-called "ami" as feed. Ami is the waste product of the industrial production of monosodium glutamate (MSG), a flavour enhancer commonly used in the food industry. Most MSG is produced by bacterial fermentation, in a process similar to the production of vinegar or yogurt: during fermentation, Corynebacterium bacteria, cultured with carbohydrates excrete amino acids into a culture broth from which MSG is isolated. The waste product is a dark coloured viscous liquid, which is further fermented prior to application in the pond. This fermented product is applied in the ponds at various rates (up to about 100 l/ha/day, but generally lower), depending on the state of the product, the primary production in the pond, the overall pond turbidity, and the Artemia densities in the pond.

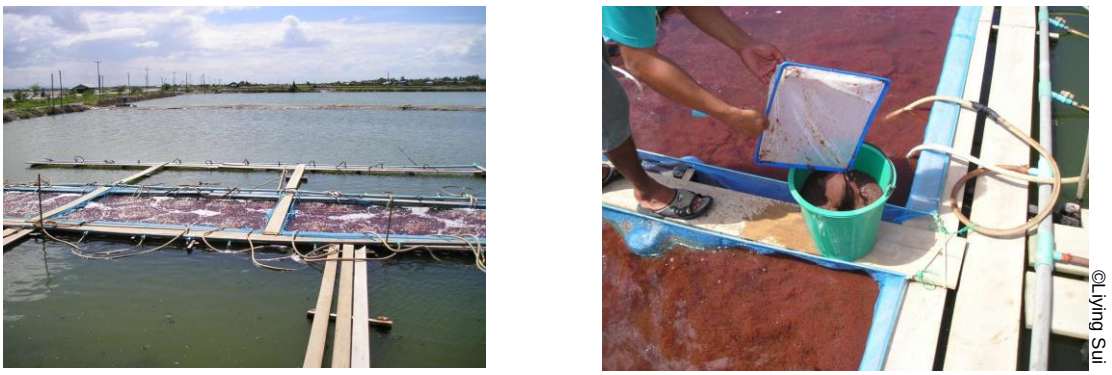

Figure 2: Intensive *Artemia* biomass production and purification system in Thailand.

Artemia may be harvested manually with harvesting nets, by light attraction, or semi-automatically. Yields are in the range of 1 500-3 000 kg wet weight/ha/month. If transported alive, the biomass are acclimated at 40-50 g/l before packing. The current annual production of *Artemia* biomass is estimated to be 500-600 tonnes with a value of USD 615 000-737 000. Of this amount, 75 percent is used for the domestic market, either live, chilled or frozen, in hatcheries of shrimp and high-value fish (such as seabass and grouper), for shrimp broodstock (as a substitute for blood worm *Glycera sp*. and sandworm *Arenicola sp*.) and for ornamental fish (replacing e.g. cladocerans or the sludge worm *Tubifex tubifex*). A quarter of the total production is exported as frozen *Artemia* biomass. Live *Artemia* is sold (generally in a 5 kg box) at the price of USD 1.0-1.5/kg; frozen *Artemia* has a price of about USD 2/kg.

The *Artemia* production procedure in Thailand thus appears relatively simple. It is therefore an attractive alternative for more elaborate production methods requiring the need to maintain an algae-rich fertilizer pond, to add supplemental feeds for the *Artemia* population etc, such as practiced in Viet Nam. In the absence of scientific study of the biochemical and biological processes ongoing in the "ami" production tanks and of the nutrient dynamics in the *Artemia* ponds, extension of the technique chiefly relies on the 'trial and error' principle. Moreover, presently decreasing market demand is a major bottleneck for further expansion of the production even in Thailand, rather than production capacity and technology.

4. Extensive *Artemia* cyst and biomass production in China

China is the world's biggest salt producer, with the Bohai Bay coastal area in north-eastern China being one of the country's main production areas with about 250 000 ha of salt evaporation ponds, mainly operated by large salt production companies. The production area has been decreasing over recent years as salt ponds have been turned into urban and industrial areas. China is also a leading country for aquaculture, with an annual aquaculture production of 47 million tonnes -excluding aquatic plants- (data of 2017, FAO, 2019). The fast development of aquaculture leads to an increasing demand for *Artemia* cysts: from 600 tonnes commercial dry product in 2000 to about 1 500 tonnes in 2012, corresponding to roughly 50 percent of the entire world production. The cysts are mainly used in the hatcheries of penaeid shrimp, giant river prawn and mitten crab, as well as in larviculture of several marine fish species. Though several hundreds of tonnes of cysts are harvested in various inland salt lakes in China and in Bohai Bay coastal saltworks, they are largely insufficient to meet the country's demands. Although statistical data are not centralized, it is estimated that an average 1 300 tonnes of cysts are imported annually from the Russian Federation, Kazakhstan and the United States of America; meanwhile about 400 tonnes of cysts are exported to Thailand, the Republic of Korea and other countries.

In the late 1980s and early 1990s, the harvesting of cysts and biomass of the local parthenogenetic strains has become a considerable industry, employing several hundreds of people. Closer biological management of the salt ponds was proposed through the scientifically-supported introduction of *A. franciscana* (Tackaert and Sorgeloos, 1991). By 1997, Bohai Bay *Artemia* production approximated 600 tonnes for cysts and 20 000 tonnes biomass. Allochtonous *A. franciscana* was prominently present in the area from the end of the twentieth century onwards (Zheng *et al.*, 2004; Van Stappen *et al.*, 2007). By the end of the century, due to the fast development of Chinese aquaculture and the shortage of *Artemia* cyst resources worldwide, extensive *Artemia* pond production received a lot of attention in the Bohai Bay area. Large areas of salt land (about 33 000 ha) were used to construct ponds for *Artemia* production. The size of these ponds varied from several hundred m^2 to 100 ha, with cyst yields reaching 3-60 kg wet weight per ha. In contrast to monsoon Southeast Asia, *Artemia* biomass and cysts are mostly produced in an extensive way: no organic manure or agriculture by-products are added to the ponds as supplemental feeds. The *Artemia* production in the Bohai Bay generally starts in June (about one month after the first spring emergence of *Artemia* nauplii) when the water temperature has increased to about 20°C. It ends towards the end of November when the water temperature drops to less than 10°C. The harvest is usually interrupted by heavy rains, often occurring from July until mid August. Generally the autumn harvest (September to end of November) accounts for 2/3 of the total harvest.

