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Challenges and opportunities of IMTA in Hawaii and beyond

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Abstract: Available consumable seafood for 7.3 billion population in 2014 was 20 kg per capita (FAO, 2016). To maintain this level of seafood supply for expected 9.7 billion population in 2050, the total world seafood supply requires additional 48 million metric tonnes. With the stagnant yield from capture fisheries, the increase has to come from aquaculture. Although the annual growth of aquaculture production has slowed down, theoretically aquaculture production will reach the targeted production level. However, current intensive mono-aquaculture practices have faced the challenges of sustainability and must change its operation to meet the criteria of sustainable development defined and adopted by UN's 193 Member in 2015. UN members adopted the 2030 Agenda for Sustainable Development and call for an integrated approach that addresses all three dimensions of sustainable development (economic, social and environmental).

Current aquaculture practices consume nature resources and compete with each other. Ecosystem based aquaculture management is essential to co-exist with other social activities and to efficiently utilize natural resources for food production and conservation of nature stocks. Integrated multi-trophic aquaculture (IMTA), an old concept with new knowledge, appears to be the answer to sustainable development in aquaculture. IMTA practice combines the cultivation of fed aquaculture species, and extractive aquaculture species (both organic and inorganic ones) to reduce wastes and to create balanced eco-systems. Additionally, IMTA can play important roles in disease control and management, climate change mitigation, and others. As a result, IMTA has received more and more attentions at the turn of the century. However, the feasibility of IMTA comparing to mono-culture has yet to be documented.

This presentation discusses the sustainability of IMTA by reviewing the practice of IMTA concept in traditional Hawaii aquaculture back to 1000 A.D. to current practices in the U.S. and beyond; updates US-Korea bilateral IMTA project; and challenges of IMTA.

Key words: IMTA, Aquaculture, Sustainability, Hawaii

Introduction

Among food production sectors in agriculture, seafood is the only one still rely on wild caught fish as the main supply channel. Indeed, the harvest of fish has reached the peak and plateaued around 90 million metric tons since early 1990 (**Fig.1**, FAO, 2016). However, as stated by Walsh (2011) "If we're all going to survive and thrive in a crowded world, we'll need to cultivate the seas just as we do the land. If we do it right, aquaculture can be one more step toward saving ourselves. And if we do it well, we may even enjoy the taste of it." With the effort by many stakeholders in seafood business, aquaculture has shown impressed growth (FAO, 2016). In 2014, the statistics showed aquaculture supplied half of edible seafood. Capture fisheries used to contribute major seafood to human consumption as show in this slide

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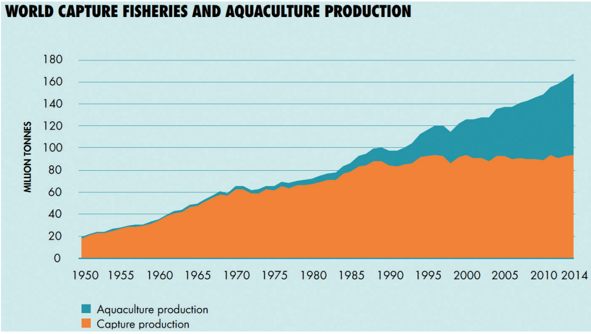

Fig. 1. World seafood production from 1950 to 2014. (FAO, 2016)

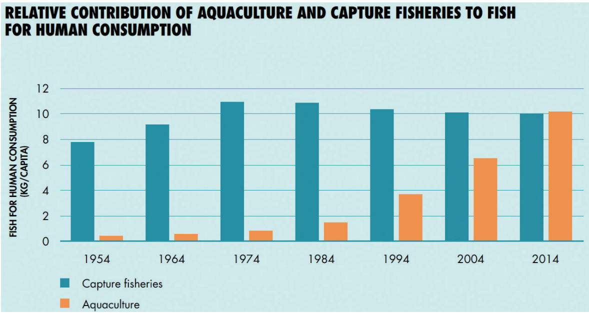

Fig. 2. Contribution to human seafood consumption from capture and aquaculture. (FAO, 2016)

