IJMS 22 (2), 53–71 (2015)

TRANSFORMING AQUACULTURE RESEARCH AND INDUSTRY FOR MANAGEMENT OF SEAFOOD SECURITY RELEVANCE OF NURTURING A UNIQUE INNOVATION ECOSYSTEM

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Abstract

Seafood security through aquaculture is a topic of strategic national importance for many countries, including Malaysia. With production from fisheries unable to meet the demand, aquaculture is set to play an increasing role in seafood supply. Aquaculture started booming in the 1990s, just when the capture fisheries showed distinct signs of stagnation. The rapid growth of aquaculture and the rising demand have created challenges which researchers and the seafood industry must address through collective action to enable this sector to grow at the rate needed for a sustainable food future. Malaysia has identified aquaculture as a key economic area under its new economic model and developed mechanisms to achieve the targets. This requires knowledge-based developments and cultivating links between the academia and the farming sector in an environment that seeks solutions through innovation. It makes a great difference when institutions of higher education decide to spearhead interdisciplinary, multidisciplinary and transdisciplinary research that has ingredients for nurturing an innovation ecosystem. This provides a platform for a link-up with the aquaculture industry and the traditional fish-farming community. The blending of modern and traditional knowledge and diversification of approaches with new perspectives focused on solutions will *probably yield positive outcomes from a policy that supports new pathways for achieving seafood security for socio-economic welfare.*

Keywords: *Seafood security, innovation ecosystem, university-industry interface.*

Introduction

Aquaculture has been in practice for some 2,500 years when it started in its most primitive form of collecting juveniles or mature fish from their natural habitat and holding them until consumption or marketing. This activity was basically in the nature of capture fisheries except that the fish caught alive were held in containment facilities for short periods. The practice gradually changed over time and became more organized only around the 1950s by the application of some basic scientific methods, resulting in a production of 1.0 million tons of fish (FAO, 2007). From that period onward the production continued to increase steadily with inputs from technology, attaining a figure of 14 million tons by mid-1980s and 27.6 million tons towards the end of the 1990s. The years that followed saw a real turning point in aquaculture. Interestingly, this coincided with the stabilization of capture fisheries mainly due to overfishing and habitat degradation. The aquaculture production doubled between 2000 and 2012 and most likely it will have to more than double between now and 2050 to meet the demand of the growing human population and the increasing interest in fish for health reasons. The credible projections made by FAO indicate a 10% reduction in capture fisheries during the period 2010-2050 due to a complexity of problems besieging the ocean ecosystem. The analysis presented by FAO (2014) suggests a linear growth in the aquaculture sector for an additional 2 million tons/year in this period (2010-2050) to meet the seafood demand of the growing human population. Looking at the current scenario, it is evident that aquaculture is the fastest growing among the food-producing sectors (FAO, 2012) and a strong pillar of global food security and economic development. It has proved its worth especially with the stagnation of capture fisheries since the 1990s and an increasing trend of the contribution of farmed fish to the seafood market and human dietary.

The general perception, backed by scientific investigations, that fish are low in saturated fats, cholesterol and carbohydrates, and that they contain high value proteins, essential micronutrients, including vitamins, minerals and polyunsaturated omega 3 fatty acids (FAO,

2012) has developed a great deal of interest in seafood in recent years to the extent that seafood is an issue for everyone! Aquaculture has now reached parity with capture fisheries in terms of its contribution to global seafood supply in the ratio of 50:50 (Hall et al., 2011). However, there are many challenges which can come in the way of aquaculture's production targets. These include biosecurity problems, loss of fertility and resilience in captive stocks hampering the sustainable production of high quality seed and increasing ecological footprint that recoils on its own production efficiency and sustainability.

Scientists have expressed different viewpoints to explain the conditions needed for further growth of the sector to meet the targets. Waite, Phillips and Brummett, (2014) have suggested five strategies to help put the growth of aquaculture on the right track:

1. Investing in technological innovation and transfer – where science can complement traditional knowledge to improve efficiency through collective efforts of research institutions, farmers, companies and government departments.
2. Focusing beyond the farm- through spatial planning and zoning to ensure that aquaculture operations stay within the surrounding ecosystem's carrying capacity. This will go beyond monitoring the aquaculture regulations and certification of the individual farms which did not often consider the cumulative impact of many farms in close proximity.
3. Shifting incentives to reward sustainability – to promote sustainability, rather than rewarding short-term gains in production through incentives.
4. Leveraging the latest information technology – for demonstrating the implications of good and bad practices, promoting sustainable methods, using knowledge to find solutions to problems around the world, and better planning and management of aquaculture operations.
5. Consuming low food chain species – to reduce demand on prey fish, maximize energy saving and reduce ecological footprint of aquaculture. Examples include tilapia, carp, bivalves and sea cucumber.