Figure 3: Harvesting of *Artemia* cysts and Biomass from Bohai Bay saltponds, Wudi, Shandong Province, China.

Figure 4: *Artemia* inoculation at Bohai Bay saltworks, Wudi, Shandong Province, China.

Since 2010, interest in *Artemia* pond production has risen again, aiming to produce high quality Bohai Bay *Artemia* cysts. This lead to the involvement of a number of saltwork managers in semi-intensive pond culture, including supplementation with chicken manure to stimulate algal blooms in the ponds. *Artemia* cysts from the Bohai Bay salt ponds on the other hand are known for higher hatchability and better nutritional value and are thus sold in China at a price 150 percent higher than inland cysts, reaching USD 75-80 per kg in 2016. Recently, so-called *Artemia* nauplii hatcheries have been established in the vicinity of fish and shellfish hatcheries, supplying shrimp and fish farmers with freshly hatched *Artemia* nauplii, as the specialized *Artemia* hatching enterprises are more professional and more efficient in cyst hatching procedures than the hatcheries, especially the smaller ones. Also *Artemia* biomass is used, mostly as fresh feed for shrimp farms. Only a small percentage of biomass is frozen, to be used during winter and early spring, when biomass is not available in the field. The price for fresh biomass was USD 0.5 per kg wet weight in 2016.

In spite of occasional upsurges of initiatives, the Bohai Bay production has been stagnating or even declining in recent years due to the reduction in the overall size of the salt production area and to overharvesting. Yields have also decreased as a consequence of extensive discharge of effluents from desalination and bromine extraction plants into lower salinity evaporation ponds (usually at 50-60 g/l), which provide the intake water for *Artemia* production ponds. The bromine extraction effluents (often acidified to pH 2-3 and deprived of live plankton organisms) have a profoundly negative impact on the salt pond ecosystem. Although the buffering capacity of the soil allows recovery to weak alkalinity (pH 7-8) after three to four steps of the evaporation procedure, there has been a marked decline in harvested quantities and hatching quality of Bohai Bay *Artemia* cysts (Sui *et al.*, 2013). The average annual production in the area presently only accounts for less than 30 percent of the production in the 1990s.

Unstable and unpredictable *Artemia* pond production thus remains a problem in China. Suitable techniques adapted to the local environment, such as fertilization regimes, still need to be developed.

5. Conclusion

The above case studies highlight integrated *Artemia* biomass and salt production. Such endeavors have proved successful in leveling-up welfare of rural communities (especially in the Viet Nam case), but have also been the basis for industrial activities as in the China case, the world's leading salt producer and second world source of *Artemia* cysts (both inland and coastal). This problem is indeed a challenge when promoting this sort of extractive aquaculture in countries needing *Artemia* cysts and biomass to boost their local aquaculture production, for example in many countries in Africa but also in countries with a well established aquaculture sector such as Latin America, where programmes for sector diversification are underway. Such diversification programmes need to overcome the many difficulties associated with the production of poorly studied species in captivity, in particular the larviculture stage and its nutritional needs. Therefore, a challenge but also an opportunity ahead is to understand what "proper management" means in terms of ecological characteristics of ponds, and what the dynamics of the *Artemia* population over production cycles will be, allowing to predict future yields, especially in a context of climate change. These aspects of *Artemia* production have hardly been studied so far. This is linked to monitoring the genotype composition of the *Artemia* population over time associated to key phenotypic traits, together with monitoring the critical stressors or selective forces acting on the gene pool over the production cycle.

Bottlenecks associated to introductions may reduce the species' genetic diversity and the ability to respond to changing local environmental circumstances. These case studies have in common that *Artemia* pond production has been initiated or accompanied with inoculation of non-indigenous *Artemia* species, *A. franciscana* being the species of choice, with cysts often from San Francisco Bay in the United States of America. The impact of *Artemia* translocation needs to be evaluated and minimized in order to comply with international agreements to protect biodiversity and in any case the need to conserve local *Artemia* biodiversity should be of paramount importance when designing future inoculation activities, as *Artemia* resources stand as a natural patrimony for the sustainable expansion of aquaculture. On the positive side such introductions can also be seen as a model system and opportunity to study adaptation, selection and interspecies competition processes.

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THE RAPID DEVELOPMENT OF THE INTEGRATED RICE-FISH, RICE-MITTEN CRAB AND RICE-CRAYFISH FARMING IN CHINA

Yongxu Cheng, Jiayao Li

1. Introduction

1.1 The integrated farming of rice and aquatic animals is the upgrade of rice-fish co-culture

The integrated farming of rice and aquatic animals developed on the basis of the traditional rice-fish co-culture systems in China. China has a long history of farming fish in rice paddies. There are records of this practice, more than 2000 years ago, in Hanzhong, Shanxi province and Chengdu, Sichuan province. But rice-fish co-culture only began to develop rapidly from the early 1980s, with the attention and support of governments and agencies at all levels. Since then, the integrated farming of rice and aquatic animals has entered a period of rapid development. From 1983 to 2000, the total area of integrated rice and aquatic animals farming has increased each year, from 4 413 ha to 1.53 million ha. In the meantime, the production of aquatic animals increased from 36 300 tonnes to 746 000 tonnes, with a yield raising from 5.5 kg/667 m^2 to 32.5 kg/667 m^2.[31]

From the end of last century to 2010 and the rise of interest in efficient agriculture, integrated farming of rice and aquaculture has been vigorously promoted due to its high comparative efficiency and important contribution to the increase of farmers' income. But at the same time, the rapid development of fish farming in rice fields has caused concerns about the sustainability of rice production, which area decreased from 1.53 million ha to 1.32 million ha. However, during this period, the decline in the cultivated area was compensated by the increase in rice yield to 1.24 million tonnes, as a result of improvements in farming technology. The fish yield also increased, from 32.5 kg/667m^2 to 61.9 kg/667 m^2. In some newly developed areas, the red carp yield even reached 75-100 kg/ 667m^2.

