Overview and history of IMTA, from ancient to modern times

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Concept and history of IMTA study

According to one of the advocators of modern IMTA (Integrated Multi-Trophic Aquaculture), Thierry Chopin, the origins of IMTA can be traced back to ancient civilizations, thousands of years ago, such as those in China and Egypt where farmers practiced a form of agriculture integrated with fish culture. It seemed like a natural course of action for people to think of utilizing waste of fish culture, not only to produce secondary crops, but to earn secondary income as well. IMTA is a concept of hitting two birds with one stone. It deals with problems of environmental pollution and insufficient profitability by mitigating the environmental impact of feeding aquaculture through diversifying nutrient flow and increasing the source of income from secondary species at the same time. A popular design of IMTA is integrating fed species, such as fish, with organic-extractive species (*i.e.* deposit feeder and/or suspension feeder) and inorganic-extractive species (*e.g.* common seaweeds) to utilize nutrients from the excrements of the primary fed species (**Figure 1**). As mentioned above, a similar concept had been practiced from ancient times, through the centuries, and up to modern times (**Figure 2**). In the 1970s, the research group of Woods Hole Oceanographic Institution developed the "integrated waste-recycling marine polyculture systems" which is considered as the grandfather of modern IMTA. They combined different trophic level organisms which realized the basic concept of IMTA.

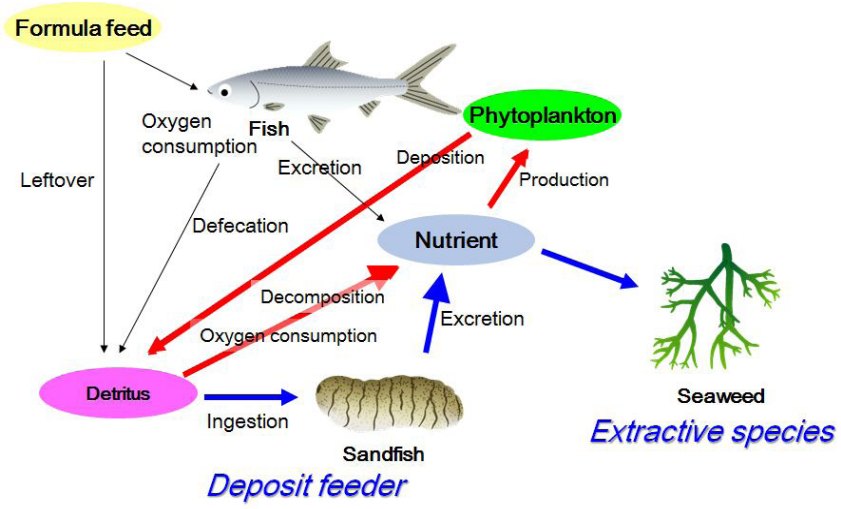

Figure 1. Schematic diagram of IMTA. Case study in Guimaras Island, Philippines

Modern IMTA

After the above-mentioned studies made in the 1970s, more IMTA practices with various modifications had been made in the 20th century. Troell *et al*. (2003) reviewed decades of these studies which could be categorized as IMTA. They summarized the achievements, problems and pointed out the future direction to implement the concept and technology of IMTA. Some of the important points in their review are the advantages (effectiveness of nutrient removal and ease of maintenance) and limitations (*e.g.* profitability) of closed circulation systems derived from the early prototype of IMTA. Hence, IMTA practices were shifted to open water systems at broader scales in the 21st century. Other examples of IMTA systems were developed over the world, reflecting the endemic geographic, climatic, and cultural features in each region. For instance, China developed the bay-scale IMTA in Sanggou Bay called "transitional IMTA" which is contrastive with "engineered IMTA" in western countries. There was also the community-based and small-scale practices such as the "*Satoumi*" in Japan and Southeast Asia.

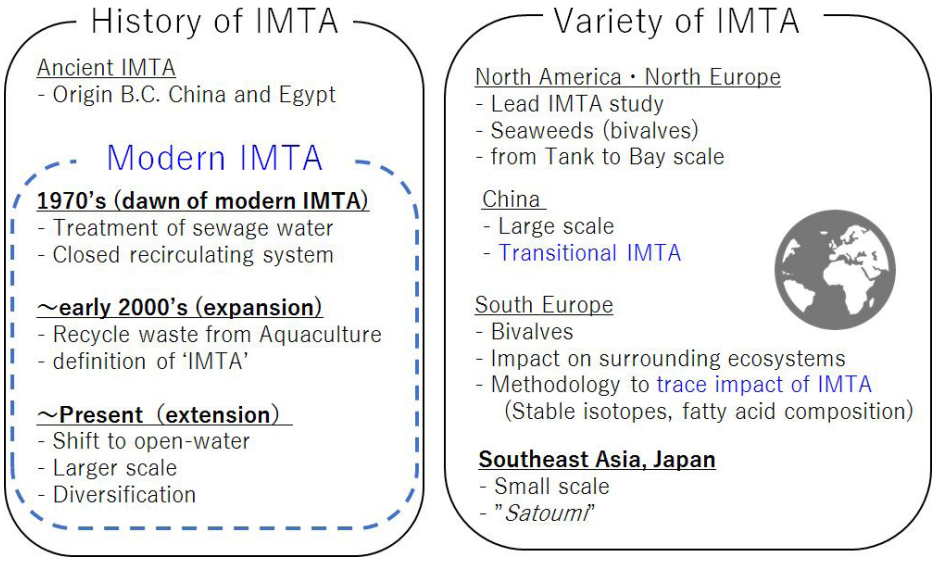

Figure 2. History and variety of IMTA practices.

Challenges for implementation of IMTA

Many concerted and dedicated efforts were made to develop IMTA by those forerunners. However, it was very difficult to evaluate the performance of IMTA systems. By way of example and extension, Sanz-Lazaro *et al*. (2017) concluded that extractive species like mussels do not directly assimilate fish farm wastes. Chopin *et al*. (2012) also discussed the increase of biodiversity near aquaculture sites could also be considered as an impact of IMTA. Recently, development plans of multi-use systems of offshore waters like in wind farms, for example, which combines IMTA. Such an integration opens the perspective of multiple stakeholders, not only of the fisheries sector but also those of other sectors including energy development, shipping, and tourism. These concepts may encourage the future implementation of IMTA in a broader sense.

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