We believe that a radical transformation of aquaculture is urgently needed to address the challenges that are currently constraining its growth and have all the ingredients of becoming more serious in the decades to come. A better organization of aquaculture activities and closer cooperation among research institutions, government agencies and the private sector aimed at environmental compatibility of the farming systems and strengthening of the small and medium enterprises as well as family-based farming units are urgently needed for sustainable development. These are not possible without transformation which can ideally take place in an innovation ecosystem.

The Scenario in Malaysia

Among the Asia-Pacific countries, Malaysia has recognized seafood production through aquaculture as a National Key Economic Area (NKEA) under the New Economic Model (NEM) to spur economic growth. This thrust on aquaculture is motivated by a number of reasons which include: attaining seafood security; lessening the pressure on wild fisheries resources and marine ecosystem in this biodiversity-rich region, a substantial part of which lies in the Coral Triangle; promoting entrepreneurship and supporting the country's rapid transformation into a high-income nation.

The Government of Malaysia realizes that a sustained investment in institutions of higher education by way of human capital development and modernization of infrastructure has reached a stage that universities are in a position to contribute towards achieving an annual revenue of up to RM20.0 billion from aquaculture. Bringing knowledge and innovation into the market for wealth creation has been elusive despite the allocation of huge amounts of funds, incentives and mechanisms to foster academia-industry linkages.

In Malaysia, the potential of academia-industry collaboration is a much talked-about subject. It has not made much headway despite expressions of benefit of doing so by both sides during meetings and forum discussions. The government has developed funding mechanisms to support the joint projects where researchers have taken their work to a level where the industry can adopt it and both the parties collectively do the commercialization. Still, there is not much to report. The industry is either not willing to apply new methods developed by the researchers, finding them too expensive to be of practical value, or not investing in R & D oriented to discovering solutions to their specific problems. The massive investment in the academia, therefore, does not find commercial outlets or contribute to knowledge-economy in a big way and we are yet to find a holy grail that can make it happen. While the industry often finds fault with the academia for not pursuing practical research; this criticism in the face of the industry's lack of investment in research in the universities does not seem justified. It could be that R & D is expensive and the industry is not willing to absorb the cost. But the industry would lose out to those who decide to come forward to invest or develop smart partnership arrangements with the R & D institutions to remain ahead in the business. The bottom line is that there is a realization of the gap between university research and industry expectations and the benefits that will accrue by bridging it. In a widely acclaimed analysis of the this problem, RCN (2005) suggested mechanisms for overcoming it. Bhujel (2008) identified the reasons why aquaculture research findings do not often get communicated to the industry. In a highly analytical report recently published by BBSRC-NERC (2015) the lack of cooperation between the aquaculture research institutions and the seafood industry was highlighted and the importance of coping with industry challenges for a collaborative research and research translation process to support businesses operating in the aquaculture sector have been elaborated.

A review of some 200 research papers published in the last 10 years by scientists working in the Malaysian government universities reflects a trend suggesting an increase in the output of the publication of books and papers in journals. Many of these publications are based on the work that utilized modern and sophisticated gadgets, and reflect an effort on the part of researchers to get their findings appear in journals with an impact factor. While it is a healthy trend that has generated a great deal of scientific knowledge, but has contributed little to the application of the knowledge towards the commercialization of aquaculture. A reorientation of research in such an applied area is, therefore, necessary if aquaculture is to contribute in a significant way towards knowledge-based economy. It has to be focused on finding solutions to the main problems hampering the industrial growth of this sector. Government investment in R & D is for output as well as outcome. The output is impressive but an applied sector, that aquaculture is, requires outcomes that develop it on a commercial scale to generate gainful employment and revenue from export besides helping the nation in import-substitution and self-reliance. In our review, there was not a single paper jointly published by the university and the industry and not a single paper was based on funding from the industry.