Traditional rice-fish co-culture is dominated by conventional fish species, mainly common carp, which does not have a high contribution to farmers' income. But the development of new integrated rice and aquatic animal farming technologies could change this. Indeed, in recent years, crabs, crayfish, loach, rice field eel, softshell turtle have replaced the traditional species, because of their high economic value and adaptation to farming. "Rice-field aquaculture technology" was the main driving technology entering the households between 2008 and 2010. The new development concept and technologies created a new balanced relationship between rice and aquaculture, bringing about a new round of development. 2010 became a key turning point. The total area of integrated farming of rice and aquatic animal stopped declining and recovered. By 2016, it had already reached 1.52 million ha, with an aquaculture production increasing from 1.24 million tonnes to 1.63 million tonnes, and a yield rising from 61.9 kg/667m^2 to 76.8 kg/667m^2. In 2017, the total integrated area reached 1.87 million ha. Rice-fish, rice-mitten crab and rice-crayfish are now the most rapidly developing models.

1.2 The maturation of integrated farming of rice and aquaculture animal model is the result of the joint efforts of all parties

The integrated farming of rice and aquaculture has undergone a fast development during the last three decades, as a result from continued innovations, the introduction of new and high-valued species, the government policies support, market drivers, improvement in cooking methods, and increasing concerns on food safety (Wang *et al.* 2017):

- The academe has continuously explored and improved the theoretical framework of rice and aquaculture symbiosis, providing the theoretical background for its development.

[31] 667 m^2 corresponds to one traditional Chinese unit of surface, the mu

- The departments in charge of fishery promotion at all levels have summed up their scientific knowledge and practical experience to make great contributions to its promotion.
- The need for social development has provided impetus for its development as:
    1. It has improved the farmers' income and greatly stimulated their enthusiasm for rice planting.
    2. It has also greatly met the need for developing a more environmentally friendly and modern agriculture and the people's demand for high-quality aquatic products.

2. Distribution and current trends

2.1 Differences between the traditional rice-fish co-culture and the integrated rice and aquatic animals farming

The integrated farming of rice and aquatic animals relates to the traditional rice-fish co-culture by four characteristics:

- First, its rice yield is not lower than with the traditional rice-fish co-culture or rice monoculture.
- Second, the farmed aquatic animals species are not only the common carps, but also some higher value species, such as crab, crayfish, softshell turtle etc.
- Third, it puts more consideration on the food safety of aquatic animal.
- Finally, it requires feeding aquatic animals with balanced formulated diet, unlike the traditional rice-fish co-culture, in which no feed is used.

2.2 Distribution of traditional rice-fish co-culture in China

The traditional rice-fish co-culture is still widely distributed in China, and more than 25 provinces and municipalities in China have also developed the integrated farming of rice and aquatic animals. In 2016, 10 provinces, including Sichuan, Hubei, Hunan, Guizhou, Yunnan, Jiangsu, Zhejiang, Anhui, Jiangxi and Liaoning, had the largest area of rice-fish co-culture, accounting for 86.7 percent of the total area in China. Sichuan, Zhejiang, Hubei, Jiangsu, Anhui, Hunan, Jiangxi, Liaoning, Yunnan and Guizhou Provinces, have the highest production, accounting for more than 96.4 percent of the total output. Among them, Sichuan province has the largest rice-fish co-culture area, higher than 0.27 million ha and accounting for 18 percent of the country output: 350 000 tonnes, worth RMB 6.5 billion[32], as well as RMB 18.5 billion of comprehensive benefits.

2.3 The change from “rice-fish co-culture” to “integrated farming of rice and aquatic animals”

The practices in rice fields depend on the historical development in the region, with two models currently coexisting: the traditional rice-fish co-culture and the new integrated farming of rice and aquatic animals. At present, both are balanced, following the transformation of the traditional fish farming model in rice field into the standardized integrated farming of rice and aquatic animals. As a result, the total area and yield of integrated rice and aquatic animals farming gradually increased. In addition, the integrated farming of rice and aquatic animals model has gradually extended to provinces where rice-fish farming was not traditional.

Among the ten main provinces practicing the traditional rice-fish co-culture, changes have been significant, with 100 percent of the total area converted to the new integrated farming of rice and aquatic animals model in Hubei province, 94.6 percent in Liaoning province and 87.6 percent in Anhui province (these provinces are classified as “sufficient transformation regions”). In Hunan and Yunnan provinces, the conversion is 74.8 percent and 59.2 percent respectively. These two provinces are ranked as “semi-sufficient transformation regions”, whereas Sichuan, Guizhou, Jiangxi, Jiangsu and Zhejiang provinces are “active transformation regions”. Gradual adoption of the integrated farming of rice and

[32] RMB 1=USD 0.15.

aquatic animals has also occurred in Jilin, Heilongjiang, Ningxia, Fujian, Guangxi, Tianjin, Henan and other provinces (regions and cities).

2.4 Typical models of integrated farming of rice and aquatic animals

2.4.1 Rice-fish

Rice-fish co-culture model has a long history and is widely distributed across China. Fish species are generally carps, black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idellus*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*) and common carp (*Cyprinus carpio*), especially the Oujiang color strain. This "field engineering transformation of rice fields" allows full use of the ecological environment and promotes mutually beneficial synergies between rice and fish. By producing an additional harvest in the same field, it permits full use of the water surface. Fish can also eat weeds, plankton and aquatic insects in rice fields, which reduces the feeding cost and the need to spread polluting pesticides. Fish also provide an organic fertilizer needed to grow rice. This model is suitable for large paddy fields with a good water quality. Stocking of fish seedlings should be as early as possible to prolong the growth period of fish without affecting the growth of rice seedlings. The fish growing-out extends to about 10 months by raising the ridges of the field to store water after rice harvest. During winter, fish can also be stored in the rice field.

2.4.2 Rice-crab

In rice-crab co-culture, the same principle of symbiosis between the crop and aquatic animal is applied. Crabs remove weeds and control pests in the field, and their excrements fertilize the water and promote the growth of rice. Moreover, rice provides an abundant natural bait and good habitat conditions for the river crabs, resulting in a mutually beneficial ecological cycle. The typical model of rice-crab co-culture is the "panshan model", under which, rice seedlings are alternately planted along a broad and narrow line. A suitable stubble control is used to prolong the growth period of crabs, and high quality crab feed is distributed to improve their quality. The rice-crab co-culture is mainly observed in Heilongjiang, Jilin, Liaoning, Ningxia, Zhejiang, Chongming county of Shanghai, Jiangsu, Hebei, Hubei and Yunnan. It is also widely used in Ningxia and Jilin provinces.