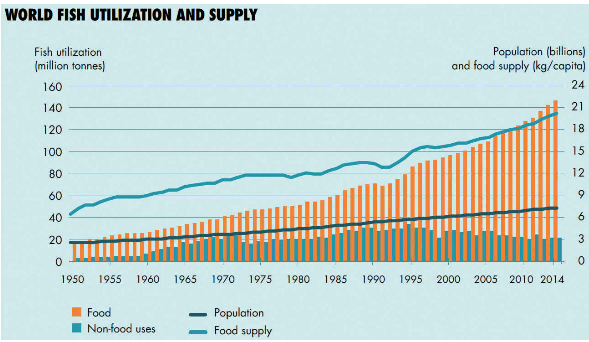

Fig. 3. World population growth and seafood supply. (FAO, 2016)

until 2014 (**Fig.2**). From 1950 to 2014, the food supply increased faster than the population increased (**Fig.3**). The available seafood for the 7.3 billion population in 2014 was 20 kg per person. If the projected 9.7 billion population in 2050 is correct, we need additional 48 million MT seafood to meet the 20 kg per capita level in 2014. Average annual growth rates for aquaculture were over 10 % in both 80s and 90s (FishStat. FAO, 2016). It has decreased since but still around an impressed rate of 6 %. The rate may decrease in the future but we should have enough seafood from aquaculture to meet the demand if the seafood consumption rate remains the same. However, the demand for seafood will probably increase as the population structure changes and several challenges may hamper the increase in aquaculture production. For the sustainable development of aquaculture, integrated approach to overcome the challenges facing aquaculture development is essential. In 2015, 193 members of United Nation adopted the "2030 Agenda for Sustainable Development" (https://www.un.org/sustainabledevelopment/development-agenda/) and its 17 Sustainable Development Goals. They call for an integrated approach that addresses all three dimensions of sustainable development: economic, environmental and social factors. At Global aquaculture alliance (GAA) 2013 meeting, the concluded five major challenges were: health and disease management, feeds, environmental/social Accountability, investment capital and market support. Therefore, a sustainable aquaculture has to be integrated approach and to address key challenges for the development. This paper discusses a practice which may meet all criteria to be a sustainable one.

Integrated Multi-Trophic Aquaculture (IMTA)

Integrated Multi-Trophic Aquaculture (IMTA) is a new term (Neori *et al*., 2004) for an old concept. Polyculture has been practiced in China since 2200 BC to fully utilize the nutrients inside an enclosed pond. IMTA takes one step further to reduce the ecological footprint from aquaculture practice and at the same time to create economic diversity and to call for social acceptability (Troell *et al*., 2009). IMTA, therefore, equals to polyculture but polyculture is not necessary an IMTA. Since aquaculture can be the farming of several aquatic organisms which interact through water in shared or connected systems, one organism wastes can be another resource (Butterworth, 2010).

When feed is offered to an aquatic organism, only portion of digested nutrients is incorporated into biomass of the target organism. The rest of unused digested nutrients, along with indigestible nutrients and un-eaten feed will increase nutrients levels and become solid waste in surrounding environment (Reid *et al*., 2007). The quality and quantity of total

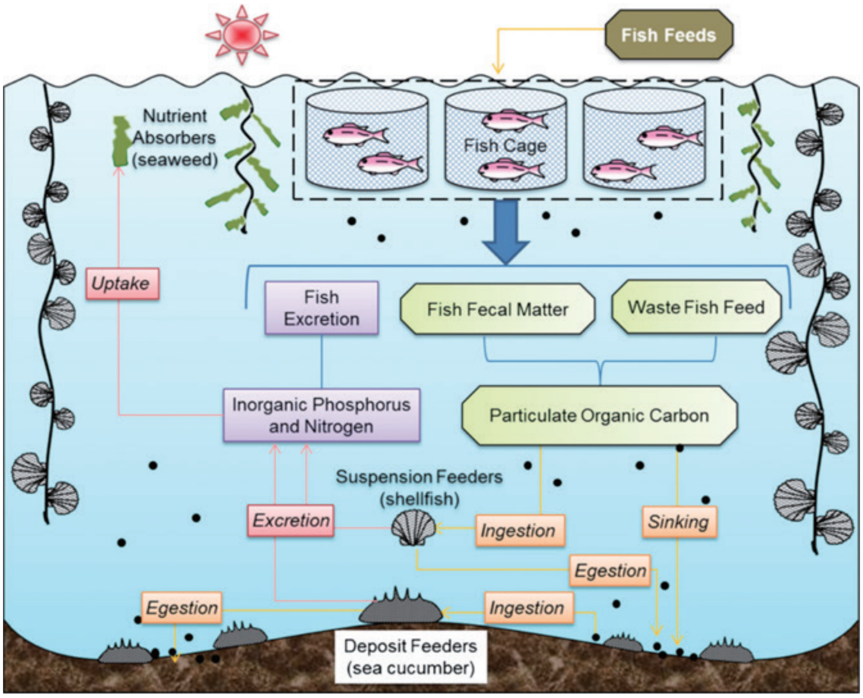

Fig. 4. Conceptual diagram of the integrated multitrophic aquaculture system. (Zhang *et al*., 2016)