A turnaround is obviously needed, focused on outcome-based research, gaining the trust of the industry by demonstrating that application of scientific knowledge can translate into economic dividends. Progress in this direction would require innovation ideas and strategies. In addition to reviewing selected papers as described above, efforts were made in this study to extract the relevant information to establish research directions and innovation search in aquaculture and seafood security using knowledge management tools, including advance search tools for data mining. Information retrieval involved screening through some of the important databases, namely FishBase, FAOSTAT, Agricol, CAB Direct, ASFA, (via ProQuest), Fish, Fisheries and Aquatic Biodiversity Worldwide (via EBSCO), Aquatic Commons, DIAS, and Biosis. Besides, tracking the citation analysis was also carried out. Such an in-depth search and analysis of information provided a valuable base for generating the data for this paper.

Involving Academia for Knowledge-based Development

In 2014, the Ministry of Education urged the universities to develop bottom-up mechanisms to achieve tangible progress in certain areas, and one of the areas was aquaculture. Universiti Malaysia Sabah (UMS), a major government institution of higher education established two decades ago, deliberated on this matter and took a bold policy-decision to identify aquaculture as the **university niche area**. This was endorsed by the University Senate and the Board of Directors on 22 September 2014. The Ministry of Education accepted this decision. The decision of UMS in favor of aquaculture was motivated by the realization that it is a topic that deals with seafood production where all the institutes, faculties and centers can contribute in some way or the other.

This initiative of UMS provides a structured basis and framework for interdisciplinary, multidisciplinary and transdisciplinary approaches to resolve complex and real world problems in the aquaculture sector. It also shapes a vision for the future of R & D directed towards seafood security with spin-off benefits in terms of employment generation, resource conservation and self-reliance, and linking research with economic growth. Inherent in this new policy are elements that can nurture an innovation ecosystem which is needed for the aquaculture of the 21st century.

It is worth mentioning that aquaculture has been the flagship program of the Borneo Marine Research institute (BMRI) of UMS ever since its inception. BMRI is a postgraduate institute and the centre of excellence of UMS. The staff of this institute comprise experts of the various disciplines of aquaculture (nutrition, pathology, water quality, breeding and hatchery technology, larval development, marine science (coastal oceanography, marine biodiversity), marine biotechnology, fisheries, and coastal and marine management. Due to this diverse expertise, there is considerable interdisciplinary work which is being carried out where efforts from different subjects are integrated and harmonized into coordinated and coherent projects. The researchers cross the traditional boundaries between these academic disciplines or sub-disciplines to address problems that require such an effort. This is evident from the synergy which exists among the various research programs when it comes to the sharing of know-how and jointly pursuing problems. For example, cage aquaculture receives inputs from marine science topics related to coastal hydrodynamics and harmful algal blooms. Aquaculture also relies on biotechnology in modulating immunity, disease identification and management, and environmental remediation. On the other hand, hatchery technology developed by the aquaculture programs helps in sea farming, stock enhancement and sea ranching. Information on biodiversity helps in simulating multiple species stocking for grow-out management. Data generated by all these subjects is used for developing climate change adaptation strategies and frameworks for sustainable development.

To raise the profile of BMRI, the Ministry of Education, granted it the status of potential Higher Institutions' Centre of Excellence (HICoE) in the field of aquaculture in 2013 with a significant financial incentive to support a research program on sustainable seed production of high value fish. This program envisages the consolidation of the efforts of BMRI's experts in the fields of broodstock management, captive breeding and larval development, health and diseases, water quality, nutrition and live-feed culture. This research program provides a practical model of interdisciplinary research which can be used as a showcase for university-wide research on the niche area of aquaculture.

With the niche area of the University now an official policy evolved through consensus, scientists of BMRI and scholars across the University can broaden their research approach through the involvement of vastly different disciplines. Positive signs of such interaction have become evident after a firm decision by UMS to implement multiple projects by different faculties in addition to BMRI on ecological aquaculture. This 5-year program (2014-2018) is supported by the Ministry of Education and is structured to resonate with the concern for environmental compatibility of production systems that should embrace the vision of 'producing something out of nothing'. This is a serious attempt at reducing externalities, waste recycling, energy conservation, reducing carbon footprint, and above all, making aquaculture environment-friendly, economically viable and sustainable.

BMRI is an obvious choice for initially facilitating aquaculture research across UMS. However, the overall management of aquaculture as a university niche area is handled by the research management center (Centre for Research and Innovation). Many areas are listed in Table 1 which the various institutes, faculties and centres of UMS can pursue should they decide to move aggressively in strengthening the niche area concept.