2.4.3 Rice-crayfish

The integrated farming of rice and crayfish is mainly distributed in southern provinces of China, such as Hubei, Jiangsu, Anhui, Hunan, Zhejiang, Yunnan, Sichuan. There are two models:

1. the rice-crayfish co-culture, in which crayfish farming is carried out with rice farming; and
2. the rotational rice-crayfish farming, in which both crayfish broodstock or seedlings are released after rice harvest, and crayfish are cultured during the idle period of rice planting.

In the rotational rice-crayfish, rice planting and crayfish farming do not overlap in time and space and the harm of rice field operation to crayfish is avoided. Due to its simple operation and high income, this model has developed rapidly in recent years and it has become the most popular integrated farming of rice and aquatic animals model in China, even becoming one of the main sources of farmed crayfish.

3. Integrated farming of rice and aquaculture

3.1 Generic technologies

One of the main reasons for the rapid development of integrated rice and aquatic animals farming is the reduction in the use of chemical fertilizers and pesticides through biological control while ensuring a double production of rice and aquatic animal. In Zhejiang for example, the use of pesticide in rice-shrimp decreased by 35 percent, and by 59 percent in rice-loach. In Ningxia, it decreased by 50 percent in rice-crab farming.

3.1.1 Fertilization

The conventional rice production relies mainly on chemical fertilizers, which can cause ecological and environmental problems when overused. With integrated farming, fertilization process has changed and new practices include:

1. Optimal fertilization based on soil testing. By determining the actual fertility of the soil and the nutrient needs for crops, the optimal fertilization ratio and fertilizer application amount are calculated using standard formula.
2. Segmented fertilization. Fertilization is provided at different stages: a basal fertilization followed several supplementary fertilizations. The principle is to consider basal fertilization as the main supply, and to supplement it by small amounts of supplementary fertilization. Organic fertilizer is mainly used in both basal and supplementary fertilizations.

3.1.2 Pests and weeds control

The control of pests and weeds in conventional rice farming mainly depends on chemical drugs, which causes problems related to pesticide residues and environmental pollution. With the integrated farming of rice and aquatic animals, the principle to prioritize the "ecological prevention and control, reducing the use of pesticides" applies.

1. Use of new pest control equipment. New insect trap lamps and insect nets have been invented and applied. The new insect net effectively blocks pests and protects rice. The new lamp uses different light sources and suitable spectral range to trap and kill pests.
2. Biological control. The competition between farmed and unwanted species is promoted in a way that allows controlling pests and weeds, by sharing the knowledge acquired through research on the biological characteristics of pests, weeds and aquaculture animals, and on the prevention and control of their performances.

3.2 Technical performance

In recent years, fourteen different integrated models grouped in five categories (rice-crab, rice-crayfish, rice-turtle, rice-fish, rice-loach) have been described. Over twenty key technologies have also been developed, allowing the traditional "rice-fish co-culture" to transform into rice, fish, crayfish and crab co-culture, rotation, intercropping etc. Some examples of innovations are described below:

3.2.1 Innovations in rice-fish farming

The “Rice-Fish Symbiosis” theory was put forward in 1981. In the integrated rice-fish ecosystem, fish can directly or indirectly control weeds and pests, utilize zoobenthos, plankton and detritus. On the other hand, residual feeds and feces from fish can also provide nutrients for rice. This system makes full use of the interaction between rice and fish, promotes multiple-level cyclic utilization of nutrients, and channels more energy flow into rice and fish (Ni and Wang, 1988).

While the integrated rice-fish farming was developing rapidly, a series of technical innovations were achieved. The most important one was digging ditch and puddle in rice fields, to provide refuge for fish during rice harvest time or the dry season. This innovation is also used for other integrated rice-field aquaculture animals such as crabs or crayfish. The width and depth of ditches are 1.5-4.0 m and 1.0-1.5 m, respectively, and the area of the refuge normally amounts to eight to ten percent of the rice field area (Zhang *et al.*, 2017). The relationship between the importance of the refuge and the fish or aquatic animal yield was studied, and the results suggest that the design of the refuge is important for both rice and fish yields (Hu *et al.*, 2016). Other infrastructure improvements are also important, in particular a dyke for water storage and fish farming during winter, or fencing for preventing predators (Gui *et al.*, 2018).

3.2.2 Research progress on rice-crab farming

Following the wide adoption of the integrated rice-fish farming, Chinese government and non-government agencies started promoting the rice-crab (crab seed) co-culture with the same success (Li *et al.*, 2007). This model has expanded in the north of China, in particular in the Liaoning and Jilin provinces where the most famous "Panshan model" is practiced. Research studies on this integrated rice-crab farming model highlighted several benefits:

1. Rice-crab farming improves soil fertility and soil texture (Wang *et al.*, 2011a, Wang *et al.*, 2013).
2. The impact of crabs on zoobenthos becomes increasingly significant with the growth of crabs, and a crab density of 10 ind.m-2 is recommended suggested to maintain the zoobenthos diversity (Li *et al.*, 2013).
3. Rice-crab farming helps to reduce the competition for nutrients and light by weeds, reducing the reliance on chemical herbicide, and thereby increasing the rice yield (Xu *et al.*, 2014).
4. Rice plants provide shelter for crabs, and keep the water temperature close to optimum levels, reducing the ratio of precocity of crabs (Wang *et al.*, 2011a; 2011b). Precocious crabs have a low value because of their poor growth rate, poor survival and short life span (Li *et al.*, 2011).
5. The study on cost-benefit suggests that further development of key technologies, increased governmental support, or higher production scale are important factors for improving cost-benefits of rice-crab farming in the future (Li *et al.*, 2014).