Table 1. Key species have been in IMTA

Key Species Cultured in Modern IMTA Systems
(Integrated mariculture, FAO-529)

Cold Seawater	*Temperate Sea water*	*Warm Seawater*
Salmo	*Pagraus major*	*Sparus aurata*
Oncorhynchus sp.	*Sparus aurata*	*Lates calcarifer*
Gadus	*Dicentrarchus labrax*	*Mugil cephalus*
	Lates calcarifer	*Chanos*
		Epinephelus sp.
Crassostrea sp.	*Mercenaria*	*Crassostea gigas*
Mytilus sp.	*Crassostea sp.*	*Tapes japonica*
Haliotis rufescens	*Ostrtrea edulis*	*Haliotis diversicolor*
Hamarus	*Mytilus*	*Penaeus spp.*
Strongylocentrotus	*Ruditapes semidecussatus*	
Paracentrotus	*Penaeus spp.*	
Laminaria sp.	*Gracilaria sp.*	*Gracilaria changii*
Macrocystis sp.	*Ulva sp.*	*Ulva lactuca*
Porphyra sp.		*Kappaphycus*
Saccharina		
Undaria		
Nereis, Arenicola, sea cucumber	*Nereis, Arenicola, sea cucumber*	*Nereis, Arenicola,sea cucumber, mullet*

nutrients released are determined by the cultivated species and the dominant fraction is in a dissolved form, particular for nitrogen (Troell *et al*., 2003). To fully utilize all nutrients as a result of feeding, IMTA practice composes of species at different trophic levels may be the solution. An essential component in IMTA are fed aquaculture and extractive aquaculture. The diagram presented by Zhang *et al*. (2016) gives a good illustration (**Fig.4**). IMTA can be implemented in freshwater system or saltwater system at either land based or open water operation. Depending on the water quality and location, a wide variety of species have been tested in IMTA system as shown in **Table 1** (Soto, 2009). Target species can cover all cultivated species from plankton, plant to invertebrate and vertebrate species. The optimal species combination should be based on meeting the goal of sustainable development mention above.

IMTA in Hawaii and USA

The "Ahupua'a" is the basic self-sustaining unit in ancient Hawaii land system, recognizes the connection between resources from mountain to the sea. It has the resources the human community needed and emphasizes the interrelationship in the activities of daily and seasonal life. Ancient Hawaiian fishpond within this land management system also practices this interrelationship concept to stock aquatic species within the aquatic compartment surrounding by coral reef and volcano rock. All target species will compromise with each other on nutritional needs and balance the essential optimal ecosystem for all in the pond. Species including carnivorous, herbivorous, omnivorous, and seaweed can be found in Hawaiian fishpond as stated in Moli'i fishpond (Sato and Lee, 2007). However, number of Hawaiian fishpond has decreased due to the socioeconomic change. Many of the sites have been converted to other social activities for greater economic return.

On December 3 and 4, 2009, an international workshop on "Bioextractive Technologies for Nutrient Remediation" was held to address the management of eutrophication and hypoxia in Long Island Sound. The positive contributions from the bio-extraction of nutrients from use of macroalgae to absorb inorganic nutrients and use of filter and deposit feeders to reduce organic waste released from fish production was presented (Rose *et al*., 2010). The nutrient bioextraction by seaweed and bivalves as reviewed by Yarish and Kim (2017) is very significant. Another benefit of IMTA practice showed by Molloy *et al*. (2011) study that individual blue mussel can remove copepodids from water column. Therefore, co-culture with blue mussel (*Mytilus edulis*) may be the potential alternative method to drug to deal with sea louse (*Lepeophtheirus salmonis*) issue in Atlantic salmon aquaculture. Furthermore, Molloy *et al*. (2014) study found that infectious salmon anaemia virus (ISAV) was ingested by blue mussels and no viable ones were found in digestive gland tissue.

Another type of IMTA practice in Hawaii is aquaponics. The nutrients from fish culture are used as fertilizer for vegetables. Current practices in freshwater system is tilapia with various type of vegetables. Although tilapia is the most popular species, it does not exclude other species which is tolerable to the water quality condition in aquaponics system. Other than the freshwater system, several studies are on-going to test seacucumber and/or seaweed with shrimp, abalone and marine finfish in marine environment. Seacucumber may plan important role in improving the benthic condition by cleaning the detritus at the bottom of rearing facility. The study by Hannah *et al*. (2013) demonstrated seacucumber is able to utilize the heavy fraction of waste from a sablefish farm. Aquaponics has also been practiced in other locations in the US as well. Other practice can be found at the publication by Bellona (2013) and Soto (2009).