Table 1

Potential areas where research can be done across UMS

Faculties/ Institutes/ Centres	Possible topics for focused studies
Faculty Cluster: Science	
Faculty of Science and Natural Resources	Examining and minimizing ecological footprint of aquaculture. Climate change effects on aquaculture and adaptations. Use of wind turbines for ventilation in hatchery facilities. Organizing aquaculture in the forests integrated with forest ecosystem, water sheds, ponds, lakes, reservoirs. Water conservation methods: Recycling, remediation, efficiency of operation.
Faculty of Food Science and Nutrition	Analysis of seafood quality and safety. Product diversification. Variations in quality related to culture conditions (RAS, flow-through system, salinity and freshwater, artificial feeds).
Faculty of Sustainable Agriculture	By-product processing. Post-harvest quality – shelf-life and keeping quality. Development of integrated aquaculture modules (fish and plant crops).

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Faculties/ Institutes/ Centres	Possible topics for focused studies
Faulty of Engineering	Use of renewal energy in aquaculture, especially the hatchery operations. Production of biofuel from marine microalgae which are generally cultured for larval feeding. Development of effective containment systems, especially design and material of sea cages and moorings which can withstand the weather conditions (waves, currents, salinity and others). Better flushing and water renewal. Control of fouling. Escape prevention. Measurement of aging process or fatigue of materials. Automatic methods for detection of damage in cage nets. Mooring system to securely and conveniently shift the cage farmsite at short notice to suitable areas. Smart aquaculture modules using information and communication tools, artificial intelligence and robotics. Use of green technology in low carbon aquaculture modules (solar cells, gravity flow of water). Rainwater harvesting, storage, use and recycling. Recirculating aquaculture systems through new biofilters, membrane filtration, etc. Artificial intelligence- development of artificial neural networks for detecting water quality signals through multi-probe meters and action to bring about necessary modulation. Robotics- robots for controlling biofouling in sea cages and some hatchery operations (automation in feeding with timer-assisted scheduling).
Faculty of Informatics and Computing	Programming for water-quality monitoring and alert systems in smart aquaculture modules. Interactive databases.
Faculty of Medicine and Health Sciences	Scientific verification of health benefits of consuming seafood. Reducing the risk of heart diseases, cancer, diabetes, asthma, Alzheimer's diseases. Improving intelligence, skin conditions, bone health. Positive influence on obesity, migraine, stress, depression, brain function. Determining the efficacy of modulating the bioactive chemical profiles of seafood organisms through nourishment on human consumers. For example, fish rich in Omega-3 fatty acids, iodine and protein among others. Laser treatment as possible substitute for eyestalk ablation in shrimp. Pathogen exclusion in a biosecurity system. Understanding of cues that influence physiological systems.

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Faculties/ Institutes/ Centres	Possible topics for focused studies
Faculty Cluster: Social Science	
Faculty of Humanities, Arts and Heritage	Socio-economic impact of aquaculture systems-employment -generation, livelihood, poverty alleviation, empowerment of indigenous communities through seafood production knowledge. Gaining insight into traditional knowledge of aquaculture and testing it for sustainability. Determining ways and means of merging it with modern knowledge to evolve innovation culture systems. Developing public education modules to explain seafood and livelihood security issues Effective extension services to fish farmers and knowledge exchange.
Faculty of Psychology and Education	Changing public perceptions about certain types of seafood (ever increasing demand for carnivorous fish), false notions about eating certain species (aphrodisiac effects). Dealing with controversies linked to halal and non-halal issues with certain types of seafood products. Popularizing sustainable seafood solutions.
Faculty of Business, Economics and Accountancy. Faculty of International Finance	Economic analysis of aquaculture modules. Marketing strategies. Creating niche market for organic seafood. International investment. Seafood export promotion.
Cluster: Research Institutes	
Borneo Marine Research Institute	Aquaculture (hatchery management, brood stock management, breeding and seed production, water quality, nutrition and feed development, live-feed culture, behavior of captive fish, biosecurity and health, sea farming). Marine science (coastal hydrodynamic processes, marine biodiversity, biology of marine organisms, marine critical habitats, harmful algal blooms, conservation methods). Biotechnology (genetic marking of marine animals, genetic basis of selection, hybridization, bioremediation of water quality, molecular diagnostics of fish diseases). Fisheries (catch composition, stock enhancement and sea ranching) Coastal and marine management (management of seafood security, bio-economic models, ocean governance, social-ecological systems).

