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INTEGRATED MULTITROPHIC AQUACULTURE: LESSONS FROM CHINA

Integrated multitrophic aquaculture has been shown to have both environmental and economic benefits in China, where it accounts for 40 percent of the country's mariculture production.

Integrated multitrophic aquaculture (IMTA) involves farming two or more aquatic species from different trophic levels together to improve efficiency, to reduce wastes and to provide ecosystem services, such as bioremediation. It is often associated with marine systems, but examples are found in brackishwater and freshwater too.

Marine and brackishwater IMTA systems tend to operate in open waters with a combination of fed aquaculture species (such as finfish or shrimp) and a variety of different types of extractive aquaculture species which feed on the wastes of the fed species – like bivalve molluscs, which extract organic matter by filter feeding; seaweed species, which extract inorganic matter; and seabed-dwelling detritivores, like sea cucumbers, sea urchins and sea worms. IMTA systems should be balanced, stable and environmentally sustainable. With product diversification and risk reduction, IMTA systems should also be economically sustainable and socially acceptable, with a reduced likelihood of resource-use conflict. IMTA systems also take advantage of circular principles, using natural integrated processes to utilize any uneaten feed and waste from the fed species, and using natural fertility to add value to organic material and leached nutrients that would otherwise be wasted or lost to the open environment.

China is by far the world's biggest producer of both captured and cultured aquatic products (FAO, 2020). Globally marine capture fisheries were declining in 2018, while the rate of increase in aquaculture production in China was also decelerating, driven by the finite amount of land and water area suitable for aquaculture and by the environmental carrying capacity limits imposed by the government on aquaculture intensification.

Mariculture production in China began in the 1950s with the monoculture of finfish, shrimp and seaweed, but from 1980 to 2000 moved to polyculture and co-culture systems of fish, with shellfish and seaweeds. After 2000, China adopted IMTA, culturing species of different trophic levels, including fed fish or shrimp alongside extractive/bioremediative species – such as shellfish, sea urchins, sea cucumbers and seaweeds – to minimize energy losses and environmental deterioration by adopting a circular economy approach.

The use of IMTA to improve nearshore water quality is receiving considerable attention and IMTA may have potential in multiple-use inshore areas by introducing environmental benefits, making use of waste products and transforming them into valuable co-products (Buck *et al.*, 2018).

China is also enforcing much stricter environmental control measures and farms in coastal areas are being closed down if nutrient levels rise above agreed levels. The State Council of China Action Plan for the Prevention of Water Pollution, issued in 2015, requires aquaculture farms to treat effluent water before discharge.

The key driver for the move to IMTA in China was pollution by aquaculture, agriculture and urban sources in areas like Sanggou Bay, near Rongcheng City, in Shandong Province. This resulted in high sediment loads, as well as high nitrogen and phosphorous levels, which caused eutrophication and increased the frequency of red tides. The strong market demand for shellfish and seaweeds in China was a secondary driver of the move to IMTA. The Sanggou Bay area delivers approximately 240 000 tonnes of mariculture production annually (Fang *et al.*, 2015).

In 2019, China produced 14 million tonnes (including shells) of shellfish and 25 million tonnes (wet weight) of seaweeds – a significantly higher volume of extractive aquatic species than other countries. However, these figures need to be understood in terms of nutritional contribution, as molluscs comprise only 6 percent on an edible-weight basis and seaweeds have very high water content; despite this, the contribution of mariculture systems in China is still impressive.

It is estimated that the proportion of mariculture from non-IMTA and IMTA is currently 60 percent and 40 percent respectively in China, and that the IMTA proportion will continue to grow (Zhu, 2021).

TECHNIQUE AND APPROACH USED

Dong *et al.* (2013) reviewed eight different IMTA systems practised in China including:

- shrimp, clams and seaweed;
- abalone, kelp and sea cucumbers;
- abalone, kelp, sea cucumbers and clams; and
- finfish, bivalves and kelp.

Seaweed harvest in the Sanggou Bay area

Due to the high market price of these species, IMTA systems culturing abalone with kelp/*Gracilaria* spp., and sea cucumbers with kelp/*Gracilaria* spp. were highly profitable and there was widespread adoption of these systems by farmers in open water areas of Fujian and Shandong provinces (Dong *et al*., 2013).

The Yellow Sea Fisheries Research Institute (YSFRI) has promoted a variety of different IMTA species combinations in the Sanggou Bay area. One of the simplest is the farming of kelp (*Saccharina japonica*) in the winter and spring and then *Gracilaria lemaneiformis* in the summer and autumn. The YSFRI has also promoted an innovative IMTA system which includes small cages containing Japanese sea bass (*Lateolabrax japonicus*), *Gracilaria* spp. on longlines and Pacific oysters in lantern nets.

In other parts of the Sanggou Bay area, oysters and kelp were being grown in a polyculture approach, but studies conducted by the YSFRI recommended that the kelp density be reduced by one-third. Farmers following this recommendation achieved a 30 percent increase in kelp production and nearly 100 percent increases in net profit. This was because the reduced kelp stocking density increased current speed and illumination by 20 percent and 30 percent respectively, which provided better conditions for both the oysters and the kelp (Fletcher, 2021).

Another IMTA species combination is abalone (*Haliotis* spp.), sea cucumber (*Holothuria* spp.) and kelp – with abalone and sea cucumber grown in lantern nets alongside the kelp longlines. While the seaweed is a low-value product, abalone and sea cucumber are higher priced. The sea cucumbers clean sediment and benthic matter off the abalone nets, thus improving water current flow and providing better growing conditions for the abalone, while also reducing the environmental impact of the farms (Fletcher, 2021).

