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Development of the Integrated multi-trophic aquaculture (IMTA) System in the World; Article Review

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Abstract

Aquaculture is a sector of activity in the world that has grown very rapidly in the last few decades. Aquaculture is a food activity sector that aims to provide human food needs, especially protein. However, currently, aquaculture is required not only to be able to meet the protein needs of humans but also to be environmentally friendly and sustainable. IMTA is a system that aims to answer these aquaculture challenges. Currently, fish farming using the IMTA system in the world continues to grow. Many studies have been carried out, such as the selection of suitable species, efficient cultivation design to economic value in fish farming activities using the İMTA system.

Keywords: Aquaculture, challenges, IMTA system

Introduction

Aquaculture and Future Challenges

Aquaculture is one of the fastest growing sectors in recent years. In 2015, the total fishery production, 53% came from aquaculture (FAO, 2018). In order to meet the increasing need for human protein, intensification in aquaculture activities needs to be done. However, there are major challenges faced by the aquaculture sector in which the production of organisms uses too much natural resources, so that it has an impact on the environment (Martinez-porchas and Martinez - Cordova, 2012). To deal with these problems, studies on the effects of pollution on the environment from aquaculture activities are still being carried out (Yokoyama, 2013; Park et al., 2015).

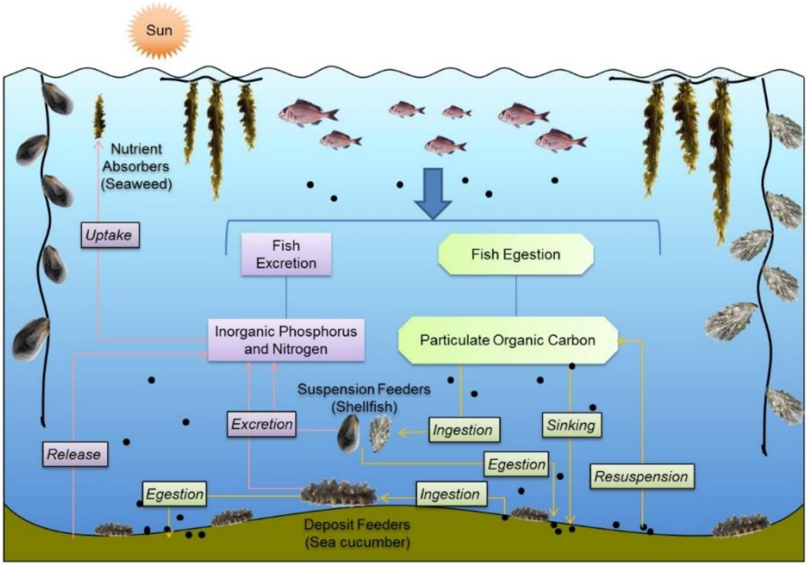

Figure 1. Integrated multi-trophic aquaculture (IMTA) system concept (Zang et al., 2019)

Sustainable aquaculture is a solution in dealing with the negative impacts of aquaculture activities. Sustainable aquaculture must be ecologically efficient, environmentally friendly, diverse in product, economically and socially beneficial. One of the systems with the concept of being environmentally friendly and sustainable is the İMTA (İntegrated multi-trophic Aquaculture) system (Chopin, 2013).

The IMTA system, strengths and weaknesses

Integrated aquaculture is actually not a new concept. This system has actually been applied for centuries in the freshwater aquaclture in China. This concept, generally referred to as “polyculture”. In its development, there is a difference between IMTA and polyculture, namely in the intensive utilization of nutrients found in culture ponds. In IMTA, species fusion is carried out referring to trophic levels or utilization of different nutrients in the same system. In addition, the cultivation of the IMTA system does not have to be done at the same location but can be done by transfering energy or nutrients through water (Chopin and Robinson, 2004; Chopin, 2006).