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Faculties/ Institutes/ Centres	Possible topics for focused studies
Institute for Tropical Biology & Conservation	Biodiversity-aquaculture linkage. Natural products from marine organisms. Feed ingredients from land-based sustainable sources. Ingredients from natural products for plankton culture.
Biotechnology Research Institute	Genetic characterization of fish using molecular tools. Brood-stock selection and control of inbreeding depression. Molecular diagnostics of diseases.
Cluster: Centers	
Centre for Industrial Relations	Seeking industry partner. Developing operational university-industry interface.
Centre for Entrepreneurship Development	Development and operation of aquaculture incubator. Forging links with SMEs for training and shared-farming.

It is evident from the aforesaid that the scope of aquaculture as a university niche area is vast but it has the potential of making a convergence of disciplines that has not happened before. All the departments can work on aquaculture drawing on knowledge from their respective disciplines and staying within their boundaries in a multidisciplinary approach in supporting the university niche. Essentially, this is a non-integrative mixture of disciplines at university level where each discipline retains its distinct identity, approaching the subject from its own methodology, tools and perspectives to address the problems of aquaculture while formulating a solution. In interdisciplinary effort, many disciplines share know how through exchange of ideas and collectively try to find a solution. Institutionalizing all these possibilities and potential synergies through the university niche-area concept has the elements of novelty which we believe can produce innovations. Considering that the growth of aquaculture in the 21st century would significantly depend on how innovationly we are able to solve the problems which exist today or those which might show up in future in a changing climate. The relevance of innovations in aquaculture is explained below.

Developing an Innovation Ecosystem

Innovation is something original which can be a new idea or a method that offers a better solution, generally breaking new ground. Bessant and Tidd (2011) have elaborated the definition of innovation as a new idea, improved technique, product, service or solution which can be translated into useful outcomes. When it comes to an applied area such as aquaculture, a creative idea implemented or adopted for socio-economic benefits qualifies for innovation. For example, a new method that evolves from an idea which improves efficiency of the production of high quality seafood, whether through a new design of farming module, a novel feed or an effective biosecurity, or in some other ways, is an innovation that contributes to value creation. To make innovations happen, we need an environment or an ecosystem.

There is a conceptual analogy between innovation ecosystem and biological ecosystem. In a biological ecosystem, the living organisms interact with each other and with their physical (non-living) environment where they live and which provides conditions for their biological needs (for example, feeding, breeding) and this whole complex functions as a unit. Obviously, the ecosystem has many components and is dynamic because situations are not static. In the case of aquaculture, the drivers, demands and knowledge are among the factors which keep on changing.

There are many players in aquaculture; the scientists and engineers who generate knowledge and technology, social-scientists who deal with the benefits to the society and the industry which uses methods and technologies for profitable production of aquatic food. Because there are many stakeholders involved in aquaculture and they have different backgrounds, concerns, approaches and interests, an innovation ecosystem for aquaculture has to be a hybrid of different perspectives. Ideally, a platform for these many players will constitute elements of the innovation ecosystem which nurtures the interplay of many actors, comprising those who conceive an idea and those who turn this idea into a solution (process, product, services) that creates value in the market. An innovation ecosystem that consists of economic (agents and relations) and non-economic (technology, institutions, sociological interactions and culture) components (Mercan & Göktaş, 2011) relates well to aquaculture.

An innovation ecosystem can thrive in an atmosphere of 'out-of-the-box' thinking; a thinking that is not constrained by established models of solutions to aquaculture problems and accepting them without question despite not so overt qualitative differences inherent in the problems for which solutions are being sought. Researchers should always remind themselves that science has no frontiers and, therefore, quest for new knowledge free from past hangovers should be an incessant endeavor to find solutions to the problems which were either unresolved or unidentified in the past or are new in the light of the trend of environmental dynamics caused by events as powerful as climate change. We should accept that the knowledge is dynamic and keeps expanding, and whatever we acquire today is going to expand virtually unlimited. We must believe that the absence of evidence is not an evidence of absence. This should motivate researchers to explore entirely new horizons of problem-solving outcomes in aquaculture. Lack of evidence today could be born out of the limitations of contemporary knowledge and this must drive efforts towards acquiring more knowledge in search of the elusive evidence. The bottom line in nurturing an innovation ecosystem is that the approach should go beyond where others have gone if the problem continues to evade solution which researchers are seeking within the domain of published data. These salient features of the innovation ecosystem are summarized in Figure 1.