3.2.3 Rotational rice-crayfish farming model

As a simple operation, rotational rice-crayfish farming has developed rapidly and become the most popular way of farming crayfish in China. Rice fields require a good water quality, and soils that retain water. The paddy size varies from one to a few hectares, with a ditch accounting for 3-6 percent of total paddy area. Levees and fencing must strong to ensure that water is withheld, and to prevent escape of crayfish (Gui *et al.*, 2018). A combined group of submerged macrophytes including *Elodea canadensis*, *Vallisneria natans*, *Ceratophyllum demersum* and other species should be transplanted into the rice field to maintain the water quality and provide refuge for molting crayfish during the growth cycle. The coverage rate of submerged macrophytes is often over 50 percent of paddy area (Gui *et al.*, 2018).

Two stocking strategies are used. In the most common one, crayfish broodstock (> 35 g/ind.) is stocked at 300-450 kg/ha, with a female to male sex ratio of 3:1. In the second strategy, young crayfish dislodged from females are stocked at a density ranging from 150 000 to 2 250 000 ind/ha (Gui *et al.*, 2018).

In order eradicate unwanted aquatic animals, quicklime is used 10-15 days prior to stocking (300-750 kg/ha). Following that, inorganic and/or organic manure is used to enhance the growth of feed organisms, and lights are also used to attract and trap insects that fall into the water, providing an additional food source. After the rice harvest, the straws are also used to cultivate feed organisms. In winter, fertilizers are used to enhance the growth of feed organisms for crayfish. Living forages are also used when available.

Due to its large scale and rapid development, a lot of studies have been done on the production and ecological effects of rice-crayfish farming. In addition to its advantages, studies also revealed the "dual character" of rice-crayfish farming:

1. In most case, rice yield of rice-crayfish model is increased by 4.6-14 percent compared with conventional rice monoculture. However, due to the higher price of crayfish, the rice management for rice was sometimes poor occasionally leading to a reduction of the rice yield.
2. Rice-crayfish farming improves the soil fertility, but aggravates the soil gleization.
3. The water use efficiency and conservation is not stable. In some cases water is conserved, but in some cases the water consumption is also increased.
4. The rice-crayfish farming decreases the use of chemical fertilizers and application of pesticides. The eutrophication risk results from the increased water nutrient concentration.

5. Crayfish in rice field can control the amounts of pests, but disease prevention and biodiversity conservation in rice-crayfish field still need further improvement (Cao *et al.*, 2017).

4. Economic performance

The ministry of agriculture established an integrated rice and aquatic animals farming demonstration area, allowing measuring some economic indicators. The rice yield was stable, at more than 500 kg per 667 m^2, and the efficiency of rice field increased by nearly 100 percent. In a national survey, the average benefit of integrated farming of rice and aquatic animals per 667 m^2 increased by more than 90 percent compared to that of rice monoculture. The average increase was RMB 524.76[33] in output value, up to > RMB 1000 yuan under the new integrated farming of rice and aquatic animals model. For example, the increase with the rice-crayfish model was RMB 1 456.28 (+258 percent), RMB 13 744.94 (+2290 percent) with the rice-turtle model, or RMB 2 484.33 (+351 percent) for the rice-crab model.

Among all models, the integrated rice-crayfish farming model developed the fastest. In 2017, the total area of crayfish farming in China reached 800 000 ha, generating a social and economic output value of about RMB 268.5 billion, with a direct output value of the farming industry at about RMB 48.5 billion. The area of integrated rice-crayfish farming alone was about 570 000 ha in 2017, accounting for 70.83 percent of the total farming area of crayfish. In 2017, the rice-crayfish farming accounted for 47.54 percent of the total area of integrated farming of rice and aquatic animals in China. This model plays an important role in promoting the efficiency of rice field and increasing farmers' income.

5. Constraints

There are still constraints in the development of these models, despite the rapid development in recent years:

1. The integrated farming of rice and aquatic animals model needs further enrichment and innovation. The current models cannot meet the various needs and specific conditions, especially the insufficient exploration of the benefits from supporting co-culture, intercropping and rotation. To popularize integrated farming of rice and aquatic animal, additional new models need to be developed.
2. Field engineering for large-scale mechanization: the trend of modern agricultural mechanization is becoming more and more obvious. The integrated farming of rice and aquatic animals often causes problems for the mechanization of harvest operations. As of now, if the stubble is not well connected, and the aquatic products in the rice field have not reached the market size, the mechanized rice harvest cannot be conducted.
3. It is urgent to formulate standards for developing integrated farming of rice and aquatic animals model. As the comparative benefit of aquaculture is usually higher than that of rice, the ditch and puddle are, sometimes, too large, deviating from the development objective of promoting rice production through aquaculture. Therefore, it is urgent to establish technical standards for clarifying technical indicators on stabilizing rice yield, ecological and environmental protection, standardizing the practices in integrated farming of rice and aquatic animal, and ensuring the sustainable and healthy development of this model.
4. Brand building needs to be further strengthened for rice produced under integrated farming of rice and aquatic animals model. At present, China has not yet established a famous brand of rice from these models of farming. The rice brand should be promoted all over the country through the joint effort of the alliance, between the provincial and municipal departments, and the enterprises.
5. Fishing methods and fishing tools need to be further improved. The rice fields differ significantly from the ponds, and the tools developed for harvesting ponds are often not

[33] RMB 1 = USD 0.15.

applicable. As a result, it often takes a long time for aquatic products to be caught and sold, and if they get injured or damaged during the fishing process, it will affect their value and the profit. Thus, new fishing tools and fishing methods need to be developed.

6. Future prospects

In China, 30 million hectares of rice fields currently produce nearly 200 million tonnes of rice, generating an apparent rice yield of about 440 kilograms per 667 m^2. In 2017, the total area of integrated farming of rice and aquatic animals in China was 1.468 million ha, accounting for only 4.5 percent of the total rice field area of China. The rice yield at the integrated farming demonstration unit established by the ministry of agriculture is higher than 500 kg per 667 m^2, which highlights great room for development as it shows that it is possible to increase significantly the economic income with the production of aquatic animals without affecting the rice yield.

In the meantime, the development of integrated farming of rice and aquatic animals model has been given a lot of attention and was strongly supported by governments at all levels by providing a good policy environment during the 13th five-year plan period. Due to its considerable economic and ecological benefit, it has also received a wide recognition from all segments, with more and more enterprises and farmers trying it to produce rice and aquaculture animals, by integrated farming in their rice fields. In support to these dynamics, several investment may have to be considered.