İMTA is a culture system that uses species with different feeding habits at different trophic levels. The goal is to be able to use waste or nutrients to be reused (Chopin et al., 2013). The application of the IMTA system in marine and freshwater aquaculture can provide the benefit for farmers, consumers and the environment through an ecosystem balance approach (Lembo et al., 2019). The advantages of the İMTA system include being able to minimize the impact of aquaculture activities on the environment and being able to increase productivity in cultivation activities by producing several products (Troel et al., 2009; Ying et al., 2018). In addition, the IMTA system has the potential to prevent and manage diseases in cultivation so that drug use can be minimized. For example, the use of shellfish in IMTA can effectively reduce diseases such as viruses, bacteria and parasites through its filtration activity. Although on the other hand it also has the potential to act as an intermediary host (Lembo et al., 2019). From a socio-economic perspective, the use of IMTA will be able to develop the local economy of a place by opening up employment opportunities. In addition, product diversification can reduce economic risk when price fluctuations occur in the market (FAO, 2009).

The weakness of implementing the IMTA system is environmental, social and economic factors. Environmental factors are very influential, especially in IMTA-based mariculture activities carried out on the coast. It is possible that aquaculture activities on the coast can cause damage to coastal ecosystems and may potentially endanger the further expansion of coastal cultivation activities (Froehlich et al., 2017). From social factors, there is a conflict of interest in land use with other sectors as well as from government policies (Buck et al., 2018).

Meanwhile, the economic factor is the determination of species which is not only for the efficiency of waste utilization but also profitable (Chopin, 2013).

Development of IMTA system

Species selection in the IMTA system

In the last few decades, studies on the possibility of implementing the IMTA system have been conducted in several countries both on land, coast and offshore. Several types of species have been tried, such as the use of shellfish and seaweed species (in the study of Buschmann et al., 2008; Fang et al., 2016; Perdikaris et al., 2016; Neori et al., 2017). As well as several other species used in several other studies can be seen in (**Table 1).**

Table 1. Types of species used in IMTA

No	Finfish (F)	Nutrient absorber (N)	Suspension feeder (S)	Deposit feeder (D)	Others (O)
1	*Anoplopoma fimbria* (Sablefish)	*Alaria esculenta* (Dabberlocks)	*Argopecten irradians* (Atlantic bay scallop)	*Apostichopus japonicas* (Japan Sea cucumber)	*Anthocidaris crassispina* (Purple sea urchin)
2	*Oncorhynchus tshawytscha* (Chinook salmon)	*Ecklonia radiate* (Kelp)	*Chlamys farreri* (Chinese scallop)	*Australostichopus mollis* (Brown sea cucumber)	*Fenneropenaeus chinensis* (Chinese white shrimp)
3	*O. mykiss* (Rainbow trout)	*Gracilaria chilensis* (Red algae)	*Crassostrea gigas* (Pacific oyster)	*Cucumaria frondosa* (Orange footed sea cucumber)	*Haliotis discus hannai* (Disk abalone)
4	*O. kisutch* (Coho salmon)	*G. birdiae*	*C. virginica* (Eastern oyster)	*Holothuria pervicax* (Stubborn sea cucumber)	*Pandalus platyceros* (Alaskan prawn)
5	*Pagrus major* (Red seabream)	*G. lemaneiformis*	*Mytilus edulis* (Blue mussel)	*Parastichopus californicus* (California sea cucumber)	*Rhopilema esculenta* (Flame jellyfish)
6	*Pseudocyanea crocea* (Large yellow croaker)	*G. verrucosa*	*M. trossulus* (Pacific blue mussel)		
7	*Salmo salar* (Atlantic salmon)	*Laminaria japonica* (Kelp)	*Perna canaliculus* (Greenshell mussel)		
8	*Seriola quinqueradiata* (Yellow tail)	*Macrocystis pyrifera* (Giant kelp)	*Patinopecten yessoensis*		
9	*Sparus aurata* (Gilthead seabream)	*Porphyra umbilicalis* (Porphyra)	*Scapharca broughtonii* (Blood clam)		
10	*Takifugu rubripes* (Japanese puffer)	*Saccharina latissima*			
11	*Thunnus orientalis* (Pacific bluefin tuna)	*Ulva lactuca* (Lettuce)			
12		*U. ohnoi*			