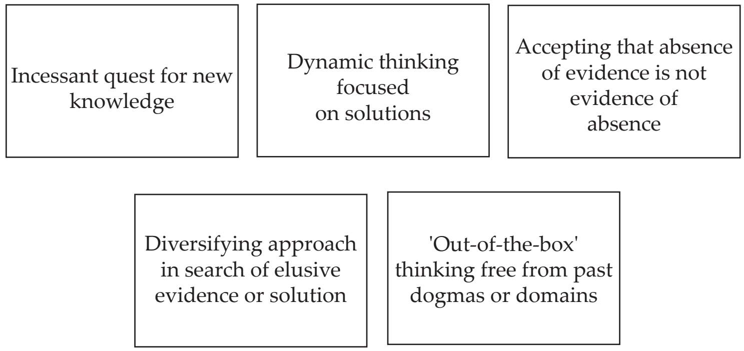

Figure 1. Salient features of an innovation ecosystem.

Aquaculture offers many innovation hot spots; some are visible, while others need to be explored. While innovations can flow naturally from an idea which might turn out to be worth widespread adoption, using real-life case studies involving hands-on experience will help in identifying what works and what does not work in aquaculture in meeting the requirements of practicality.

While we encourage intellectual freedom in exploring innovation solutions, in a parallel effort, we should also develop an innovation pathway as a generic route to innovation that can make a real difference by addressing the major problems hindering progress in aquaculture development. Such a pathway could have landmarks which can be reached with gradual progress through time or in a quantum leap. There are three most appropriate pathways to develop the aquaculture innovation ecosystem as shown in Figure 2.

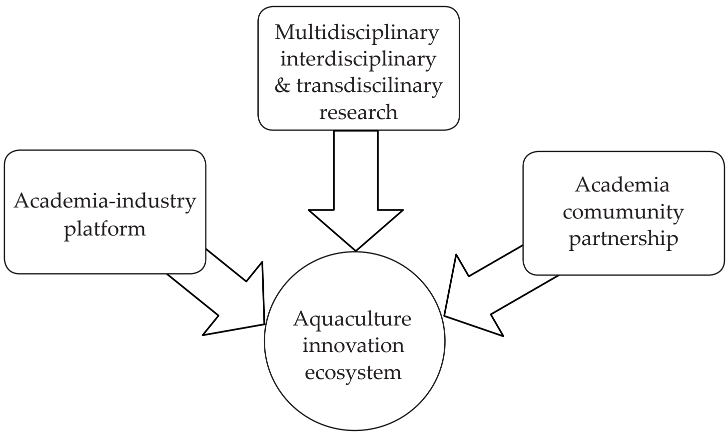

Figure 2. Pathways for developing the innovation ecosystem in aquaculture.

Aquaculture is an applied area where input from any discipline that makes a positive difference is a welcome development. For example, engineering as an academic discipline can contribute a great deal to aquaculture but there have not been many linkages between the two. Many areas of modern aquaculture require engineering solutions which can pave the way for aquaculture innovations and inventions. This can attract the industry to develop a long-term strategic collaboration with the University. It is where interdisciplinary effort can be pooled to generate a solution. Researchers of different backgrounds will think differently, and the potential solution could turn out to be very effective in a rapid resolution of the problem. It might be unprecedented by its very nature due to divergence from the way experts of the core area of aquaculture traditionally solve a problem through intensive research and experimental trials. Globally, the multiple dimensions of aquaculture and seafood supply from the diversified fields of studies with a convergence of interest are evident from many thought-provoking publications which include: those from science (Soto, 2009; Tidwell, 2012; Timmons & Ebeling, 2013; Mustafa & Shapawi, 2015), social science (Makay, 1992; Buadaeng

& Eckert, 1993; Brumnett, 1994; Diana, Egna, Chopin, Peterson, Ling Cao, Pomeroy, Verdegem, Slack, Bondad-Reantaso & Cabello, 2013), environmental perspectives (Midlen & Theresa, 1998; Cochrane, De Young, Soto & Bahri, 2009; Diana, 2009), and economics (Allen, Botsford, Shuur & Johnston, 1984) and human nutrition and food security (Cynthia & Morgan, 2014; Sampson, Sanchirico, Roheim, Bush, Taylor, Allison, Anderson, Ban, Fujita, Jupiter & Wilson, 2015).