Challenges for IMTA

The above background information on IMTA proves this system can protect the surrounding environment around the farm site and diversify products. The concept of IMTA is also supported by the aquaculture industry in Norway. Norwegian aquaculture industry has shown significant growth since 1970s and targeted to triple the production by 2025 from over 1.3 million tonnes level in 2012. However, Bellona report in 2013 (Bellona, 2013) clearly indicated it is an unsustainable target unless IMTA concept is introduced. IMTA is also supported by publics. According to the survey conducted by Yip *et al*. (2012) at Northwest USA, it revealed 44.3 % of consumers favored the IMTA operation and were willing to pay a price premium of 9.8 %.

On contrary to those favor of IMTA, the practice of IMTA in large scale is still very limited. The recent survey conducted by Kinney (2017) also indicated that financial returns for IMTA did not justify the continuous operation of majority farmers. Only two aquaculturists out of eight continued after the initial trial. Therefore, the challenges to the implementation of IMTA have to be overcome. A workshop at Port Angeles, Washington (Thomas, 2011) was conducted to analyze strength, weakness, opportunity, and threat on IMTA regarding ecological, economic and social impacts. Information from this workshop should provide good base for strengthening the positive impacts from the practice of IMTA.

In conclusion, if we do it right, IMTA can overcome at least some of the 4 out of 5 major challenges to aquaculture development. Before IMTA can be widely applied to aquaculture production, more research in IMTA are needed. To fully understand the optimal ration of fed to extractive organisms is critical. The startup cost and profitability have to be improved to be affordable and acceptable by farmers. Then, the research module has to be able to expand to commercial scale. Finally, the products from IMTA have to be distinguishable from other traditional practice to command higher price.

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An oral history of a man, George Uyemura who spent 70 years of his life at Molii Pond was documented at this book to share his knowledge and experience in managing the fish pond. This book offers a look at the history and methodology of sustainable management of Hawaiian fishponds. It is a start reference book to know more about Hawaiian fishpond.

(2) Soto D. (ed.), 2009: Integrated mariculture- A global review, FAO Fisheries and Aquaculture Technical Paper 529, FAO, Rome, 184pp.

This report contains three desk studies encompassing global views of practices and future prospects for integrated aquaculture in coastal and marine areas in three climatic zones: temperate, tropical and Mediterranean Sea as a special Mediterranean enclosed ecosystem. The commissioned review papers describing integrated aquaculture in coastal and marine environments were technically supervised by Mrs. Doris Soto, Senior Fisheries Officer (FIMA). The activity and the publication have been partly funded through a Japanese Trust Fund Project (Towards Sustainable Aquaculture: Selected Issues and Guidelines). It is a good reference report to get start to know about integrated mariculture.

(3) Thomas S. A. (ed.) 2011: Integrated Multi-Trophic aquaculture: A Workshop at Peninsula College Port Angeles, Washington. *Bull. Aquacul. Assoc. Canada*, **109-2**, 13. https://www.researchgate.net/publication/257819653

This report summarized the first US-based workshop on integrated multi-trophic aquaculture (IMTA). The two days' workshop included presentation and breakout sessions to conduct "strengths-weaknesses-opportunities-threats" (SWOT) analysis for ecological, economic, and social impacts of IMTA. It concluded IMTA could help to move the US toward becoming a major aquaculture producer in the world, because it might resolve some of the issues that seem to be limiting such progress. This is a good reference base for any further SWOT analysis.

(4) Bellona, 2013: Traditional and Integrated Aquaculture. Bellona report 2013, The Bellona Foundation, Oslo, 113pp. https://www.bellona.org

Bellona has been involved in the hunt for new solutions, new resources and new products that will be important for the future. This report points out that salmonid industry has high ambitions for growth, but it must happen in harmony with the ecosystem. It explains why aquaculture should progress from salmonid monoculture to integrated and sustainable ecosystems and how. Also, this progress depends on the aquaculture industry, research institutions and politicians working together. It is a good lesson for other aquaculture industry to learn from a mature salmonid industry to think ahead.

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This review article examines the potential negative impacts of saltwater mono-aquaculture operations and how the novel approach such as IMTA, constructed wetlands and saltwater aquaponics will mitigate the negative impacts.