More recently, the YSFRI has commenced trials to link land-based recirculating aquaculture systems (RAS), pond IMTA and salt fields in Shandong Province in a circular economy system. Effluent water from intensive fish culture RAS facilities is piped to intensive shrimp culture ponds and then on to IMTA ponds with various fish, shellfish and seaweed species, including the amphipod crustaceans *Gammarus* spp., which eat the seaweed and are food for the cultured shrimp and sea cucumbers, before the effluent water is used in salt fields to first produce brine shrimp and thereafter salt (Fletcher, 2021).

Other fisheries research institutes in China are promoting rice–shrimp and rice–fish aquaponics, including the restoration of saline and alkaline land in Inner Mongolia for the integrated cultivation of salt-tolerant rice, whiteleg shrimp and hairy crab (Zhu, 2021).

IMTA in the Sanggou Bay area, with cage culture of fish in the foreground and extractive seaweed culture in the background

SCOPE AND SCALE OF APPLICATION

There is strong support by government institutions in China for the promotion of IMTA systems nationwide, across both freshwater and marine environments. These systems include agriculture/aquaculture systems such as rice–fish and rice–shrimp, including the use of rice–shrimp to bring unproductive land back into production in Inner Mongolia using a rice strain that is tolerant of salt levels of up to 6 parts per thousand.

The primary focus for the promotion of IMTA systems is, however, on inshore coastal regions along the entire coastline of China. Large-scale production of extractive aquatic species is needed to mitigate coastal eutrophication (Wilberg *et al.*, 2011) and the YSFRI has been able to demonstrate the high bioremediation capacity of IMTA in China to address the impacts of land-based nutrient runoff into coastal waters. This was achieved through large-scale culture of seaweed, which reduced nitrogen levels, controlled phytoplankton blooms and limited the frequency of toxic algal blooms (Xiao *et al.*, 2017).

Despite considerable research interest globally, IMTA has yet to demonstrate substantial commercial success in other areas of the world (Hughes and Black, 2016; Sickander, 2020). The salmon industries in both Norway and Canada have conducted IMTA trials with salmon, seaweeds and bivalves. It is estimated that 7 kg to 13 kg of seaweed would be needed to remove the wastes for each 1 kg of salmon produced, which would require large-scale seaweed production and refining (Schuitemaker, 2017).

IMTA trials have been conducted in other Asian countries, but most of these have been small scale. One example is the double net round cage system, which is used in Indonesia to culture different trophic species – including grouper, whiteleg shrimp, rabbit fish, sea cucumbers and seaweed – in different sections of the cage (Putro, Suhartana and Muhammad, 2015).

Largo, Diola and Marababol (2016) conducted IMTA culture of donkey's ear abalone (*Haliotis asinina*) as the fed species and the seaweeds (*Gracilaria heteroclada* and *Eucheuma denticulatum*) as inorganic extractive species in open coastal waters of southern Cebu in the Philippines. However, the impact on environmental parameters was inconclusive with the quantity of seaweeds used.

There are still barriers to IMTA expansion relating to the use of water surface and the seabed for farm sites, ownership or leasing of sites, and food safety concerns. When shellfish are cultivated in waters that receive large quantities of domestic or urban sewage there can also be food safety concerns, because the shellfish can absorb viruses, bacteria, toxic algae and polluted organic particles from the environment. The safety of shellfish as food needs to be monitored and shellfish require thorough depuration before sale.

The accumulation of heavy metals and other substances is an additional concern, especially where industrial effluents enter receiving waters, and this cannot be mitigated by depuration.

Although IMTA can be part of a strategy to address nutrient pollution and to mitigate likely impacts of nutrient runoff and eutrophication, prevention by source control should still be the primary focus and polluters cannot continue to release uncontrolled discharges, assuming that using IMTA will solve the problem.

ACCESSIBILITY

IMTA systems are extremely flexible and can be established in open-water or land-based areas, in marine or freshwater and in temperate or tropical zones. The key issue is to ensure the selection of appropriate organisms from multiple trophic levels with complementary ecosystem functions, which have economic value or potential (Chopin, 2013).

The IMTA systems being promoted in China use relatively low technology techniques and there are few barriers to entry. This is because they rely on locally available species and resources which are appropriate to small-scale, medium-scale and large-scale farms.

The YSFRI and the South China Sea Fisheries Research Institute (SCSFRI) have been conducting training programmes across northern and southern coastal areas of China to raise awareness of the improved IMTA 'eco-farming' model and uptake by farmers has been rapid.

THE OUTCOME AND BENEFITS

Farmers practising IMTA in the Sanggou Bay area have benefited from both improved incomes and better environmental conditions.

Farmers produce 1 500 tonnes of seaweed per square kilometre which remove an estimated 40 tonnes of nitrogen, 5 tonnes of phosphorus and 500 tonnes of carbon respectively from the coastal ecosystem (Fang *et al.*, 2015).

According to a study by the YSFRI, in the IMTA of Japanese sea bass, Pacific oysters and *Gracilaria* spp., 30 percent and 5.6 percent of the nutrients needed by the oysters were provided by the fish faeces and uneaten food respectively. Moreover, the system resulted in a 30 percent increase in oyster meat production compared to oyster monoculture production systems (Fang *et al.*, 2015).

The YSFRI reports that channelling water from RAS fish farms through IMTA ponds and salt fields in Shandong Province resulted in the phosphorous and nitrogen levels in the effluent water being reduced by 31 percent and 76 percent respectively.

The promotion of IMTA in the Sanggou Bay area has ensured that the benthic environment is healthy, even after 60 years of intensive mariculture production.

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FAO Regional Office for Asia and the Pacific
FAO-RAP@fao.org
www.fao.org/asiapacific/en/

Food and Agriculture Organization of the United Nations
Bangkok, Thailand