13		*Zostera marina* (Eelgrass)			
14	*Labeo catla* (South asian carp)	*Ipomoea aquatic* (Water spinach)		*Viviparus bengalensis* (Banded-pond snail)	*Heteropneustes fossilis* (Stingray-catfish) *Labeo rohita* (Roho labeo) *Cirrhinus mrigala* (Ray-finned fish) *Hypophthalmichthys molitrix* (Silver carp)
15	*Dicentrarchus labrax* (European seabass) *Sparus aurata*	*Chaetomorpha linum* (Green algae) *G. bursa pastoris*	*M. galloprovincialis* (Mediterranean mussel)	*Sabella spallanzanii* (Mediterranean fanworm)	*Sarcotragus spinosulus* (Demospongia)
16			*P. viridis* (Green mussel) *Anadara granosa*	*Holothuria scabra* (Sand sea cucumber)	
17	*Litopenaeus vannamei* (Pacific-white shrimp)	*G. Gracillaria*	*P. viridis*	*Holthuria scabra*	*Chanos chanos* (Milk fish) *Oreochromis niloticus* (Tilapia saline)
18	*Paralichthys olivaceus* (Olive flounder))			*Ophryotrocha craigsmithi* (Rockworm)	

Based on (Table 1), several candidate species used in the İMTA. Rapid species selection is key in the IMTA. Species selection is not only seen from its ability to work effectively in the system, but also from a commercial perspective, local markets and customs in the area. The application of the IMTA system at each cultivation location uses different species. This is due to natural factors, envi - sosio conditions, profit levels and prevailing customs. Some of the benefits obtained by using the IMTA system in aquaculture activities (Table 2).

Table 2. Summary of aquaculture using IMTA systems in several countries

Country	Location	Candidate organisms					Benefit	Reference
		F	N	S	D	O		
Canada	Kyuquot Sound	F1	N10	S3	D5		Blade length of N10 increased to 3.8 times after 67 days	Blasco (2012)
Canada	Bay of Fundy	F7	N1	S8 S5	D5		Growth rates are 46% (N1, N10) and 50% (S5) higher	Troell *et al.* (2009); Chopin *et al.* (2013)
China	Sungo Bay	-	N10 N7	S2	-	O3	Annual production: 8.0×104 t (N7);	Shi *et al.* (2011)

							1.2×105 t (S2, S5, O3) a	
China	Sishili Bay	-	-	S5 S2 S1	D1	-	Recovery rate is 114.8% (D1) higher	Zhou *et al.* (2006)
China	Cofferdam in Rongcheng	-	-	S3	D1	O2 O5	Biomass increased after 13 months: 1.3×104 (D1), 1.0×105 (O5) kg km2	Li *et al.* (2014)
Japan	Zhangzidao Island	-	N7	S9	D1	O1	Total production in 2005: 28,000 t, and a net profit of US $18 million	Troell *et al.* (2009)
Japan	Gokasho Bay	F5	N12	S8 -	D1	O3	Growth rates are 62% (N12) and 58% (D1) higher	Yokoyama & Ishihi (2010)
Japan	Goshoura Island	F5 F10	N7		D1	O3	Seaweed cultivation (N7) would be effective for supplying oxygen to water in fish farms at upper layers	Kadowaki & Kitadai (2017)
Bangladesh	Bangladesh Agricultural University (BAU) campus	F14	N14		D14	O14	Can increase the production in traditional systems	Kibria & Haque (2018)
Japan	West coast of Japan	F11	N7	-	D4		The blade length of seaweed (N7) growth rate 3.28 cm d-1 (Fig. 2)	Zhang et al. (2019)
Italy	Mar Grande of Taranto	F15	N15	S15	D15	O15	The relative abundance of bivalves and Polychaeta increased at the end of the reared. Produced 1.4 tonnes of biomass at final harvested.	Giangrande et al. (2020)
Indonesia	Demak beach			S16	D16		The SGR of blood clams is 1.59%; Green mussels (2.97%); sea cucumber (0.58%) during the rearing period. SR obtained at the end of maintenance from blood clams (87.50%); dn green shellfish and sea cucumber (100%).	Sri-Rejeki et al. (2012)
Indonesia	Demak beach	F17	N17	S17	D17	O17	SGR during the culture period is 2.34% / day; 3.83% / day; 3.07% / day; 2.82% / day and 4.60% / day. Financially, the	Firdaus et al. (2016); Sri-Rejeki et al. (2018).