6.1 Strengthening innovation of models and technologies

- In order to support the development goals of "stabilizing rice production and efficiency, promoting rice by aquaculture, ensuring quality and safety, and promoting ecological and environmental protection", continuous investment in new technological models will be needed to cope with the different ecological and geographical conditions, and farm specifications.
- Innovative key technologies for integrated farming are needed in many areas, including rice planting, aquaculture, pests prevention and control, stubbles joint, water and fertilizer management, field engineering, aquatic animals harvesting and processing, quality control etc.

6.2 Accelerating the demonstration and promotion of models and technologies

- Create a batch of large-scale and cost-effective demonstration units, with emphasis on scale, standardization, branding and industrialization.
- Organize the compilation of unified training materials and strengthen the training of key technical people.

6.3 Establish standards as soon as possible

- Organize the research to develop relevant standards for integrated rice and aquatic animals farming, and to accelerate the development of sub-standards for specific models of rice-crab, rice-crayfish, rice-turtle, rice-loach, rice-fish, etc.
- Document the technical performance of various integrated farming of rice and aquatic animals models in stabilizing rice production, increasing efficiency and product quality, protecting the environment, etc.
- Define technical performance requirements and technical evaluation methods, and gradually form a standard system for demonstration and promotion.

6.4 Strengthen the theoretical background

- Breeding of rice varieties suitable for integrated farming of rice and aquatic animal that are disease resistance and have appropriate growth cycle and taste.
- Study the role of biodiversity in building a suitable environment for the growth of aquatic animals, and to improve the use of natural feed in rice field.

- Study the ecological and economic effects of integrated farming of rice and aquatic animals system, by focusing on improving the efficient use of nitrogen, phosphorus and other nutrients.

6.5 Strengthen brand-building strategies

- Explore the ecological value of integrated farming of rice and aquatic animals model and build brands highlighting the ecological and healthy rice and aquatic products.
- Promote the production of rice field products in accordance with the requirements of pollution-free, green and organic food in various regions, and focus on ecological and health brands.
- Government departments should make use of their own advantages to increase guidance and publicity, so that the green ecological characteristics of rice field crops and aquatic products are well known.

6.6 Support new agricultural business entities and improve modern agricultural management system

- Support new types of agricultural business entities such as large professional households, family farms, leading enterprises and professional cooperatives.
- Strengthen the industrialization and actively promote the integrated farming of rice and aquatic animal.
- Establish an integrated value chain through unified varieties, management, service, distribution and brand to further enhance the industrialization.

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IMPROVING LIVELIHOODS OF INDIGENOUS AND LOCAL COMMUNITIES THROUGH INTEGRATION OF FISH IN TERRACED RICE FIELDS IN YUNNAN, PEOPLE'S REPUBLIC OF CHINA

Yanni Xiao

1. Introduction

Yunnan province is situated in the southwestern border of China. Complex geographical conditions in Yunnan have led to the formation of water resources in many rivers and lakes. Many major rivers originate in the province, there are more than 40 large natural lakes, dams and ponds with a surface area of 32 400 hectares. The unique climatic and geographical conditions in Yunnan have created rich and varied environments and, relatedly, a rich biodiversity. It has been particularly important for the development of the aquatic biodiversity and abundant fishery resources in Yunnan. As of 2013, 629 species of fish have been recorded in Yunnan province, of which 594 were indigenous fish, ranking first among all provinces in the country.

Honghe County is located in the southern part of Yunnan province. It is a key target county in the country's poverty alleviation and development strategy, which is characterized as "border area, ethnic minority, mountain area and poverty-prone". The land area of the entire county is 2 028.5 square kilometers, with 96 percent covered by mountainous area. The total area of the terraced fields is about 20 000 hectares. The aggregate population of Honghe County is 340 600. Minority nationalities account for 96.2 percent of the total population which includes Hani, Yi, Dai, Yao and other ethnic groups. As of the end of 2016, there were 15 413 families (66 771 people) recorded as "under-poverty".

The Honghe Hani terraced fields have a history of more than 1 300 years. They are also the birthplace of China's distinctive high quality red rice. Over 9 300 hectares of paddy fields are retaining water and producing rice as the staple food for the indigenous people and community. At the thirty-seventh World Heritage conference on 22 June 2013, the Honghe Hani terraces were listed as a World Heritage Site for culture, and also as a Globally Important Agricultural Heritage Site (GIAHS). This site is the forty-fifth World Heritage Site in China.

Figure 1: Typical landscapes in the Honghe County, Yunnan province.

However, the Hani terraced fields are facing many problems limiting sustainable development. First, the overall development level of the economy is limited, the infrastructure of the rice paddies is poor, and the economic return of rice production is low due to low productivity and poor market price.

Second, there is hardly any use of mechanized equipment in terraced rice-field, and rather farmers still depend on physical labour for agriculture activities like tilling, ploughing, planting and harvesting. Third, the willingness of many locals to continue to rice farming is diminishing, and young people are emigrating away from the land, preferring to work in cities instead of staying in the country. Fourth, the phenomenon of abandoned terrace rice-paddy has emerged, and caused collapse of paddy dikes. Fifth, to reduce the agricultural labour required, instead of planting rice, some farmers replant sugarcane or vegetables in the terraced fields, and the spraying of pesticides/herbicides on these crops causes pollution also of the terraced rice fields. Sixth, local farmers are poorly educated and lack the knowledge for technical innovation. There is a need for capacity building so that they understand and use modern science and technology.

There is a proverb in Honghe County, "No matter the height of the mountain, there is a water spring at the top" that means water keeps running in the Honghe Hani terraces all over the year, no matter the height (山有多高，水有多高). The natural resources are available, especially water, but they have not been fully utilized.

In 2016, to combat the challenges of livelihood improvement and poverty reduction in the Honghe County, the Yunnan Zhonghai Fishery Company (YZFC) began work on technology innovations in terraced rice paddies, and was technically supported by the Freshwater Fisheries Research Center (FFRC) of the Chinese Academy of Fishery Sciences (CAFS). The first postdoctoral research station in Yunnan province was set up in Honghe County to study locally-appropriate solutions. The researchers extensively studied the production, protection and sustainable development of Hani terraced fields and determined that the terraced field area is suitable for integrated rice-fish farming. There are more than 6 700 ha terraced rice paddies that could be benefit from this integrated practices in Honghe County. Moreover, it was found that the water quality in the rice fields conforms to the national standard for raising "pollution-free fish". It was concluded that it is feasible to promote the integrated rice-fish system in Hani terrace fields.