A structured and institutionalized form of this approach will contribute a great deal to developing an innovation ecosystem in aquaculture. While anyone can develop a new idea training and skills improve the innovation capabilities. The interdisciplinary and multidisciplinary efforts may evolve into a transdisciplinary approach when researchers see the need to develop a platform for exchanging ideas and working together in trying to collectively provide a solution to the problem.

A transdisciplinary approach can happen at various levels – from the very beginning when the project is in a discussion or planning stage and continues to progress, or at a later stage when multidisciplinary research has advanced to a stage when experts of different disciplines have used their individual expertise to find answers to a given problem, and then come together, bringing their individually-evolved ideas, to formulate a comprehensive solution.

Aquaculture researchers do come across problems that they encounter in hatcheries or wherever they conduct experiments, but the nature of the problems facing commercial aquaculture could be different. In such a situation, researchers can volunteer help to the industry which should be able to fund research on the specific problem. Such research is highly focused, solution-oriented and time-bound, making the researcher explore all the possible avenues and think innovationly in an attempt to find a solution. The feeling of being part of the solution, the intellectual property it creates, the self-confidence it instills and the faith reposed by the industry contribute to nurturing an innovation ecosystem that can breed and inspire endless innovation practical solutions to the aquaculture problems.

Creating a platform for an academia-industry collaboration and an academia-traditional farming community are essential elements of an aquaculture innovation ecosystem. As far as the former is concerned, our experience is that the high-end aquaculture industries generally resist any radical transformation. They have invested heavily in modern infrastructure and have economically benefitted, so they are not too inclined towards changing the existing systems. These industries do encounter problems but they seek ad-hoc solutions, favoring fixing a problem as it appears, and are not too much concerned about the environmental impact. They believe they can sustain the aquaculture through this approach. On the other hand, the small and medium enterprises (SMEs) have modest infrastructure, and in many cases, it is old as well. They show a greater degree of keenness to scientific viewpoints.

Regarding the link-up with the traditional-farming sector, this is a very promising area in several ways. First, for scientists, environmental compatibility of aquaculture is important. In traditional farming, this is embedded in the culture of aquaculture. That provides a solid basis to start with. Second, this sector is keen to grow for better economic benefits but either have a primitive or very modest infrastructure. Working with the universities which help them use modern facilities or get funding from the R & D agencies of the government where a structured form of cooperation with the universities is a prerequisite for financial support. With the know-how available from the universities and funds from the government, the traditional-farming community easily embraces transformation, retaining those core practices which are rooted in the environment and sustainability. We believe a fusion of traditional knowledge with its green perspectives and modern knowledge focused on production efficiency is a key to innovations targeted at sustainable development. The traditional-farming sector has proved its survival strategies over time through adaptions in innovation ways. They have weathered and lived through many challenges although the scale of their operations is small and efficiency of production low but resilience is high.

To carry forward this 'fusion aquaculture' approach we recently, on 11 December 2014, announced a partnership farming initiative envisaging links between the university and the fish-farming community and received an overwhelming response. This raises hope for a symbiotic arrangement that looks like a very important component of the innovation ecosystem. It gives farmers an opportunity to adapt to new methods, and scientists to apply and test new techniques.

With progress somewhere in this sort of arrangements, possibilities might emerge for the universities to engage their wholly-owned companies (university-link holdings) which can operate in a corporate culture and are free of other commitments that characterize academic life, where researchers will guide the aquaculture development. If this emerges as a model of successful aquaculture, the industry might be inclined to work with the academia.

Conclusion

Seafood security is a matter of national importance. Aquaculture is the only way to meet the demand. It has started booming since the 1990s, coinciding with stagnation in capture fisheries and is expected to grow still more rapidly to supply fish to the growing human population and addressing the shortfall in capture fisheries. There are many challenges which have to be overcome in developing this sector. In this context, innovation solutions provide the way forward. For an applied area that aquaculture is, innovations that meet practicality hold key to seafood security. This will happen through interdisciplinary, multidisciplinary and transdisciplinary research that look into the problems from all the possible angles, and developing a workable platform for interaction among the academia, the traditional fish-farming community and the industry. Incubating smart ideas and knowledge management are crucially important for progress along the pathways considered most appropriate for the 21st century aquaculture.

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