Table Continue ...

				payback period can be achieved in three cycles of cultivation production.	
South Korean	Jinhae Bay	F18	D18	The rockworm *Marphysa sanguinea* could grow readily by feeding on fish feces and uneaten feed of flounders as a food source. Can increase the biomass production at the end of culture period.	Kim et al. (2014)

Description: Finfish (F); Nutrient absorber (N); Suspension feeder (S); Deposit feeder (D); Others (O)

The use of suspension feeder species and other organic extractive species has also been tried in several IMTA studies such as research by Kim et al., (2014); Nederlof et al. (2020) and Giangrande et al. (2020) using Polychaeta species such as *Ophryotrocha craigsmithi* and *Capitella* sp. and sponges. The results show that the use of these species can increase the efficiency of waste utilization and increase profitability (Giangrande et al., 2020).

Model of IMTA System

The development of the İMTA study is not only on the species selection used, but also the type of cultivation. Currently, the İMTA study is also being developed on land-based aquaculture. One of them which is quite popular is called aquaponics (Chopin et al., 2016). In land-based aquaculture, the IMTA system can be combined with a variety of cultivation systems from traditional to intensive using RAS system. The layout of the IMTA experiment in the land-based area can be seen in the following pictures. In inland aquaculture, IMTA can be applied to traditional to intensive scale systems.

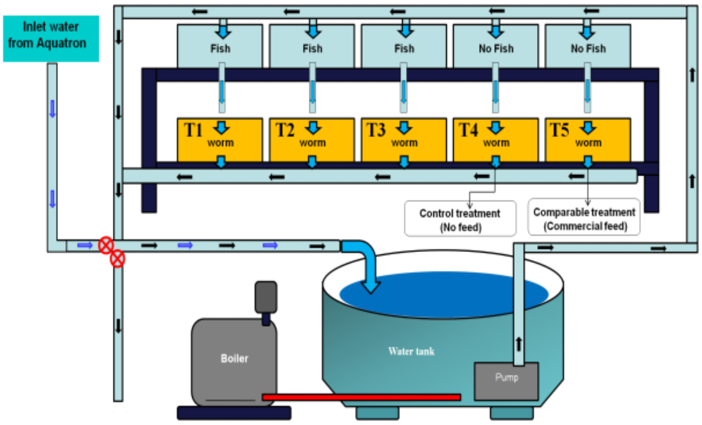

Figure 2. Experiments on IMTA cultivation using the *Ophryotrocha craigsmithi* (Polychaeata) species to utilize organic particles from Olive flounder fish (*Ophryotrocha craigsmithi*) cultivation with a semi-recirculation system (Kim et al., 2014).

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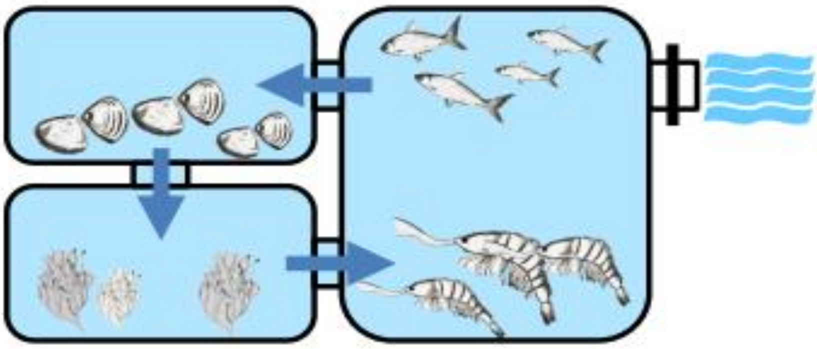