As a complementary and symbiotic agricultural ecological circulation system, the "integrated rice-fish system" efficiently combines rice cultivation and aquaculture. It has the advantages of increasing rice yields while saving land and labour, and thus provides economic, ecological and social benefits for Hani people and their terraced fields. The integrated system will build a strong foundation for the sustainable development of Hani terraced fields in the future; it will provide a mature technology model for improving yields from paddy fields in Yunnan province in general and therefore be an effective way to reduce poverty.

The principle of rice-fish farming in Honghe County basically includes three parts: Economic Benefit, Ecological Benefit, and Social Benefit. By the end of 2020, with the goal of building 6 670 ha high yield demonstration fields in the whole county, the total economic output value can reach RMB 1.2 billion[34] annually. Each household can improve their income of RMB 40 000 each year. The economic benefits of rice-fish co-cultivation can encourage local farmers to reuse abandoned paddy fields, or reduce planting area of sugarcane and corn, therefore, reducing the input of fertilizer and pesticide. On the other hand, before rice-fish farming, farmers need to reinforce ridges and dredge ditches. It improves the ability of drought resistance and flood drainage. Through increasing output value and terrace facilities construction, rural labor force was retained and accumulated practical experience for promoting the protection of Hani terrace and the development of ecological agriculture.

According to the experiment and demonstration analysis from Yunnan Zhonghai Fishery Company, the breeding loaches in the paddy field were obtained by the purchase price of RMB 24 per kilogram. Terraced fields of 0 to 700 meters above sea level can breed loaches for three seasons each year, with the annual output amount of 22 500 kg per hectare (1 500 kg per mu) and the output value of more than RMB 30 000. Terraced fields above 700 meters above sea-level can breed loaches for two seasons each year, with the output value of RMB 10 000 per mu. In accordance with the goal of building 6 670 ha high yield demonstration fields in the whole county, especially in terrace fields area, the total economic

[34] RMB 1 = USD 0.15.

output value can reach RMB 1.2 billion annually. Each household can improve the income of RMB 40 000 each year. In this way, more than 22 860 families in the county can improve their incomes and get rich, more than 12 860 households, 51 200 people can cast off poverty. (The minimum income to be "not poverty is RMB 4 000/person/year). The traditional cultivation mode of Hani terrace fields in the past is only planted one crop of rice in summer and full of water in winter, otherwise, Terraces were suffering the risk of collapsing. In this season, we call it "winter fallow fields" (冬闲田). Terraces become natural ponds for fish farming, which provides enough natural food for fish growth. With the current stocking density of 300 kg per ha fish fry, the expected total output reaches 1 500 kg of carps per ha.

At present, YZFC focuses on making full use of the unique water resources during implementation of the "integrated rice-fish system" in Honghe County. Rice fields provide a suitable living environment and rich natural food organisms for loach resulting in good fish growth. Therefore, farmers neither need to do the extra feeding work, nor aeration. Loaches and other fish activities not only loosen the soil for rice roots and thus promote rice growth, but also provide organic manure which acts as fertilizer for the rice. According to the analysis, the rice grain yield can be increased by more than 5 percent per unit area. In order to increase the yield of rice and fish, it is necessary to maintain the paddy dikes and deepen the peripheral ditches regularly. The ability to resist drought and drainage in terraced fields has also been effectively improved.

YZFC has established the production chain from species selection, breeding, grow-out production, processing, to product marketing. The extension and management model was a combination of Government-support, capacity development of farmers and their organization into cooperatives, and development of private enterprise. The overall goal is poverty alleviation in terrace rice culture region of Yunnan province. The results showed that the "integrated rice-fish system" has great significance for the protection and development of Hani terraced fields.

The seed supply is the most important input in the innovative agro-aquaculture system. In order to provide good quality and a sufficient amount of loach fingerlings to the demonstration and extension of the rice-fish farming project, FFRC and YZFC have jointly invested USD 9.23 million to build a hatchery in Meng Long village, Honghe County. The first phase of the hatchery occupies an area of 30 ha and a 1 100 m^2 indoor hatching workshop. The hatchery has a capacity to produce 3 billion loach fingerlings (body length: 5–7 cm), with an output value of USD 185 million. It can meet the stocking demand of 6 700 ha terraced rice-field for high yield demonstration in the county. The hatchery contributed to promote integrated rice-fish demonstration to the county's terrace rice-paddy, and potentially to benefit for more than 1 million poor households. Furthermore, it fills the gap of fish seed supply in Yunnan Province, by providing a guarantee for the scaling up for "rice and fish integration".

Since 2016, FFRC has successfully provided two new aquaculture varieties to the hatchery in Honghe county and Hekou County for trial demonstration in rice-paddy. These are a farmed type of common carp called "Furui Carp No. 2" (福瑞鲤2号) and a farmed type of tilapia called "吉富罗" (JIFU – Genetically Improved Farmed Tilapia). Currently, the hatchery has 60 000 pairs of loach breeders, 30 000 pairs of 吉富罗 (JIFU) tilapia brooders and 14 000 pairs of Furui carp No. 2 "福瑞鲤2号" breeders. The fine breeder lines guaranteed the quality fish seed supply for the project implementation of rice-fish integration for Hani terraced rice-paddy innovation and poverty reduction.

In addition, YZFC has also carried out the following measures for the implementation of the "integrated rice-fish system" in the Hani Terrace rice-paddy.

2. Training

"Give a man a fish, you feed him a day; teach a man to fish, you feed him the whole life" is an eminent old saying in China, that means it is better to teach farmers some aquaculture skills than give them fish directly. YZFC has conducted technical training program on aquaculture for farmers in Honghe County

since 2016. Up to the end of 2017, there are more than 20 000 people were trained on aquaculture, they are from 13 townships, 120 village committees and 360 natural villages in Honghe County. The training courses were taught by specialists and experts from FFRC and YZFC. Before the training, specialists and experts did deep investigation on the local situation and resources in each village, by walking from town to town, village to village. The aquaculture models and techniques were taught based on local specific conditions, and on-site technical guidance were conducted accordingly. After the training, many local people became professional workers with rice-fish integration management skills, harvest and marketing knowledge. Some became "local experts" and provided technical service to neighbor farmers, capable in helping other poor families in fighting poverty in Honghe County.