Figure 3. Experiments on IMTA cultivation using *Meretrix lusoria* (Bivalve) and *Gracillaria* sp. (red algae) to utilize organic and inorganic waste in the cultivation of Milk fish (*Chanos chanos*) or vannaemi shrimp (*Litopenaeus vannamei*) with a traditional system (Ying et al., 2018).

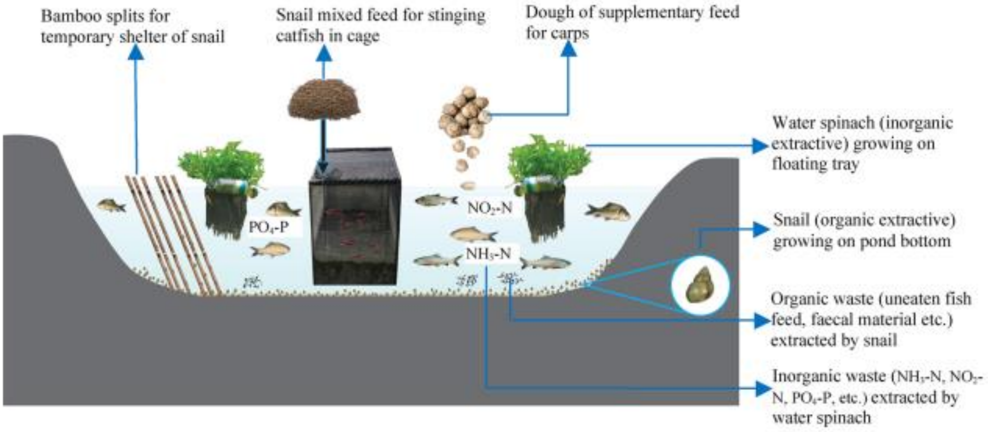

Figure 4. IMTA study on Carp (*Labeo catla*) cultivation using snail (*Viviparus bengalensis*) and water spinach (*Ipomoea aquatic*) to utilize organic and inorganic waste in traditional systems (Kibria and Haque, 2018).

The development of IMTA mariculture began with the application of long-term experiments using extractive species in open sea cages started in 1990 by the University of New Hempshire. Then in 2001, research developed on the concept of using extractive species in combination with fish and the use of wind farm was carried out at the German bight (Buck and Langan, 2017; Buck et al., 2017a, b). Furthermore, the offshore system must be able to withstand waves, currents and storms, and must be minimal maintenance (mostly automated routines) so that maintenance costs can be minimized. Therefore, technological developments in making large cage designs equipped with sophisticated systems and technology have also been carried out (Myrseth, 2017).

Figure 5. Cage design in offshore fish farming which is equipped with several technologies and facilities that can assist in offshore aquaculture activities (Buck et al., 2018).

Research about the impact of IMTA system implementation on the economic level is currently being carried out by many researchers. The research includes 3 main points, namely (i) an economic study that considers environmental externalities; (ii) financial analysis aimed to the profitability; and (iii) market analysis that looks at public and consumer perceptions and acceptance of the IMTA system, and willingness to pay for IMTA products (Knowler et al., 2020).

Conclusion

The current IMTA system is developing to use extractive species that have potential work in the system and have commercial value. In addition, the use of technology with “the concept of multi-use aquaculture” can utilize natural energy so that it is more efficient in energy use. The challenges will be more related to the economic side, the design of larger scale systems, the application of technology, finding sustainable feed and the impact of weather changes on water temperature and chemistry (Troell et al., 2017; Buck et al., 2018; Oyinlola et al., 2018).

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