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Figure 2: Training courses on aquaculture for farmers in Honghe County.

3. Cooperative creation

The cooperative of rice-fish integration is organized by local community farmers engaged in terrace rice-paddy spontaneously, aiming to share technical experience, unite farmers for inputs purchasing and contracts with leading enterprises in seed supply, farming standards, product marketing, etc. The Honghe county government actively encourage the poor households to join professional cooperatives, explains the advantage and working mechanism, and liaisons governmental poverty alleviation funds to find any financial loan support. By joining professional cooperatives, farmers can easily solve problems of fish seed supply, technical services, financial support and products marketing. To incentive the standardized farming operation and quality products, the Honghe county government provided bonus of USD 300 to each poor household who has joined the program. Public banks and rural credit cooperatives offered interest-free loan (maximum USD 7 700) for each family when they are endorsed by professional cooperatives. At present, there are 196 professional cooperatives on standardized rice-fish farming in Honghe County.

4. Land transfer and consolidation

In cases of farmers who own land but lack operational laborers and ability in farming management, they are encouraged the transfer of their rice paddy to farmers who are capable in production scaling up. The households receive rent through the transfer of land and paid labor work in participating through the production cycle. So that the poor householder will convert from "aid receiver" into "self-aided" for a sustainable poverty alleviation manner.

6 Guaranteed price

Yunnan Zhonghai Fishery Company guarantees provision of aquaculture seedlings at a price below 30 percent of the market price of Yunnan seedlings. 2017 to 2018, the loach seedling price and the carp seedling price which provided for standardized farming-breeding professional cooperatives and

communities were RMB[35] 0.1 per tail and RMB 25 per kilogram. When carp and loach grow up to the market-required specifications, Zhonghai Fishery company buys them back at a predetermined price (loaches are RMB 24 per kilogram and the carps are RMB 35 per kilogram in 2017 to 2018). This cooperation model has effectively solved the problems of farmers' lack of breeding technology and marketing connection.

From 2016 to 2017, YZFC provided a total of 160 million fish fingerlings to Hani terrace rice-fields, with an area of 1 500 ha, and associated more than 2 000 households covering 13 towns, 112 village committees, 336 natural villages, which helped 10 000 people to get out of poverty and become rich. In 2018, the overall implementation area of rice-fish co-cultivation is 1 667 hectares (Fish: 1 000 ha, Loach: 667 ha). At the beginning of 2018, Zhonghai Fishery Company had started the experiments on the development of integrated rice-bullfrog system on the edge of the terrace fields and paddy fields which rarely uses in rice production.

On June 15, 2017, FAO officially opened the YZFC Hani Terrace "Integrated Rice-Fish System Research and Training Center" which is the first of its kind with such an award by FAO in China.

Fig, 3: Official opening of the YZFC Hani Terrace "Integrated Rice-Fish System Research and Training Center".

On October 9, 2018, Mr. Tang Qisheng, academician of the Chinese Academy of Engineering, Mr. Zhang Xianliang, the director of Fisheries Bureau, Ministry of Agriculture and Rural affairs of China, and 36 experts from the Chinese Academy of Engineering, the Chinese Academy of Aquatic Sciences held a technical seminar on rice and fish comprehensive cultivation in Hani terraced fields in Honghe County. On the same day, Academician Workstation of Tang Qisheng was officially established in Honghe County.

[35] RMB 1 = USD 0.15.

Figure 4: Technical seminar on rice and fish comprehensive cultivation in Hani terraced fields.

In March 2017, several senior government officers of Yunnan province visited the hatchery of YZFC and sites of "integrated rice-fish system" in Hani terrace rice-fields, as well as the local participating households, they highly prized the contribution of FFRC and YZFC. They stated that "integrated rice-fish system" is an innovative approach in agro-aquaculture system. This model is not only the development of agroecology and circular economy, but also benefit to improve the livelihood of the indigenous people through double income sources (i.e. revenue is received from both the rice and the fish). The government departments have pledged to support the further development of leading agricultural companies, such as YZFC, to expand in meeting more and more demand of poverty reduction in the province. In addition, the government will support the branding establishment for ecological agriculture in Yunnan province.

Figure 5: In March 2017, several senior government officers of Yunnan province visited the hatchery of YZFC and sites of "integrated rice-fish system" in Hani terrace rice-fields.

FFRC and Zhonghai's "integrated rice-fish system" has just started. In 2019, several problems remain to be tackled. At macro level:

1. The basic research on rice and fishery comprehensive cultivation is still weak. The rice-fish integrated breeding models and techniques suitable for different regions and altitudes still need to be further studied, screened and matured. We will keep exploring more models which are suitable for different regions.
2. The strength and effectiveness of technical training still needs to be improved. We need to explore appropriate teaching methods so that local people can understand and learn as soon as they see them.

3. Lack of special funds to support ecological recycling agriculture projects in national agricultural comprehensive development zones in Yunnan province. We will actively apply for policy support and financial support from the government with our own resources. At the same time, we appeal to all people and enterprises who are concerned about Hani terraces to invest in Honghe.

At the company level, YZFC will continue to promote the work of rice-fish farming in Hani terraced fields, and actively establish the brand of products such as Well-known Trademark, organic products etc. On the other hand, we will operate modern technology and networks to build online sales platforms. Let more people know about Hani terrace fields and purchase products in efficient ways to help local people.

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A workshop, aimed at collecting and documenting the diversity of integrated agriculture aquaculture practices (IAA), was organized on 25 August 2018 in Montpellier, France, during the International conference AQUA 2018 of the World and European Aquaculture Societies. The objectives were to clarify how an IAA implemented within an agroecological approach could help alleviating poverty and hunger, and to identify the knowledge gaps to be filled to ensure the sustainability of IAA. Twenty five speakers presented background information and case studies in front of a full room.

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